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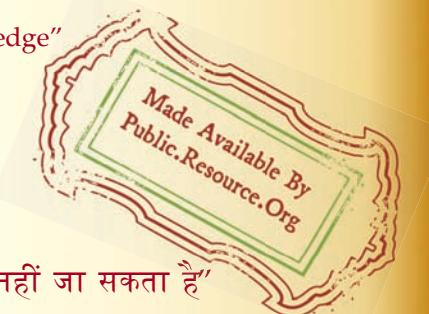
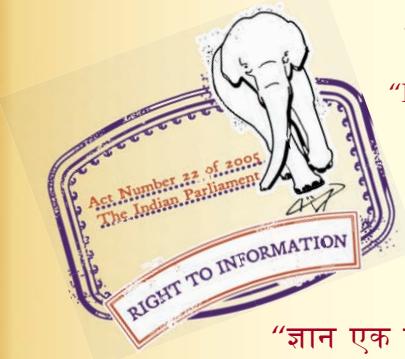
“Step Out From the Old to the New”

SP 36-1 (1987): Compendium of Indian Standards on Soil Engineering: Part-1 Laboratory Testing of Soils for civil Engineering Purposes [CED 43: Soil and Foundation Engineering]

“ज्ञान से एक नये भारत का निर्माण”

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“ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है”

Bhartṛhari—Nītiśatakam

“Knowledge is such a treasure which cannot be stolen”



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COMPENDIUM OF INDIAN STANDARDS ON SOIL ENGINEERING

Part 1 Laboratory Testing of Soils for Civil Engineering Purposes

SP 36 (Part 1) : 1987

COMPENDIUM OF INDIAN STANDARDS ON SOIL ENGINEERING

PART 1

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

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PREFACE

The Soil Engineering Sectional Committee, BDC 23 of the Bureau of Indian Standards has so far formulated 84 Indian Standards which relate to classification, glossary, subsurface investigation, methods of laboratory testing, methods of field testing, soil testing equipment and soil based product. However, these are not serially numbered nor the Indian Standards belonging to specific area of soil engineering are grouped together. It may be difficult for the user to have information about the full availability of Indian Standards. The committee, therefore, recommended the publication of a compendium of all the Indian Standards formulated by it and this has resulted in this publication.

In order to establish uniform procedure for the determination of different characteristics of soils and also for facilitating comparative studies of the results, the Bureau of Indian Standards has brought out Indian Standards on methods of test for soils both for laboratory and field. It has also been recognised that reliable and comparable test results can be obtained only with standard testing equipment capable of giving the desired level of accuracy. The Bureau is, therefore, bringing out series of Indian Standards covering specification of equipments used for testing of soils so as to encourage the development and manufacture in the country. All such Indian Standards published so far have been included in this compendium.

For convenience of reference and use this compendium is being brought out in two parts. The first part covers laboratory testing of soils for civil engineering purposes and the second part covers rest of the Indian Standards. The Indian Standards in each part have been arranged subject-wise details of which have been indicated in the contents. An index of Indian Standards arranged serial-wise has also been provided for easy location of any Indian Standard covered in this compendium.

In reporting the result of test or analysis made in accordance with any of the Indian Standards, if the final value, observed or calculated, is to be rounded off, it should be done in accordance with IS: 2-1960 'Rules for rounding off numerical values'.

This publication covers Indian Standards issued up to 31 March 1987 and incorporates at the appropriate place all the amendments issued up to that time.

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SECTION 1

Glossary of Terms and Symbols Relating to Soil Engineering and Soil Dynamics

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Indian Standard

GLOSSARY OF TERMS AND SYMBOLS RELATING TO SOIL ENGINEERING

(First Revision)

0. FOREWORD

0.1 A series of Indian Standards covering soil testing, site investigation for foundations, etc, is being published; this includes a large number of terms relating to soil engineering. The extensive use of these terms has necessitated the preparation of this glossary.

0.2 A number of definitions including symbols and the units of measurements are indicated. The symbols appear immediately after the name of the term, followed by the unit in parentheses. No significance should be placed on the order in which the symbols are presented where two or more are given for an individual term. The physical dimensions of quantities are indicated by capital letters as follows:

F = Force
L = Length
T = Time
D = Dimensionless

0.2.1 Where synonymous terms are cross-referenced, the definition is included with the earlier term alphabetically. Where this is not the case, the later term is the more significant.

1. SCOPE

1.1 This standard covers definitions of terms relating to soil engineering. The symbols that are used to represent some of the terms are also given.

2. DEFINITIONS

2.1 Absorbed Water — Water held mechanically (by surface tension) in a soil mass and having physical properties not different from ordinary water at the same temperature and pressure.

2.2 Active Earth Pressure — See 'Earth Pressure'.

2.3 Active State of Plastic Equilibrium — See 'Plastic Equilibrium'.

2.4 Activity — Ratio of the plasticity index to the clay fraction.

2.5 Adhesion — Shearing resistance between soil and another material under zero externally applied pressure:

	Symbol	Unit
Unit adhesion	c_a	FL^{-2}
Total adhesion	C_a	F or FL^{-1}

2.6 Adobe — A light coloured clay and silt that has been deposited in shallow desert basins or lakes.

2.7 Adsorbed Water — Water in a soil mass, held by physico-chemical forces, having physical properties substantially different from absorbed or free water or chemically combined water at the same temperature and pressure.

2.8 Aeolian Deposits — Wind-deposited material, such as dune sands and loess deposits.

2.9 'A' Horizon — See 'Horizon'.

2.10 Air Entry Value — The minimum pressure of air or suction that destroys the capillary tension of water in the pores of a saturated porous stone.

2.11 Air-Space Ratio, $G_a(D)$ — Ratio of volume of water that can be drained from a saturated soil under the action of the force of gravity to total volume of voids, as determined in a specified testing method.

2.12 Air Void Ratio $e_a(D)$ — The ratio of the volume of air space to the volume of solids in a soil mass.

2.13 Allowable Bearing Pressure (Gross), $q_a(Gross)$ (FL^{-2}) — The maximum allowable gross loading intensity on the ground in any given case, taking into account the maximum safe bearing capacity (gross), the amount and kind of settlement expected, and the ability of the given structure to take up this settlement. It is, therefore, a combined function of both the site conditions and characteristics of the particular structure it is proposed to erect thereon.

2.14 Allowable Bearing Pressure (Nett), $q_a(Nett)$ (FL^{-2}) — The allowable bearing pressure (gross) minus the surcharge.

2.15 Allowable Pile Bearing Load (Allowable Load on Pile), $Q_a(F)$ — The load which may be safely applied to a pile after taking into account its ultimate bearing resistance, pile spacing, overall bearing capacity of the ground below the piles and allowable settlement.

2.16 Alluvium — A general term for all detrital deposits resulting from the operation of rivers, thus including the sediments laid down in river beds,

flood plains, lakes, fans at the foot of mountain slopes and estuaries. Unless otherwise indicated, alluvium is unconsolidated.

2.17 Angle of Internal Friction (Angle of Shearing Resistance), ϕ (Degrees) — Angle between the abscissa and the tangent to the curve representing the relationship between the shearing resistance at failure to normal stress acting within a soil.

2.18 Angle of Obliquity, Ψ (Degrees) — The angle between the direction of the resultant stress or force acting on a given plane and the normal to that plane.

2.19 Angle of Repose, α (Degrees) — Angle between the horizontal and the maximum slope that a soil assumes through natural processes. For granular soils, the effect of height of slope is negligible; for cohesive soils, the effect of height of slope is so great that the angle of repose is meaningless.

2.20 Angle of Wall Friction, δ — Angle between the abscissa and the tangent of the curve representing the relationship of shearing resistance to normal stress acting between soil and surface of another material.

2.21 Anisotropic Mass — A mass having different properties in different directions at any given point.

2.22 Apparent Cohesion — See 'Cohesion'.

2.23 Aquifer — A water bearing formation that provides a ground water reservoir.

2.24 Arching — The transfer of load by shear from a yielding part of a soil mass to adjoining less-yielding or restrained parts of mass.

2.25 Area of Influence of a Well, a (L^{-2}) — Area surrounding a well within which the piezometric surface has been lowered when pumping has produced the maximum steady rate of flow.

2.26 Area Ratio of a Sampling Spoon, Sampler or Sampling Tube, A_r (D) — The area ratio is an indication of the volume of soil displaced by the sampler in proportion to the volume of the sample, calculated as follows:

$$A_r (\%) = \frac{D_e^2 - D_i^2}{D_i^2} \times 100$$

where

D_e = maximum external diameter of the sampling spoon, and

D_i = minimum internal diameter of the sampling spoon at the cutting edge.

2.27 Base Course (Base) — A layer of specified or selected material of planned thickness constructed on the subgrade or sub-base for the purpose of serving one or more functions, such as distributing load, providing drainage and minimizing frost action.

2.28 Base Exchange — The physico-chemical process whereby one type of ions (cations) adsorbed on soil particles are replaced by another type. The base exchange capacity signifies the capacity of soil to retain bases up to its highest limit; it also defines the power of the soil to combine with base in such a manner that they cannot be easily removed by leaching with water, but can be exchanged by an equivalent amount of other bases. In other words, it represents a limit beyond which the saloids would be highly hydrolyzed.

2.29 Bearing Capacity Factor (D) — Non-dimensional factors first proposed by Terzaghi for the computation of bearing capacity.

2.30 Bearing Capacity, Maximum Safe, q_o (FL^{-2}) — The maximum intensity of loading that the soil will safely carry with a factor of safety against shear failure irrespective of any settlement that may result.

2.31 Bearing Capacity of Pile, Ultimate, Q_p (F) — The load per pile required to produce a condition of failure.

2.32 Bearing Capacity, Ultimate — See 'Ultimate Bearing Capacity'.

2.33 Bearing Pressure, Allowable — See 'Allowable Bearing Pressure'.

2.34 Bedrock (Ledge) — Any *in-situ* solid rock below soil.

2.35 Bentonitic Clay (Bentonite) — A clay with a high content of the mineral montmorillonite, usually characterized by high swelling on wetting.

2.36 Berm — A shelf that breaks the continuity of a slope.

2.37 'B' Horizon — See 'Horizon'.

2.38 Black Cotton Soil — Black cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. They are predominantly montmorillonitic in structure and black or blackish grey in colour. They are characterized by high shrinkage and swelling properties.

2.39 Boglime (Lake Marl) — A white fine-grained powdery calcareous deposit precipitated by plant action, on the bottom of many ponds; also found in glaciated areas and closely associated with peat deposits.

2.40 Boulder — A more or less rounded block or fragment of rock and of average dimension 300 mm or greater. Usually boulders are rounded by being carried or rolled along by water or ice; sometimes also by weathering in place in which case they are known as boulders of weathering, disintegration or exploitation.

2.41 Bulb of Pressure — See 'Pressure Bulb'.

2.42 Bulking — The increase in volume of a material due to handling. Rock bulk upon excavation; damp sand bulks if loosely deposited, as by dumping, because the apparent cohesion prevents movement of the soil particles to form a reduced volume.

2.43 Caliche — Soil cemented by porous calcium carbonate.

2.44 California Bearing Ratio, CBR (D) — The ratio of the force per unit area required to penetrate a soil mass with a circular piston of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration of a standard material. The ratio is usually determined for penetrations of 2.5 mm and 5 mm. Where the ratio at 5 mm is consistently higher than that at 2.5 mm, the ratio at 5 mm is used.

2.45 Capillary Action (Capillarity) — The rise or movement of water in the interstices of a soil due to capillary forces.

2.46 Capillary Flow — See 'Capillary Migration'.

2.47 Capillary Fringe Zone — The zone above the free water elevation in which water is held by capillary action.

2.48 Capillary Head, h (L) — The potential, expressed in head of water, that causes the water to flow by capillary action.

2.49 Capillary Migration (Capillary Flow) — The movement of water by capillary action.

2.50 Capillary Rise (Height of Capillary Rise), h_c (L) — The height above a free water elevation to which water will rise by capillary action.

2.51 Capillary Water — Water subject to the influence of capillary action.

2.52 Centrifuge Moisture Equivalent, CME — See 'Moisture Equivalent'.

2.53 'C' Horizon — See 'Horizon'.

2.54 Clay — An aggregate of microscopic and sub-microscopic particles derived from the chemical decomposition and disintegration of rock constituents. It is plastic within a moderate to wide range of water content.

2.55 Clay Size — That portion of the soil finer than 0.002 mm.

2.56 Cobble — A rock fragment, usually rounded or semi-rounded, with an average dimension between 80 and 300 mm.

2.57 Coefficient of Absolute Viscosity — See 'Coefficient of Viscosity'.

2.58 Coefficient of Active Earth Pressure — See 'Coefficient of Earth Pressure'.

2.59 Coefficient of Compressibility (Coefficient of Compression) (a_v) ($L^2 F^{-1}$) — The secant slope, for

a given pressure increment, of the effective pressure-void ratio curve.

2.60 Coefficient of Consolidation, c_v ($L^2 T^{-1}$) — A coefficient utilized in the theory of consolidation, containing the physical constants of a soil affecting its rate of volume change:

$$c_v = \frac{K (1 + e)}{a_v \gamma_w}$$

where

k = coefficient of permeability, LT^{-1} ;

e = void ratio, D ;

a_v = coefficient of compressibility, $L^2 F^{-1}$; and

γ_w = unit weight of water, FL^{-3} .

NOTE — In the literature published prior to 1935, the coefficient of consolidation, usually designated c , was defined by the equation:

$$c = \frac{k}{a_v \gamma_w (1 + e)}$$

This original definition of the coefficient of consolidation may be found in some more recent papers and care should be taken to avoid confusion.

2.61 Coefficient of Curvature (C_c) — It is given by

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

where D_{10} , D_{30} , D_{60} are the diameters of particles corresponding to 10, 30, and 60 percent finer.

2.62 Coefficient of Earth Pressure, K (D) — The ratio between the lateral effective pressure and vertical effective pressure at any point in the soil mass.

2.62.1 Coefficient of Earth Pressure, Active, K_A (D) — The smallest value of the coefficient of earth pressure resulting when the soil expands laterally till failure.

2.62.2 Coefficient of Earth Pressure, at Rest, K_o (D) — Value of the coefficient of earth pressure when the soil is permitted neither to expand nor compress laterally.

2.62.3 Coefficient of Earth Pressure, Passive, K_p (D) — The maximum value of coefficient of earth pressure resulting when the soil is compressed laterally thereby inducing failure in the soil.

2.63 Coefficient of Permeability (Permeability), k (LT^{-1}) — The rate of flow of water under laminar flow conditions through a unit cross-sectional area of porous medium under a unit hydraulic gradient and standard temperature conditions (usually $27^\circ C$).

2.64 Coefficient of Subgrade Reaction (Modulus of Subgrade Reaction), k (FL^{-3}) — Ratio of load per unit area (applied through a centrally loaded rigid body) of horizontal surface of a mass of soil to corresponding settlement of the surface. It is determined as the slope of the secant drawn between the

point corresponding to zero settlement and the point of 1.25 mm settlement, of a load-settlement curve obtained from a plate load test on a soil using a 75-cm or greater loading plate.

2.65 Coefficient of Uniformity, C_u (D) — The ratio D_{60}/D_{10} , where D_{60} is the particle diameter corresponding to 60 percent finer on the grain-size curve and D_{10} is the particle diameter corresponding to 10 percent finer on the grain-size curve.

2.66 Coefficient of Viscosity (Coefficient of Absolute Viscosity), μ (FTL^{-2}) — The shearing force per unit area required to maintain a unit difference in velocity between two parallel layers of a fluid, a unit distance apart.

2.67 Coefficient of Volume Compressibility (Modulus of Volume Change), m_v ($\text{L}^{-2}\text{F}^{-1}$) — The compression of a soil layer per unit of original thickness due to a given unit increase in pressure. It is numerically equal to the coefficient of compressibility divided by one plus the original void ratio, or

$$\frac{a_v}{1 + e}$$

2.68 Cohesion, c (FL^{-2}) — The portion of the shear strength of a soil indicated by the term c , in Coulomb's equation, $s = c + p \tan \phi$.

2.68.1 Cohesion, Apparent — Cohesion in granular soils due to capillary forces.

2.69 Cohesionless Soil — A soil that, when unconfined, has little or no strength when air-dried and that has little or no cohesion when submerged.

2.70 Cohesive Soils — A soil that, when unconfined, has considerable strength when air-dried and that has significant cohesion when submerged.

2.71 Colloidal Particles — Soil particles that are so small that the surface activity has an appreciable influence on the properties of the mass. The physico-chemical forces dominate the gravitational forces.

2.72 Compaction — The densification of a soil by means of mechanical manipulation.

2.73 Compaction Curve (Moisture-Density Curve) — The curve showing the relationship between the dry unit weight (density) and the water content of a soil for a given compactive effort.

2.74 Compaction Test (Moisture-Density Test) — A laboratory compaction test procedure whereby a soil at a known water content is placed in a specified manner into a mould of given dimensions, subjected to a compactive effort of controlled magnitude and the resulting unit weight determined. The procedure is repeated for various water contents sufficient to establish a relation between water content and dry unit weight.

2.75 Compressibility — Property of a soil pertaining to its susceptibility to decrease in volume, when subjected to load.

2.76 Compression Curve — See 'Pressure-Void Ratio Curve'.

2.77 Compression Index, C_c (D) — The slope of the linear portion of the pressure-void ratio curve on a semi-log plot, with pressure on the log scale.

2.78 Concentration Factor, n (D) — A parameter used in modifying the Business equations to describe various distributions of vertical stress.

2.79 Consistency — The degree of resistance offered by a fine grained soil to deformation.

2.80 Consistency Index (Relative Consistency), I_c (D) — Ratio of the liquid limit minus the natural water content to the plasticity index of a soil:

$$I_c = \frac{w_L - w_o}{I_p}$$

where

w_L = liquid limit,

w_o = natural moisture content, and

I_p = plasticity index.

2.81 Consolidated-Drained Test (Slow Shear Test)

— A soil test in which a soil specimen is first allowed to consolidate fully under an applied stress and shear stresses are then applied in such a manner that there is full dissipation of excess pore water pressure development during shear.

2.82 Consolidated-Undrained Test (Consolidated Quick Test) — In this case, the soil is consolidated under applied normal loads but no drainage of water from the soil is permitted to take place during shear.

2.83 Consolidation — The gradual reduction in volume of a soil mass partly or fully saturated resulting from an increase in and continued application of compressive stress and is due to the expulsion of water from the pores.

2.83.1 Initial Consolidation (Initial Compression) — A comparatively sudden reduction in volume of a soil mass under an applied load due principally to expulsion and compression of gas in the soil voids preceding primary consolidation.

2.83.2 Primary Consolidation (Primary Compression) (Primary Time Effect) — The reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to squeezing out of water from the void spaces of the mass and accompanied by a transfer of the load from the soil water to the soil solids.

2.83.3 Secondary Consolidation (Secondary Compression) (Secondary Time Effect) — The reduction in volume of a soil mass caused by the application of a sustained load to the mass and due

principally to the adjustment of the internal structure of the soil mass after most of the load has been transferred from the soil water to the soil solids.

2.84 Consolidation Curve — See 'Consolidation Time Curve'.

2.85 Consolidation Ratio, U_z (D) — The ratio of the amount of consolidation at a given point within the subsoil and at a given time to the total amount of consolidation obtainable at that point under a given stress increment.

2.86 Consolidation Test, One Dimensional — A test in which the specimen is laterally confined in a ring and is compressed between porous plates.

2.87 Consolidation Time Curve (Time Curve) (Consolidation Curve) (Theoretical Time Curve) — A curve that shows the relation between the degree of consolidation, and the elapsed time after the application of given increment of load.

2.88 Contact Pressure, p (FL^{-2}) — The soil reaction per unit area at the surface of contact between the foundation and the underlying soil mass, produced by the self weight of the foundation and all the forces acting on it.

2.89 Controlled Strain Test — A test in which the load is so applied that a controlled rate of strain results (a test in which a specific rate of deformation is applied and the reaction to this deformation is measured).

2.90 Controlled Stress Test — A test in which the stress to which a specimen is subjected is applied at a controlled rate.

2.91 Creep

- Slow movement of soil and rock waste down slopes usually imperceptible except to observations of long duration.
- The time dependent deformation behaviour of soil under constant compressive stress.

2.92 Critical Circle (Critical Surface) — The sliding surface assumed in a theoretical analysis of the stability of a soil mass for which the factor of safety is a minimum.

2.93 Critical Density — The unit weight of a saturated granular material below which it will lose strength and above which it will gain strength when subjected to rapid deformation.

2.94 Critical Height, H_c (L) — The maximum height at which a vertical or sloped bank of soil will stand unsupported under a given set of conditions.

2.95 Critical Hydraulic Gradient — See 'Hydraulic Gradient'.

2.96 Critical Slope — The maximum angle with the horizontal at which a sloped bank of soil of given height will stand unsupported.

2.97 Critical Surface — See 'Critical Circle'.

2.98 Critical Void Ratio, e_c (D) — Void ratio prior to the process of shear in which nett volume change at failure is zero.

2.99 Cryology — The study of the properties of snow ice and frozen ground.

2.100 Deflocculating Agent (Deflocculant) (Dispersing Agent) — An agent that prevents fine soil particles in suspension from coalescing to form flocs.

2.101 Degree of Compaction, D_c (D) — The ratio of dry density of compacted material in the field to the laboratory standard maximum dry density of the material multiplied by 100.

2.102 Degree of Consolidation (Percent Consolidation), U (D) — The ratio, expressed as a percentage of the amount of consolidation at a given time, within a soil mass to the total amount of consolidation obtainable under a given stress condition.

2.103 Degree of Saturation (Percent Saturation), S_s (D) — The ratio, expressed as a percentage, of the volume of water in a given soil mass to the total volume of voids.

2.104 Density — See 'Unit Weight'.

NOTE — Although it is recognized that density is defined as mass per unit volume in the field of soil mechanics, the term is frequently used in place of unit weight.

2.105 Density Index (Relative Density) (Degree of Density), I_D (D) — The ratio of the difference between the void ratio of a cohesionless soil in the loosest state and any given void ratio, to the difference between its void ratios in the loosest and in the densest states:

$$I_D = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \times 100$$

where

e_{\max} = void ratio in loosest state,
 e = void ratio in the field, and
 e_{\min} = void ratio in its densest state obtainable in the laboratory.

2.106 Deviator Stress σ_d (FL^{-2}) — The difference between the major and minor principal stresses in a triaxial test.

2.107 Dilatancy — The expansion of cohesionless soils when subject to shearing deformation.

2.108 Direct Shear Test — A shear test in which soil under an applied normal load is stressed to failure by moving one section of the soil container (shear box) relative to the other section.

2.109 Discharge Velocity, v (LT^{-1}) — Rate of discharge of water through a porous medium per unit of total area perpendicular to the direction of flow.

2.110 Dispersing Agent — See 'Deflocculating Agent'.

2.111 Drawdown (L) — Vertical distance of the free water elevation is lowered, or the reduction of the pressure head due to the removal of free water.

2.112 Dry Density (Dry Unit Weight), γ_d (FL^{-3}) — The weight of oven dry soil per unit volume of soil mass.

2.113 Earth Pressure — The pressure or force exerted by soil on any boundary:

	Symbol	Unit
Pressure	p	FL^{-2}
Force	P	F or FL^{-1}

2.113.1 Active Earth Pressure, P_a , p_a — The minimum value of earth pressure. This condition exists when a soil mass is permitted to yield sufficiently to cause its internal shearing resistance along a potential failure surface to be completely mobilized.

2.113.2 Earth Pressure at Rest, P_o , p_o — The value of the earth pressure when the soil mass is in its natural state without having been permitted to yield or without having been compressed.

2.113.3 Passive Earth Pressure, P_p , p_p — The maximum value of earth pressure. This condition exists when a soil mass is compressed sufficiently to cause its internal shearing resistance along a potential failure surface to be completely mobilized.

2.114 Effective Diameter (Effective Size), D_{10} (L) — Particle diameter corresponding to 10 percent finer on the grain-size curve.

2.115 Effective Drainage Porosity — See 'Effective Porosity'.

2.116 Effective Force, \bar{F} (F) — The force transmitted through a soil mass by inter-granular pressures.

2.117 Effective Porosity (Effective Drainage Porosity), n_e (D) — The ratio of the volume of the voids of a soil mass that can be drained by gravity to the total volume of the mass.

2.118 Effective Pressure — See 'Stress'.

2.119 Effective Size — See 'Effective Diameter'.

2.120 Effective Stress — See 'Stress'.

2.121 Effective Unit Weight — See 'Unit Weight'.

2.122 Elastic State of Equilibrium — State of stress within a soil mass when the internal resistance of the mass is not fully mobilized.

2.123 Equipotential Line — Line joining various points in a soil mass at which the piezometric head is the same (that is, water will rise to the same elevation in piezometric tubes).

2.124 Equivalent Diameter (Equivalent Size), D (L) — The diameter of a hypothetical sphere composed of material having the same specific gravity as

that of the actual soil particle and of such size that it will settle in a given liquid at the same terminal velocity as the actual soil particle.

2.125 Equivalent Fluid — A hypothetical fluid having a unit weight such that it will produce a pressure against a lateral support presumed to be equivalent to that produced by the actual soil. This simplified approach is valid only when deformation conditions are such that the pressure increases linearly with depth and the wall friction is neglected.

2.126 Excess Hydrostatic Pressure — See 'Hydrostatic Pressure'.

2.127 Exchange Capacity (Base Exchange Capacity) — The capacity to exchange ions as measured by the quantity of exchangeable ions in a soil.

2.128 Failure by Rupture — See 'Shear Failure'.

2.129 Field Moisture Equivalent — See 'Moisture Equivalent'.

2.130 Filter (Protective Filter) — A layer or combination of layers of pervious materials designed and installed in such a manner as to provide drainage, yet prevent the movement of soil particles due to percolating water.

2.131 Fines — Portion of a soil finer than a 75-micron IS Sieve.

2.132 Floc — Loose, open-structured mass formed in a suspension by the aggregation of minute particles.

2.133 Flocculation — The process of forming flocs.

2.134 Flocculent Structure — See 'Soil Structure'.

2.135 Flow Channel — The portion of a flow net bounded by two adjacent flow lines.

2.136 Flow Curve — The locus of points obtained from a standard liquid limit test using the mechanical device plotted on a graph representing water content as ordinate on an arithmetic scale and the number of drops as abscissa on a logarithmic scale.

2.137 Flow Failure — Failure in which a soil mass moves over relatively long distances in a fluid-like manner.

2.138 Flow Index, I_f (D) — The slope of the flow curve obtained from a liquid limit test using the mechanical device (given by the difference in water contents at 10 blows and at 100 blows).

2.139 Flow Line — The path that a particle of water follows in its course of seepage under laminar flow conditions.

2.140 Flow Net — A graphical representation of flow lines and equipotential lines used in the study of seepage phenomena.

2.141 Flow Slide — The failure of a sloped bank of soil in which the movement of the soil mass does not take place along a well-defined surface of sliding.

2.142 Flow Value, $N\phi$ (Degrees) — A quantity

$$\text{equal to } \tan^2 \left[45^\circ + \frac{\phi}{2} \right],$$

where ϕ is the angle of internal friction of soil.

2.143 Footing — A spread constructed in brick-work, masonry or concrete under the base of a wall or column for the purpose of distributing the load over a larger area.

2.144 Foundation — That part of the structure which is in direct contact with and transmits loads to the ground.

2.145 Free Water (Gravitational Water) (Ground Water) (Phreatic Water) — Water that is free to move through a soil mass under the influence of gravity.

2.146 Free Water Elevation (Water Table) (Ground Water Surface) (Free Water Surface) (Ground Water Elevation) — Elevations at which the pressure in the ground water is zero with respect to the atmospheric pressure.

2.147 Frost Action — Freezing and thawing of moisture in materials and the resultant effects on these materials and on structures of which they are a part or with which they are in contact.

2.148 Frost Boil

- a) Softening of soil occurring during a thawing period due to the liberation of water from ice lenses or layers.
- b) The hole formed in flexible pavements by the extrusion of soft soil and melt waters under the action of wheel loads.
- c) Breaking of a highway or airfield pavement under traffic and the ejection of subgrade soil in a soft and soupy condition caused by the melting of ice lenses formed by frost action.

2.149 Frost Heave — The raising of a surface due to the accumulation of ice in the underlying soil.

2.150 General Shear Failure — See 'Shear Failure'.

2.151 Glacial Till (Till) — Generally unstratified, unconsolidated and heterogeneous mixture of clay, sand, gravel and boulders, deposited directly by glacier-ice, not by glacier waters, though it may be locally modified by them. It may be:

- a) englacial (carried within the ice mass),
- b) superglacial (borne on the ice surface), or
- c) subglacial (dragged along beneath the glacier).

2.152 Gradation (Grain-Size Distribution) (Soil Texture) — Proportion of material of each grain size present in a given soil.

2.153 Grain-Size Analysis (Mechanical Analysis) — The process of determining gradation.

2.154 Gravel — Angular, rounded or semi-rounded particles of rock or soil of particle size between 4.75 mm and 80 mm.

2.155 Gravitational Water — See 'Free Water'.

2.156 Ground Water — See 'Free Water'.

2.157 Ground Water Elevation — See 'Free Water Elevation'.

2.158 Ground Water Surface — See 'Free Water Elevation'.

2.159 Hardpan — Layer of extremely dense soil.

NOTE — Hardpan is a formation which forms by precipitation of dissolved materials, such as calcium carbonate or silica at depths below the surface year after year. When this accumulation takes place, the subsoil is more or less firmly cemented and limits downward movement of water. This formation does not soften when wetted with water.

2.160 Heave — Upward movement of soil caused by expansion or displacement resulting from phenomena, such as moisture absorption, removal of overburden, driving of piles, frost action and hydrostatic pressure.

2.161 Height of Capillary Rise — See 'Capillary Rise'.

2.162 Homogeneous Mass — A mass that exhibits essentially the same physical properties at every point throughout the mass.

2.163 Honeycomb Structure — See 'Soil Structure'.

2.164 Horizon (Soil Horizon) — One of the layers of the soil profile, distinguished principally by its texture, colour, structure and chemical content.

2.164.1 'A' Horizon — The uppermost layer of a soil profile from which inorganic colloids and other soluble materials have been leached. Usually contains remnants of organic matter.

2.164.2 'B' Horizon — The layer of a soil profile in which material leached from the overlying 'A' horizon is accumulated.

2.164.3 'C' Horizon — Undisturbed parent material from which the overlying soil profile has been developed.

2.165 Humus — A brown or black material formed by the partial decomposition of vegetable or animal matter; the organic portion of soil.

2.166 Hydraulic Gradient, i_s (D) — The difference or drop of hydraulic head per unit distance of flow,

$$\frac{dh}{dL}$$

2.166.1 Critical Hydraulic Gradient, i_c (D) — Hydraulic gradient at which the inter-granular pressure in a mass of cohesionless soil is reduced to zero by the upward flow of water.

2.167 Hydrostatic Pressure, u_o (FL^{-2}) — The

pressure in a liquid under static conditions; the product of the unit weight of the liquid and the difference in elevation between the given point and the free water elevation.

2.167.1 Excess Hydrostatic Pressure (Hydrostatic Excess Pressure), \bar{u} , u (FL^{-2}) — The pressure that exists in pore water in excess of the hydrostatic pressure.

2.168 Hygroscopic Capacity (Hygroscopic Coefficient), w_0 (D) — Ratio of the weight of water absorbed by a dry soil in a saturated atmosphere at a given temperature to the weight of the oven-dried soil.

2.169 Hygroscopic Water Content, w_H (D) — The water content of an air-dried soil.

2.170 Initial Consolidation (Initial Compression) — See 'Consolidation'.

2.171 Inorganic Silt — See 'Silt'.

2.172 Intergranular Pressure — See 'Stress'.

2.173 Intermediate Principal Plane — See 'Principal Plane'.

2.174 Intermediate Principal Stress — See 'Stress'.

2.175 Isochrone — A curve showing the distribution of the excess hydrostatic pressure in a soil layer or strata at a given time during a process of consolidation.

2.176 Isotropic Mass — A mass having the same property (or properties) in all directions.

2.177 Kaolin — A variety of clay containing a high percentage of kaolinite.

2.178 Laminar Flow (Streamline Flow) (Viscous Flow) — That type of flow in which the path of any particle is not intersected by that of the other particle and in which head loss is proportional to the first power of the velocity.

2.179 Landslide (Landslide) (Slide) — The failure of a sloped bank of soil hillside, or mass of rock or soil, in which movement of the mass takes place.

2.180 Leaching — The removal of soluble soil elements and colloids by percolating water.

2.181 Ledge — See 'Bedrock'.

2.182 Linear Expansion, L_E (D) — The increase in one dimension of soil mass, expressed as a percentage of that dimension at the shrinkage limit, when the water content is increased from the shrinkage limit to any given water content.

2.183 Linear Shrinkage, L_s (D) — Decrease in one dimension of a soil mass, expressed as a percentage of the original dimension, when the water content is reduced from a given value to the shrinkage limit.

2.184 Line of Creep — The path that water follows along the surface of contact between the foundation

soil and the base of a hydraulic or other structure.

2.185 Line, Phreatic — See 'Phreatic Line'.

2.186 Liquidity Index (Water-Plasticity Ratio) (Relative Water Content), I_L (D) — The ratio expressed as a percentage of the natural water content of soil minus its plastic limit to its plasticity index.

2.187 Liquid Limit, w_L — The water content, expressed as a percentage of the weight of the oven dry soil, at the boundary between liquid and plastic states of consistency of soil.

Note — For the purpose of determination of liquid limit, it is defined as the water content at which a pat of soil, cut by a groove of standard dimensions, will flow together for a distance of 12 mm under the impact of 25 blows in a standard liquid limit apparatus; or as the water content of a soil paste, prepared in a specified mould, into which a cone of specified dimensions and weight penetrates by 25 mm when dropped onto the paste in a specified manner.

2.188 Loam — A soil containing sand, silt and clay, or a combination of any of these, with or without organic matter.

2.189 Local Shear Failure — See 'Shear Failure'.

2.190 Loess — A uniform, aeolian deposit of silty material having an open structure and relatively high cohesion due to cementation of clay or calcareous material at grain contacts. A characteristic of loess deposits is that they can stand with nearly vertical slopes.

2.191 Made-up Ground — Refuse, excavated soil or rock deposited for the purpose of filling a depression or raising a site above the natural surface level of the ground.

2.192 Major Principal Plane — See 'Principal Plane'.

2.193 Major Principal Stress — See 'Stress'.

2.194 Mass Unit Weight — See 'Unit Weight'.

2.195 Mechanical Analysis — See 'Grain-Size Analysis'.

2.196 Minor Principal Plane — See 'Principal Plane'.

2.197 Minor Principal Stress — See 'Stress'.

2.198 Modulus of Elasticity (Modulus of Deformation), E (FL^{-2}) — The ratio of stress to strain for a material under given loading conditions; numerically equal to the slope of the tangent or the secant of stress-strain curve. The use of the term Modulus of Elasticity is recommended for material that deform in accordance with Hooke's law; the term Modulus of Deformation for materials that deform otherwise.

2.199 Modulus of Subgrade Reaction — See 'Coefficient of Subgrade Reaction'.

2.200 Modulus of Volume Change — See 'Coefficient of Volume Compressibility'.

2.201 Mohr Circle — A graphical representation of the stresses acting on the various planes at a given point.

2.202 Mohr Envelope (Rupture Envelope) (Failure Envelope) (Rupture Line) — The envelope of a series of Mohr circles representing stress conditions at failure for a given material. According to Mohr rupture hypothesis, a rupture envelope is the locus of points the co-ordinates of which represent the combinations of normal and shearing stresses that will cause a given material to fail.

2.203 Moisture Content (Water Content), w (D) — The ratio expressed as percentage of the weight of water in a given soil mass to the weight of solid particles under a specified testing condition.

2.204 Moisture-Density Curve — See 'Compaction Curve'.

2.205 Moisture-Density Test — See 'Compaction Test'.

2.206 Moisture Equivalent

2.206.1 Centrifuge Moisture Equivalent, W_c CME (D) — The water content of a soil after it has been saturated with water and then subjected for one hour to a force equal to 1 000 times that of gravity.

2.206.2 Field Moisture Equivalent, FME — The minimum water content expressed as a percentage of the weight of the oven-dried soil, at which a drop of water placed on a smoothed surface of the soil will not immediately be absorbed by the soil but will spread out over the surface and give it a shiny appearance.

2.207 Moraine — Used to designate unstratified glacial deposit (that has not been subjected to the sorting action of water) consisting of stiff clay (rock flour) packed with subangular stones varying in size range from clay to boulders.

2.208 Muck — An organic soil of very soft consistency.

2.209 Mud — A mixture of soil and water in a fluid or weak solid-state.

2.210 Neutral Stress — See 'Stress'.

2.211 Normally Consolidated Soil Deposit — A soil deposit that has never been subjected to an effective pressure greater than the existing effective overburden pressure.

2.212 Normal Stress — See 'Stress'.

2.213 Optimum Water Content (Optimum Moisture Content), w_o (D) — The water content at which a soil can be compacted to the maximum dry unit weight by a given compactive effort.

2.214 Organic Silt — A silt with high organic content.

2.215 Organic Soil — Soil with high organic content. In general, organic soils are very compressible and have poor load sustaining properties.

2.216 Over-Consolidated Soil Deposit — A soil deposit that has been subjected to an effective pressure greater than the present effective over-burden pressure.

2.217 Parent Material — Material from which a soil has been derived.

2.218 Passive Earth Pressure — See 'Earth Pressure'.

2.219 Passive State of Plastic Equilibrium — See 'Plastic Equilibrium'.

2.220 Peat — A fibrous mass of organic matter in various stages of decomposition generally dark brown to black in colour and of spongy consistency.

2.221 Penetration Resistance, P_R — Force required to produce a given penetration into soil of a pile, casing, sampling tube or penetrometer.

2.222 Penetration Resistance Curve (Penetration Curve) — The curve showing the relationship between the penetration resistance and the water content.

2.223 Percentage Air Voids, n_a — Volume of air in a soil mass to the total volume of the soil mass.

2.224 Percent Compaction — The ratio expressed as a percentage of dry unit weight of soil to maximum dry unit weight obtained in the laboratory compaction test over the same soil.

2.225 Percent Consolidation — See 'Degree of Consolidation'.

2.226 Percent Saturation — See 'Degree of Saturation'.

2.227 Perched Water Table — A water table usually of limited area maintained above the normal free water elevation by the presence of an intervening relatively impervious confining stratum.

2.228 Percolation — See 'Seepage'.

2.229 Permafrost — Perennially frozen soil.

2.230 Permeability — The property of soil which permits percolation.

2.231 pH (D) — The pH value of hydrogen-ion concentration is a measure of the acidity or alkalinity (basicity) of a soil. It is expressed as follows:

$$\text{pH} = \log \frac{1}{(\text{H}^+)} \text{ where}$$

H^+ = the hydrogen-ion concentration in moles/l.

2.232 Phreatic Line — The upper free water surface of the zone of seepage.

2.233 Phreatic Surface — See 'Free Water Elevation'.

- 2.234 Phreatic Water** — See 'Free Water'.
- 2.235 Piezometer** — An instrument for measuring pressure in the pore fluid.
- 2.236 Piezometric Surface** — The surface at which water will stand in a series of piezometers.
- 2.237 Pile** — Relatively slender structural element which is driven, or otherwise introduced, into the soil, usually for the purpose of providing vertical or lateral support.
- 2.238 Piping** — The movement of soil particles by percolating water leading to internal erosion and the development of channels in the soil mass.
- 2.239 Plastic Deformation** — See 'Plastic Flow'.
- 2.240 Plastic Equilibrium** — State of stress within a soil mass or a portion thereof, which has been deformed to such an extent that its ultimate shearing resistance is mobilized.
- 2.240.1 Active State of Plastic Equilibrium** — Plastic equilibrium obtained by an expansion of a mass.
- 2.240.2 Passive State of Plastic Equilibrium** — Plastic equilibrium obtained by a compression of a mass.
- 2.241 Plastic Flow (Plastic Deformation)** — The deformation of a material beyond the point of recovery, accompanied by continuing deformation with no further increase in stress.
- 2.242 Plasticity** — The property of soil which allows it to be deformed beyond the point of recovery without cracking or appreciable volume change.
- 2.243 Plasticity Index, I_p (D)** — Numerical difference between the liquid limit and the plastic limit.
- 2.244 Plastic Limit, w_p (D)** — The water content, expressed as a percentage of the weight of oven dry soil, at the boundary between the plastic and the semi-solid states of consistency of the soil.
- NOTE** — For purposes of determination, plastic limit is defined as the water content at which a soil will just begin to crumble when rolled into a thread approximately 3 mm in diameter.
- 2.245 Plastic Range (Plastic State)** — The range of consistency within which a soil exhibits plastic properties. The water content in this range varies between the liquid limit and the plastic limit.
- 2.246 Plastic Soil** — A soil that exhibits plasticity.
- 2.247 Pore Pressure (Pore Water Pressure)** — See 'Neutral Stress' under 'Stress'.
- 2.248 Pore Pressure Coefficients (D)** — The change in pore pressure due to changes in applied stresses is expressed in terms of empirical coefficients known as pore pressure coefficients.
- 2.249 Porosity, n (D)** — The ratio, usually expressed as a percentage, of the volume of voids of a given soil mass, to the total volume of the soil mass.
- 2.250 Potential Drop, Δh (L)** — The difference in pressure head between two equipotential lines.
- 2.251 Preconsolidation Pressure (Prestress), p_o (FL^{-2})** — The maximum effective pressure to which a soil has been subjected.
- 2.252 Pressure, p (FL^{-2})** — The load divided by the area over which it acts.
- 2.253 Pressure Bulb** — The zone in a loaded soil mass bounded by an arbitrarily selected isobar of stress.
- 2.254 Pressure Void Ratio Curve (Compression Curve)** — A curve representing the relationship between effective pressure and void ratio of a soil as obtained from a consolidation test. The curve has a characteristic shape when plotted on a semilog paper with pressure on the log-scale.
- 2.255 Primary Consolidation (Primary Compression) (Primary Time Effect)** — See 'Consolidation'.
- 2.256 Principal Plane** — Each of three mutually perpendicular planes through a point in a soil mass on which the shearing stress is zero.
- 2.256.1 Intermediate Principal Plane** — The plane normal to the direction of the intermediate principal stress.
- 2.256.2 Major Principal Plane** — The plane normal to the direction of the major principal stress.
- 2.256.3 Minor Principal Plane** — The plane normal to the direction of the minor principal stress.
- 2.257 Principal Stress** — See 'Stress'.
- 2.258 Profile** — See 'Soil Profile'.
- 2.259 Progressive Failure** — Failure in which the ultimate shearing resistance is progressively mobilized along the failure surface.
- NOTE** — In progressive failure, the ultimate shearing resistance may be considerably less than the peak shearing resistance.
- 2.260 Protective Filter** — See 'Filter'.
- 2.261 Quick Condition (Quick Sand)** — Condition in which water is flowing upwards with sufficient velocity to reduce the shear resistance of the soil through a decrease in inter-granular pressure.
- 2.262 Quick Test** — See 'Unconsolidated Undrained Test'.
- 2.263 Radius of Influence of a Well (L)** — Distance from the centre of well to the closest point at which the piezometric surface is not lowered when pumping has produced the maximum steady rate of flow.
- 2.264 Relative Consistency** — See 'Consistency Index'.
- 2.265 Relative Density** — See 'Density Index'.

2.266 Remoulded Soil — Soil that has had its natural structure modified by manipulation.

2.267 Residual Soil — Soil formed by the *in-situ* weathering of the parent rock.

2.268 Rock — Natural solid mineral matter connected by strong and permanent cohesive forces, occurring in large masses or fragments.

2.269 Rock Flour — *See 'Silt'.*

2.270 Rupture Envelope (Rupture Line) — *See 'Mohr Envelope'.*

2.271 Sand — Cohesionless aggregates of angular, sub-angular, sub-rounded, rounded, flaky or flat fragments of more or less unaltered rocks, or mineral of size between 4.75 mm and 75 microns.

2.272 Sand Boil — The loosening and lifting up of soil particles due to quick conditions prevailing in the soil mass.

2.273 Saturated Unit Weight — *See 'Unit Weight'.*

2.274 Saturation Curve — *See 'Zero Air Voids Curve'.*

2.275 Secondary Consolidation (Secondary Compression) (Secondary Time Effect) — *See 'Consolidation'.*

2.276 Seepage (Percolation) — Slow movement of gravitational water through the soil.

2.277 Seepage Force, $f(F)$ — The force transmitted to the soil grains by seepage.

2.278 Seepage Line — The path that water follows during seepage.

2.279 Seepage Velocity, v_s (LT^{-1}) — The rate of discharge of seepage water through a porous medium per unit area of void space perpendicular to the direction of flow.

2.280 Sensitivity — The ratio of the unconfined compressive strength of an undisturbed specimen of the soil to the unconfined compressive strength of specimen of the same soil after remoulding at unaltered water content. The effect of remoulding on the consistency of a cohesive soil.

2.281 Shaking Test — A test used to indicate the presence of significant amounts of rock flour, silt, or very fine sand in a fine grained soil. It consists of shaking a pat of wet soil, having a consistency of thick paste, in the palm of the hand observing the surface for a glossy or livery appearance, then squeezing the pat, and observing if a rapid apparent drying and subsequent cracking of the soil occurs.

2.282 Shear Failure (Failure by Rupture) — Failure in which movement caused by shearing stresses in a soil mass is of sufficient magnitude to destroy or seriously endanger a structure.

2.282.1 General Shear Failure — Failure in

which the ultimate strength of the soil is mobilized along the entire potential surface of sliding.

2.282.2 Local Shear Failure — Failure in which the ultimate shearing strength of the soil is mobilized only locally along the potential surface of sliding.

2.283 Shear Strength, s (FL^{-2}) — The maximum resistance of a soil to shearing stresses.

2.284 Shear Stress (Shearing Stress) (Tangential Stress) — *See 'Stress'.*

2.285 Shrinkage Index, I_s (D) — The numerical difference between the plastic and shrinkage limit (remoulded soil).

2.286 Shrinkage Limit (Remoulded Soil), w_s (D) — The maximum water content expressed as percentage of oven-dry weight at which any further reduction in water content will not cause a decrease in volume of the soil mass, the soil mass being prepared initially from remoulded soil.

2.287 Shrinkage Limit (Undisturbed Soil), w_{su} (D) — The maximum water content expressed as percentage of oven-dry weight at which any further reduction in water content will not cause a decrease in volume of the soil mass, the soil mass being initially of soil in its undisturbed state.

2.288 Shrinkage Ratio, R (D) — The ratio of a given volume change, expressed as a percentage of the dry volume, to the corresponding change in water content above the appropriate shrinkage limit, expressed as a percentage of the weight of the oven-dried soil.

2.289 Silt (Inorganic Silt) (Rock Flour) — Fine-grained soil or fine-grained portion of soil which exhibits a little or no plasticity and has a little or no strength when air-dried.

2.290 Silt Size — The portion of a soil finer than 75-micron IS Sieve and coarser than 0.002 mm and exhibiting properties indicated in 2.289.

2.291 Single-Grained Structure — *See 'Soil Structure'.*

2.292 Skin Friction, f (FL^{-2}) — The frictional resistance developed between soil and a structure.

2.293 Slaking — The process of breaking up or sloughing when an indurated soil is immersed in water.

2.294 Slow Test — *See 'Consolidated-Drained Test'.*

2.295 Soil (Earth) — Sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter.

2.296 Soil, Black Cotton — *See 'Black Cotton Soil'.*

2.297 Soil-Forming Factors — Factors, such as parent material, climate, vegetation, topography, organism and time involved in the transformation of an original geologic deposit into a soil-profile.

2.298 Soil Horizon — See 'Horizon'.

2.299 Soil Mechanics — That branch of engineering which deals with the application of soil science, the static and dynamic laws and principles of mechanics and hydraulics to engineering problems dealing with soil as structural material.

2.300 Soil Profile (Profile) — Vertical section of soil, showing the nature and sequence of the various layers, as developed by deposition or weathering, or both.

2.301 Soil Stabilization — Chemical or mechanical treatment designed to increase or maintain the stability of a mass of soil or otherwise to improve its engineering properties.

2.302 Soil Structure — Arrangement of soil particles in soil mass.

2.302.1 Flocculent Structure — An arrangement composed of flocs of soil particles instead of individual soil particles.

2.302.2 Honeycomb Structure — An arrangement of soil particles having a comparatively loose, stable structure resembling a honeycomb.

2.302.3 Single-Grained Structure — An arrangement composed of individual soil particles, characteristic structure of coarse-grained soils.

2.303 Soil Suspension — Highly diffused mixture of soil and water.

2.304 Soil Texture — See 'Gradation'.

2.305 Specific Gravity

2.305.1 Apparent Specific Gravity, G_a (D) — Ratio of the weight in air of given volume of the impermeable portion of a permeable material (that is, the solid matter including its impermeable pores or voids) at a stated temperature, to the weight in air of an equal volume of distilled water at the stated temperature.

2.305.2 Bulk Specific Gravity (Specific Mass Gravity), G_m (D) — Ratio of the weight in air of given volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature, to the weight in air of an equal volume of distilled water at the stated temperature.

2.305.3 Specific Gravity of Solids, G (D) — Ratio of the weight in air of given volume of soil solids at a stated temperature, to the weight in air of an equal volume of distilled water at the stated temperature.

2.306 Specific Surface (L^{-1}) — The surface area per unit volume of soil particles.

2.307 Stability Number, N_s (D) — A pure number used in the analysis of the stability of a soil embankment, defined by the following equation:

$$N_s = \frac{c_d}{\gamma_c H_c}$$

where

c_d = mobilized cohesion,

γ_c = effective unit weight, and

H_c = critical height of the sloped bank.

2.308 Stability Factor (D) — It is the reciprocal of the stability number.

2.309 Stabilization — See 'Soil Stabilization'.

2.310 Standard Compaction — See 'Compaction Test'.

2.311 Standard Penetration Resistance — Number of blows required for 30 cm penetration of a standard sampling spoon with a 65 kg hammer falling freely through a height of 75 cm.

2.312 Strain, ϵ, e (D) — The change in length per unit of length in a given direction.

2.313 Streamline Flow — See 'Laminar Flow'.

2.314 Stress, $\sigma, p, f(FL^{-2})$ — The force per unit area acting within the soil mass.

2.314.1 Effective Stress (Effective Pressure) (Inter-granular Pressure), $\bar{\sigma}, f(FL^{-2})$ — The average normal force per unit area transmitted from grain to grain of a soil mass. It is the stress which, to a large extent, controls the mechanical behaviour of a soil.

2.314.2 Neutral Stress (Pore Pressure) (Pore Water Pressure), $u, u_w(FL^{-2})$ — Stress transmitted through the pore water (water filling the voids of the soil).

2.314.3 Normal stress, $\sigma, p(FL^{-2})$ — The stress component normal to a given plane.

2.314.4 Principal Stress, $\sigma_1, \sigma_2, \sigma_3(FL^{-2})$ — Stresses acting normal to three mutually perpendicular planes intersecting at a point in a body, on which the shearing stress is zero.

2.314.4.1 Intermediate principal stress, $\sigma_2(FL^{-2})$ — The principal stress whose value is neither the largest nor the smallest (with regard to sign) of the three.

2.314.4.2 Major principal stress, $\sigma_1(FL^{-2})$ — The largest (with regard to sign) principal stress.

2.314.4.3 Minor principal stress, $\sigma_3(FL^{-2})$ — The smallest (with regard to sign) principal stress.

2.314.5 Shear Stress (Shearing Stress) (Tangential Stress), $\tau, s(FL^{-2})$ — The stress component tangential to a given plane.

2.314.6 Total Stress, $\sigma, f(FL^{-2})$ — The total force per unit area acting within a mass of soil. It is the sum of the neutral and effective stresses.

2.315 Structure — See 'Soil Structure'.

2.316 Sub-base — A layer used in a pavement system between the subgrade and base course, or between the subgrade and cement concrete pavement.

2.317 Subgrade — The soil prepared and compacted to support the pavement system.

2.318 Subgrade Surface — The surface of the earth or rock prepared to support the pavement system.

2.319 Submerged Unit Weight — See 'Unit Weight'.

2.320 Subsoil

- a) Soil below a subgrade or fill.
- b) That part of a soil profile occurring below 'A' horizon.

2.321 Talus — Rock fragments mixed with soil at the foot of a natural slope from which they have been separated.

2.322 Tangential Stress — See 'Stress'.

2.323 Theoretical Time Curve — See 'Consolidation Time Curve'.

2.324 Thermo-Osmosis — The process by which water is caused to flow in the pores of a soil mass due to differences in temperature within the mass.

2.325 Thixotropy — It is the property of certain clays by virtue of which they regain, on standing for a short time, a part of the original strength lost due to remoulding, at unaltered moisture content.

2.326 Till — See 'Glacial Till'.

2.327 Time Curve — See 'Consolidation Time Curve'.

2.328 Time Factor, T_v , $T(D)$ — Dimensional factor, utilized in the theory of consolidation, containing the physical constants of a soil stratum influencing its time-rate of consolidation, expressed as follows:

$$T = \frac{k(1+e)t}{a_v \gamma_w H^2} = \frac{c_v t}{H^2}$$

where

k = coefficient of permeability (LT^{-1});

e = void ratio (dimensionless);

t = elapsed time that the stratum has been consolidated (T);

a_v = coefficient of compressibility ($L^2 F^{-1}$);

γ_w = unit weight of water (FL^{-3});

c_v = coefficient of consolidation ($L^2 T^{-1}$); and

H = thickness of stratum drained on one side only. If stratum is drained on both sides, its thickness equals $2H$ (L).

2.329 Top Soil — Surface soil, usually containing organic matter.

2.330 Torsional Shear Test — A shear test in which

a relatively thin test specimen of solid circular or annular cross-section, usually confined between rings, is subjected to an axial load and to shear in torsion. In-place torsion shear tests may be performed by pressing a dentated solid circular or annular plate against the soil and measuring its resistance to rotation under a given axial load.

2.331 Total Stress — See 'Stress'.

2.332 Toughness Index, $I_T(D)$ — The ratio of the plasticity index to the flow index.

2.333 Transformed Flow Net — A flow net whose boundaries have been properly modified (transformed) so that a net consisting of curvilinear squares can be constructed to represent flow conditions in an anisotropic porous medium.

2.334 Transported Soil — Soil transported from the place of its origin by wind, water, or ice.

2.335 Triaxial Shear Test (Triaxial Compression Test) — A test in which a cylindrical specimen of soil encased in an impervious membrane is subjected to a confining pressure and then loaded axially to failure.

2.336 Turbulent Flow — That type of flow in which any particle may move in any direction with respect to any other particle, and in which the head loss is approximately proportional to the second power of the velocity.

2.337 Ultimate Bearing Capacity (Gross), q_0 (gross), q_{ult} (gross) (FL^{-2}) — The gross intensity of loading at the base of a foundation which causes shear failure of the soil support.

2.338 Ultimate Bearing Capacity (Nett), q_0 (nett), q_{ult} (nett) (FL^{-2}) — The nett intensity of loading at the base of a foundation which causes shear failure of the soil support, in excess of that at the same level due to the surrounding surcharge, that is, ultimate bearing capacity (gross) minus the surcharge.

2.339 Unconfined Compressive Strength, $p_c q_u$ (FL^{-2}) — The load per unit area at which an unconfined prismatic or cylindrical specimen of standard dimensions of a soil will fail in a simple compression test.

2.340 Unconsolidated-Undrained Test (Quick Test) — A soil test in which the water content of the test specimen remains practically unchanged during the application of the confining pressure and the additional axial (or shearing force).

2.341 Under-Consolidated Soil Deposit — A deposit that is not fully consolidated under the existing effective overburden pressure.

2.342 Undisturbed Sample — A soil sample that has been obtained by methods in which every precaution has been taken to minimize disturbance to the sample.

2.343 Unit Weight, γ (FL^{-3}) — Weight per unit volume of a soil mass.

2.343.1 Dry Unit Weight, γ_d (FL^{-3}) — The weight of oven dry soil (soil solids) per unit of total volume of soil mass.

2.343.2 Effective Unit Weight, γ_e (FL^{-3}) — That unit weight of a soil which, when multiplied by the height of the overlying column of soil, yields the effective pressure due to the weight of the overburden.

2.343.3 Saturated Unit Weight, γ_{sat} (FL^{-3}) — The unit weight of a soil mass when saturated.

2.343.4 Submerged Unit Weight, γ_{sub} (FL^{-3}) — The weight of the solids in air minus the weight of water displaced by the solids per unit volume of soil mass; the saturated unit weight minus the unit weight of water.

2.343.5 Wet Unit Weight (Mass Unit Weight), γ_m , γ_{wet} (FL^{-3}) — The weight (solids plus water) per unit of total volume of soil mass, irrespective of the degree of saturation.

2.344 Uplift — The upward water pressure on a structure:

	Symbol	Unit
Unit uplift	u	FL^{-2}
Total uplift	U	F

2.345 Vane Shear Test — A laboratory or in-place shear test in which a rod with thin radial vanes at the end is forced into the soil and the resistance to rotation of the vane is determined.

2.346 Varved Clay — Alternating thin layers of silt (or fine sand) and clay formed by variations in sedimentation during the various seasons of the year, often exhibiting contrasting colours when partially dried.

2.347 Virgin Compression Curve — See 'Compression Curve'.

2.348 Viscous Flow — See 'Laminar Flow'.

2.349 Void — Space in a soil mass not occupied by solid mineral matter. This space may be occupied by air, water, or other gaseous or liquid material.

2.350 Void Ratio, e (D) — The ratio of the volume of void space to the volume of solid particles in a given soil mass.

2.350.1 Critical Void Ratio, e_c (D) — The void ratio prior to the process of shear in which the nett volume change at failure is zero.

2.351 Volumetric Shrinkage (Volumetric Change), V_s (D) — The decrease in volume, expressed as a percentage of the soil mass when dried, of a soil mass when the water content is reduced from a given percentage to the appropriate shrinkage limit.

2.352 Wall Friction, f' (FL^{-2}) — Frictional resistance mobilized between a wall and the soil in contact with the wall.

2.353 Water Content — See 'Moisture Content'.

2.354 Water Holding Capacity (D) — The smallest value to which the water content of a soil can be reduced by gravity drainage.

2.355 Water Plasticity Ratio — See 'Liquidity Index'.

2.356 Water Table — See 'Free Water Elevation'.

2.357 Water Voids Ratio, e_w (D) — Ratio of volume of water to volume of solids in a soil mass.

2.358 Wet Unit Weight — See 'Unit Weight'.

2.359 Zero Air Voids Curve (Saturation Curve) — Dry density moisture content curve for 100 percent saturation.

Indian Standard

GLOSSARY OF TERMS RELATING TO SOIL DYNAMICS

(First Revision)

0. FOREWORD

0.1 A number of Indian Standards covering testing, site investigation for foundations, etc, has been either published or is under preparation; these include a large number of technical terms relating to soil engineering. The extensive use of these terms has necessitated the preparation of this glossary. This standard was originally published in 1964. This revision has been prepared so as to include a number of new terms besides making the existing terms up-to-date.

1. SCOPE

1.1 This standard covers definitions of terms relating to soil dynamics. The symbols of some of the terms are also given.

2. DEFINITIONS

2.1 Accelerograph — An instrument for recording ground acceleration as picked up by the acceleration pick-up.

2.2 Accelerogram — A graphical record of acceleration *versus* time obtained from the accelerograph.

2.3 Acceleration Pick-up — An instrument for measuring the absolute accelerations of vibrations.

2.4 Amplitude — Maximum displacement from mean position or position of static equilibrium.

2.4.1 Double Amplitude — Amplitude measured from peak-to-peak of the wave.

2.5 Anvil — A base block for a hammer on which material is forged into shape by repeated striking of the tup.

2.6 Attenuation — Decay or reduction of amplitude or change in waveform due to energy dissipation with distance and time.

2.7 Coefficient of Elastic Non-uniform Compression (C_{ϕ}) — It is the ratio of external non-uniform pressure to the elastic part of the settlement.

2.8 Coefficient of Elastic Uniform Compression (C_u) — It is the ratio of external uniform pressure to the elastic part of the settlement.

2.9 Coefficient of Elastic Non-uniform Shear (C_v) — It is the ratio of the external moment applied to

the vertical axis to the product of polar moment of inertia of contact area of base of foundation and the angle of rotation of the foundation.

2.10 Coefficient of Elastic Uniform Shear (C_r) — It is the ratio of average shear stress at the foundation contact area to the elastic part of the displacement in sliding.

2.11 Coefficient of Subgrade Reaction (C_p) — It is the ratio of the pressure intensity to the corresponding settlement.

2.12 Critical Hydraulic Gradient (i) — It is the hydraulic gradient at which the seepage force balances the weight of the soil.

2.13 Cycle — The full sequence of a periodic quantity occurring during a period.

2.14 Damping Characteristics — Characteristics of the system by which the motion is retarded by energy dissipation.

2.14.1 Critical Damping Coefficient (C_c) — It is the value of damping coefficient which determines the case between periodic and aperiodic motion.

2.14.2 Damping Coefficient (C) — It is the ratio of the damping forces to the velocity.

2.14.3 Damping Factor (D) — It is the ratio of the damping coefficient (C) to the critical damping coefficient (C_c).

2.14.4 Viscous Damping — Where damping force is proportional to the velocity of the system.

2.15 Damage Potential — A measure of the damage causing capacity of a ground motion.

2.16 Degree of Freedom — Number of independent co-ordinates required to define a vibratory system.

2.17 Drop Hammer — A forge hammer used for die stamping where the side frame is mounted on the anvil.

2.18 Dynamic Compaction — Compaction produced by vibration or impact or blasting.

2.18.1 Blasting — Detonating small charges of explosive at predetermined points to increase the density of the soil.

2.18.2 Impact — Increasing the density of the soil by the application of pressure, by impact or falling of weights at predetermined points.

2.19 Dynamic Loading — A phenomenon giving rise to dynamic loading.

2.19.1 Earthquake — Soil samples are subjected to simplified load patterns taking into account the stress prior to and during the occurrence of earthquake.

2.19.2 Transient — Loading of short duration, generally applied on soil sample to simulate the condition of blast loading.

2.19.3 Vibratory — A load which repeats with time and has period comparable in relation to period of the system.

2.20 Dynamic Load Factor — Ratio of dynamic response to static response of the system.

2.21 Dynamic Shear Apparatus — An apparatus with provision for applying shear stresses (stress-controlled) or shear strains (strain-controlled) similar to one expected during a dynamic phenomenon.

2.21.1 Oscillatory Shear Box — A dynamic shear apparatus where soil samples are subjected to simple shear deformation under known shear stresses at known frequencies.

2.21.2 Direct Shear — A dynamic shear apparatus, where the normal and shear stresses can be cycled either independently or simultaneously.

2.21.3 Dynamic Triaxial — A dynamic shear apparatus where the deviator stress and the confining pressure can be cycled at known frequency, either independently or simultaneously.

2.21.4 Resonance Column Apparatus — An apparatus in which a cylindrical (solid and hollow) sample of soil can be excited at different frequencies for determination of dynamic soil properties (dynamic shear modulus).

2.22 Excursion — Variation of dependent variables from mean value or variation of wave from centre line.

2.23 Flow Slides Due to Vibration — The flow of loose soil mass because of earthquake loading.

2.24 Forced Vibration — Motion of a system, when an external periodic force is impressed on the system.

2.25 Free Vibration — Vibrations of a system when displaced from its equilibrium position and left free to vibrate.

2.26 Frequency — The rate at which a motion is repeated in a vibrating system, expressed in radians/second, cycles/second or rev/min.

2.26.1 Damped Natural Frequency — The natural frequency considering damping in the system.

2.26.2 Natural Frequency — The frequency at which a system vibrates under the effect of forces inherent in the system.

2.26.3 Operating Frequency — The frequency at which the machine is operating.

2.26.4 Resonant Frequency — The frequency at which the maximum response occurs in a system subjected to forced vibrations.

2.26.5 Undamped Natural Frequency — Natural frequency without considering damping.

2.27 Frequency Ratio — The ratio of the forcing frequency to the natural frequency of a system.

2.28 Inertia Force — The product of the mass of a system and the acceleration.

2.29 Liquefaction — The phenomenon by which a submerged cohesionless soil loses its strength.

2.30 Logarithmic Decrement — The natural logarithm of the ratio of any two successive amplitudes of same sign in decay curve obtained in free vibration.

2.31 Loading — See 2.19.

2.32 Magnification Factor — It is ratio of the dynamic amplitude to the static displacement.

2.33 Mass Ratio (*b*) — It is the ratio of the mass of machine foundation to the product of mass density and cube of the equivalent radius of the base.

2.34 Mode of Vibration — A characteristic pattern assumed by a system in which the motion of every particle is simple harmonic with same frequency.

2.35 Modulus of Deformation — It is the secant modulus of a soil between the pressure range of zero and half yield stress.

2.36 Modulus of Subgrade Reaction — It is the ratio of the pressure intensity to the corresponding total settlement.

2.37 Motion

2.37.1 Aperiodic — When there is non-regularity of the system in crossing its equilibrium position during motion.

2.37.2 Periodic — When the system in motion crosses the equilibrium position at definite intervals of time.

2.37.3 Steady State — When a system is under a sinusoidal forced vibration and the response of the system is also sinusoidal.

2.37.4 Transient — When a system is subjected to a sudden displacement.

2.38 Natural Frequency — See 2.26.2.

2.39 Node — Point, line or surface of standing wave system at which amplitude is zero.

2.40 Oscillator

2.40.1 Electromagnetic — Electromagnetic unit to produce oscillation. Dynamic load is constant and independent of frequency.

2.40.2 Mechanical — Mechanical unit to produce sinusoidal, unidirectional force with action line through centre of oscillator by means of two unbalanced rotating masses. Dynamic load of a mechanical oscillator is frequency dependent.

2.41 Period — Time interval at which the cycle repeats.

2.42 Periodic Motion — See 2.37.2.

2.43 Phase Angle (Phase Difference) — Difference between phase angles of two waves of same frequency.

2.44 Pitching — Rotational vibration motion of the foundation block about the shorter horizontal axis.

2.45 Pressure Cell — A transducer to transform pressure into another physical quantity (usually electrical) whose magnitude can be more easily or conveniently measured.

2.46 Pseudostatic Analysis — Analysis in which dynamic action is replaced by an inertia force assumed to remain static.

2.47 Pulsating Stress — Stress which varies with time.

2.48 Resonance Characteristics — Quantitative expression of input *versus* output. Variables, such as force, displacement, velocity, acceleration, or power input are functions of frequency.

2.49 Resonance — A condition of maximum increase in amplitude of a vibrating system.

2.50 Resonant Frequency — See 2.26.

2.51 Resonant Tamping — Compaction by impact with blows at critical frequency.

2.52 Response Spectrum — The dynamic response of an idealized structure to an earthquake motion. The response can be expressed in terms of the maximum relative velocity S_v .

2.53 Rigid Body Response — Response of a system treating it as a rigid body.

2.54 Rocking — Rotational motion of the foundation block about the longer horizontal axis.

2.55 Screening of Vibrations — Protecting structure from influence of energy of elastic waves propagative in soils.

2.56 Seismic Coefficient — The rates of the design acceleration due to earthquake and the acceleration due to gravity.

2.57 Seismic Wave — Waves produced by any seismic activity.

2.58 Simple Harmonic — Simple harmonic motion

defined as the motion of a point in a straight line, such that acceleration of the points is proportional to the distance of the point from the mean position, and is always directed towards it.

2.59 Similitude — The technique of representing one system with another system with respect to force, time and length such that the result of one can be accurately predicted by the observations from the other.

2.60 Sinusoidal — Quantity varying according to sine law with line.

2.61 Spectral Response — See 2.52.

2.61.1 Spectral Acceleration — Spectral response expressed in terms of the maximum relative acceleration.

2.61.2 Spectral Displacement — Spectral response expressed in terms of the maximum relative displacement.

2.61.3 Spectral Velocity — Spectral response expressed in terms of the maximum relative velocity.

2.62 Strain Amplitude — The maximum strain from its position of rest, to extreme position of the vibrating particle.

2.63 Strain Gauge — Gauge for measuring strains in an elastic element of vibration.

2.64 Synchronous — Two rotating machines having identical frequency.

2.65 Time of Loading — It is the time from the application of stress to the time of reaching the maximum stress.

2.66 Time Period — See 2.41.

2.67 Torsional Vibrations — Vibrations in torsional mode.

2.68 Transducer — Pick-up unit to transform mechanical input into electrical output.

2.69 Transient Strength — Strength of soil under transient loading.

2.70 Transmissibility

2.70.1 Force — Force transmitted by a vibrating system to its support.

2.70.2 Motion — Motion transmitted by a vibrating system to its support.

2.71 Tuning Factor — Ratio of exciter frequency to natural frequency.

2.72 Tup — Falling part of the hammer.

2.73 Vibrations Absorber — Pad of an elastic material introduced to reduce transmissibility of vibrations.

2.74 Vibrometer — Instrument which measures the phase, velocity and acceleration of vibrations.

2.75 Wave — Disturbance propagated in medium in such a manner that at any point in medium the amplitude is a function of time, while at any instant the displacement at point is function of position of point.

2.76 Wave Front — The surface which is the locus of all points having motion in identical phase propagating in a wave, the direction of propagation being perpendicular to the wave front.

2.77 Wavelength — Normal distances between two wave fronts with periodic characteristics in which amplitudes have phase difference of one complete cycle.

2.78 Wave Types

2.78.1 Longitudinal Wave or Primary Wave — Wave in which direction of displacement at each point of medium is normal to wave front with propagation velocity, calculated as follows:

$$v_1 \text{ or } v_p = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \\ = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

where

v_1, v_p = velocity of longitudinal wave,
 ρ = mass density,
 E = Young's modulus,
 λ, μ = Lame's constants, and
 ν = Poisson's ratio.

2.78.2 Rayleigh Wave — Dispersive surface wave in which element has retrograding elliptic orbit with one major vertical and one minor horizontal component, both in plane of propagation velocity.

v_R = velocity of Rayleigh wave
 $= \alpha v_t$ with $0.910 < \alpha < 0.995$
for $0.25 < \nu < 0.50$

where

α = angle of obliquity, and
 v_t = propagation velocity of transverse waves.

2.78.3 Reflected (or Refracted) Wave — Components of wave incident upon second medium and reflected into first medium (or refracted into second medium).

2.78.4 Shear Wave (Rotational Equivoluminal) — Wave in which medium changes shape without change of volume (shear plane wave in isotropic medium is transverse wave).

2.78.5 Transverse Wave — Wave in which the direction of displacement of element of medium is parallel to wave front. The propagation velocity v_t is calculated as follows:

$$v_t = \sqrt{\frac{G}{\rho}} = \sqrt{\frac{\mu}{\rho}} = \sqrt{\frac{E}{2\rho(1+\nu)}}$$

where

G = shear modulus,
 ρ = mass density,
 ν = Poisson's ratio,
 E = Young's modulus, and
 μ = Lame's constant.

2.79 Yawing — Rotational motion of the foundation block about its vertical axis.

2.80 Yield Acceleration — The acceleration at which yielding of a slope of material occurs.

2.81 Zoning — The various zones into which a country may be divided for design of structures, etc, based upon the seismic coefficient.

SECTION 2

Classification and Identification of Soils

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Indian Standard

CLASSIFICATION AND IDENTIFICATION OF SOILS FOR GENERAL ENGINEERING PURPOSES

(First Revision)

0. FOREWORD

0.1 Soil survey and soil classification are at present being done by several organizations in this country for different purposes. The engineering departments and research laboratories have done a great deal of work in regard to soil exploration and classification in fields relating to irrigation, buildings, roads, etc. The investigations relating to the field of irrigation have two objectives, namely, the suitability of soil for the construction of dams and other kinds of hydraulic structures, and the effect on the fertility of soil when it is irrigated. With regard to roads and highways, investigations have been undertaken to classify them from the point of view of their suitability for construction of embankments, sub-grades and wearing surfaces. In the field of buildings, soil investigation and classification is done to evaluate the soil as regards its bearing power to a certain extent. Soil survey and soil classification are also done by agriculture departments from the point of view of the suitability of the soil for crops and its fertility. Each of these agencies was adopting different systems for soil classification. The adoption of different methods by various agencies led to difficulties in interpreting the results of soils investigated by one agency by the other and quite often results were found to be not easily comparable. This Indian Standard was, therefore, published in 1959 to provide a common basis for soil classification.

0.2 Soils seldom exist in nature separately as sand, gravel or any other single component but are usually found as mixture with varying proportions of particles of different sizes. This revision is essentially based on the Unified Soil Classification System with the modification that the fine-grained soils have been subdivided into three subdivisions of low, medium and high compressibility, instead of two subdivisions of the original Unified Soil Classification System. The system is based on those characteristics of the soil which indicate how it will behave as a construction material. This system is not limited to a particular use or geographical location. It does not conflict with other systems; in fact, the use of geologic, pedologic, textural or local terms is encouraged as a supplement to, but not as a substi-

tute for, the definitions, terms and phrases established by this system and which are easy to associate with actual soils.

1. SCOPE

1.1 This standard covers a system for classification and identification of soils for general engineering purposes. The information given in this standard should be considered for guidance only for treating the soil for engineering purposes.

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS : 2809-1972 'Glossary of terms and symbols relating to soil engineering (*first revision*)' and the following shall apply.

2.1 Clay — An aggregate of microscopic and sub-microscopic particles derived from the chemical decomposition and disintegration of rock constituents. It is plastic within a moderate to wide range of water content.

2.2 Silt — A fine-grained soil with little or no plasticity. If shaken in the palm of the hand, a part of saturated inorganic silt expels enough water to make its surface appear glossy. If the pat is pressed or squeezed between the fingers, its surface again becomes dull.

2.3 Sand and Gravel — Cohesionless aggregates of angular, sub-angular, sub-rounded, rounded, flaky or flat fragments of more or less unaltered rocks or minerals.

According to this system, gravel is a fraction of the soil material between 80 mm and the 4.75-mm IS Sieve size, and sand is the material between the 4.75-mm IS Sieve size and the 75-micron IS Sieve size.

3. CLASSIFICATION AND IDENTIFICATION

3.1 Division — Soils shall be broadly divided into three divisions as given in 3.1.1 to 3.1.3.

3.1.1 Coarse-Grained Soils — In these soils, more than half the total material by weight is larger than 75-micron IS Sieve size.

3.1.2 Fine-Grained Soils — In these soils, more

than half of the material by weight is smaller than 75-micron IS Sieve size.

3.1.3 Highly Organic Soils and Other Miscellaneous Soil Materials — These soils contain large percentages of fibrous organic matter, such as peat, and particles of decomposed vegetation. In addition, certain soils containing shells, concretions, cinders, and other non-soil materials in sufficient quantities are also grouped in this division.

3.2 Subdivision — The first two divisions (see 3.1.1 and 3.1.2) shall be further divided as given in 3.2.1 and 3.2.2.

3.2.1 Coarse-Grained Soils — The coarse-grained soils shall be divided into two subdivisions, namely:

- Gravels** — In these soils, more than half the coarse fraction (+75 micron) is larger than 4.75-mm IS Sieve size. This subdivision includes gravels and gravelly soils.
- Sands** — In these soils, more than half the coarse fraction (+75 micron) is smaller than 4.75-mm IS Sieve size. This subdivision includes sands and sandy soils.

3.2.2 Fine-Grained Soils — The fine-grained soils shall be further divided into three subdivisions on the basis of the following arbitrarily selected values of liquid limit:

- Silts and clays of low compressibility** — having a liquid limit less than 35 (represented by symbol *L*),
- Silt and clays of medium compressibility** — having a liquid limit greater than 35 and less than 50 (represented by symbol *I*), and
- Silts and clays of high compressibility** — having a liquid limit greater than 50 (represented by symbol *H*).

NOTE — In this system the fine-grained soils are not divided according to particle size but according to plasticity and compressibility. The term 'compressibility' here shall imply volume change, shrinkage during dry periods and swelling during wet periods, as well as, consolidation under load. Soil particles finer than 2-micron may, however, be designated as clay-size particles and the particles between 75-micron and 2-micron as silt-size particles.

3.3 Groups — The coarse-grained soils shall be further divided into eight basic soil groups. The fine-grained soils shall be further divided into nine basic soil groups (see Table 2).

3.3.1 Highly organic soils and other miscellaneous soil materials shall be placed in one group. The groups shall be designated by symbols.

NOTE — These groups are broad, based on basic properties of soil; therefore, supplemental detailed word descriptions are required to point out peculiarity of a particular soil and differentiate it from others in the same group.

3.3.2 The basic soil components are given in Table 1.

3.3.3 The various subdivisions, groups and group symbols are given in Table 2.

3.4 Field Identification and Classification Procedure — The field method is used primarily in the field to classify and describe soils. Visual observations are employed in place of precise laboratory tests to define the basic soil properties. The procedure is, in fact, a process of elimination beginning on the left side of the classification chart (Table 2) and working to the right until the proper group name is obtained. The group name should be supplemented by detailed word descriptions, including the description of the in-place conditions for soils to be used in place as foundations. A representative sample of the soil is selected which is spread on a flat surface or in the palm of the hand. All particles larger than 75 mm are removed from the sample. Only the fraction of the sample smaller than 75 mm is classified. The sample is classified as coarse-grained or fine-grained by estimating the percentage by weight of individual particles which can be seen by the unaided eye. Soils containing more than 50 percent visible particles are coarse-grained soils, soils containing less than 50 percent visible particles are fine-grained soils.

If it has been determined that the soil is coarse grained, it is further identified by estimating and recording the percentage of: (a) gravel sized particle, size range from 75 mm to 4.75-mm IS Sieve size (or approximately 5 mm size); (b) sand size particles, size range from 4.75 to 75-micron IS Sieve size; and (c) silt and clay size particles, size range smaller than 75-micron IS Sieve.

NOTE — The fraction of soil smaller than 75-micron IS Sieve, that is, the clay and silt fraction is referred to as fines.

3.4.1 Gravelly Soils — If the percentage of gravel is greater than that of sand, the soil is a gravel. Gravels are further identified as being clean (containing little or no fines, that is, less than 5 percent) or dirty (containing appreciable fines, that is, more than 12 percent) depending upon the percentage of particles not visible to the unaided eye. Gravels containing 5 to 12 percent fines are given boundary classification. If the soil is obviously clean, the classification shall be either: (a) well-graded gravel (GW), if there is good representation of all particle sizes; or (b) poorly graded gravel (GP), if there is an excess or absence of intermediate particle sizes. A well-graded soil has a reasonably large spread between the largest and the finest particles, and has no marked deficiency in any size. If the soil obviously is dirty, the classification will be either (c) silty gravel (GM), if the fines have little or no plasticity; or (d) clayey gravel (GC), if the fines are of low to medium or high plasticity (see 3.2.2).

3.4.2 Sandy Soils — If the percentage of sand is greater than gravel, the soil is a sand. The same procedure is applied as for gravels except that the word sand replaces gravel and the symbols S replaces G. The group classification for the clean sands will be either: (a) well-graded sand (SW) or (b) poorly-graded sand (SP), and the dirty sands shall be classified as (c) silty sand (SM), if the fines have little or no plasticity; or (d) clayey sand (SC), if the fines are of low to medium or high plasticity (see 3.2.2).

3.4.3 Boundary Classification for Coarse-Grained Soils — When a soil possesses characteristics of two groups, either in particle size distribution or in plasticity, it is designated by combinations of group symbols. For example, a well-graded coarse-grained soil with clay binder is designated by GWG.

3.4.3.1 Boundary classification can occur within the coarse-grained soil division, between soils within the gravel or sand grouping, and between gravelly and sandy soils. The procedure is to assume the coarser soil, when there is a choice, and complete the classification and assign the proper group symbol; then, beginning where the choice was made, assume a finer soil and complete the classification, assigning the second group symbol.

3.4.3.2 Boundary classifications within gravel or sand groups can occur. Symbols such as GW-GP, GM-GC, GW-GM, GW-GC, SW-SP, SM-SC, SW-SM and SW-SC are common.

3.4.3.3 Boundary classifications can occur between the gravel and sand groups. Symbols such as GW-SW, GP-SP, GM-SM and GC-SC are common.

3.4.3.4 Boundary classifications can also occur between coarse and fine grained soils. Classifications such as SM-ML and SC-CL are common.

3.4.4 Descriptive Information for Coarse-Grained Soils — The following descriptive information shall be recorded for coarse-grained soils:

- a) Typical name;
- b) Maximum size, and fraction larger than 75 mm in the total material;
- c) Percentage of gravel, sand and fines in the soil or fraction of soil smaller than 75 mm
- d) Description of average size of sand or gravel;
- e) Shape of the particles—angular, subangular, subrounded, rounded;
- f) The surface coatings, cementation and hardness of the particles and possible breakdown, when compacted;
- g) The colour and organic content;
- h) Plasticity of fines;
- j) Local or geologic name, if known; and
- k) Group symbol.

3.4.5 Fine-Grained Soils — If it has been determined that the soil is fine-grained, it is further identified by estimating the percentage of gravel, sand, silt and clay size particles and performing the manual identification tests for dry strength, dilatancy, and toughness. By comparing the results of these tests with the requirements given for the nine fine-grained soil groups, the appropriate group name and symbol is assigned. The same procedure is used to identify the fine-grained fraction of coarse-grained soil to determine whether they are silty or clayey.

3.4.6 Manual Identification Tests — The following tests for identifying the fine-grained soils shall be performed on the fraction of the soil finer than the 425-micron IS Sieve:

- a) *Dilatancy (reaction to shaking)* — Take a small representative sample in the form of a soil pat of the size of about 5 cubic centimetres and add enough water to nearly saturate it. Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. Squeeze the pat between the fingers. The appearance and disappearance of the water with shaking and squeezing is referred to as a reaction. This reaction is called quick, if water appears and disappears rapidly; slow, if water appears and disappears slowly; and no reaction, if the water condition does not appear to change. Observe and record type of reaction as descriptive information.
- b) *Toughness (consistency near plastic limit)* — Dry the pat used in the dilatancy test by working and moulding, until it has the consistency of putty. The time required to dry the pat is the indication of its plasticity. Roll the pat on a smooth surface or between the palms into a thread about 3 mm in diameter. Fold and reroll the thread repeatedly to 3 mm in diameter so that its moisture content is gradually reduced until the 3 mm thread just crumbles. The moisture content at this time is called the plastic limit and the resistance to moulding at the plastic limit is called the toughness. After the thread crumbles, lump the pieces together and continue the slight kneading action until the lump crumbles. If the lump can still be moulded slightly drier than the plastic limit and if high pressure is required to role the thread between the palms of the hand, the soil is described as having high toughness. Medium toughness is indicated by a medium thread and a lump formed of the threads slightly below the plastic limit will crumble; while low toughness is indicated by a weak thread that breaks easily and cannot be lumped together when drier than the plastic

limit. Highly organic clays have very weak and spongy feel at the plastic limit. Non-plastic soils cannot be rolled into thread of 3 mm in diameter at any moisture content. Observe and record the toughness as descriptive information.

- c) *Dry strength (crushing resistance)* — Completely dry the prepared soil pat. Then measure its resistance to crumbling and powdering between fingers. This resistance, called dry strength, is a measure of the plasticity of the soil and is influenced largely by the colloidal fraction content. The dry strength is designated as low, if the dry pat can be easily powdered; medium, if considerable finger pressure is required and high, if it cannot be powdered at all. Observe and record the dry strength as descriptive information.

NOTE — The presence of high-strength water soluble cementing materials, such as calcium carbonates or iron oxides may cause high dry strength. Non-plastic soils, such as caliche, coral, crushed lime stone or soils containing carbonaceous cementing agents may have high dry strength, but this can be detected by the effervescence caused by the application of diluted hydrochloric acid.

- d) *Organic content and colour* — Fresh wet organic soils usually have a distinctive odour of decomposed organic matter. This odour can be made more noticeable by heating the wet sample. Another indication of the organic matter is the distinctive dark colour. In tropical soils, the dark colour may be or may not be due to organic matter; when not due to organic matter, it is associated with poor drainage. Dry organic clays develop an earthy odour upon moistening, which is distinctive from that of decomposed organic matter.

e) *Other identification tests*

- 1) *Acid test* — Acid test using dilute hydrochloric acid (HCl) is primarily a test for the presence of calcium carbonate. For soils with high dry strength, a strong reaction indicates that the strength may be due to calcium carbonate as cementing agent rather than colloidal clay. The results of this test should be included in the soil description, if pertinent.
- 2) *Shine test* — This is a quick supplementary procedure for determining the presence of clay. The test is performed by cutting a lump of dry or slightly moist soil with a knife. The shiny surface imparted to the soil indicates highly plastic clay, while a dull surface indicates silt or clay of low plasticity.
- 3) *Miscellaneous test* — Other criteria undoubtedly may be developed by the indi-

vidual as he gains experience in classifying the soils. For example, differentiation between some of the fine-grained soils depends largely upon the experience in the feel of the soils. Also wet clay sticks to the fingers and dries slowly but silt dries fairly quickly and can be dusted off the fingers leaving only a stain. Frequent checking by laboratory tests is necessary to gain this experience.

3.4.7 Boundary Classification for Fine-Grained Soils — Boundary classifications can occur within the fine-grained soil divisions, between low and medium or between medium and high liquid limits, and between silty and clayey soils. The procedure is comparable to that given for coarse-grained soils (see 3.4.3), that is, first assume a coarse soil, when there is a choice, and then a finer soil and assign dual group symbols. Boundary classifications, which are common are as follows:

ML-MI, CL-CI, OL-OI, MI-MH, CI-CH, OI-OH, CL-ML, ML-OL, CL-OL, CI-MI, MI-OI, CI-OI, MH-CH, MH-OH, and CH-OH.

3.4.8 Very Highly Organic Soils — Peat or very highly organic soils may be readily identified by colour, sponginess or fibrous texture.

3.4.9 Descriptive Information for Fine-Grained Soils — The following descriptive information shall be recorded for fine-grained soils:

- a) *Typical name;
- b) Percentage of gravel, sand and fines;
- c) Colour in moist condition and organic content;
- d) Plasticity characteristics;
- e) Local or geologic name, if known; and
- f) Group symbol.

3.4.10 Description of Foundation Soils — The following information shall be recorded to define the in-place condition of soils which are to be utilized as foundation for hydraulic or other structures:

a) *For coarse-grained soils:*

- 1) Natural moisture content (as dry, moist, wet and saturated);
- 2) Perviousness or drainage properties in the natural condition;
- 3) Structure (as stratified, uniform, un cemented, lensed; and attitude, that is, strike and dip);
- 4) Type and degree of cementation; and
- 5) Degree of compactness (as loose or dense).

b) *For fine-grained soils:*

- 1) Natural moisture content (as dry, moist, wet and saturated);
- 2) Perviousness or drainage properties;
- 3) Structures (as stratified, homogeneous,

varved, honeycomb, root-holes, blocky, fissured, lensed; and attitude, that is, strike and dip). The thickness of lenses, fissures, etc, shall be noted;

- 4) Type and degree of cementation; and
- 5) Consistency (very soft, soft, firm, hard, very hard, sticky, brittle, friable and spongy).

NOTE — The consistency and the compactness of undisturbed soil should be defined clearly from the consistency of the soil when disturbed and manipulated. For example, a very thick stratum of hard, dense shale or pre-consolidated clay of high bearing capacity, not requiring piling, may be correctly classified as a fat clay (CH) of high plasticity. Obviously the classification without description of undisturbed condition might cause the interpreter to erroneously conclude that it is soft and plastic in its natural state.

3.5 Laboratory Identification and Classification Procedure

The laboratory method is intended for precise delineation of the soil groups by using results of laboratory tests, for gradation and moisture limits, rather than visual estimates. Classification by these tests alone does not fulfil the requirements for complete classification, as it does not provide an adequate description of the soil. Therefore, the descriptive information required for the field method should also be included in the laboratory classification.

3.5.1 Classification Criteria for Coarse-Grained Soils — The laboratory classification criteria for classifying the coarse-grained soils are given in Tables 3 and 4.

3.5.2 Boundary Classification for Coarse-Grained Soils — The coarse-grained soils containing between 5 and 12 percent of fines are classified as border line cases between the clean and the dirty gravels or sands as, for example, GW-GC, or SP-SM. Similarly border line cases might occur in dirty gravels and dirty sands, where the I_p is between 4 and 7 as, for example, GM-GC or SM-SC. It is possible, therefore, to have a border line case of a border line case. The rule for correct classification in this case is to favour the non-plastic classification. For example, a gravel with 10 percent fines, a Cu of 20, a Cc of 2.0 and I_p of 6 would be classified GW-GM rather than GW-GC (I_p is the plasticity index of the soil).

3.5.3 Classification Criteria for Fine-Grained Soils — The laboratory classification criteria for classifying the fine-grained soils are given in the plasticity chart shown in Fig. 1 and Table 4. The 'A' line has the following linear equation between the liquid limit and the plasticity index:

$$I_p = 0.73 (w_L - 20)$$

where

I_p = plasticity index, and

w_L = liquid limit.

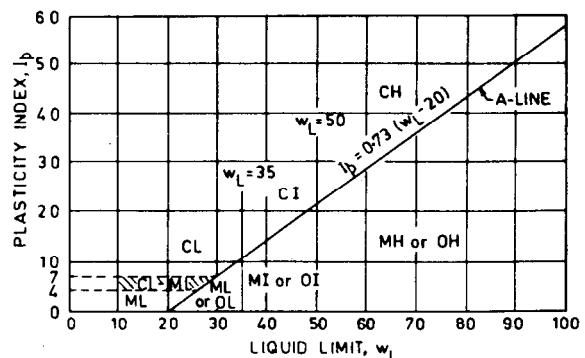


FIG. 1 PLASTICITY CHART

3.5.3.1 Organic silt and clays are usually distinguished from inorganic silts which have the same position on the plasticity chart, by odour and colour. However, when the organic content is doubtful, the material can be oven-dried, remixed with water, and retested for liquid limit. The plasticity of fine-grained organic soils is greatly reduced on oven-drying, owing to irreversible changes in the properties of the organic material. Oven drying also affects the liquid limit of inorganic soils, but only to a small degree. A reduction in liquid limit after oven drying to a value less than three-fourth of the liquid limit before oven drying is positive identification of organic soils.

3.5.4 Boundary Classification for Fine-Grained Soils — The fine-grained soils whose plot on the plasticity chart falls on, or practically on:

- a) 'A' line,
- b) ' $w_L = 35$ ' line and
- c) ' $w_L = 50$ ' line;

shall be assigned the proper boundary classification. Soils which plot above the 'A' line, or practically on it, and which have plasticity index between 4 and 7 are classified ML-CL.

3.6 Black Cotton Soils — Black cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. They are predominantly montmorillonitic in structure and black or blackish grey in colour. They are characterized by high shrinkage and swelling properties. The majority of the soils, when plotted on the plasticity chart, lie along a band above the 'A' line. The plot of some of the black cotton soils is also found to lie below the 'A' line. Care should, therefore, be taken in classifying such soils.

3.7 Some other inorganic clays, such as kaolin, behave as inorganic silts and usually lie below the 'A' line and shall be classified as such (ML, MI, MH), although they are clays from mineralogical stand-point.

3.8 Relative Suitability for General Engineering Purposes — Table 5 gives the characteristics of the

various soil groups pertinent to roads and air-fields. Table 6 gives the characteristics pertinent to embankments and foundations. Table 7 gives the characteristics pertinent to suitability for canal sections, compressibility, workability as a construction material and shear strength. The information given in these tables should be considered as a guidance only for treating a soil for a particular engineering

purpose.

3.9 Degree of Expansion — Fine-grained soils, depending upon the presence of clay mineral, exhibit low to very high degree of expansion. Based upon Atterberg's limits and free swell for the soils, the degree of expansion and degree of severity for soils is shown in Table 8.

TABLE I BASIC SOIL COMPONENTS
(Clause 3.3.2)

SL No.	SOIL	SOIL COMPONENT	SYMBOL	PARTICLE-SIZE RANGE AND DESCRIPTION
(1)	(2)	(3)	(4)	(5)
i)	Coarse-grained components	Boulder	None	Rounded to angular, bulky, hard, rock particle; average diameter more than 300 mm
		Cobble	None	Rounded to angular, bulky, hard, rock particle; average diameter smaller than 300 mm but retained on 75 mm IS Sieve
		Gravel	G	Rounded to angular bulky, hard, rock particle; passing 75 mm IS Sieve but retained on 4.75-mm IS Sieve Coarse: 75 mm to 20-mm IS Sieve Fine: 20-mm to 4.75-mm IS Sieve
		Sand	S	Rounded to angular, bulky, hard, rock particle; passing 4.75-mm IS Sieve but retained on 75-micron IS Sieve Coarse: 4.75-mm to 2.0-mm IS Sieve Medium: 2.0-mm to 425-micron IS Sieve Fine: 425-micron to 75-micron IS Sieve
ii)	Fine-grained components	Silt	M	Particles smaller than 75-micron IS Sieve; identified by behaviour, that is, slightly plastic or non-plastic regardless of moisture and exhibits little or no strength when air dried
		Clay	C	Particles smaller than 75-micron IS Sieve; identified by behaviour, that is, it can be made to exhibit plastic properties within a certain range of moisture and exhibits considerable strength when air dried
		Organic matter	O	Organic matter in various sizes and stages of decomposition Coarse: 75 micron to 7.5 micron Fine: 75 micron to 2 micron

NOTE — A comparison between the size classifications of IS : 1498-1959 'Classification and identification of soils for general engineering purposes' and the present revision is shown in Appendix A.

TABLE 2 SOIL CLASSIFICATION (INCLUDING FIELD IDENTIFICATION AND DESCRIPTION)
(Clauses 3.3, 3.3.3 and 3.4)

DIVISION	SUB-DIVISION	GROUP LETTER SYMBOL	HATCHING	MAPPING COLOUR	TYPICAL NAMES	FIELD IDENTIFICATION PROCEDURES (EXCLUDING PARTICLES LARGER THAN 80 mm AND BASING FRACTIONS ON ESTIMATED WEIGHTS)			INFORMATION REQUIRED FOR DESCRIBING SOILS
						1	2	3	
COARSE-GRAINED SOILS More than half of material is larger than 75-micron IS Sieve size The smallest particle visible to the naked eye	Gravels More than half of coarse fraction is larger than 4.75-mm IS Sieve size (For visual classification the 5-mm size may be used as equivalent to the 4.75-mm IS Sieve size)	Clean gravels (Little or no fines)	GW		Red	Well graded gravels, gravel-sand mixtures; little or no fines	Wide range in grain sizes and substantial amounts of all intermediate particle sizes	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics	
		Gravels with fines (Appreciable amount of fines)	GP		Red	Poorly graded gravels or gravel-sand mixtures; little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing	Give typical name; indicate approximate percentages of sand and gravel; maximum size, angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses	
		Clean sands (Little or no fines)	GM		Yellow	Silty gravels, poorly graded gravel-sand-silt mixtures	Non-plastic fines or fines with low plasticity (for identification procedures, see ML and MI below)	Examples: Silty sand, gravelly; about 20 percent hard angular gravel particles, 10 mm maximum size; rounded and subangular sand grains; about 15 percent non-plastic fines with a low dry strength; well compacted and moist; inplace; alluvial sand (SM)	
		Sands with fines (Appreciable amount of fines)	GC		Yellow	Clayey gravels, poorly graded gravel-sand-clay mixtures	Plastic fines (for identification procedures, see CL and CI below)		
		Clean sands (Little or no fines)	SW		Red	Well graded sands, gravelly sands; little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes		
		Sands with fines (Appreciable amount of fines)	SP		Red	Poorly graded sands or gravelly-sands; little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing		
		SM		Yellow	Silty sands, poorly graded sand-silt mixtures	Non-plastic fines or fines with low plasticity (for intermediate procedures, see ML and MI below)			
		SC		Yellow	Clayey sands, poorly graded sand-clay mixtures	Plastic fines (for identification procedures, see CL and CI below)			
	Silts and clays with low compressibility and liquid limit less than 35 Silts and clays with medium compressibility and liquid limit greater than 35 and less than 50 Silts and clays with high compressibility and liquid limit greater than 50	ML				IDENTIFICATION PROCEDURES (ON FRACTION SMALLER THAN 425-MICRON IS SIEVE SIZE)			
				Blue	Inorganic silts and very fine sands rock flour, silty or clayey fine sands or clayey silts with none to low plasticity	None to low	Quick	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions
				Green	Inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of low plasticity	Medium	None to very slow	Medium	
				Brown	Organic silts and organic silty clays of low plasticity	Low	Slow	Low	
		ML		Blue	Inorganic silts, silty or clayey fine sands or clayey silts of medium plasticity	Low	Quick to slow	None	
				Green	Inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of medium plasticity	Medium to high	None	Medium	
		OL		Brown	Organic silts and organic silty clays of medium plasticity	Low to medium	Slow	Low	
				Blue	Inorganic silts of high compressibility, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Low to medium	Slow to none	Low to medium	
		CH		Green	Inorganic clays of high plasticity, fat clays	High to very high	None	High	
				Brown	Organic clays of medium to high plasticity	Medium to high	None to very slow	Low to medium	
Highly Organic Soils	Pt		Orange	Peat and other highly organic soils with very high compressibility	Readily identified by colour, odour, spongy feel and frequently by fibrous texture				

Note.—Boundary classification : Soil possessing characteristics of two groups are designated by combinations of group symbols, for example, GW-GC. Well-graded, gravel-sand mixture with clay binder.

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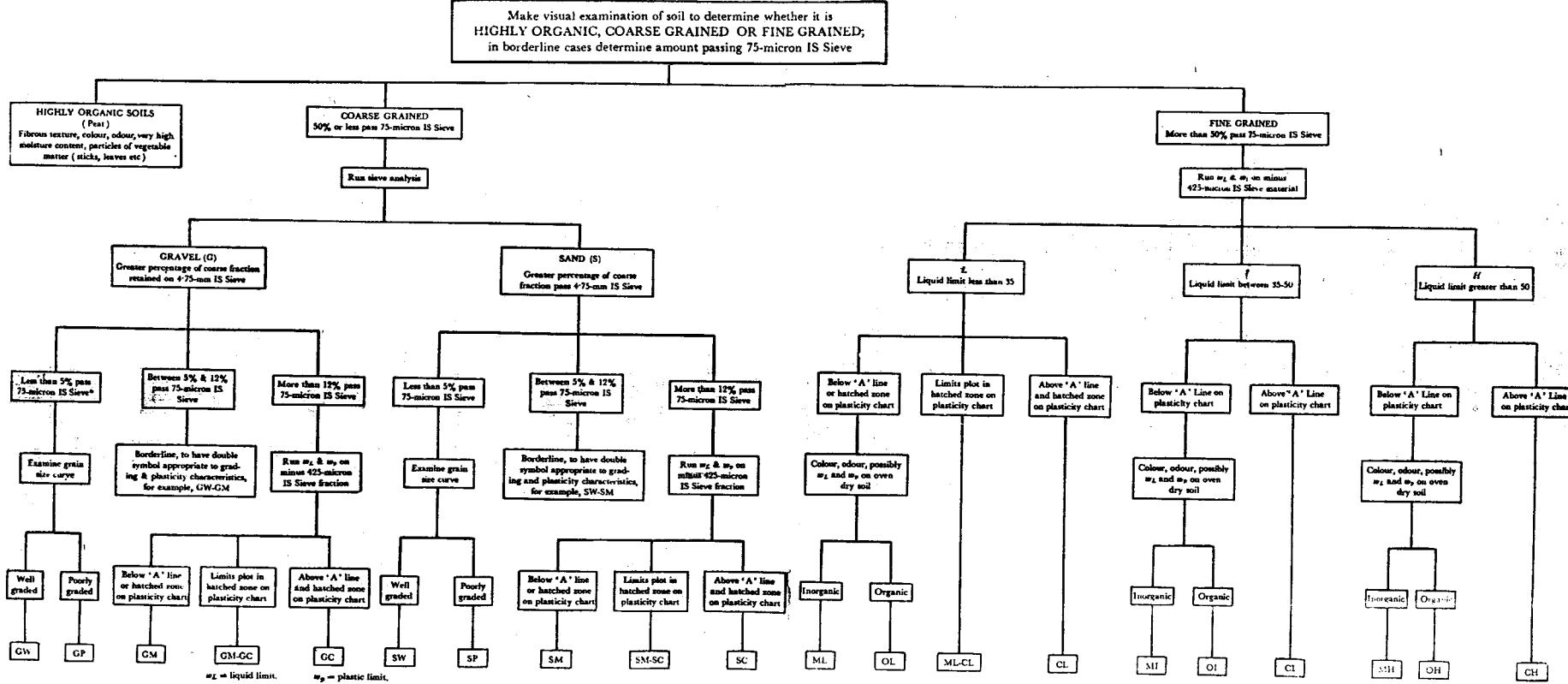
TABLE 3 CLASSIFICATION OF COARSE-GRAINED SOILS (LABORATORY CLASSIFICATION CRITERIA)
(Clause 3.5.1)

GROUP SYMBOLS	LABORATORY CLASSIFICATION CRITERIA	
GW	C_u Greater than 4 C_u Between 1 and 3	Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than 75-micron IS Sieve) coarse-grained soils are classified as follows:
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below 'A' line or I_p less than 4	Limits plotting above 'A' line with I_p between 4 and 7 are border line cases requiring use of dual symbols
GC	Atterberg limits above 'A' line with I_p greater than 7	Less than 5% GW, GP, SW, SP More than 12% GM, GC, SM, SC 5% to 12% Border line cases requiring use of dual symbols Uniformity coefficient, $C_u = \frac{D_{60}}{D_{10}}$
SW	C_u greater than 6 C_c between 1 and 3	Coefficient of curvature $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ where D_{60} = 60 percent finer than size D_{30} = 30 percent finer than size D_{10} = 10 percent finer than size
SP	Not meeting all gradation requirements for SW	
SM	Atterberg limits below 'A' line or I_p less than 4	Limits plotting above 'A' line with I_p between 4 and 7 are border line cases requiring use of dual symbols
SC	Atterberg limits above 'A' line with I_p greater than 7	

I_p = plasticity index

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TABLE 4 AUXILIARY LABORATORY IDENTIFICATION PROCEDURE
(Clauses 3.5.1 and 3.5.3)



*If fines interfere with free drainage properties use double symbol, such as GW-GM.

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TABLE 5 CHARACTERISTICS PERTINENT TO ROADS AND AIRFIELDS
(Clause 3.8)

SOIL GROUP	VALUE AS SUB-GRADE WHEN NOT SUBJECT TO FROST ACTION	VALUE AS SUB-BASE WHEN NOT SUBJECT TO FROST ACTION	VALUE AS BASE WHEN NOT SUBJECT TO FROST ACTION	POTENTIAL FROST ACTION	COMPRESSIBILITY AND EXPANSION	DRAINAGE CHARACTERISTICS	COMPACTION EQUIPMENT	UNIT DRY WEIGHT g/cm ³	CBR VALUE PERCENT	SUB-GRADE MODULUS (k) kg/cm ³
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
GW	Excellent	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tyred roller, steel-wheeled roller	2.00-2.24	40-80	8.3-13.84
GP	Good to excellent	Good	Fair to good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tyred roller, steel-wheeled roller	1.76-2.24	30-60	8.3-13.84
GM	d Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tyred roller, sheep's-foot roller, close control of moisture	2.00-2.32	40-60	8.3-13.84
	u Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tyred roller, sheep's-foot roller	1.84-2.16	20-30	5.53-8.3
GC	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tyred roller, sheep's-foot roller	2.08-2.32	20-40	5.53-8.3
SW	Good	Fair to good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tyred roller	1.76-2.08	20-40	5.53-11.07
SP	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tyred roller	1.68-2.16	10-40	4.15-11.07
SM	d Fair to good	Fair to good	Poor	Slight to high	Very light	Fair to poor	Rubber-tyred roller, sheep's-foot roller, close control of moisture	1.92-2.16	15-40	4.15-11.07
	u Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tyred roller, sheep's-foot roller	1.60-2.08	10-20	2.77-8.3
SC	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tyred roller sheep's-foot roller	1.60-2.16	5-20	2.77-8.3
ML, MI	Poor to fair	Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tyred roller, sheep's-foot roller, close control of moisture	1.44-2.08	15 or less	2.77-5.53
CL, CI	Poor to fair	Not suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tyred roller, sheep's-foot roller	1.44-2.08	15 or less	1.38-4.15
OL, OI	Poor	Not suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber-tyred roller, sheep's-foot roller	1.44-1.68	5 or less	1.38-2.77
MH	Poor	Not suitable	Not suitable	Medium to very high	High	Fair to poor	Sheep's-foot roller, rubber-tyred roller	1.28-1.68	10 or less	1.38-2.77
CH	Poor to fair	Not suitable	Not suitable	Medium	High	Practically impervious	Sheep's-foot roller, rubber-tyred roller	1.44-1.84	15 or less	1.38-4.15
OH	Poor to very poor	Not suitable	Not suitable	Medium	High	Practically impervious	Sheep's-foot roller, rubber-tyred roller	1.28-1.76	5 or less	0.69-2.77
Pt	Not suitable	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical	—	—	—

NOTE 1 — Column 1 : Division of GM and SM groups into sub-division of d and u are for roads and airfields only; sub-division is on basis of Atterberg limits; suffix d (for example GM d) will be used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u will be used otherwise.

NOTE 2 — The equipment listed in col 8, will usually produce the required densities with a reasonable number of passes when moisture condition and thickness of layer are properly controlled. In some instances, several types of equipment are listed because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.

- a) *Processed base materials; other angular materials* — Steel-wheeled and rubber-tyred rollers are recommended for hard, angular materials with limited fines or screenings. Rubber-tyred equipment is recommended for softer materials subject to degradation.
- b) *Finishing* — Rubber-tyred equipment is recommended for rolling during final shaping operations for most soils and processed materials.
- c) *Equipment Size* — The following sizes of equipment are necessary to assure the high densities required for airfield construction: Crawler-type tractor: Total weight in excess of 13 600 kg. Rubber-tyred equipment: Wheel load in excess of 6 800 kg, wheel loads as high as 18 100 kg may be necessary to obtain the required densities for some materials (based on contact pressure of approximately 4.57 to 10.5 kg/cm²). Sheep's-foot roller: Unit pressure (on 38.7 to 77.4 cm²) to be in excess of 17.5 kg/cm² and unit pressure as high as 46 kg/cm² may be necessary to obtain the required densities for some materials. The area of the feet should be at least 5 percent of the total peripheral area of the drums using the diameter measured to the face of the feet.

NOTE 3 — Unit dry weights in column 9 are for compacted soil at optimum moisture content for Indian Standard heavy compaction effort [see IS : 2720 (Part VIII)-1965].

NOTE 4 — Column 10 : The maximum value that can be used in design of airfields, is in some cases, limited by gradation and plasticity requirements. The values are representative of saturated or nearly saturated conditions.

NOTE 5 — In most of the expansive soils, the CBR values after soaking are often found to be less than 2. The thickness of the pavements for such small values turn out to extremely high and impracticable. A minimum CBR value of 2 is recommended for use for design purposes in such soil.

*Methods of test for soils: Part VIII Determination of moisture content-dry density relationship using heavy compaction.

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TABLE 6 CHARACTERISTICS PERTINENT TO EMBANKMENTS AND FOUNDATIONS
(Clause 3.8)

SOIL GROUP	VALUE OF EMBANKMENT	PERMEABILITY cm/s	COMPACTION CHARACTERISTICS	UNIT DRY WEIGHT g/cm ³	VALUE OF FOUNDATION	REQUIREMENTS FOR SEEPAGE CONTROL
(1)	(2)	(3)	(4)	(5)	(6)	(7)
GW	Very stable; pervious shells of dikes and dams	$K > 10^{-2}$	Good; tractor, rubber tyred, steel-wheeled roller	2.00-2.16	Good bearing value	Positive cutoff
GP	Reasonably stable, pervious shells of dikes and dams	$K > 10^{-2}$	do	1.84-2.00	do	do
GM	Reasonably stable; not particularly suited to shells, but may be used for impervious cores or blankets	$K = 10^{-3}$ to 10^{-6}	Good; with close control, rubber-tyred, sheeps-foot roller	1.92-2.16	do	Toe trench to none
GC	Fairly stable; may be used for impervious core	$K = 10^{-6}$ to 10^{-8}	Fair; rubber-tyred, sheeps-foot roller	1.84-2.08	do	None
SW	Very stable; pervious sections, slope protection required	$K > 10^{-3}$	Good; tractor	1.76-2.08	do	Upstream blanket and toe drainage or wells
SP	Reasonably stable; may be used in dike section with flat slopes	$K > 10^{-3}$	Good; tractor	1.60-1.92	Good to poor bearing value depending on density	do
SM	Fairly stable; not particularly suited to shells, but may be used for impervious cores or dikes	$K = 10^{-3}$ to 10^{-6}	Good; with close control, rubber-tyred, sheeps-foot roller	1.76-2.00	do	do
SC	Fairly stable; use for impervious core for flood control structures	$K = 10^{-6}$ to 10^{-8}	Fair; sheeps-foot roller, rubber tyred	1.68-2.00	Good to poor bearing value	None
ML, MI	Poor stability; may be used for embankments with proper control	$K = 10^{-3}$ to 10^{-6}	Good to poor, close control essential; rubber-tyred roller, sheeps-foot roller	1.52-1.92	Very poor, susceptible to liquefaction	Toe trench to none
CL, CI	Stable; impervious cores and blankets	$K = 10^{-6}$ to 10^{-8}	Fair to good; sheeps-foot roller, rubber-tyred	1.52-1.92	Good to poor bearing	None
OL, OI	Not suitable for embankments	$K = 10^{-4}$ to 10^{-6}	Fair to poor; sheeps-foot roller	1.28-1.60	Fair to poor bearing, may have excessive settlements	do
MH	Poor stability; core of hydraulic fill dams not desirable in rolled fill construction	$K = 10^{-4}$ to 10^{-6}	Poor to very poor; sheeps-foot roller	1.12-1.52	Poor bearing	do
CH	Fair stability with flat slopes; thin cores, blankets and dike sections	$K = 10^{-6}$ to 10^{-8}	Fair to poor; sheeps-foot roller	1.20-1.68	Fair to poor bearing	do
OH	Not suitable for embankments	$K = 10^{-6}$ to 10^{-8}	Poor to very poor; sheeps-foot roller	1.04-1.60	Very poor bearing	do
Pt	Not used for construction	—	Compaction not practical	—	Remove from foundation	—

NOTE 1 — Values in Column 2 and 6 are for guidance only. Design should be based on test results.

NOTE 2 — The equipment listed in Column 4 will usually produce densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled.

NOTE 3 — Unit dry weights in column 5 are for compacted soil at optimum moisture content for Indian Standard light compaction effort [see IS : 2720 (Part VII)-1965*].

*Methods of test for soils : Part VII Determination of moisture content-dry density relation using light compaction.

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TABLE 7 SUITABILITY FOR CANAL SECTIONS, COMPRESSIBILITY, WORKABILITY AS A CONSTRUCTION MATERIAL AND SHEAR STRENGTH

(Clause 3.8)

SOIL GROUP	RELATIVE SUITABILITY FOR CANAL SECTIONS*		COMPRESSIBILITY WHEN COMPACTED AND SATURATED	WORKABILITY AS A CONSTRUCTION MATERIAL	SHEARING STRENGTH WHEN COMPACTED AND SATURATED
	Erosion Resistance	Compacted Earth Lining			
GW	1	—	Negligible	Excellent	Excellent
GP	2	—	Negligible	Good	Good
GM	4	4	Negligible	Good	Good
GC	3	1	Very low	Good	Good to Fair
SW	6	—	Negligible	Excellent	Excellent
SP	7, if gravelly	—	Very low	Fair	Good
SM	8, if gravelly	5 (Erosion critical)	Low	Fair	Good
SC	5	2	Low	Good	Good to Fair
ML, MI	—	6 (Erosion critical)	Medium	Fair	Fair
CL, CI	9	3	Medium	Good to Fair	Fair
OL, OI	—	7 (Erosion critical)	Medium	Fair	Poor
MH	—	—	High	Poor	Fair to Poor
CH	10	8 (Volume change critical)	High	Poor	Poor
OH	—	—	High	Poor	Poor
P _t	—	—	—	—	—

*Number 1 is the best.

TABLE 8 SHOWING THE DEGREE OF EXPANSION OF FINE GRADED SOILS

(Clause 3.9)

LIQUID LIMIT (W_L)	PLASTICITY INDEX (I_p)	SHRINKAGE INDEX (I_s)	FREE SWELL (PERCENT)	DEGREE OF EXPANSION	DEGREE OF SEVERITY
20-35	< 12	< 15	< 50	Low	Non-critical
35-50	12-23	15-30	50-100	Medium	Marginal
50-70	23-32	30-60	100-200	High	Critical
70-90	> 32	> 60	> 200	Very High	Severe

APPENDIX A

(Table 1)

COMPOSITION BETWEEN SIZE CLASSIFICATION OF IS : 1498 - 1959 AND IS : 1498 - 1970

Particle Size in millimetres.

IS:1498-1959	CLAY SIZE	SILT SIZE		SAND		GRAVEL						
	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE						
	0.006	0.02		0.06	0.2	0.6	2					
IS:1498-1970	CLAY SIZE	SILT SIZE		SAND		GRAVEL			COBBLE	Boulder		
				FINE	MEDIUM	COARSE	FINE	COARSE				
				0.075	0.425	2	4.75	20	75	300		

SECTION 3

Preparation of Soil Samples

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Indian Standard

METHODS OF TEST FOR SOILS

PART 1 PREPARATION OF DRY SOIL SAMPLES FOR VARIOUS TESTS

(Second Revision)
(Incorporating Amendment No. 1)

0. FOREWORD

0.1 With a view to establishing uniform procedure for the determination of different characteristics of soils, Indian Standards on methods of test for soils (IS : 2720) have been formulated in various parts. This part covers method of preparation of samples for the various laboratory tests covered in the standard. This part was first published in 1966 and revised in 1972. Since then more parts of this standard have been published covering additional characteristics besides some of the published parts have been revised wherein requirements have been modified. This revised version has, therefore, been formulated in order to update in this respect.

1. SCOPE

1.1 This standard (Part 1) covers the method of preparation of dry samples from the bulk soil sample received from the field for various laboratory tests.

2. APPARATUS

2.1 Wooden Mallet — for breaking soil clods.

2.2 Trays — for air-drying of soil, of suitable size and of non-rusting material.

2.3 Pulverizing Apparatus — Either mortar and rubber covered pestle or a mechanical device consisting of mortar and a power-driven rubber covered pestle suitable for breaking up the aggregation of soil particles without reducing the size of the individual grains. Pestle and mortar made of soft wood may also be used.

2.4 Sampler — A suitable riffle sampler or sample splitter for quartering the samples (*see IS : 1607-1960 'Methods for dry sieving'*).

2.5 Sieves — of sizes 75-mm, 63-mm, 37.5-mm, 19-mm, 13.2-mm, 9.50-mm, 6.7-mm, 4.75-mm, 2.00-mm and 425-micron [*see IS : 460 (Part 1)-1978 'Specification for test sieves : Part 1 Wire cloth test sieves (second revision)'*].

2.6 Drying Apparatus

- a) **Drying Oven** — Thermostatically controlled, with interior of non-corroding material to maintain the temperature between 105 and 110°C.

b) Other suitable drying apparatus.

2.7 Balances

- a) Capacity 10 kg and minimum sensitivity 100 g.
- b) Capacity 1 kg and minimum sensitivity 1 g.
- c) Capacity 250 g and minimum sensitivity 0.01 g.

3. PREPARATION OF SAMPLE FOR TESTS

3.1 General — Soil sample, as received from the field, shall be dried in the air or in sun. In wet weather, a drying apparatus may be used in which case the temperature of the sample should not exceed 60°C. The clods may be broken with a wooden-mallet to hasten drying. The organic matter, like tree roots and pieces of bark should be removed from the sample. Similarly, matter other than soil, like shells should also be separated from the main soil mass. A noting shall be made of such removals and their percentage of the total soil sample noted. When samples are to be taken for estimation of organic content, lime content, etc, total sample should be taken for estimation without removing shells, roots, etc.

3.2 Drying of the Sample — The amount of drying depends upon the proposed test to be conducted on the particular sample. The type, temperature and duration of drying of soil samples for different tests are given in Table 1. When oven is used for drying, the temperature in the oven shall not exceed 110°C (*see Note*). Chemical drying of samples should not be adopted for any tests.

Note — Soils containing organic or calcareous matter should not be dried at temperature above 60°C.

3.3 Degree of Pulverization — The big clods may be broken with the help of wooden mallet. Further pulverization may be done in pestle and mortar. The pulverized soil shall be passed through the specified sieve for the particular test and the soil retained on that sieve shall be again pulverized for sieving. This procedure should be repeated until on further attempts at pulverizing very little soil passes through the specified sieve. Care should be taken not to break up the individual soil particles (*see Table 1*).

TABLE I QUANTITY OF SOIL SAMPLE REQUIRED FOR CONDUCTING THE TESTS

(Clauses 3.2, 3.3 and 4.1)

Sl. No.	TEST	TYPE, TEMPERATURE AND DURATION OF DRYING	AMOUNT OF SOIL SAMPLE REQUIRED FOR TEST	DEGREE OF PULVERIZATION (PASSING IS SIEVE SIZE)	REF TO PART OF IS : 2720
(1)	(2)	(3)	(4)	(5)	(6)
i)	Water content	Oven, 24 h	As given in Table 2	—	Part 2
ii)	Specific gravity	Oven 105-110°C, 24 h	50 g for fine-grained soils 400 g for fine, medium and coarse-grained soils	2 mm —	Part 3/Sec 1 Part 3/Sec 2
iii)	Grain size analysis	Air drying	As given in Table 3	—	Part 4
iv)	Liquid limit	do	270 g	425 micron	Part 5
v)	Plastic limit	do	60 g	do	do
vi)	Shrinkage factors	Air drying	100 g	425 micron	Part 6
vii)	Compaction				
a)	Light compaction	do	6 kg (15 kg if soil is susceptible to crushing)	19 mm	Part 7
b)	Heavy compaction	do	do	19 mm	Part 8
c)	Constant mass	do	2 kg	4.75 mm	Part 9
viii)	Unconfined compressive strength	Oven 110°C ± 5°C	1 kg	—	Part 10
ix)	Triaxial compression (unconsolidated)	do	1 kg/5 kg	—	Part 11
x)	Triaxial compression (consolidated)	do	do	—	Part 12
xi)	Direct shear	Air drying/Oven 110°C ± 5°C	1 kg	4.75 mm	Part 13
xii)	Density index (relative density)	Oven, 105-110°C, 24 h	As per size of particle given below: 75 mm 45 kg 37.5 „ 12 „ 19 „ 12 „ 9.50 „ 12 „ 4.75 „ 12 „	—	Part 14
xiii)	Consolidation properties	Air drying/Oven 110°C ± 5°C	500 g	—	Part 15
xiv)	CBR	Air drying	6 kg	19 mm	Part 16
xv)	Permeability	Oven, 105-110°C, 24 h	2.5 kg (100 mm dia)/ 5 kg (200 mm dia)	9.5 mm	Part 17
xvi)	Field moisture equivalent	Air drying	15 g	425 micron	Part 18
xvii)	Centrifuge moisture equivalent	do	10 g	do	Part 19
xviii)	Linear shrinkage	do	450 g	do	Part 20
xix)	Chemical tests				
a)	Total soluble solids	Oven, 105-110°C, 24 h	10 g	2 mm	Part 21
b)	Organic matter	Air drying	100 g	do	Part 22
c)	Chalcium carbonate	Oven, 105-110°C, 24 h	5 g	—	Part 23
d)	Cation exchange capacity	do	80-130 g	—	Part 24
e)	Silica sesquioxide ratio	do	15 g	—	Part 25
f)	pH value	do	30 g	425 micron	Part 26
g)	Total soluble sulphates	do	30 g	—	Part 27
xx)	Vane shear	Air drying/oven 110°C ± 5°C	250 g	—	Part 30
xxi)	Negative pore water pressure	do	1 kg/5 kg	—	Part 35

(Continued)

TABLE 1 QUANTITY OF SOIL SAMPLE REQUIRED FOR CONDUCTING THE TESTS — *Contd*

SL NO.	TEST	TYPE, TEMPERATURE AND DURATION OF DRYING	AMOUNT OF SOIL SAMPLE REQUIRED FOR TEST	DEGREE OF PULVERIZATION (PASSING IS SIEVE SIZE)	REF TO PART OF IS : 2720
(1)	(2)	(3)	(4)	(5)	(6)
xxii)	Permeability of granular soils	Air drying/oven 110°C ± 5°C	1 kg/5 kg	—	Part 36
xxiii)	Sand equivalent value	105 ± 5°C	1 500 g	4.75 mm	Part 37
xxiv)	Direct shear	Air drying	up to 120 g	Above 4.75 mm	Part 39/Sec 1
xxv)	Free swell index	Oven dry	20 g	425 micron	Part 40
xxvi)	Swelling pressure	Air drying/ Oven dry	2 kg	2 mm	Part 41

4. QUANTITY OF SAMPLE

4.1 The quantities of soil sample required for conducting various laboratory tests are given in Table 1 for guidance.

NOTE — For actual quantities, corresponding part of IS : 2720 shall be referred.

4.2 When a smaller quantity has to be taken out of a bigger soil mass, the representative sampling shall be done by quartering or riffling.

NOTE — In the case of coarse gravel or gravelly soils, quartering by forming a cone shall not be done. The entire sample shall be thoroughly mixed and spread on a flat surface. The sample so spread shall be divided into four quadrants and diagonally opposite quadrants mixed. This process shall be repeated till the desired quantity of sample is obtained.

TABLE 2 QUANTITY OF SAMPLE REQUIRED FOR DETERMINATION OF WATER CONTENT

SIZE OF PARTICLES MORE THAN 90 PERCENT PASSING	MINIMUM QUANTITY OF SOIL SPECIMEN TO BE TAKEN FOR THE TEST MASS IN g
425-micron IS Sieve	25
2-mm IS Sieve	50
4.75 mm IS Sieve	200
9.50 mm IS Sieve	300
19 mm IS Sieve	500
37.5 mm IS Sieve	1 000

TABLE 3 QUANTITY OF SOIL REQUIRED FOR GRAIN SIZE ANALYSIS

MAXIMUM SIZE OF MATERIAL PRESENT IN SUBSTANTIAL QUANTITIES	MASS TO BE TAKEN FOR TEST
mm	kg
75	60
37.5	25
19	6.5
13.2	3.5
9.5	1.5
6.7	0.75
4.75	0.4

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SECTION 4
Determination of Water Content

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Indian Standard

METHODS OF TEST FOR SOILS

PART 2 DETERMINATION OF WATER CONTENT

(Second Revision)

0. FOREWORD

0.1 This part was first published in 1964 and revised in 1969 to include two rapid field methods for the determination of water content in soils. In this second revision, rapid determination of water content with infra-red lamp torsion balance moisture meter and rapid determination of water content from the gas pressure developed by the reaction of calcium carbide with the free water content of the soil have been included.

SECTION 1 OVEN-DRYING METHOD (STANDARD METHOD)

1. SCOPE

1.1 This method covers the determination of water content of soils expressed as a percentage of the oven-dry weight.

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS : 2809-1972 'Glossary of terms and symbols relating to soil engineering (*first revision*)' shall apply.

3. APPARATUS

3.1 Container — Any suitable non-corrodible airtight container.

3.2 Balance — of sufficient sensitivity to weigh the soil samples to an accuracy of 0.04 percent of the weight of the soil taken for the test (*see 4.1*).

3.3 Oven — thermostatically controlled, with interior of non-corroding material to maintain the temperature at $110 \pm 5^\circ\text{C}$.

3.4 Desiccator — A desiccator with any suitable desiccating agent.

4. SOIL SPECIMEN

4.1 The soil specimen taken shall be representative of the soil mass. The size of the specimen selected depends on the quantity required for good representation, which is influenced by the gradation and the maximum size of particles, and on the accuracy of

weighing. The following quantities are recommended for general laboratory use:

<i>Size of Particles More Than 90 Percent Passing</i>	<i>Minimum Quantity of Soil Specimen to be Taken for Test, Mass in g</i>
425- μm IS Sieve	25
2-mm IS Sieve	50
4.75-mm IS Sieve	200
9.5-mm IS Sieve	300
19-mm IS Sieve	500
37.5-mm IS Sieve	1 000

NOTE 1 — For sizes of sieves, *see* IS : 460 (Part 1)-1978 'Specification for test sieves: Part 1 Wire cloth test sieves (*second revision*)'.

NOTE 2 — Drier the soil, the greater shall be the quantity of the soil taken.

NOTE 3 — Water content specimen should be discarded and should not be used in any other tests.

5. PROCEDURE

5.1 Clean the container with lid, dry and weigh (W_1). Take the required quantity of the soil specimen in the container crumbled and placed loosely, and weigh with lid (W_2). Then keep it in an oven with the lid removed, and maintain the temperature of the oven at $110 \pm 5^\circ\text{C}$ (*see Note*). Dry the specimen in the oven for 24 h. Every time the container is taken out for weighing, replace the lid on the container and cool the container in a desiccator. Record the final mass (W_3) of the container with lid with dried soil sample.

NOTE — Oven-drying at $110 \pm 5^\circ\text{C}$ does not result in reliable water content values for soil containing gypsum or other minerals having loosely bound water of hydration or for soil containing significant amounts of organic material. Reliable water content values for these soils can be obtained by drying in an oven at approximately 60 to 80°C .

6. CALCULATION

6.1 The percent of water content shall be calculated as follows:

$$w = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

where

- w = water content percent,
- W_2 = mass of container with lid with wet soil in g,
- W_3 = mass of container with lid with dry soil in g, and
- W_1 = mass of container with lid in g.

7. REPORT

7.1 The water content (w) of the soil shall be reported to two significant figures.

7.2 The results of the test shall be suitably recorded. A recommended *pro forma* for this record is given in Appendix A.

SECTION 2 SAND-BATH METHOD (SUBSIDIARY METHOD)

8. SCOPE

8.1 This method covers the determination of the water content of a soil as a percentage of its dry mass. It is intended as rapid alternative to the method given in Section 1 but is less accurate and more suitable as a field test. The method shall not be used if it is suspected that the soil contains a large proportion of gypsum, calcareous matter or organic matter.

9. APPARATUS

9.1 **Container** — any suitable non-corrodible airtight container.

9.2 **Heat-Resistant Tray** — of suitable metal and about 5 to 7 cm deep.

9.3 **Balance** — of sufficient sensitivity to weigh the soil samples to an accuracy of 0.4 percent of the mass of the soil taken for the test.

9.4 **Sand-Bath** — of suitable size and containing clean sand to a depth of at least 3 cm.

9.5 **Equipment for Heating the Sand-Bath** — kerosene stove or spirit lamp.

9.6 **Palette Knife or Steel Spatula** — a convenient size is one having a blade 10 cm long and 2 cm wide.

9.7 **Scoop** — a convenient size is one about 20 cm long and 10 cm wide.

10. SOIL SPECIMEN

10.1 The mass of soil specimen taken for the test shall be in accordance with 4.1.

11. PROCEDURE

11.1 Clean the container with lid or the tray, as the case may be, dry and weigh (W_1). Take the required quantity of the soil specimen in the container crumbled and placed loosely and weigh (W_2). Add a

few pieces of white paper, if necessary (see Note). Place the container with the lid removed or the tray on the sand-bath and heat the sand-bath. Care shall be taken not to get the sand-bath too hot. During heating, the specimen shall be turned frequently and thoroughly with the palette knife to assist the evaporation of water, care being taken to see that no soil is lost in the process. Dry the specimen to constant mass indicated by the difference between two consecutive masses of the container with lid or the tray with the dried specimen taken at suitable intervals after initial drying, being a maximum of 0.1 percent of the original mass of the soil specimen. When drying is complete, remove the container or the tray from the sand-bath, cool and weigh (W_3). The container should be weighed with lid.

Note — Avoid overheating. A convenient method of detecting overheating of the soil is by the use of small pieces of white paper mixed with the soil. Overheating is indicated if the paper turns brown.

12. CALCULATION

12.1 The percentage of water content shall be calculated as follows:

$$w = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

where

- w = water content percent,
- W_2 = mass of container with lid (or tray) with wet soil in g,
- W_3 = mass of container with lid (or tray) with dry soil in g, and
- W_1 = mass of container with lid (or tray) in g.

13. REPORT

13.1 The water content and the results of tests shall be reported in accordance with 7.1 and 7.2.

SECTION 3 ALCOHOL METHOD (SUBSIDIARY METHOD)

14. SCOPE

14.1 This method covers the determination of the water content of a soil as a percentage of its dry mass. It is intended as a rapid alternative to the method given in Section 1 but is less accurate and is more suitable as a field test. Since methylated spirit is used, care shall be taken against risk of fire. The method shall not be used if the soil contains a large proportion of clay, gypsum, calcareous matter or organic matter.

15. APPARATUS

15.1 **Evaporating Dish** — 10 to 15 cm in diameter.

15.2 **Palette Knife or Steel Spatula** — having a blade 10 cm long and 2 cm wide.

15.3 Balance of sufficient sensitivity to weigh the soil samples to an accuracy of 0.4 percent of the mass of the soil taken for the test.

15.4 Methylated Spirit

16. SOIL SPECIMEN

16.1 The soil specimen taken shall be representative of the soil mass. The size of the specimen selected depends on the quantity required for good representation, which is influenced by the gradation and the maximum size of particles, and on the accuracy of weighing. The following quantities are recommended for general use:

<i>Size of Particles More Than 90 Percent Passing</i>	<i>Minimum Quantity of Soil Specimen to be Taken for Test, Mass in g</i>
2-mm IS Sieve	30
19-mm IS Sieve	300

NOTE 1 For sizes of sieves, see IS : 460 (Part 1)-1978.

NOTE 2 Drier the soil, the greater shall be the quantity of the soil taken.

NOTE 3 Water content samples should be discarded and should not be used in any other tests.

17. PROCEDURE

17.1 Clean the evaporating dish, dry and weigh (W_1). Take the required quantity of the soil specimen in the evaporating dish and weigh (W_2). Pour over the soil methylated spirit at the rate of about one millilitre for every gram of soil taken so that the soil is well covered. Work the methylated spirit well into the soil with the palette knife and break up any large lumps of soil. Place the evaporating dish on a surface which will not be affected by heat and ignite the methylated spirit. Stir the soil constantly with the spatula or knife, care being taken to see that none of the soil is lost. After the methylated spirit has burnt away completely, allow the dish to cool and weigh it with the contents (W_3).

18. CALCULATION

18.1 The percentage of water content shall be calculated as follows:

$$w = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

where

w = water content percent,

W_2 = mass of dish with wet soil in g,

W_3 = mass of dish with dry soil in g, and

W_1 = mass of dish in g.

19. REPORT

19.1 The water content and the results of tests shall be reported in accordance with 7.1 and 7.2.

SECTION 4 RAPID DETERMINATION OF WATER CONTENT WITH INFRA-RED LAMP TORSION BALANCE MOISTURE METER

20. SCOPE

20.1 This section describes a method for rapid determination of water content of soils employing a device providing infra-red lamp for drying and torsion balance for getting percentage of water on wet basis from a scale, and the results obtained are convertible to water content on dry basis.

NOTE — The water estimation with this method takes 15 to 30 min depending upon the type of soil and quantity of water present. Plastic soils might take about 30 min. The reproducibility of readings is within ± 0.25 percent. The probable error is about ± 0.3 percent water content in case of granular soils and about 0.8 to 1 percent in case of clays.

21. APPARATUS

21.1 Infra-red Lamp and Torsion Balance Moisture Meter — The moisture meter is illustrated in its essential details in Fig. 1 and 2.

21.1.1 The equipment should be of two main parts, the infra-red lamp and the torsion balance. The infra-red radiation should be provided by 250 watt lamp built in the balance for use with an alternating current 220-230 V, 50 cycle, single phase mains supply. Provision should be made to adjust the input voltage to the infra-red lamp to control the heat for drying of specimen. A suitable thermometer graduated from 40 to 150°C should be provided for ascertaining the temperature of drying in the pan housing. The weighing mechanism, a torsion balance, should have a built in magnetic damper. The balance scale should be divided in terms of water percentages from 1 to 100 percent water content in 0.2 percent divisions.

21.2 Palette Knife or Steel Spatula — having a blade 10 cm long and 2 cm wide.

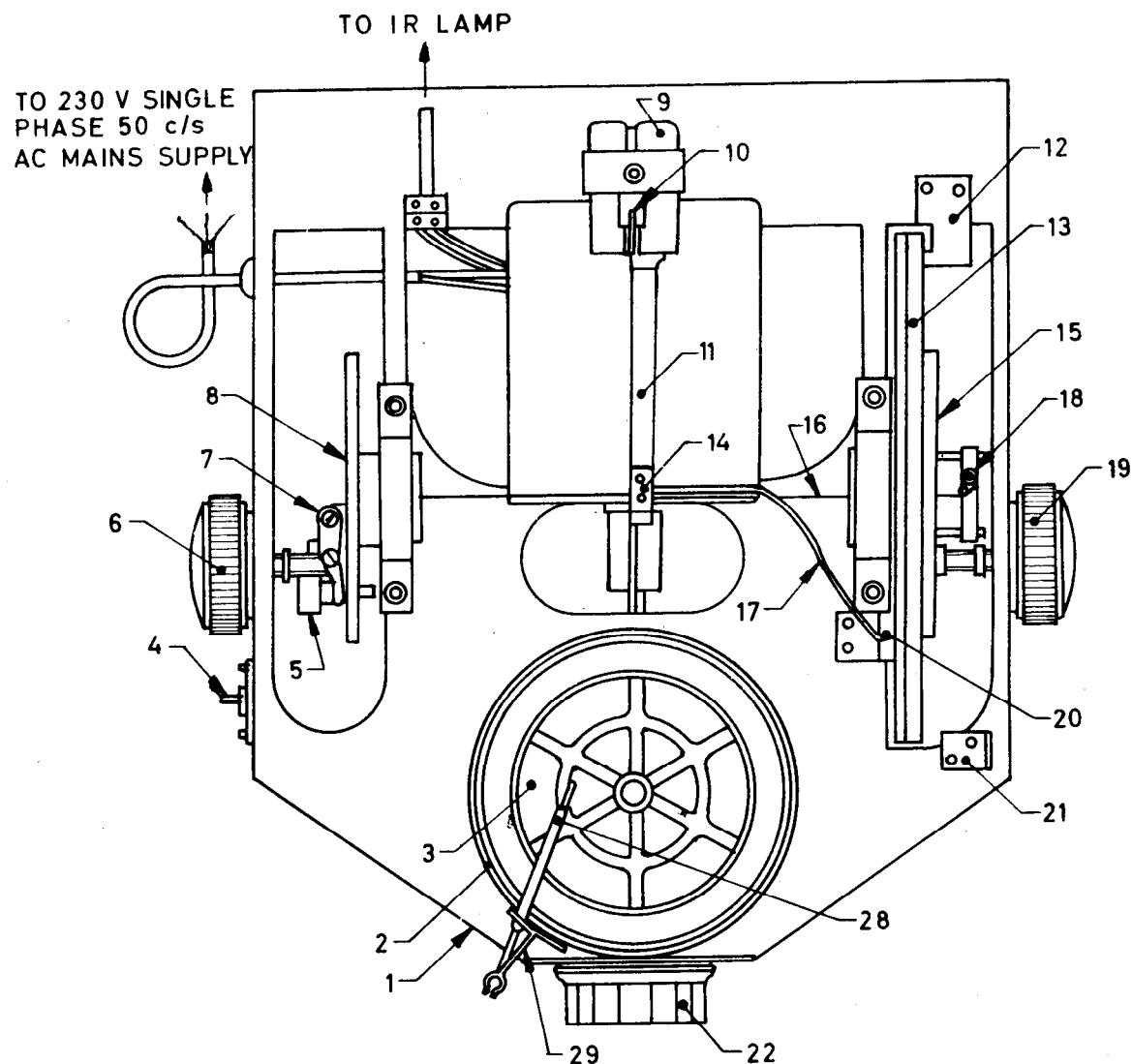
22. SOIL SPECIMEN

22.1 The soil specimen taken shall be representative of the soil mass. The specimen should weigh 25 g. As this moisture meter is calibrated to use 25 g of soil, the maximum size of particle present in the specimen shall be less than 2 mm.

23. PROCEDURE

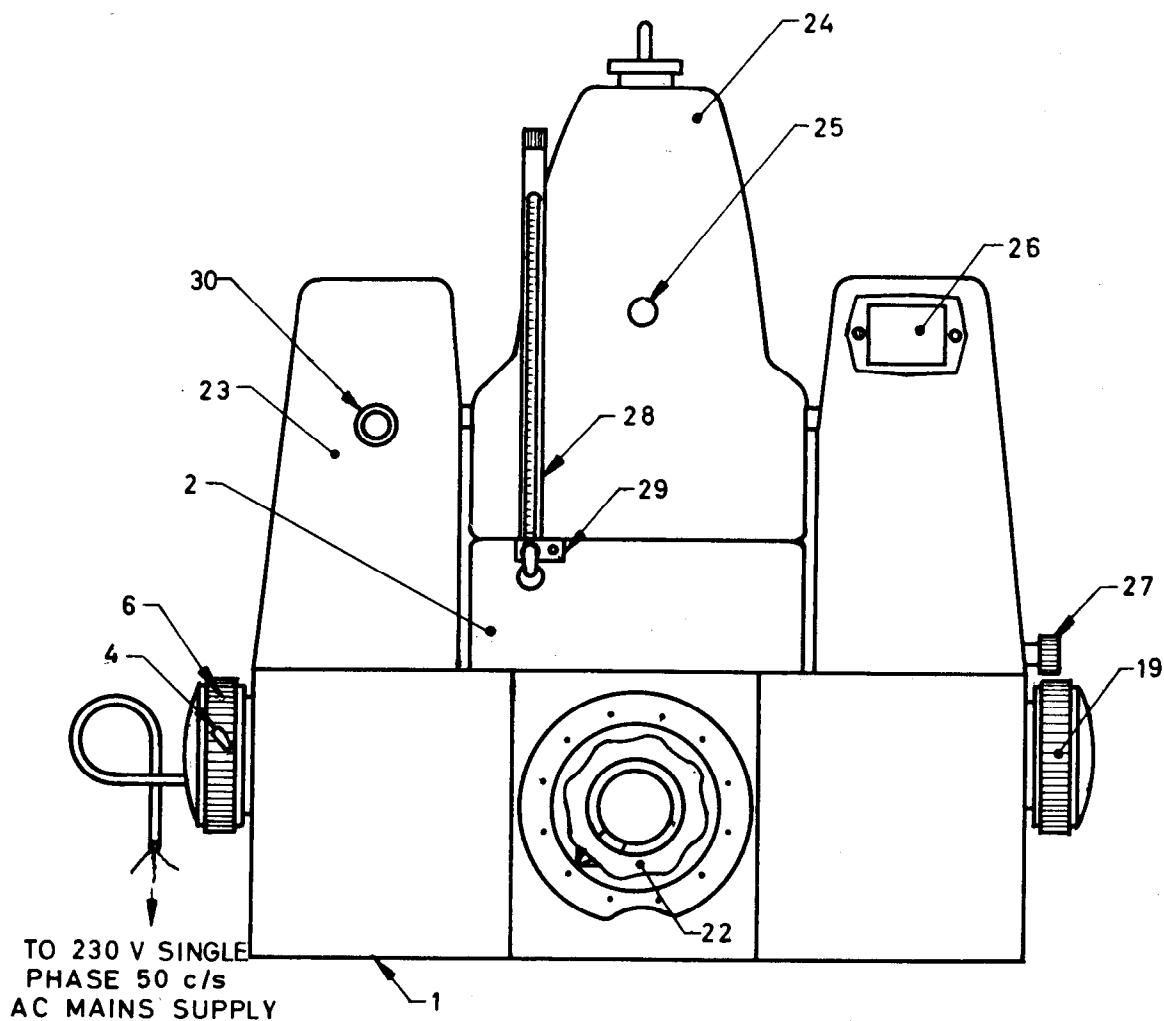
23.1 Keep the test samples always in suitable containers so that the water content to be determined is not affected by ambient conditions.

23.2 Set the 100 percent scale division of the calibrated drum to align with the index mark with the help of drum drive knob.



<i>Description</i>	<i>Description</i>
1. Base	13. Calibrated drum
2. Pan housing	14. Wire grip for balance
3. Pan	15. Gear
4. On-off switch	16. Torsion wire
5. Wire tensioner	17. Pointer
6. Initial adjustment knob	18. Right-hand wire grip
7. Left-hand wire grip	19. Drum drive knob
8. Gear	20. Index mark
9. Damping magnet	21. Lock
10. Damping vane	22. Variac knob (for heat control)
11. Balance arm	28. Thermometer
12. Stopper	29. Thermometer bracket

FIG. 1 TORSION BALANCE MOISTURE METER (0-100 PERCENT) — PLAN (COVER REMOVED)

*Description*

1. Base
2. Pan housing
4. On-off switch
6. Initial adjustment knob
19. Drum drive knob
22. Variac knob (for heat control)
23. Cover

Description

24. Lamp housing
25. Lifting handle
26. Viewing lens
27. Locking screw
28. Thermometer
29. Thermometer bracket
30. Indicating lamp

FIG. 2 TORSION BALANCE MOISTURE METER (0-100 PERCENT) — FRONT VIEW

percent scale division. If not, set the pointer with the help of initial setting knob.

23.4 Rotate the drum drive knob anti-clockwise and bring the 0 percent scale division in line with the index mark, thus prestressing the wire through an amount equal to 100 percent (this represents the amount of unbalance). The pointer will now be above the index mark.

23.5 Raise the lamp housing and carefully distribute the test material evenly on the sample pan until the pointer returns to the index mark (approximately 25 g of the material will be needed in one operation).

23.6 Lower the lamp housing and switch on the infra-red lamp with the help of the switch provided on the left-hand side. Insert the thermometer in its socket and bracket. Adjust the variac control knob between 95 and 100 on the scale if it is desired that the temperature of drying is around 110°C. The sample will now begin to lose water and the pointer will rise above the index.

Note Keep a watch on the column of mercury on the thermometer when the thermometer records a temperature of 105°C. Control the variac in such a manner that there is no more rise in the temperature beyond 110°C and the temperature in the housing is maintained at $110 \pm 5^\circ\text{C}$. If, for a particular sample, the temperature is to be higher or lower than 110°C, the variac control knob can be adjusted accordingly.

23.7 To determine the percentage reduction of mass at any instant, rotate the drum scale by turning the drum drive knob until the pointer returns to the index. Read the percentage directly from the scale. The percent water which is read from the scale is the percent water based upon the initial mass of the sample, that is, the wet mass of the sample.

23.8 The criterion for taking the final reading is that the pointer should remain steady on the index mark which shows that the sample has dried to constant mass. Note the drum scale reading against the pointer which is the percent water on the total mass taken. Remove the thermometer from its bracket.

23.9 Repeat steps 23.1 to 23.8 with a fresh sample using a cool and clean pan.

24. CALCULATION

24.1 From the water content (m) as obtained on the moisture balance scale, the water content (w) on the dry weight basis shall be calculated as follows:

$$w = \frac{m}{100 - m} \times 100 \text{ percent}$$

SECTION 5 RAPID DETERMINATION OF WATER CONTENT FROM THE GAS PRESSURE DEVELOPED BY THE REACTION OF CALCIUM CARBIDE WITH THE FREE WATER OF THE SOIL

25. SCOPE

25.1 The section describes a method for rapid determination of water content from the gas pressure developed by the reaction of calcium carbide with the free water of the soil. From the calibrated scale of the pressure gauge, the percentage of water on total (wet) mass of soil is obtained and the same is converted to water content on dry mass of soil.

26. APPARATUS

26.1 Metallic Pressure Vessel — with clamp for sealing cup, and a gauge calibrated in percentage water content (see Fig. 3).

26.2 Counterpoised Balance — for weighing sample as shown in Fig. 3.

26.3 Scoop — for measuring absorbent (calcium carbide)

26.4 One Bottle of the Absorbent (Calcium Carbide).

26.5 One Cleaning Brush

26.6 Steel Balls — three steel balls of about 12.5 mm diameter and one steel ball of 25 mm diameter.

27. SOIL SPECIMEN

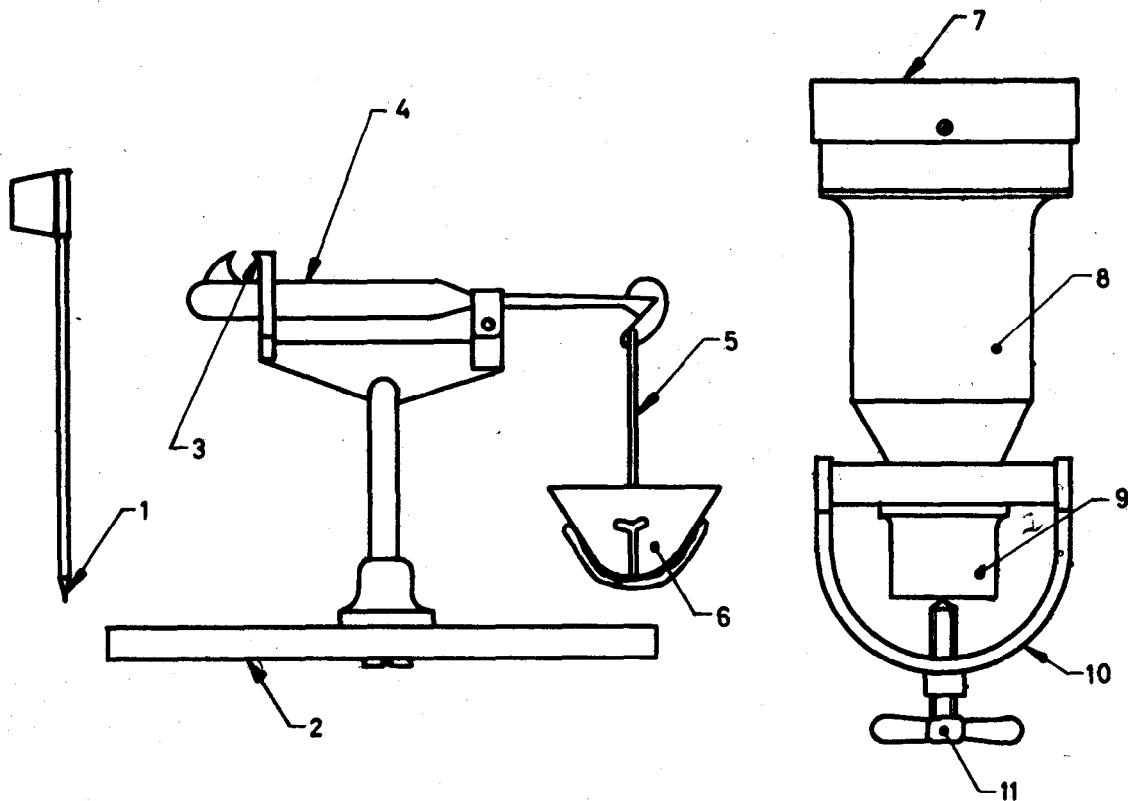
27.1 Sand requires no special preparation. Coarse powders may be ground and pulverized. Cohesive and plastic soils and material are tested with addition of steel balls in the pressure vessels. This test requires about 6 g of soil sample.

28. TEST PROCEDURE

28.1 Set up the balance. Place sample in pan till the mark on the balance arm mass lines up with the index mark.

28.2 Unclamp the clamping screw of the instrument sufficient to move the U-clamp off the cup. Lift off the cup. Check that cup and body are clean, otherwise clean it using a brush.

28.3 Hold the body horizontal and gently deposit one level scoopful of absorbent (calcium carbide) halfway inside the chamber. Then lay the chamber down without disturbing the absorbent charge. Transfer the soil weighed out as above from the pan to the cup. Holding cup and chamber approximately horizontal, bring them together without disturbing sample or absorbent, bring the U-clamp round and clamp the cup tightly into place.

*Description*

1. Scoop
2. Balance base
3. Index mark
4. Balance arm
5. Stirrup
6. Pan

Description

7. Gauge 0-50 percent
8. Body
9. Cup
10. U-clamp
11. Clamp screw

FIG. 3 RAPID MOISTURE METER

NOTE -- If the sample is bulky, reverse the above placement, that is, put the sample in the chamber and the absorbent in the cup. In the case of clayey soils and pastes, place the 3 smaller and one bigger steel balls in the body along with the absorbent.

28.4 With gauge downwards (except when the steel balls are used), shake the moisture meter up and down vigorously for 5 seconds, then quickly turn it so that the gauge is upwards, give a tap to the body of the moisture meter to ensure that all the contents fall into the cup. Hold the rapid moisture meter downwards, again shake for 5 seconds, then turn it with gauge upwards and tap. Hold for one minute. Repeat this for a third time. Once more invert the rapid moisture meter and shake up and down to cool the gas. Turn the rapid moisture meter with the gauge upwards and dial horizontal held at chest

height. When the needle comes to rest, take the reading. The readings on the meter are the percentages of water on the wet mass basis.

NOTE -- When steel balls are used, place the three smaller and one bigger balls in the body along with the absorbent and the sample in the cup and seal up the unit as usual. Hold the rapid moisture meter vertical with the cup downwards and allow the absorbent with the balls to fall into the cup. Shake the unit up and down vigorously in this position for about 15 seconds. Now invert the unit and allow the material to fall into the body. Now holding the unit horizontal, rotate it for 10 seconds so that the balls rolled round the inside circumference of the body. Rest for 20 seconds. Repeat the above cycle until the gauge reading is constant (usually this takes 4 to 8 min). Note the reading as usual.

28.5 Finally release the pressure slowly (away from the operator) by opening the clamp screw and

taking the cup out, empty the contents and clean the instrument with a brush.

29. CALCULATION

29.1 From the water content (m) obtained on the wet mass basis as the reading on the rapid moisture meter, the water content (w) on the dry mass basis shall be calculated as follows:

$$w = \frac{m}{(100 - m)} \times 100 \text{ percent}$$

NOTE — The absorbent is highly susceptible to absorption of moisture and so shall not be exposed to atmosphere; as a result, the absorbent suffers deterioration and will give results on the lower side. Replace the lid of the absorbent container firmly as soon as the required amount of the absorbent for a test is taken from the bottle. The absorbent suffers deterioration with time.

APPENDIX A

(Clause 7.2)

PRO FORMA FOR RECORD OF RESULTS OF TEST FOR THE DETERMINATION OF WATER CONTENT OF SOIL

Details of soil sample : Tested by :

Method of test adopted :

Oven drying :

Sand-bath :

Alcohol :

1.	Container No.	
2.	Mass of container and wet soil W_2 , in g	
3.	Mass of container and dry soil W_3 , in g	
4.	Mass of container W_1 , in g	
5.	Mass of dry soil ($W_3 - W_1$), in g	
6.	Mass of moisture ($W_2 - W_3$), in g	
7.	Water content $w = \frac{W_2 - W_3}{W_3 - W_1} \times 100\%$	

Indian Standard

METHODS OF TEST FOR SOILS

PART 18 DETERMINATION OF FIELD MOISTURE EQUIVALENT (Incorporating Amendment No. 1)

0. FOREWORD

0.1 This standard (Part 18) deals with the method of test for determination of field moisture equivalent of soils, which gives an indication of the percentage moisture at which a drop of water placed on a smooth surface of soil pat will not be immediately absorbed but will spread out over the surface and give it a shining appearance. In fine-grained soils, the test assists in the determination of the moisture content at which air in the interstices between particles becomes sealed in by the moisture films around individual particles so that the capillary forces can no longer draw moisture into the soil. In coarse-grained soils, the test indicates that all voids in the material are filled with water. A field moisture equivalent equal to or greater than the centrifuge moisture equivalent indicates the presence of organic material in detrimental quantities.

1. SCOPE

1.1 This standard (Part 18) lays down a method for determining the field moisture equivalent of soils.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definition shall apply.

2.1 Field Moisture Equivalent, FME — The minimum water content expressed as a percentage of the weight of the oven-dried soil, at which a drop of water placed on a smoothed surface of the soil will not immediately be absorbed by the soil but will spread out over the surface and give it a shiny appearance.

3. APPARATUS

3.1 Evaporating Dish — a porcelain evaporating dish about 12 cm in diameter.

3.2 Spatula — a flexible spatula having a blade about 8 cm in length and 2 cm in width.

3.3 Dropper — a pipette, burette or similar device for adding water dropwise.

3.4 Containers — suitable containers, such as matched watch glasses which will prevent loss of moisture during weighing.

3.5 Balance — a balance sensitive to 0.01 g [see IS : 1433-1965 'Specification for beam scales (revised)'].

3.6 Pestle and Mortar

3.7 Oven — thermostatically controlled oven with interior of non-corroding material to maintain the temperature between 105 and 110°C.

3.8 Sieves — 4.75-mm IS Sieves, 2-mm IS Sieves and 425-micron IS Sieves [see IS : 460 (Part 1)-1978].

4. PREPARATION OF SAMPLE

4.1 The soil sample as received from the field shall be exposed to air at room temperature until dried thoroughly. The aggregations shall then be thoroughly broken up in a mortar with a rubber-covered pestle or using a mortar and pestle made of soft wood. A representative sample of the amount required to perform the desired test shall then be selected by the use of a sampler.

4.2 The portion of the air-dried sample selected for the purpose of tests shall be weighed and the weight recorded as the weight of the total test sample uncorrected for hygroscopic moisture. The test sample shall be separated by sieving with a 2-mm IS Sieve. That fraction retained on the 2-mm IS Sieve shall be ground in a mortar with a rubber-covered pestle until the aggregations of soil particles are broken up into the separate grains. The ground soil shall then be separated into two fractions by sieving with a 2-mm IS Sieve. The remaining portion of the material passing the 2-mm IS Sieve shall then be separated into two parts by means of a 425-micron IS Sieve. The fraction retained on the 425-micron IS Sieve shall be discarded. The fraction passing 425-micron IS Sieve shall be used for the test.

4.3 Soil Specimen — A specimen weighing about 30 g from the thoroughly mixed portion of the material passing 425-micron IS Sieve shall be taken for the test.

5. PROCEDURE

5.1 Place the air-dried specimen in an evaporating dish. Add distilled water to the specimen in small amounts and mix the specimen thoroughly after each addition of water. When the wetted soil forms into balls under manipulation, smooth the sample with a light stroke of the spatula and place a drop of water on the smoothed surface. If the drop of water disappears in 30 seconds, mix a few drops of water

with sample, and repeat the procedure until the drop of water placed on the smoothed surface does not disappear in 30 seconds but spreads over the smoothed surface leaving a shiny appearance (see Note). Then remove a small portion of the soil on which the last drop of water was placed and keep in a suitable container previously weighed (W_1). Determine the weight of the container and wet soil (W_2). Oven-dry the soil sample to constant weight at 105 to 110°C and record it (W_3).

NOTE — In case of some sandy soils, the shiny appearance may not be apparent. In such a case, press the finger or spatula on the soil. When the finger or spatula is removed slowly, a film of moisture will raise slightly with it, if the *FME* has been reached.

6. CALCULATION

6.1 The Field Moisture Equivalent (*FME*) shall be calculated as follows:

$$FME = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

where

W_2 = weight of container with wet soil in g,

W_3 = weight of container and oven-dried soil in g, and

W_1 = weight of container in g.

7. REPORT

7.1 The test results shall be tabulated as given below:

- | | |
|--|--|
| 1. Weight of container (W_1), in g | |
| 2. Weight of container with wet soil (W_2), in g | |
| 3. Weight of container and oven-dried sample (W_3), in g | |
| 4. Weight of moisture present, in g | |
| 5. Field moisture equivalent | |

Remarks:

7.2 The Field Moisture Equivalent shall be reported to two significant figures.

Indian Standard

METHODS OF TEST FOR SOILS

PART 19 DETERMINATION OF CENTRIFUGE MOISTURE EQUIVALENT

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 This standard (Part 19) deals with the method of test for determination of centrifuge moisture equivalent of soils. The value of the centrifuge moisture equivalent is useful in assessing the relative permeability of soils.

0.2 This standard is intended chiefly to cover the technical provisions relating to the method of test for the determination of centrifuge moisture equivalent of soils, and it does not include all the necessary provisions of a contract.

1. SCOPE

1.1 This standard (Part 19) lays down the method for determining the centrifuge moisture equivalent of soils.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definition shall apply.

2.1 Centrifuge Moisture Equivalent (CME) — The centrifuge moisture equivalent of a soil is the amount of moisture, expressed as a percentage of the weight of the oven-dried soil retained by the soil which has been first saturated with water and then subjected to a force equal to 1000 times the force of gravity for one hour.

3. APPARATUS

a) *Gooch Crucible* — porcelain, with perforated bottom. The crucible shall be about 40 mm in height and the diameter shall be about 25 mm at the top and 20 mm at the bottom, all outside dimensions.

b) *Filter Paper* — circular piece, just large enough to cover the inside bottom of the Gooch crucible. A Whatman filter paper No. 42 or equivalent is found suitable.

c) *Trunnion Cup* — a Babcock trunnion cup fitted with a brass cap and with a suitable device for supporting the Gooch crucible 12 mm above the bottom of the cup in such a manner that the water ejected during the centrifuging operation shall not come in contact

with the crucible and contents and furthermore, that air may circulate freely about the crucible within the cup. Suitable fittings for the cup are shown in Fig. 1.

- d) *Centrifuge* — one of such size and so driven that a force equal to 1000 times the force of gravity may be exerted at the centre of gravity of the soil sample.
- e) *Balance* — sensitive to 0.001 g (see IS : 1433-1965).
- f) *Oven* — thermostatically controlled with interior of non-corroding material to maintain the temperature between 105 and 110°C.

4. SOIL SPECIMEN

4.1 A 5 g soil specimen shall be taken from the thoroughly mixed portion of the material passing the 425-micron IS Sieve obtained in accordance with IS : 2720 (Part 1)-1983.

5. PROCEDURE

5.1 Weigh the Gooch crucible empty and with a piece of dry filter paper which just covers the bottom of the crucible. Then place the soil specimen in the crucible. Place the crucible with the soil specimen in a pan of distilled water and allow specimen to take up moisture until completely saturated, as indicated by the presence of free water on the surface of the specimen. Then place the crucible in a humidifier for at least 12 hours to ensure uniform distribution of moisture throughout the soil mass. Pour off all free water remaining on the surface of the sample and place the crucible in a Babcock trunnion cup fitted as described in 3(c).

Centrifuge the soil specimen for a period of one hour at a speed which, for the diameter of head used, will exert a centrifugal force 1000 times the force of gravity at the centre of gravity of the soil specimen. Immediately after centrifuging, weigh the crucible and contents, and record the weight. Then oven-dry the specimen to constant weight at a temperature of 105 to 110°C, weigh the crucible and contents and record the weight.

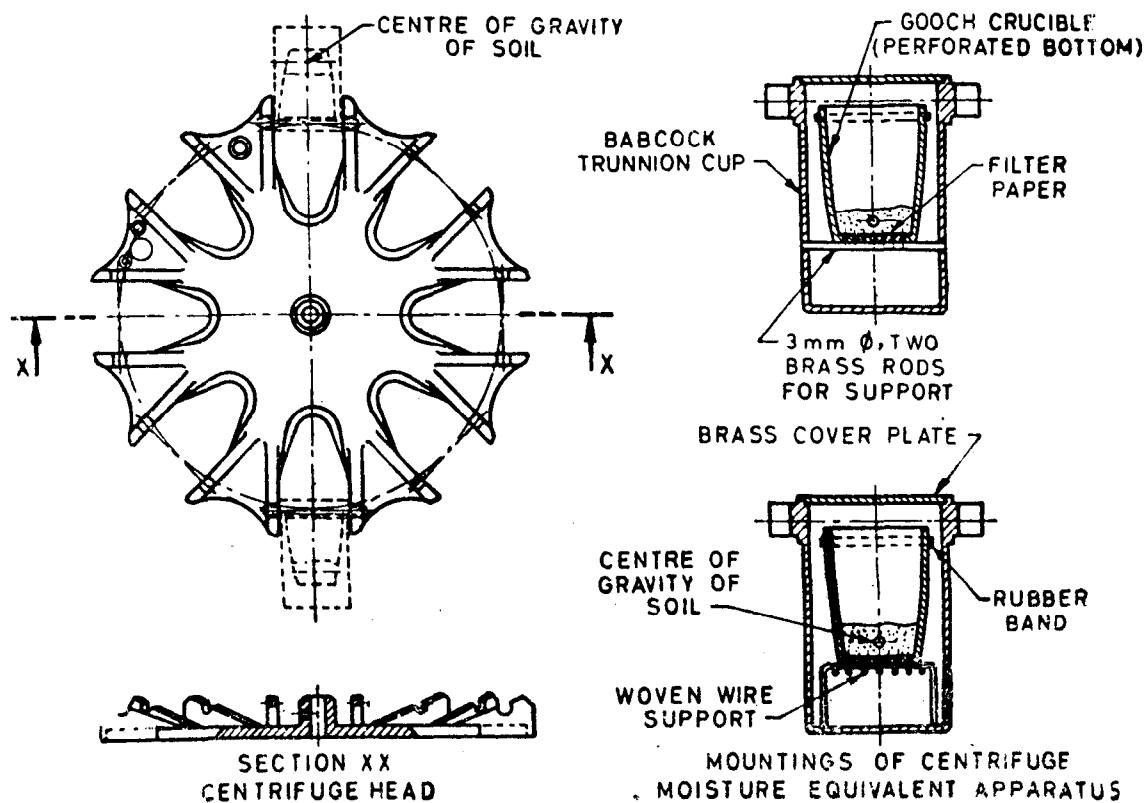


FIG. 1 CENTRIFUGE APPARATUS

If the soil is waterlogged, that is, when free water is observed on the top of the specimen after the centrifuging operation, do not remove the free water but weigh it with the specimen.

The test should be conducted at a temperature of $27 \pm 2^\circ\text{C}$.

An allowance of 0.02 g shall be made for the moisture remaining in the filter paper after centrifuging.

6. CALCULATION

6.1 The centrifuge moisture equivalent of the soil shall be calculated by the following formula:

$$CME = \frac{(W_2 - W_1 - 0.02) - (W_3 - W_1)}{(W_3 - W_1)} \times 100$$

where

CME = centrifuge moisture equivalent;

W_2 = weight of crucible and contents after centrifuging, in g;

W_1 = weight of crucible with dry filter paper, in g; and

W_3 = weight of crucible and contents after oven-drying, in g.

7. REPRODUCIBILITY OF RESULTS

7.1 The tests shall be made in duplicate. The variation between the two values obtained in the duplicate tests should not exceed one percent for values of CME up to 15 and 2 percent for values above 15. If the results disagree by more than the limits specified, the tests shall be repeated.

8. REPORT

8.1 The average of the two results obtained (see 7.1) shall be reported as the Centrifuge Moisture

Equivalent.

8.2 The results of the tests may be reported in the form given below:

1.	Determination No.	1	2
2.	Weight of crucible with dry filter paper (W_1), in g		
3.	Weight of crucible and contents after centrifuging (W_2), in g		
4.	Weight of crucible and content after ovendrying (W_3), in g		
5.	Centrifuge moisture equivalent		
Average:			
Remarks:			

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SECTION 5
Determination of Specific Gravity

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Indian Standard
METHODS OF TEST FOR SOILS
PART 3 DETERMINATION OF SPECIFIC GRAVITY
Section 1 Fine Grained Soils

(First Revision)

0. FOREWORD

0.1 This standard (Part 3) deals with the method of test for determination of specific gravity of soils which finds application in finding out the degree of saturation and unit weight of moist soils. The unit weights are needed in pressure, settlement and stability problems in soil engineering. This standard was published in the year 1964. In view of the further work done in this field in this as well as in other countries, the revision has been prepared so as to give the latest method of test which has separate provision for fine-grained and coarse soils. The revision is being prepared in two sections: Section 1, dealing with the method for fine-grained soil which is basically a laboratory method and Section 2 for fine, medium and coarse-grained soils which is field method.

1. SCOPE

1.1 This standard (Part 3/Sec 1) lays down the methods of test for the determination of the specific gravity of soil particle of fine grained soils (*see Note*).

NOTE — The method may also be used for medium and coarse grained soils if the coarse particles are grained to pass 4.75 mm IS sieve before using.

2. TERMINOLOGY

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

3. APPARATUS

3.1 The following apparatus is required:

- a) Two density bottles (pyknometers) of approximately 50 ml capacity with stoppers.
- b) A water-bath maintained at a constant temperature to within $\pm 0.2^\circ\text{C}$. (If standard density bottles are used, this constant temperature is 27°C .)
- c) A vacuum desiccator (a convenient size is one about 200 mm to 250 mm in diameter).
- d) A desiccator (a convenient size is one about 200 mm to 250 mm in diameter) containing anhydrous silica gel.

- e) A thermostatically controlled drying oven, capable of maintaining a temperature of 105 to 110°C .
- f) A balance readable and accurate to 0.001 g.
- g) A source of vacuum, such as a good filter pump or a vacuum pump.
- h) A spatula (a convenient size is one having a blade 150 mm long and 3 mm wide; the blade has to be small enough to go through the neck of the density bottle), or piece of glass rod about 150 mm long and 3 mm diameter.
- j) A wash bottle, preferably made of plastics, containing air-free distilled water (*see Note*).
- k) A sample divider of the multiple slot type (riffle box) with 7 mm width of opening.
- m) A length of rubber tubing to fit the vacuum pump and the desiccator.

NOTE — Obtain the air-free distilled water for at least 30 minute in a container that can be sealed from the atmosphere during cooling. Take care to see that the container is strong enough to resist the reduction in pressure inside it during cooling.

4. PROCEDURE

4.1 The complete density bottle with stopper shall be dried at 105 to 110°C , cooled in the desiccator and weighed to the nearest 0.001 g (m_1) (*see Note 1*).

4.2 The 50 g sample obtained as described in the procedure for the preparation of disturbed samples for testing shall, if necessary, be ground to pass a 2-mm IS test sieve. A 5 to 10 g subsample shall be obtained by riffling, and oven-dried at 105 to 110°C (*see Note 2*). This sample shall be transferred to the density bottle direct from the desiccator in which it has been cooled. The bottle and contents together with the stopper shall be weighed to the nearest 0.001 g (m_2).

4.3 Sufficient air-free distilled water (*see Note 3*) shall be added so that the soil in the bottle is just covered. The bottle containing the soil and liquid, but without the stopper, shall be placed in the vacuum desiccator, which shall then be evacuated gradually. The pressure shall be reduced to about

20 mmHg. When using a water pump, because of variation in mains pressure, care shall be taken to ensure that the required vacuum is maintained. Care shall be taken during operation to see that the air trapped in the soil does not bubble too violently so as to prevent small drops of the suspension being lost through the mouth of the bottle. The bottle shall be allowed to remain in the desiccator for at least 1 hour until no further loss of air is apparent.

4.4 The vacuum shall be released and the lid of the desiccator removed. The soil in the bottle shall be stirred carefully with the spatula, or the bottle vibrated. Before removing the spatula from the bottle, the particles of soil adhering to the blade shall be washed off with a few drops of air-free liquid. The lid of the desiccator shall then be replaced and the desiccator evacuated again.

4.5 The procedure outlined in **4.3** and **4.4** shall be repeated until no more air is evolved from the soil (see Note 4).

4.5.1 Alternately, the entrapped air can be removed by getting heating the pyknometer placed on a water-bath or sand-bath.

4.6 The bottle and contents shall then be removed from the desiccator and further air-free liquid added until the bottle is full. The stopper shall then be inserted. The stoppered bottle shall be immersed up to the neck in the constant temperature bath for approximately 1 hour or until it has attained the constant temperature of the bath (see Note 5).

If there is an apparent decrease in volume of the liquid, the stopper shall be removed and further liquid added to fill the bottle and the stopper replaced. The bottle shall then be returned to the bath and sufficient time shall be allowed to elapse after this operation to ensure that the bottle and its contents again attain the constant temperature of the bath. If the bottle is still not completely full, this process shall be repeated.

4.7 The stoppered bottle shall then be taken out of the bath, wiped dry and the whole weighed to the nearest 0.001 g (m_3).

4.8 The bottle shall then be cleaned out and filled completely with air-free liquid, the stopper inserted and then the whole immersed in the constant temperature bath for 1 hour or until it has attained the constant temperature of the bath. If there is an apparent decrease in the volume of the liquid, the stopper shall be removed and further liquid added to fill the bottle and the stopper replaced. The stoppered bottle shall then be returned to the batch and sufficient time shall be allowed to elapse after this operation to ensure that the bottle and its contents again attain the constant temperature. If the bottle is still not completely full, this process shall be repeated. The bottle shall then be taken out of the

bath, wiped dry and the whole weighed to the nearest 0.001 g (m_4) (see Note 6).

4.9 Two determinations of the specific gravity of the same soils sample shall be made (see Notes 7 and 8).

NOTE 1 — Standard Density Bottles — If a density bottle is used then, in order to avoid distortion, it should not be dried by placing it in an oven. It may be dried by rinsing with acetone or an alcohol-ether mixture and then blowing warm air through it.

NOTE 2 — Oven-drying of the soil has been specified for convenience. If there is any reason to believe that this will change the specific gravity due to loss of water of hydration, the soil should be dried at not more than 80°C. This fact should be reported.

NOTE 3 — Alternative Liquids for Specific Gravity Determination — With certain soils, for example, those containing soluble salts, kerosene (paraffin oil) or white spirit may be preferred. If one of these is used, record the fact and carry out a separate experiment to determine the specific gravity of the liquid at the room temperature of the test. The equation for the specific gravity of the soil particles, G , given in **5.1** then becomes:

$$G = \frac{G_L (m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)}$$

where

G_L = specific gravity of the liquid used at the constant temperature;

m_1 = mass of density bottle in g;

m_2 = mass of bottle and dry soil in g;

m_3 = mass of bottle, soil and liquid in g; and

m_4 = mass of bottle when full of liquid only in g.

NOTE 4 — Experience has shown that the largest source of error in the test is due to the difficulty in ensuring the complete removal of air from the sample. To obtain reliable results, the soil should be left under vacuum for several hours, preferably overnight. Shaking the bottle in hand once or twice interrupting the vacuum gives quicker results.

NOTE 5 — If a constant temperature room or cabinet is available, then this procedure need not be carried out in a water-bath.

NOTE 6 — If method given in **4.8** is used to find the volume of the density bottle, then the test may be carried out at any temperature, provided it is constant throughout the test.

NOTE 7 — Many soils have a substantial proportion of heavier or lighter particles. Such soils will give erratic values for the specific gravity even with the greatest care in testing and a number of repeated tests may be needed to obtain a good average value.

NOTE 8 — Clean quartz and flint sands generally have a specific gravity close to 2.65; low values would suggest presence of organic matter.

5. CALCULATION

5.1 The specific gravity of the soil particles G shall be measured at room temperature. If water has been used as the air-free liquid, then the following equation shall be used:

$$G = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

where

- m_1 = mass of density bottle in g;
- m_2 = mass of bottle and dry soil in g;
- m_3 = mass of bottle, soil and water in g; and
- m_4 = mass of bottle when full of water only in g.

If some other air-free liquid has been used, reference should be made to Note 3.

5.2 The specific gravity shall be calculated at 27°C. If the room temperature is different than 27°C, the following correction shall be done:

$$G' = K G$$

where

$$G' = \frac{\text{corrected specific gravity at } 27^\circ\text{C, and}}{\text{Relative density of water at room}} \\ \text{temperature}$$

$$K = \frac{\text{Relative density of water at } 27^\circ\text{C}}{\text{Relative density of water at } 27^\circ\text{C}}$$

6. REPORTING OF RESULTS

6.1 The average of the values obtained shall be taken as the specific gravity of the soil particles and shall be reported to the nearest 0.01. If the two results differ by more than 0.03, the tests shall be repeated.

Indian Standard
METHODS OF TEST FOR SOILS
PART 3 DETERMINATION OF SPECIFIC GRAVITY
Section 2 Fine, Medium and Coarse Grained Soils

(First Revision)

0. FOREWORD

0.1 This part deals with the method of test for determination of specific gravity of the soils which is used in finding out the degree of saturation and unit weight of moist soils. The unit weights are needed in pressure, settlement and stability problems in soil engineering. This standard was published in 1964. In view of the further work done in this field in this country and overseas, the revision has been prepared so as to give the latest method of test. The revision is being prepared in two sections: Section 1 dealing with fine grained soil which is basically a laboratory method; and Section 2 dealing with the method for fine, medium and coarse-grained soils which is basically a field method.

1. SCOPE

1.1 This standard (Part 3/Sec 2) lays down the method of test for the determination of the specific gravity of soil particle of fine, medium and coarse-grained soils. It is not suitable for soils containing more than 10 percent of stones retained on a 40-mm IS sieve and such stones should be broken down to less than this size.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definition shall apply.

2.1 Specific Gravity (*G*) — The ratio of the weight in air of a given volume of soil solids at a stated temperature to the weight in air of an equal volume of distilled water at that temperature.

3. APPARATUS

3.1 The following apparatus is required:

- a) A gas jar of 1 litre capacity, fitted with a rubber bung (see Note 1) (see Fig. 1);
- b) A ground-glass plate or a plastic slip cover for closing the gas jar (see Fig. 1);
- c) A mechanical shaking apparatus capable of rotating the gas jar, end-over-end, at about 50 rev/min (see Note 2);
- d) A balance readable and accurate to 0.2 g; and

e) A thermometer to cover the temperature range 0 to 50°C, readable and accurate to 1°C.

4. PROCEDURE

4.1 A sample weighing 200 g in the case of fine-grained soil and 400 g in the case of medium and coarse-grained soils, shall be obtained in accordance with the procedure for the preparation of disturbed soil samples for testing. This sample shall have been oven-dried (see Note 3) and then stored in an air-tight container until required.

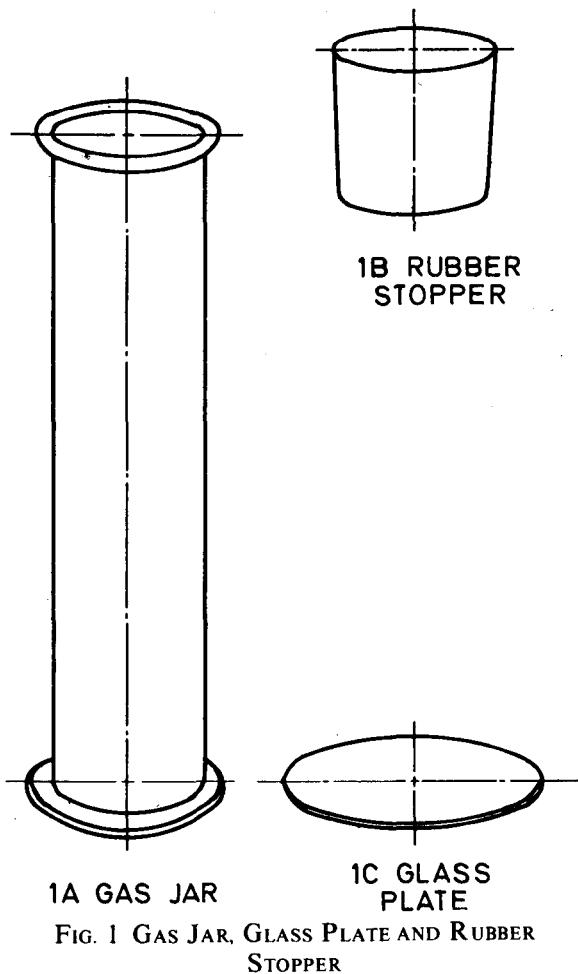


FIG. 1 GAS JAR, GLASS PLATE AND RUBBER STOPPER

4.2 The gas jar and ground glass plate/plastic slip cover shall be dried and weighed to the nearest 0.2 g (m_1).

4.3 Approximately 200 g of fine-grained soil or 400 g of medium or coarse-grained soil shall be introduced into the gas jar directly from the container in which it has been cooled. The gas jar, ground-glass plate/plastic slip cover and contents shall be weighed to the nearest 0.2 g (m_2).

4.4 Approximately 500 ml of water at a temperature within $\pm 2^\circ\text{C}$ of the average room temperature during the test (see Note 4) shall be added to the soil. The rubber stopper shall then be inserted into the gas jar and in the case of medium and coarse-grained soils, the gas jar and contents shall be set aside for at least 4 hours. At the end of this period, or immediately after the addition of water in the case of fine-grained soils, the gas jar shall be shaken by hand until the particles are in suspension and then placed in the shaking apparatus and shaken for a period of 20 to 30 minutes.

4.4.1 The stopper shall then be removed carefully and any soil adhering to the stopper or the top of the gas jar shall be washed carefully into the jar; any froth that has formed shall be dispersed with a fine spray of water. Water shall then be added to the gas jar to within 2 mm of the top. The soil shall be allowed to settle for a few minutes and the gas jar then filled to the brim with more water. The ground-glass plate/plastic slip cover shall then be placed on the top of the jar taking care not to trap any air under the plate. The gas jar and plate shall then be carefully dried on the outside and the whole weighed to the nearest 0.2 g (m_3).

4.5 The gas jar shall be emptied, washed out thoroughly and filled completely to the brim with water. The glass plate shall be placed in position taking care not to trap any air under the plate. The gas jar and plate shall then be dried carefully on the outside and the whole weighed to the nearest 0.2 g (m_4).

4.6 The procedure outlined in **4.1** to **4.4** shall be repeated on a second sample of the same soil so that two values for specific gravity are obtained.

5. CALCULATIONS

5.1 The specific gravity, G , of the soil particles shall be calculated from the equation:

$$G = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

where

m_1 = mass of gas jar and ground glass plate;

m_2 = mass of gas jar, plate and soil;

m_3 = mass of gas jar, plate, soil and water;

and

m_4 = mass of gas jar, plate and water.

5.2 The specific gravity shall be calculated at 27°C . If the room temperature is different than 27°C , the following corrections shall be done:

$$G' = KG$$

where

G' = corrected specific gravity at 27°C , and

Relative density of water at room temperature

$$K = \frac{\text{Relative density of water at } 27^\circ\text{C}}{\text{Relative density of water at room temperature}}$$

6. REPORTING OF RESULTS

6.1 The specific gravity of the soil particles shall be reported to the nearest 0.01.

6.2 Three determinations of the specific gravity of the same soil sample shall be made. The average of the values obtained shall be taken as the specific gravity of the soil particles and shall be reported to the nearest 0.01. If the results differ by more than 0.03 from the average value, the tests shall be repeated.

NOTE 1 — A gas jar has been found to make a very effective pyknometer but any container of similar capacity can be used, provided that it can be shaken in a mechanical shaking apparatus, and provided that the mouth can be sealed in such a way that its volume is constant.

NOTE 2 — An end-over-end shaker has been specified but shaking machines giving a vibrating motion would also be suitable. The choice of shaking machine depends on the type of pyknometer used.

NOTE 3 — Oven drying of the soil has been specified for convenience. If there is any reason to believe that this will change the specific gravity due to loss of water of hydration, the soil should be dried at not more than 80°C . This fact should be reported.

NOTE 4 — If there is a large difference from the air temperature, sufficient water should be drawn for the required number of tests and allowed to stand in the room in which the tests are being done until the temperature is within the given range.

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SECTION 6
Grain Size Analysis

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Indian Standard
METHODS OF TEST FOR SOILS
PART 4 GRAIN SIZE ANALYSIS

(Second Revision)

0. FOREWORD

0.1 This part, which was originally published in 1965 and revised in 1975, deals with the method for the determination of grain size distribution in soils. An analysis of this kind express quantitatively the proportions by mass of the various sizes of particles present in the soil. In a soil, the gravel, sand, silt and clay fractions are recognized as containing particles of decreasing magnitude. The actual range of dimensions of the particles are given in IS : 1498-1970. The results of grain size analysis may also be represented graphically in the form of a grain size distribution curve in which the cumulative percentages finer than known equivalent grain sizes are plotted against these sizes, the latter being on a logarithmic scale. The results of grain size analysis are widely used in soil classification. The data obtained from grain size distribution curves is used in the design of filters for earth dams to determine the suitability of soils for road construction.

0.2 In this second revision of the standard, grain sizes have been brought in line with IS: 1498-1970. A plummet balance method, as an alternative method, has been included.

1. SCOPE

1.1 This standard (Part 4) covers the method for the quantitative determination of grain size distribution in soils.

1.1.1 Two methods are given for finding the distribution of grain sizes larger than 75-micron IS Sieve; the first method, wet sievings, shall be applicable to all soils and the second, dry sieving, shall be applicable only to soils which do not have an appreciable amount of clay.

1.1.2 For the determination of distribution of grain sizes smaller than 75-microns, the pipette method is given as the standard method; the hydrometer method is given as a subsidiary method. This method shall be not applicable if less than 10 percent of the material passes the 75-micron IS Sieve (determined as given in 4).

2. TERMINOLOGY

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

3. SIEVE ANALYSIS OF SOILS FRACTION RETAINED ON 4.75 mm IS SIEVE (DRY METHOD)

3.1 Apparatus

3.1.1 Balance — Sensitive to 0.1 percent of the weight of sample to be weighed.

3.1.2 Sieves — 100-mm IS Sieve, 75-mm IS Sieve, 19-mm IS Sieve and 4.75-mm IS Sieve conforming to the requirement of IS : 460 (Part 1)-1978.

3.1.3 Rubber Pestle and Mortar

3.2 Preparation of Sample — The soil sample received from the field shall be prepared as specified in IS : 2720 (Part 1)-1983. The soil fractions retained on and passing 4.75-mm IS Sieve shall be taken separately for the analysis.

3.3 Procedure — The portion of the soil sample retained on 4.75-mm IS Sieve, selected as given in 3.2, shall be weighed and the mass recorded as the mass of the sample uncorrected for hygroscopic moisture. The quantity of the soil sample taken shall depend on the maximum particle size contained in the soil (see Note 1). The sample shall be separated into various fractions by sieving through the Indian Standard Sieves specified in 3.1.2. Other sieves may be introduced between the sieves mentioned in 3.1.2 depending upon the additional information that may be desired to be obtained from the analysis. While sieving through each sieve, the sieve shall be agitated so that the sample rolls in irregular motion over the sieve. Any particle may be tested to see if they will fall through but they shall not be pushed through. The material from the sieve may be rubbed, if necessary, with the rubber pestle in the mortar taking care to see that individual soil particles are not broken and re-sieved to make sure that only individual particles are retained. The quantity taken each time for sieving on each sieve shall be such that the maximum weight of material retained on each sieve at the completion of sieving does not exceed the values given in Note 2.

NOTE 1 — Depending on the maximum size of material present in substantial quantities in the soil, the mass of soil sample taken for analysis may be as follows:

<i>Maximum Size of Material Present in Substantial Quantities mm</i>	<i>Mass to be Taken for Test kg</i>
75	60
40	25
25	13
19	6.5
12.5	3.5
10	1.5
6.5	0.75
4.75	0.4

NOTE 2 Maximum weight of material to be retained on each sieve at the completion of sieving shall be as follows:

<i>IS Sieve Designation</i>	<i>450-mm Dia Sieves kg</i>	<i>300-mm Dia Sieves kg</i>
80-mm	15	6
20-mm	4	2
4.75-mm	1.0	0.5

The mass of the material retained on each sieve shall be recorded. If the sample appears to contain over 5 percent moisture, the water content of the material shall be determined in accordance with IS : 2720 (Part 2)-1973 and the masses corrected accordingly. When the sample contains less than 5 percent moisture, it is not necessary to determine the content for dry weight computations and all the determinations may be made on the basis of wet weight only. If the soil contains more than about 20 percent gravel particles and the fines are very cohesive with considerable amounts adhering to the gravel after separation, the gravel shall be washed on 4.75-mm IS Sieve using sodium hexametaphosphate solution, if necessary. For further analysis, a fresh portion of the fraction passing 4.75-mm IS Sieve shall be taken.

3.4 Calculations — The percentage of soil retained on each sieve shall be calculated on the basis of the total mass of soil sample taken and from these results the percentage passing through each of the sieves shall be calculated.

4. SIEVE ANALYSIS OF SOIL PASSING 4.75 mm IS SIEVE AND RETAINED ON 75-MICRON IS SIEVE

4.1 Apparatus

4.1.1 Balance — sensitive to 0.1 percent of the mass of sample to be weighed.

4.1.2 Sieves — The following Indian Standard Sieves conforming to IS : 460 (Part 1)-1978:

2-mm IS Sieve, 425-micron IS Sieve and 75-micron IS Sieve.

The sieves should be periodically checked up for aperture sizes.

4.1.3 Oven — Thermostatically controlled to

maintain the temperature between 105 and 110°C, with interior of non-corroding material.

4.1.4 Trays or Bucket — two or more large metal or plastic watertight trays or a bucket about 30 cm in diameter and 30 cm deep (convenient sizes of the trays are in the range of 45 to 90 cm² and 8 to 15 cm deep).

4.1.5 Brushes — sieve brushes and a wire brush or similar stiff brush.

4.1.6 Mortar with a Rubber Covered Pestle

4.1.7 Mechanical Sieve Shaker (Optional)

4.1.8 Riffler

4.2 Reagents — Sodium hexametaphosphate (chemically pure) or a mixture of sodium hydroxide [conforming to IS: 376-1976 'Specification for sodium hydroxide, analytical reagent (*second revision*)'] and sodium carbonate [analytical grade conforming to IS: 296-1974 'Specification for sodium carbonate, anhydrous (*second revision*)'] or any other dispersing agent which has been found suitable.

4.3 Procedure

4.3.1 Analysis by Wet Sieving — The portion of the soil passing 4.75-mm IS Sieve obtained as given in 3.2 shall be oven-dried at 105 to 110°C. The oven-dried material shall then be riffled so that a fraction of convenient mass is obtained. This shall be about 200 g if a substantial proportion of the material only, just passes the 4.75-mm IS Sieve or less if the largest size is smaller. The fraction shall be weighed to 0.1 percent of its total mass and the mass recorded. The riffled and weighed fraction shall be spread out in the large tray or bucket and covered with water.

4.3.1.1 Two grams of sodium hexametaphosphate or one gram of sodium hydroxide and one gram of sodium carbonate per litre of water used should then be added to the soil (see Note 1). The mix should be thoroughly stirred and left for soaking. The soil soaked specimen should be washed thoroughly over the nest of sieves specified in 4.1.2 (see Note 2), nested in order of their fineness with the finest sieve (75-micron IS Sieve) at the bottom. Washing shall be continued until the water passing each sieve is substantially clean. Care shall be taken to see that the sieves are not overloaded in the process (see Note 3). The fraction retained on each sieve should be emptied carefully without any loss of material in separate trays. Oven dried at 105 to 110°C and each fraction weighed separately and the masses recorded.

Alternatively, the soaked soil specimen may be washed on the 75-micron IS Sieve until the water passing the sieve is substantially clean. The fraction retained on the sieve should be tipped without loss

of material in a tray, dried in the oven and sieved through the nest of sieves specified in 4.1.2 (see Note 2) either by hand or by using mechanical sieve shaker. The fraction retained on each sieve should be weighed separately and the masses recorded.

NOTE 1 — The amount of dispersing agent may be varied depending on the type of soil. A dispersing agent may not be required in the case of all soils; in such cases the wet sieving may be carried out without the addition of dispersing agent.

NOTE 2 — The sieves listed in 4.1.2 correspond to the limits of coarse, medium and fine sand specified in IS: 1498-1970. Other sieves may be introduced depending on the additional information that may be desired to be obtained from the analysis.

NOTE 3 — The permissible maximum mass of sample on the 200-mm diameter sieves shall be as follows:

IS Sieve Designation	Maximum Mass of Sample g
2-mm	200
425-micron	50
75-micron	25

4.3.2 Analysis by Dry Sieving

4.3.2.0 In the case of clayey soils, this method shall not be used; wet sieving shall be used.

4.3.2.1 The portion of the soil passing 4.75-mm IS Sieve obtained as in 3.2 shall be oven-dried at 105 to 110°C and weighed to 0.1 percent of its total mass.

The sieve or sieves shall be agitated so that the sample rolls in irregular motion over the sieve. No particle shall be pushed through the sieve. The material retained on the sieve shall be rubbed with the rubber pestle in mortar in re-sieved to make sure that only individual particles are retained on the sieve. The amount retained on the sieve shall be weighed. The material retained in the receiver shall be transferred to a steel tray and the receiver fitted to the next largest sized sieve. The contents of the steel tray shall then be placed on this sieve and the operations indicated above repeated. These operations shall be repeated through all the sieves specified in 4.1.3 (see Note 2 of 4.3.1.1). If a mechanical shaker is available, these tests may be performed in one operation. Care shall be taken to ensure that sieving is complete. A minimum of 10 minutes shaking shall be used. The soil fraction retained on each sieve shall be carefully collected in containers and the mass of each fraction determined and recorded.

4.4 Calculation — The cumulative mass of soil fraction retained on each sieve shall be calculated. The percentage of soil fraction retained on each sieve shall be calculated on the basis of the mass of the sample passing 4.75-mm IS Sieve taken for the initial analysis. The combined gradation on the basis of the total soil sample taken for analysis shall then be calculated.

5. GRAIN SIZE ANALYSIS OF THE FRACTION PASSING 75-MICRON IS SIEVE OUT OF THE PORTION PASSING 4.75-mm IS SIEVE

5.1 Pipette Method (Standard Method)

5.1.0 This method is not applicable if less than 10 percent of the material passes 75-micron IS Sieve as obtained in 4.3.1.

5.1.1 Apparatus

5.1.1.1 Sampling pipette — of the type illustrated in Fig. 1 fitted with a pressure and suction inlet and having a capacity of approximately 10 ml. The pipette shall be so arranged that it can be inserted to a fixed depth into a sedimentation tube when the latter is immersed in a constant temperature bath (see also Fig. 4).

5.1.1.2 Glass sedimentation tubes — a minimum of two of 50 mm diameter and approximately 350 mm long marked at 500 ml volume with rubber bungs to fit.

5.1.1.3 Weighing bottles — required number, fitted with round stoppers or crucibles with suitable lids approximately 25 mm in diameter and 50 mm high. The bottles or crucibles shall be weighed to the nearest 0.001 gram.

5.1.1.4 Constant temperature bath — capable of being maintained at $27 \pm 0.1^\circ\text{C}$, into which the sedimentation tube can be immersed up to 500 ml mark. The bath shall not vibrate the sample (optional).

5.1.1.5 Stirring apparatus — a mechanical stirring device in which a suitable mounted electric motor turns a vertical shaft at a speed of 8 000 to 10 000 rev/min when loaded. The shaft shall be equipped with a replaceable stirring paddle of either of the types shown in Fig. 2 and, made of metal, plastic or hard rubber. The shaft shall be of such length that the stirring paddle will operate neither less than 20 mm nor more than 35 mm above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 3 shall be provided to hold the sample while it is being dispersed.

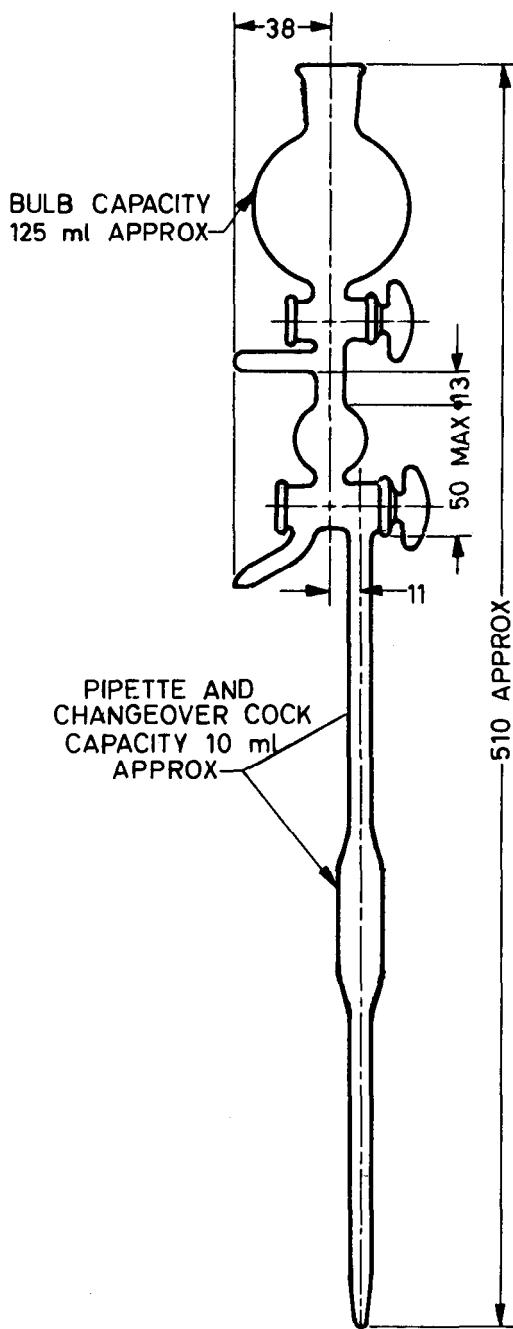
The container and baffles shall be of such material as will not be attacked by the reagents placed in the container. The motion of the soil suspension shall be sufficient to mix the contents thoroughly but it shall not be so vigorous that the particles will be crushed or lost through splashing; neither shall it be so sluggish as to leave unmixed material in the bottom of the container.

NOTE — Any other suitable dispersing device, such as mechanical bottle shaker and air-jet dispersing device which produce comparable dispersion of the soil, may also be used.

5.1.1.6 Sieves — 2-mm, 425-micron, 75-micron IS Sieves and receiver.

5.1.1.7 Balance — to weigh up to 0.001 g.

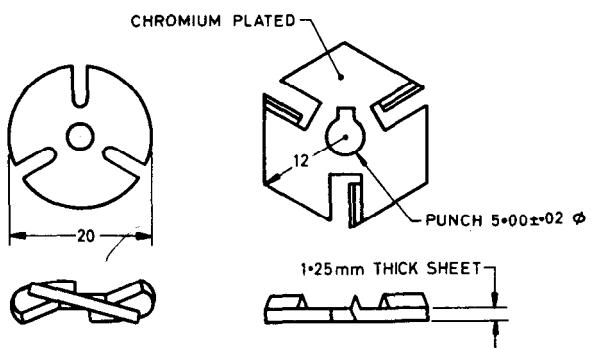
5.1.1.8 Oven — thermostatically controlled to maintain temperature of 105 to 110°C with interior of non-corroding material.



NOTE — Bore of tube to be 4 mm ϕ where possible.

All dimensions in millimetres.

FIG. 1 SAMPLING PIPETTE



All dimensions in millimetres.

FIG. 2 STIRRING PADDLES FOR STIRRING APPARATUS

5.1.1.9 Stop watch

5.1.1.10 Desiccator

5.1.1.11 Evaporating dish

5.1.1.12 Conical beaker — 650 ml or one litre capacity and a cover glass to fit and a smaller beaker.

5.1.1.13 Funnel — Buchner or Hirsch about 7 cm in diameter.

5.1.1.14 Filter flask — to take the funnel (about 500 ml).

5.1.1.15 Measuring cylinder — 100 ml capacity.

5.1.1.16 Pipette — 25 ml capacity.

5.1.1.17 Glass filter funnel — about 10 cm in diameter.

5.1.1.18 Wash bottle — containing distilled water.

5.1.1.19 Filter papers

5.1.1.20 Blue litmus paper

5.1.1.21 Glass rod — about 15 to 20 cm long, 4 to 5 mm in diameter fitted at one end with a rubber policeman.

5.1.1.22 Thermometer — 0 to 50°C, accurate to 0.5°C.

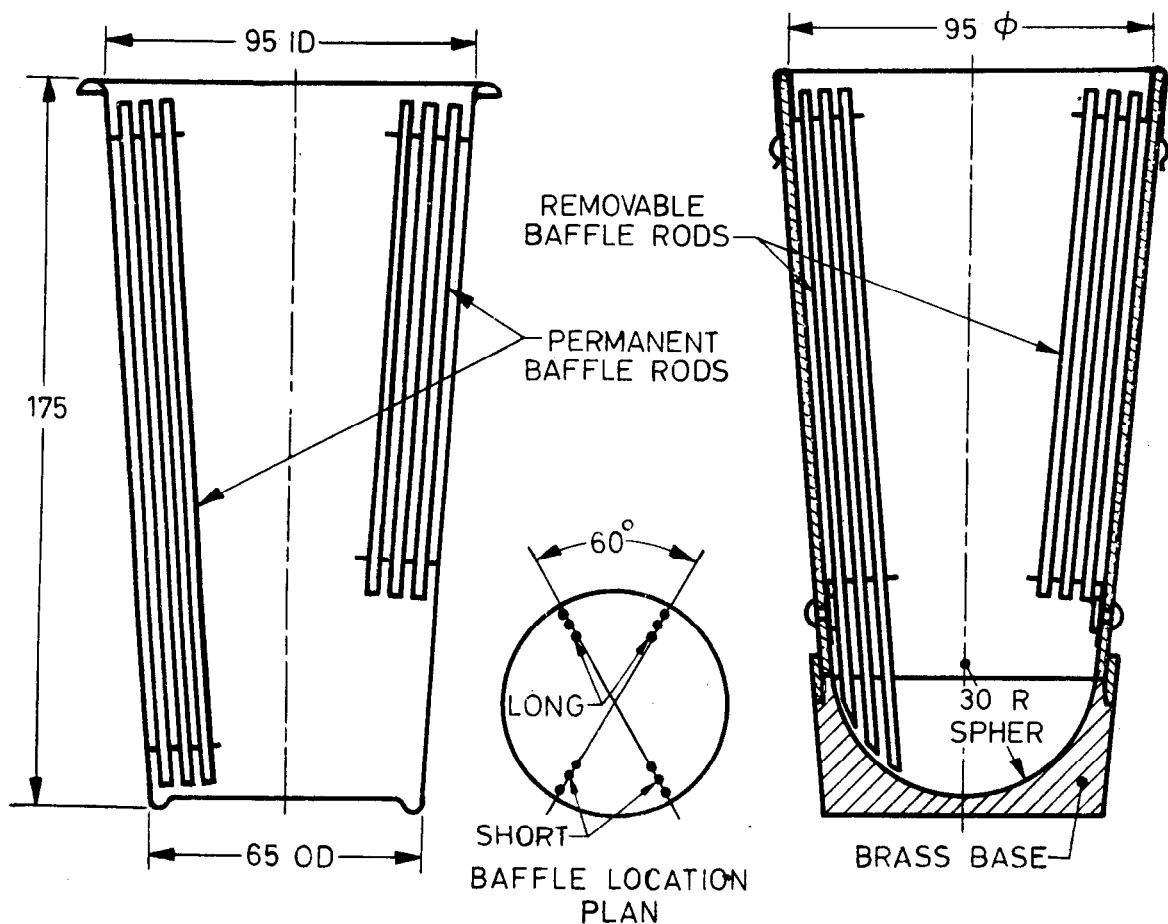
5.1.2 Reagents — The reagents shall be of analytical quality.

5.1.2.1 Hydrogen peroxide — 20 volume solution.

5.1.2.2 Hydrochloric acid approximately 1 N solution — 89 ml of concentrated hydrochloric acid (specific gravity 1.18) diluted with distilled water to make one litre of solution.

5.1.2.3 Sodium hexametaphosphate solution — Dissolve 33 g of sodium hexametaphosphate and seven grams of sodium carbonate in distilled water to make one litre of solution.

NOTE 1 — This solution is unstable and shall be freshly prepared approximately once a month. The date of preparation shall be recorded on the bottle.



All dimensions in millimetres.

FIG. 3 DISPERSION CUPS

NOTE 2 — Solution hexametaphosphate has been found to be ineffective when dealing with certain highly flocculated soils. In such cases, incomplete dispersion obtained is indicated by the formation of relatively large crumbs or flocks of soil which fall rapidly through the water leaving a sharply defined clear layer above the suspension and in such cases dispersion may be carried out by adding N sodium hydroxide solution at the rate of 4 ml per 10 g of soil.

NOTE 3 — Any other dispersing agent which has been proved suitable for dispersing soils may be used.

5.1.3 Procedure

5.1.3.0 If the soil fraction passing 75-micron IS Sieve during wet sieving specified in 4.3.1 has been collected, this can be oven-dried and used for pipette analysis, provided the soil has been pre-treated as specified in 5.1.3.2. Where necessary, the oven-dried fraction shall be powdered in a mortar with a rubber covered pestle taking care that the individual grains are not crushed. 25 to 50 g (depending on the soil type) of this soil shall be used for the analysis. The other relevant portions of the procedure specified in 5.1.3, 5.1.3.1, 5.1.3.3 and 5.1.3.4, shall be followed for further analysis.

5.1.3.1 Calibration of sampling pipette — The sampling pipette shall be thoroughly cleaned and dried and the nozzle shall be immersed in distilled water. The tap *B* shall be closed and the tap *E* opened (see Fig. 4). By means of a rubber tube attached to *C*, water shall be sucked up in the pipette until it rises above *E*. The tap *E* shall be closed and the pipette removed from the water. Surplus water drawn up into the cavity above *E'* shall be poured off through *F* into the small beaker by opening the tap *E* in such a way as to connect *D* and *F*. The water contained in the pipette and tap *E* shall be discharged into a glass weighing bottle of known mass and the mass determined. From this mass, the internal volume (V_p , ml) of the pipette and the tap shall be calculated to the nearest 0.05 ml. Three determinations of the volume shall be made and the average taken.

5.1.3.2 Pre-treatment of soils — The percentage of soluble salts in the soil shall be determined as specified in IS:2720 (Part 21)-1977. In case it is more than one percent, the soil shall be washed with

water before further treatment taking care to see that soil particles are not lost (see Note 1).

Two samples out of the soil passing 4.75-mm IS Sieve obtained as described in 3.2 weighing about 30 g shall be obtained by riffling from the bulk sample. The water content (w) of the one sample shall be determined by the method prescribed in IS : 2720 (Part 2)-1973.

The other sample shall be sub-divided by riffling. The actual mass of soil required may vary according to the type of soil, 50 g with a sandy soil and about 20 g with a clay soil. This sample shall be weighed to 0.001 g (W_a) and placed in the 650-ml conical beaker. 50 ml of distilled water shall be added to this and the soil suspension gently boiled until the volume is reduced to about 40 ml. After cooling, 75 ml of hydrogen peroxide shall be added and the mixture allowed to stand overnight covered with cover glass. The suspension shall then be gently heated. Care shall be taken to avoid frothing over and the contents of the beaker shall be agitated frequently either by stirring or by shaking the beaker. As soon as vigorous frothing has subsided and when there is no further reaction by the addition of fresh hydrogen peroxide, the volume shall be reduced to about 30 ml by boiling.

In the case of soils containing calcium compounds (see Note 2), the mixture shall be allowed to cool and about 10 ml of hydrochloric acid shall be added. The solution shall be stirred with a glass rod for a few minutes and allowed to stand for about one hour or for longer periods, if necessary. The treatment shall be continued till the solution gives an acid reaction to litmus. If the soil contains considerable amount of calcium salts, more acid may be required.

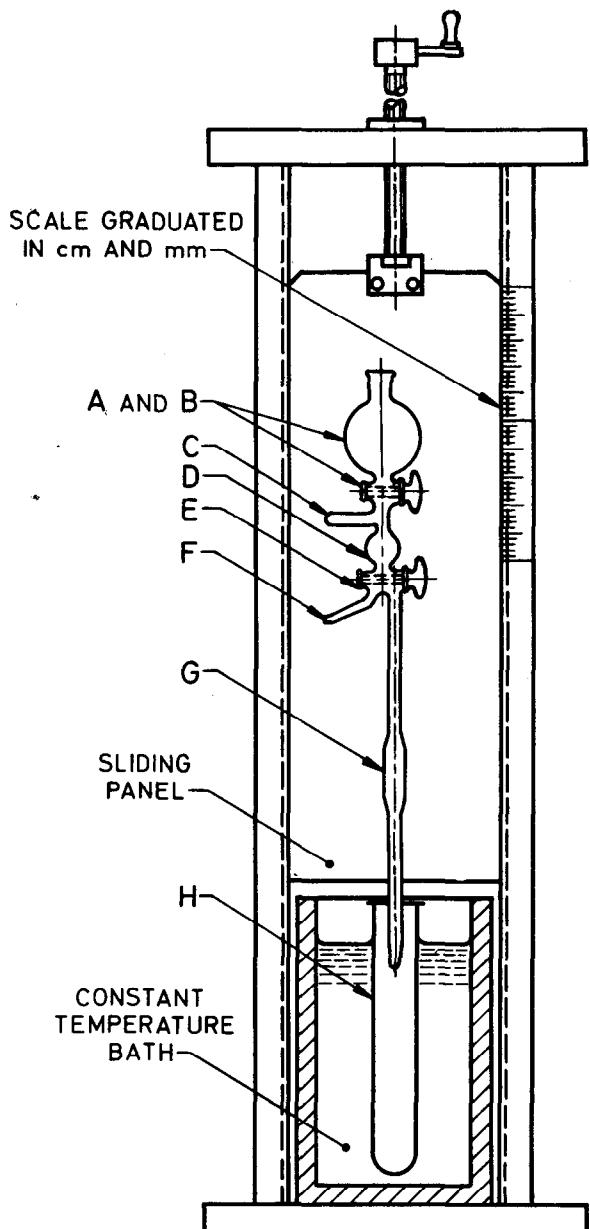
In the case of soils containing no calcium compounds or soluble salts and having a low organic content (less than 2 percent), the pre-treatment prescribed may be omitted and the dispersing agent shall be added as prescribed in 5.1.3.3 direct to the soil taken for analysis.

The mixture after pre-treatment with peroxide and acid or acid alone shall be filtered using the Buchner or Hirsch funnel and washed with warm water until the filtrate shows no acid reaction to litmus. The wet soil on the filter paper and funnel shall be transferred without any loss whatsoever to the glass evaporating dish (weighed to 0.001 g) using a jet of distilled water. Only a minimum quantity of distilled water shall be used. The dish and contents shall be dried in an oven maintained at 105 to 110°C. The dish and contents shall then be cooled in a desiccator and weighed to 0.001 g. The mass of the soil remaining after pre-treatment shall be recorded (W_b).

NOTE 1 — Owing to the removal of calcium, iron, etc, by the acid during the pre-treatment of the soil, the above method is not suitable for the determination of the particle size distribution in soils predominantly containing chalk or lime and it may, therefore, be necessary to adopt different methods of treatment with these and other soils having similar special characteristics. Dispersion may be assisted by rubbing the particles of soil in the suspension against the side of the evaporating dish with a glass rod fitted with a rubber policeman. In some cases a longer mixing time may help.

Lateritic soils will also be attacked by the acid but, unless they contain calcium, they need not be given the acid treatment.

NOTE 2 — Acid treatment shall be carried out only for soils containing insoluble calcium salts.



NOTE — G — sampling pipette, and
 H — sedimentation tube.

FIG. 4 ARRANGEMENT FOR LOWERING THE SAMPLING PIPETTE

5.1.3.3 Dispersion of soil — 25 ml sodium hexametaphosphate solution shall be added to the soil in the evaporating dish together with about 25 ml of distilled water and the soil brought into suspension by stirring with a glass rod. The mixture shall be warmed gently for 10 minutes and then transferred to the cup of the mechanical mixer using a jet of distilled water to wash all traces of the soil out of the evaporating dish. Any soil adhering to the dish shall be rubbed off with the rubber policeman. The amount of water used shall not exceed 150 ml. The soil suspension shall then be stirred well for 15 minutes or longer in the case of highly clayey soils (*see Note*).

The suspension shall then be transferred to 75-micron IS Sieve placed on a receiver and the soil shall be washed on this sieve using a jet of distilled water from a wash-bottle. Particular care shall be taken to wash off all traces of suspension adhering to the dispersion cup. The amount of distilled water used during the operation shall not exceed 150 ml. The suspension, that has passed through this sieve, shall then be transferred to the sedimentation tube using the glass funnel and the volume of liquid is made up to 500 ml with distilled water.

The material retained on the 75-micron IS Sieve may be oven-dried and treated as prescribed in 4.3.2, and the cumulative percentages of the soil fraction retained on each sieve shall be calculated.

NOTE — Any other suitable stirring device other than the one specified in 5.1.1.5 such as the bottle shaker, may be used and the stirring time shall be adjusted suitably.

5.1.3.4 Sedimentation — 25 ml of sodium hexametaphosphate solution shall be added from a pipette to a graduated 500-ml sedimentation tube (comparison tube) and diluted with distilled water to exactly 500 ml. This sedimentation tube, together with the tube containing the soil suspension, shall be immersed in the constant temperature bath (where used), the temperature of the bath noted (*see Notes 1 and 2*), the rubber bungs inserted and the tubes allowed to stand until they have reached the temperature of the bath. The tubes with their contents shall then be thoroughly shaken by inverting the tubes several times. They shall then be replaced in the apparatus, simultaneously starting the stop watch. The rubber bungs shall then be carefully removed without agitating the tubes.

The pipette with the tap *E* closed shall be lowered vertically into the soil suspension until the end is 100 ± 1 mm below the surface of the suspension. It shall be lowered with great care some 15 seconds before the sample is due to be taken. Approximately 10 seconds shall be taken to complete this operation. The tap *E* shall be opened and a sample (V_p ml) drawn up into the pipette. The pipette and the bore in the tap *E* shall be filled with solution and tap *E*

then closed. This operation shall take 10 seconds to complete.

After each sampling operation, the pipette shall be withdrawn from the suspension, taking approximately 10 seconds to complete the operation.

During the sampling, a small amount of the suspension may have been drawn up into the bulb *D* above the bore of the tap *E*. This surplus shall be washed away into the beaker down the outlet tube *F* by opening the tap *E* in such a way as to connect *D* and *F*. Distilled water shall then be allowed to run from the bulb funnel *A* into *D* and out through *F*, until no solution remains in the system.

A tared weighing bottle shall be placed under the end of the pipette and the tap *E* opened so that the contents of the pipette are delivered into the bottle. Any suspension left on the inner walls of the pipette shall be washed into the weighing bottle by allowing distilled water from the bulb *A* to run through *B*, *D* and *E* into the pipette. This procedure shall be repeated at the end of each time corresponding to particle diameters 0.02 mm, 0.006 mm, 0.002 mm, 0.001 mm calculated on the basis of equation given in 5.1.4.3 (a). Table 1 gives the time of settling to a depth of 100 mm of particles of various diameters for temperatures ranging from 10 to 35°C for an average specific gravity of soil of 2.68. The weighing bottles and contents shall be placed in the oven maintained at 105 to 110°C and the sample evaporated to dryness. After cooling in a desiccator, the weighing bottle and contents shall be weighed to the nearest 0.001 g and the mass of the solid material in the sample determined (W_1 , W_2 , W_3 and W_4 for each respective sampling time).

Between any of the times in which the above sampling is taking place, a sample (V_p ml) shall be taken from the tube containing the sodium hexametaphosphate solution. The mass of solid material in the sample shall be determined (W_s).

The specific gravity of the soil fraction passing the 75-micron IS Sieve shall be determined by the method specified in IS : 2720 (Part 3/Sec 1)-1980.

NOTE 1 — If a constant temperature bath is not available for the test, the test may be performed at room temperature. The temperature shall be noted at the time of sampling and suitable correction made in the calculation of the equivalent diameter of soil grains on the basis of equation in 5.1.4.3 (a).

NOTE 2 — Asymmetrical heating of the suspension causes convection currents which affect the sedimentation process. The suspension should, therefore, be kept out of direct sunlight and away from any local source of heat. Evaporation should be retarded by keeping a cover on the measuring cylinder between readings.

NOTE 3 — It is not necessary to measure the specific gravity of every sample used for fine analysis. An average value for samples from the same area or soil type in an area may be used without loss of accuracy. It is essential that the specific gravity used is that of the fraction passing 75-micron IS Sieve.

5.1.4 Calculations

5.1.4.1 Loss in mass in pre-treatment — The loss in mass in pre-treatment of the soil in percentage shall be calculated as follows:

$$P = 100 - \frac{W_b (100 + w)}{W_a}$$

where

P = loss in mass in percentage,

W_b = mass of soil after pre-treatment,

w = air dry moisture content of the soil taken for analysis, and

W_a = mass of air dry soil used.

5.1.4.2 Sieving — The percent of soil sample passing each of the sieves used in the analysis shall be calculated using the mass of the pre-treatment soil (W_b).

5.1.4.3 Sedimentation

a) **Diameter of particle** — The diameter of the particle in suspension at any sampling time t shall be calculated from the formula:

$$D = \sqrt{\frac{30 \mu}{980 (G - G_1)}} \sqrt{\frac{H}{t}}$$

where

D = diameter of particle in suspension, in mm;
 μ = coefficient of viscosity of water in poises at the temperature of suspension at the time of sampling;

G = specific gravity of the soil fraction used in the sedimentation analysis, in g/cm³;

G_1 = specific gravity of water, in g/cm³;

H = height of fall of the particles or sampling depth, in cm; and

t = time elapsed before sampling, in minutes.

b) Percentage finer than D

1) The mass of solid material in 500 ml of suspension for each respective sampling time shall be calculated from the formula:

M_1 or M_2 or M_3

or M_4 , etc, or

M_s , in g

$$= \frac{W_1 \text{ or } W_2 \text{ or } W_3 \text{ or } W_4, \text{ etc, or } W_s}{V_p} \times 500$$

where

M_1 M_2 M_3 M_4 etc } = mass of material in 500 ml from respective samplings,

M_s = mass of sodium hexametaphosphate in 500 ml of solution,

W_1 W_2 W_3 W_4 etc } = mass of material in V_p ml from respective samplings,

W_s = mass of sodium hexametaphosphate in V_p ml of solution, and

V_p = volume in ml of sample pipetted for respective samplings.

2) The percentage by mass (W), of particles finer than diameter D shall be calculated from the formula:

$$W = \frac{(M_1 \text{ or } M_2 \text{ or } M_3 \text{ or } M_4, \text{ etc}) - M_s}{W_b} \times 100$$

where

M_1 M_2 M_3 M_4 etc } = mass of material in 500 ml from respective samplings,

M_s = mass of sodium hexametaphosphate in 500 ml of solution, and

W_b = mass of soil after pre-treatment.

5.1.4.4 Combined gradation — Combined gradation for each of the particle sizes covered by 5.1.3.4 shall be calculated on the basis of the total soil sample taken for analysis.

5.2 Hydrometer Method (Subsidiary Method)

5.2.0 This method is not applicable, if less than 10 percent of the material passes 75-micron IS Sieve.

5.2.1 Apparatus

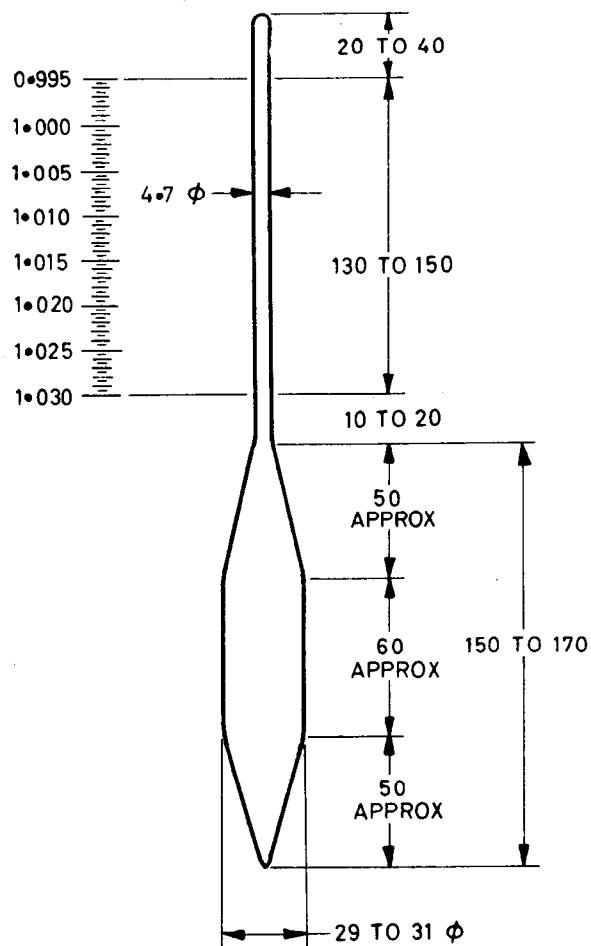
5.2.1.1 Hydrometer — of the type illustrated in Fig. 5 and fulfilling the following requirements:

- a) There shall be no abrupt changes in the cross-section of the hydrometer, such as will hinder cleaning or drying or permit air bubbles to be trapped.
- b) The hydrometer shall be graduated on the basis of a liquid having a surface tension of 55 dynes/cm.
- c) The graduation lines shall be at intervals of 0.0005, every alternate line shall extend beyond the shortest lines, every tenth graduation shall exceed that of all the intervening lines and shall be numbered in full. A recommended scale is shown in Fig. 5.
- d) The basis of the scale shall be density (g/ml) at 27°C.
- e) The maximum permissible scale error on the hydrometer is plus or minus one scale division.

TABLE 1 RATIO OF SETTLING OF PARTICLES AT VARIOUS TEMPERATURES
 (Average Specific Gravity of Soil Assumed as 2.68)
(Clause 5.1.3.4)

TEMPERATURE °C	DIAMETER, mm																			
	.001 .002 .003 .004 .005 .006 .007 .008 .009 .01										.02 .03 .04 .05 .06 .07 .08 .09 .1									
	(Time					for					a					fall				
	h					min					s					100				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	
10	40.80	10.19	4.53	2.55	98.0	68.0	53.0	38.3	30.2	24.5	367	163	92	59	40.8	31.8	22.9	18.1	14.7	
11	39.64	9.91	4.40	2.48	95.2	66.1	51.5	37.2	29.3	23.8	357	158	89	57	39.6	30.9	22.3	17.6	14.3	
12	38.55	9.63	4.28	2.41	92.6	64.2	50.1	36.1	28.5	23.1	347	154	87	55	38.5	30.0	21.7	17.1	13.9	
13	37.48	9.37	4.16	2.34	90.0	62.5	48.7	35.1	27.7	22.5	337	150	84	54	37.5	29.2	21.1	16.7	13.5	
14	36.39	9.10	4.04	2.28	87.6	60.8	47.3	34.2	27.0	21.9	328	146	82	52	36.4	28.4	20.5	16.2	13.1	
15	35.45	8.86	3.93	2.22	85.1	59.2	46.1	33.3	26.2	21.3	319	142	80	51	35.4	27.6	19.9	15.8	12.7	
16	34.49	8.62	3.83	2.16	82.8	57.6	44.9	32.4	25.5	20.7	310	138	78	50	34.5	26.9	19.4	15.3	12.4	
17	33.64	8.41	3.73	2.10	80.8	56.1	43.7	31.5	24.9	20.2	302	134	76	48	33.6	26.2	18.9	14.8	12.1	
18	32.73	8.18	3.64	2.04	78.6	54.6	42.5	30.7	24.2	19.6	294	131	74	47	32.7	25.2	18.4	14.5	11.8	
19	31.89	7.98	3.54	1.99	76.6	53.2	41.4	29.9	23.6	19.1	287	127	72	46	31.9	24.8	17.9	14.1	11.5	
20	31.10	7.77	3.45	1.94	74.6	51.8	40.4	29.1	23.0	18.6	280	124	70	45	31.1	24.2	17.5	13.8	11.5	
21	30.28	7.57	3.36	1.89	72.7	50.6	39.4	28.4	22.4	18.2	273	121	68	44	30.3	23.6	17.0	13.4	10.9	
22	29.55	7.38	3.28	1.85	70.9	49.3	38.4	27.7	21.8	17.7	266	118	66	42	29.5	23.0	16.6	13.1	10.6	
23	28.81	7.21	3.20	1.80	69.2	48.1	37.5	27.0	21.3	17.3	259	115	65	41	28.8	22.4	16.2	12.8	10.4	
24	28.12	7.03	3.12	1.76	67.5	46.9	36.6	26.4	20.8	16.9	253	113	63	40	28.1	21.9	15.8	12.5	10.1	
25	28.78	6.86	3.05	1.72	65.9	45.8	35.7	25.8	20.3	16.5	247	110	62	39	27.8	21.4	15.5	12.2	9.9	
26	26.81	6.71	2.98	1.68	64.4	44.7	34.8	25.2	19.8	16.1	241	107	60	39	26.8	20.9	15.1	11.9	9.6	
27	26.19	6.54	2.91	1.64	62.9	43.7	34.0	24.6	19.4	15.7	236	105	59	38	26.2	20.4	14.7	11.6	9.4	
28	25.60	6.40	2.84	1.60	61.4	42.7	33.2	24.0	19.0	15.4	231	102	58	37	25.6	19.9	14.4	11.4	9.2	
29	25.04	6.25	2.78	1.56	60.1	41.7	32.5	23.4	18.5	15.0	226	100	56	36	25.0	19.4	14.1	11.1	9.0	
30	24.46	6.12	2.72	1.53	58.8	40.8	31.8	22.9	18.1	14.9	221	98	55	35	24.5	19.0	13.8	10.8	8.8	
31	23.95	5.98	2.66	1.50	57.5	39.9	31.1	22.4	17.7	14.4	216	96	54	34	23.9	18.6	13.5	10.6	8.6	
32	23.44	5.86	2.60	1.47	56.3	39.1	30.4	21.9	17.3	14.1	221	94	53	34	23.4	18.2	13.2	10.4	8.5	
33	22.95	5.74	2.55	1.44	55.1	38.3	29.8	21.5	17.0	13.8	206	92	52	33	22.9	17.8	12.9	10.2	8.4	
34	22.50	5.62	2.50	1.41	54.0	37.5	29.2	21.1	16.6	13.5	202	90	51	32	22.5	17.5	12.6	10.0	8.1	
35	22.01	5.50	2.45	1.38	52.9	36.7	28.6	20.7	16.3	13.2	198	89	50	32	22.0	17.2	12.4	9.8	7.9	

- f) The other general requirements shall satisfy those specified in IS : 3104-1965 'Specification for density hydrometers'.



All dimensions in millimetres.

FIG. 5 HYDROMETER

5.2.1.2 Glass measuring cylinders — two of 1 000 ml capacity with ground glass or rubber stoppers about 7 cm diameter and 33 cm high marked at 1 000 ml volume.

5.2.1.3 Thermometer — to cover the range 0.50°C accurate to 0.5°C.

5.2.1.4 Water-bath or constant temperature room (optional) — for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature. Such a device is illustrated in Fig. 6.

5.2.1.5 Stirring apparatus — as specified in 5.1.1.5.

5.2.1.6 Sieves — as specified in 5.1.1.6.

5.2.1.7 Balance — accurate to 0.01 g.

5.2.1.8 Oven — thermostatically controlled to maintain a temperature of 105 to 110°C, with interior of non-corroding material.

5.2.1.9 Stop watch

5.2.1.10 Desiccator

5.2.1.11 Centimetre scale

5.2.1.12 Porcelain evaporating dishes — four, about 15 cm in diameter.

5.2.1.13 Wide-mouth conical flask or conical beaker — of 1 000 ml capacity.

5.2.1.14 Buchner or Hirsch funnel — about 10 cm in diameter.

5.2.1.15 Filter flask — to take the funnel.

5.2.1.16 Measuring cylinder — of 100 ml capacity.

5.2.1.17 Wash bottle — containing distilled water.

5.2.1.18 Filter papers

5.2.1.19 Blue litmus paper

5.2.1.20 Glass rod — about 15 to 20 cm long and 4 to 5 mm in diameter.

5.2.2 Reagents — The reagents shall be of analytical quality.

5.2.2.1 Hydrogen peroxide — See 5.1.2.1.

5.2.2.2 Hydrochloric acid N solution — See 5.1.2.2.

5.2.2.3 Sodium hexametaphosphate solution — See 5.1.2.3 and Notes 1, 2 and 3 thereunder.

5.2.3 Calibration of Hydrometer

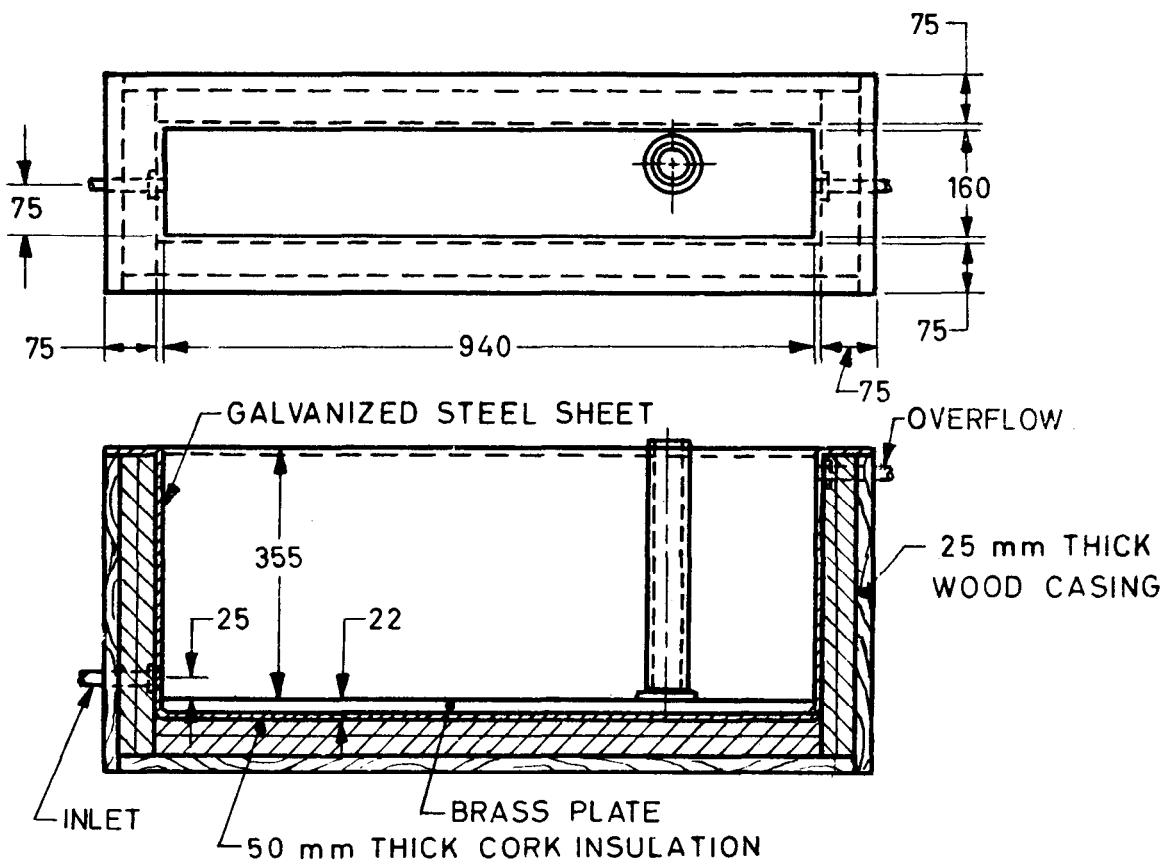
5.2.3.1 Volume — The volume of the hydrometer bulb (V_h) shall be determined in one of the following ways:

a) *From the volume of water displaced* — Approximately 800 ml of water shall be poured into the 1 000 ml measuring cylinder. The reading of the water level shall be observed and recorded.

The hydrometer shall be immersed in the water and the level shall again be observed and recorded.

The difference between the two readings shall be recorded as the volume of the hydrometer bulb in millilitres plus the volume of that part of the stem that is submerged. For practical purposes, the error due to the inclusion of this stem volume may be neglected.

b) *From the mass of the hydrometer* — The hydrometer shall be weighed to the nearest 0.1 g.



All dimensions in millimetres.

FIG. 6 ILLUSTRATED WATER BATH

The mass in grams shall be recorded as the volume of the hydrometer in millilitres. This includes the volume of bulb plus the volume of the stem below the 1.000 graduation mark. For practical purposes, the error due to the inclusion of this stem may be neglected.

5.2.3.2 Calibration

- The sectional area of the 1 000 ml measuring cylinder in which the hydrometer is to be used shall be determined by measuring the distance between two graduations. The sectional area (A) is equal to the volume included between the two graduations divided by the measured distance in centimetres between them.
- The distance from the lowest calibration mark on the stem of the hydrometer to each of the other major calibration marks (R_h) shall be measured and recorded.
- The distance from the neck of the bulb to the nearest calibration mark shall be measured and recorded.
- The distance H corresponding to a reading R_h is the sum of the distances measured in (b) and (c).

- The distance (h) from the neck to the bottom of the bulb shall be measured and recorded as the height of the bulb.

NOTE — The distance $h/2$ locates the centre of volume of assymmetrical bulb. If any assymmetrical bulb is used, the centre of volume can be determined with sufficient accuracy by projecting the shape of the bulb on to a sheet of paper and locating the centre of gravity of the projected area.

- The effecting depth (H_R) corresponding to each of the major calibration marks (R_h) shall be calculated from the following formula:

$$H_R = H_1 + \frac{1}{2} \left[h - \frac{V_h}{A} \right]$$

where

H_R = effective depth;

H_1 = length from neck of bulb, to graduation R_h , in cm;

h = twice the length from neck of bulb to its centre of volume, in cm;

V_h = volume of hydrometer bulb, in ml; and

A = area of measuring cylinder in cm^2 .

NOTE — The factor $\frac{V_h}{A}$ in the above equation shall not be applied to hydrometer reading taken after periods of sedimentation of half, one, two and four minutes as specified in 5.2.4.3 (a).

- g) The relationship between H_R and R_h may be plotted as a smooth curve which may be used for finding the effective depth (H_R) corresponding to hydrometer reading (R_h) obtained during test.

5.2.3.3 Meniscus correction — The hydrometer shall be inserted in a 1 000-ml measuring cylinder containing about 700 ml water. By placing the eye slightly below the plane of the surface of the liquid, and then raising it slowly until the surface seen as an ellipse becomes a straight line, the point where the plane intersects the hydrometer scale shall be determined. By placing the eye slightly above the plane of the surface of the liquid, the point where the upper limit of the meniscus intersects the hydrometer scale shall be determined. The difference between the two readings shall be recorded as the meniscus correction C_m . This is a constant for a given hydrometer.

5.2.4 Procedure

5.2.4.1 Pre-treatment of soil — The percentage of soluble salts shall be determined. In case it is more than one percent, the soil shall be washed with water before further treatment, taking care to see the soil particles are not lost (see Note 1 under 5.1.3.2).

Two samples each of mass 50 to 100 g approximately shall be obtained by riffling from the air dried sample passing the 4.75-mm IS Sieve obtained as in 3.3. The actual amount of soil required will vary according to the type of soil, 50 g with a clay soil and 100 g with a sand soil. The moisture content (w) of one sample shall be determined by the method given in IS : 2720 (Part 2)-1973. The other sample shall be accurately weighed (W_a) to the nearest 0.01 g and placed in the wide mouth conical flask. 150 ml of hydrogen peroxide shall then be added and the mixture stirred gently with a glass rod for a few minutes after which it shall be covered with a cover glass and left to stand overnight. The mixture in the conical flask shall be gently heated. Care shall be taken to avoid frothing over and the contents of the dish shall be periodically stirred. As soon as vigorous frothing has subsided, the volume shall be reduced to about 50 ml by boiling. With organic soils, additional peroxide may be required to complete the oxidation.

In the case of soils containing calcium compounds (see Note 2 under 5.1.3.2), the mixture shall be allowed to cool and about 50 ml of hydrochloric acid added. The solution shall be stirred with a glass rod for a few minutes and allowed to stand for one

hour or for longer periods, if necessary. If the soil contains a considerable amount of calcium salts, more acid may be required. When the treatment is complete, the solution shall have an acid reaction to litmus.

In the case of soils containing no calcium compounds or soluble salts and having a low organic content (less than 2 percent), the pre-treatment prescribed may be omitted and the dispersing agent shall be added as in 5.2.4.2 direct to the soil taken for analysis.

The mixture shall then be filtered and washed with warm water until the filtrate shows no acid reaction to litmus. The damp soil on the filter paper and funnel shall be transferred without any loss whatsoever to the evaporating dish (weighed to 0.01 g) using a jet of distilled water. Only the minimum quantity of distilled water shall be used. The dish and contents shall be placed in an oven and dried at 105 to 110°C. The dish and contents shall then be transferred to the desiccator and allowed to cool. They shall then be weighed to 0.01 g, and the mass of soil remaining after pre-treatment shall be recorded (W_b).

5.2.4.2 Dispersion of soil — To the soil in the evaporating dish, 100 ml of sodium hexametaphosphate solution shall be added and the mixture shall then be warmed gently for about 10 minutes and then transferred to the cup of the mechanical mixer using a jet of distilled water to wash all traces of the soil out of the evaporating dish. The amount of water used may be about 150 ml. The soil suspension shall then be stirred well for 15 minutes.

The suspension shall then be transferred to the 75-micron IS Sieve placed on a receiver and the soil shall be washed on this sieve using a jet of distilled water from a wash bottle. Particular care shall be taken to wash off all traces of suspension adhering to the dispersion cup. The amount of distilled water during this operation may be about 500 ml. The suspension that has passed through the sieve shall be transferred to the 1 000 ml measuring cylinder and made up to exactly 1 000 ml with distilled water. This suspension shall then be used for the sedimentation analysis.

The material retained on the 75-micron IS Sieve may be over-dried and analyzed as specified in 4.3.2.1 and the cumulative percentages of the soil fraction retained on each sieve shall be calculated.

5.2.4.3 Sedimentation

- a) A rubber bung shall be inserted in the mouth of the measuring cylinder which shall then be shaken vigorously and finally be inverted end over end. Immediately the shaking has ceased, the measuring cylinder shall be allowed to stand (in the constant temperature bath, if

used) and the stop watch started. The hydrometer shall be immersed to a depth slightly below its floating position and then allowed to float freely. Hydrometer readings shall be taken after periods of half, one, two and four minutes. The hydrometer shall then be removed slowly, rinsed in distilled water and kept in a cylinder of distilled water at the same temperature as the soil suspension.

- b) The hydrometer shall be re-inserted in the suspension and readings taken after periods of 8, 15 and 30 minutes, one, two and four hours after shaking (see Note). The hydrometer shall be removed, rinsed and placed in the distilled water after each reading. After 4 hours, hydrometer readings shall be taken once or twice within 24 hours, the exact periods of sedimentation being noted. Finally a reading may be taken at the end of 24 hours. In taking all readings, insertion and withdrawal of the hydrometer before and after taking a reading shall be done carefully to avoid disturbing the suspension unnecessarily. Ten seconds shall be allowed for each operation. Vibration of the sample shall be avoided.

NOTE — Other suitable time intervals may be used, provided they give nearly equally spaced points on the grain size distribution curve.

- c) The temperature of the suspension shall be observed and recorded once during the first 15 minutes and then after every subsequent reading. The temperature shall be read with an accuracy of at least $\pm 0.5^{\circ}\text{C}$. Hydrometer readings shall also be taken in pure distilled water at the corresponding temperatures and the temperature correction (M_t) calculated as the difference between this reading and the reading corresponding to the density of water at the calibration temperatures. A chart of such corrections for all temperatures may also be prepared for ready use.

NOTE — The temperature of the suspension over the period of the test should not differ from the mean temperature by more than $\pm 2^{\circ}\text{C}$ in order not to cause an error in the particle size of more than 2 percent. This requirement will generally be fulfilled if the maximum difference in room temperature is not greater than about 8°C . If the variation in temperature is likely to be greater than this, the constant temperature bath should be used (see also Note 2 under 5.1.3.4).

- d) The correction (x) to be applied for the dispersing agent shall be ascertained by placing exactly 50 ml of the sodium hexameta-phosphate solution in a previously weighed glass weighing bottle and after evaporating the water by drying at 105 to 110°C in an oven, the mass of dispersing agent (W_d) shall be calculated.

The dispersing agent correction (x) shall then be calculated from the formula:

$$x = 2 W_d$$

This correction is independent of the temperature.

Alternatively, the correction may be obtained directly by making up a 1 000 ml cylinder full of distilled water containing the same proportion of dispersing agent and at the same temperature, and placing the hydrometer in this solution. The corrected zero reading may then be read directly. This correction shall be corrected for temperature.

5.2.5 Calculations

5.2.5.1 Loss in mass in pre-treatment — The loss in mass in pre-treatment of the soil shall be calculated using the formula given in 5.1.4.1.

5.2.5.2 Sieving — The percent of soil sample passing each of the sieve used in the analysis shall be calculated using the mass of the pre-treated soil and as percentage of the total soil sample taken for analysis.

5.2.5.3 Sedimentation

a) Diameter of the particles — The diameter of the particle in suspension at any sampling time t shall be calculated from the formula:

$$D = \sqrt{\frac{30 \mu}{980 (G - G_1)}} \sqrt{\frac{H_R}{t}}$$

where

D = diameter of particle in suspension, in mm;
 μ = coefficient of viscosity of water at the temperature of the suspension at the time of taking the hydrometer reading, in poises;

G = specific gravity of the soil fraction used in the sedimentation analysis;

G_1 = specific gravity of water;

H_R = effective depth corresponding to R_h (see 5.2.3.2), in cm [see Note under 5.2.3.2 (f)]; and

t = time elapsed between the beginning of sedimentation and taking of hydrometer reading in minutes.

The hydrometer reading corrected for meniscus (R_h) shall be calculated from the following formula:

$$R_h = R'_h + C_m$$

where

R_h = hydrometer reading corrected for meniscus,

R'_h = hydrometer reading at the upper rim of the meniscus, and

C_m = meniscus correction.

NOTE -- A nomographic chart for solving the above equation is given in Fig. 7.

- b) *Percentage finer than D* — The percentage by mass (W) of particles smaller than corresponding equivalent particle diameters shall be calculated from the formula:

$$W = \frac{100G_s}{W_b(G_s - 1)} (R_h + M_t - x)$$

where

G_s = specific gravity of soil particles,

W_b = weight of soil after pre-treatment;

R_h = hydrometer reading corrected for meniscus (for the type of hydrometer graduations illustrated in Fig. 5, R_h is obtained by reading the decimals only and placing the decimal point between the third and the fourth decimal places);

M_t = temperature correction; and

x = dispersion agent correction.

The values of W shall be calculated for all the values of D obtained and shall be expressed as

percentages of particles finer than the corresponding value of D . These percentages shall then be expressed as combined percentages of the total soil sample taken for analysis.

5.3 Plummet Balance (Alternative Method)

5.3.1 Principle — Plummet balance is essentially a specific gravity balance and is designed on the principle that adjustment for depth of immersion of the plummet is more rapid requiring less precision than adjustment for weight. The only manipulation is adjustment of the height of the balance so that the plummet sinks to the right depth. This permits, at any time, to directly read percentage of soil in suspension with easy computation of diameter of the particle by Stoke's law.

5.3.2 Apparatus

5.3.2.1 Plummet balance — Figure 8 illustrates the basic components. The plummet balance consists of a base with three levelling screws over which an upright pillar is fixed. A light weight pointer beam mounted with the help of steel pivot and jewel bearings on to the scale arm. At the end of this scale arm, a scale shall be fixed. The pointer shall be allowed on to move over the scale. The scale arm shall be fixed on two blocks acting as guides to

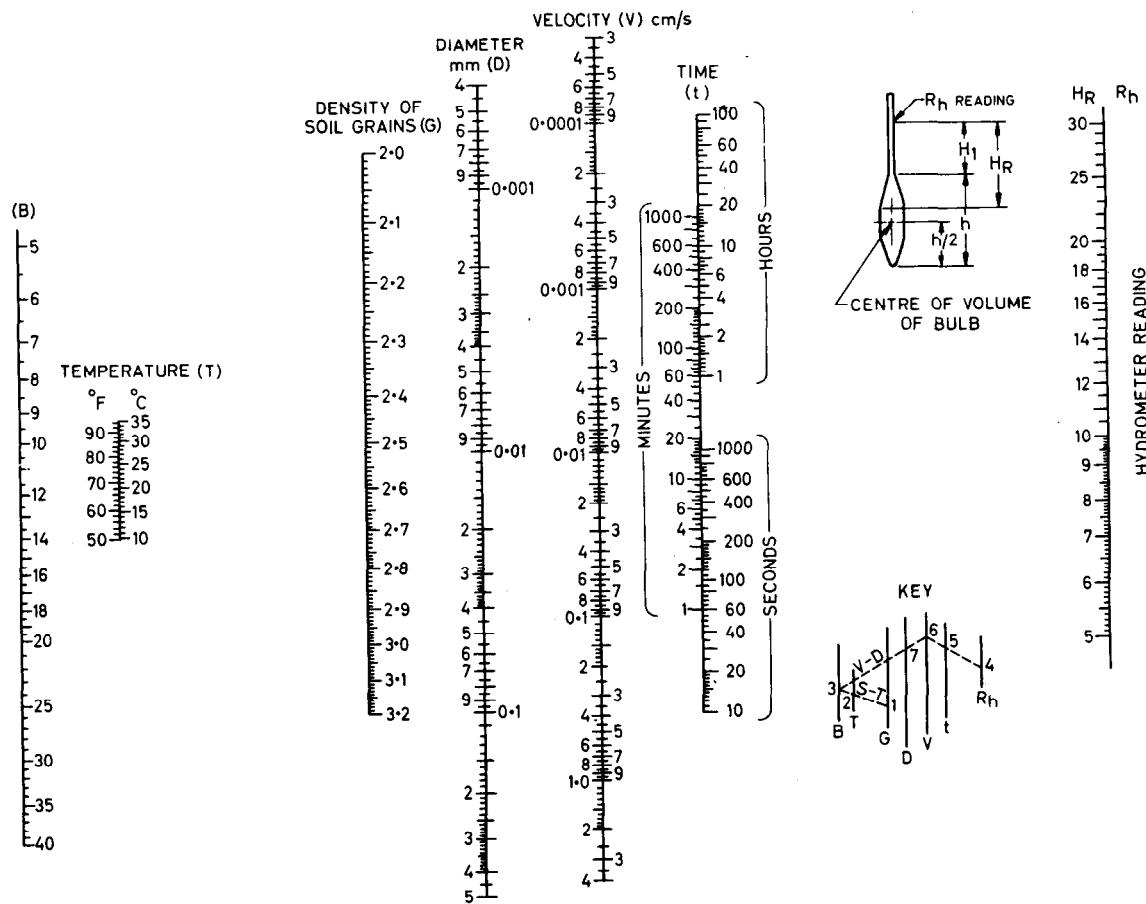


FIG. 7 NOMOGRAPHIC CHART

move on the upright pillar. A pinion knob and a rack and pinion arrangement facilitates easy movement of this scale arm assembly to move up and down as desired. The pointer has two adjusting screws allowing the adjustment of the zero reading. A plummet made of perspex with a string and hook for hanging to the pointer shall be provided. This plastic plummet shall weigh 3 g in water. A plumb bob shall be provided on the scale arm carrier for adjustment of the level of the instrument.

5.3.2.2 Glass measuring cylinders — Two, 1 000 ml capacity with ground glass or rubber stoppers about 7 cm diameter and 33 cm high marked at 1 000 ml volume.

5.3.2.3 Thermometer — to cover the range up to 50°C accurate up to 0.5°C.

5.3.3 Procedure — See Fig. 8.

5.3.3.1 Initial setting and adjustment—Level the instrument with the help of plumb bob and levelling screws. Two rider weights provided with the apparatus shall be used for checking calibration and for any adjustment. The weight marked 100 when hung on to the hook provided for hanging the plummet on the beam should read 100 and when the weight marked zero is hung, the pointer should read zero. If adjustments are necessary at any time to obtain 0 and 100 readings, adjusting screws shall be used for changing the range and the other screw for setting the zero. Then the plummet shall be hooked to the beam after lowering in a container filled with distilled water. The pinion knob is then operated to bring the centre of the plummet at a depth of 9 cm or any other specified depth at which the usual readings are taken. Make a mark on the string. If the pointer does not read zero then adjust the screw. Do

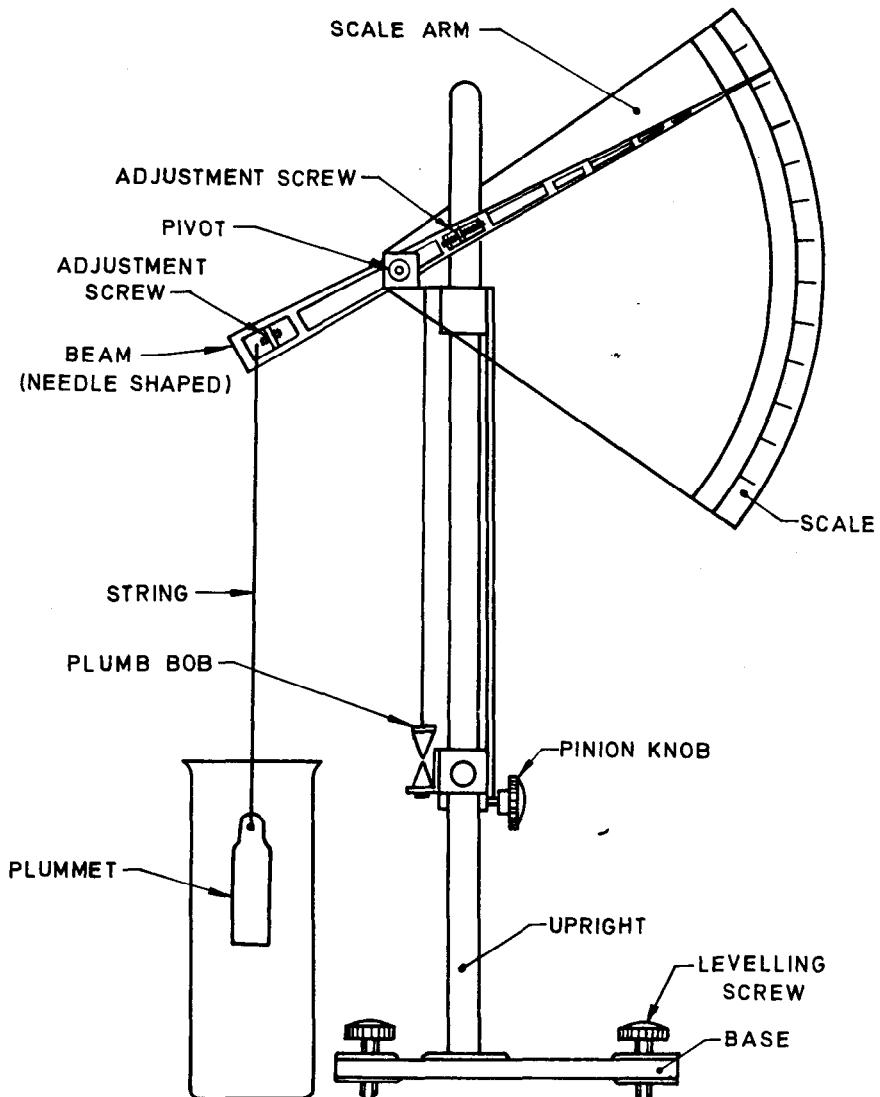


FIG. 8 DETAILS OF PLUMMET BALANCE

not temper with the adjustment of the screw for doing this adjustment. The balance is now ready for use.

5.3.3.2 Pre-treatment of soil — The material retained on the 75-micron IS Sieve is oven dried and analyzed as specified in 4.3.2.1. The pre-treatment is done as per the procedure as in 5.2.4.

5.3.3.3 Dispersion of soil — The procedure is same as in 5.2.4.2.

5.3.3.4 Sedimentation — A rubber bung shall be inserted into the mouth of the measuring cylinder which shall then be shaken vigorously and finally by inverted end over the end. Immediately after the shaking has ceased, the measuring cylinder is placed on the stand of the plummet balance and the stop watch is started. This marks the beginning of sedimentation.

5.3.3.5 Data — The plummet then shall be lowered into the suspension and hooked on to the balance. The plummet is brought to the present depth by turning the pinion. The percentage of soil in suspension is directly read by the pointer and noted down at half, one, two, four minutes and subsequently at further intervals lasting over up to six to seven hours. The balance is sufficiently sensitive to allow readings to be made to the nearest percentage unit in 2 percent suspensions.

5.3.3.6 Computations — Particle diameter D in mm is computed as detailed below for each of the percentages read out by the pointer:

$$D \text{ (mm)} = k \sqrt{\frac{Z_c \text{ (cm)}}{t \text{ (min)}}}$$

where

Z_c = effective depth of immersion of the plummet which is the depth in cm, from the surface of the suspension to centre of the

plummet, that is, predetermined distance (say 9 cm) from the mark on the string to centre of the plummet;

t = time in minutes when pointer readings are taken. Time intervals are adjusted such that square root of time can directly be computed; and

k = coefficient from Fig. 9 to aid in solving Stoke's equation for known temperature condition and specific gravity of particles either determined or assumed (range 2.65 to 2.8).

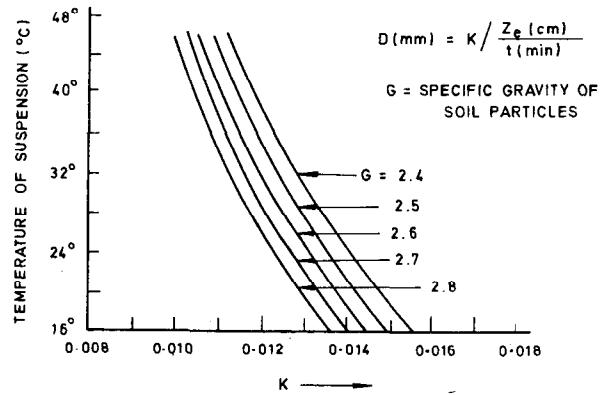


FIG. 9 CHART FOR AID IN SOLVING STOKE'S EQUATION

6. REPORT

6.1 The results of the grain size analysis shall be reported in a suitable form. A recommended *pro-forma* is given in Appendix A. A grain size distribution curve shall be drawn on semi-logarithmic chart, plotting particle size on the log scale against percentage finer than the corresponding size on the ordinary scale. A chart for showing grain size distribution is shown in Fig. 10.

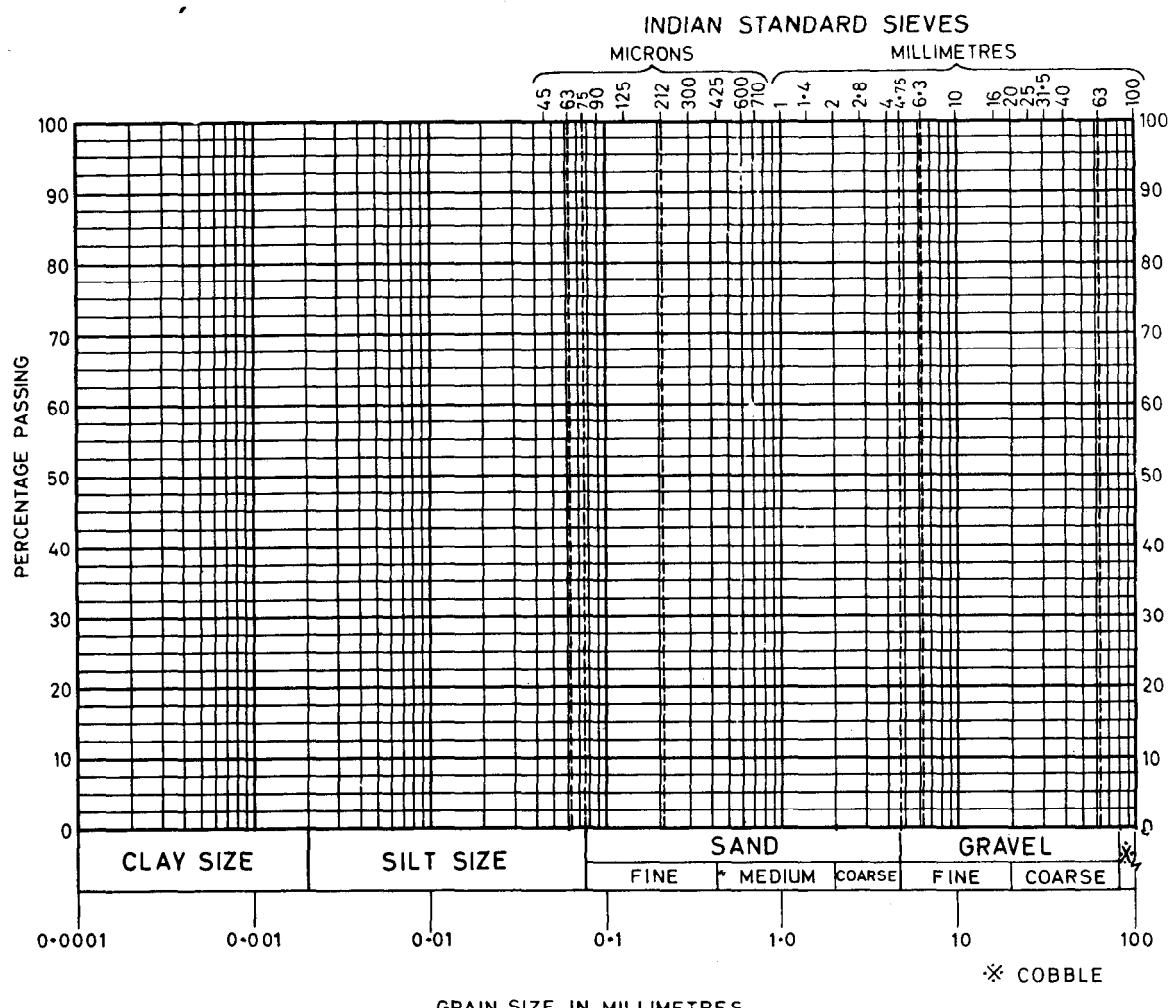


FIG. 10 CHART FOR RECORDING GRAIN SIZE DISTRIBUTION

A P P E N D I X A
(Clause 6.1)
**FORM FOR THE RECORD OF RESULTS OF
 GRAIN SIZE ANALYSIS**

PROJECT

DETAILS OF SOIL SAMPLE

SIEVE ANALYSIS OF FRACTION RETAINED ON 4.75-mm IS SIEVE

Weight of total soil sample taken for analysis

Water content

IS SIEVE DESIG- NATION	MASS OF SOIL RE- TAINED	MASS OF CON- AINER	MASS OF SOIL RETAI- NED	CUMULATIVE MASS RETAI- NED	SOIL RETAI- NED AS PER- CENTAGE OF SOIL TAKEN	SOIL PASSING AS PER- CENTAGE OF SOIL TAKEN	COMBINED PERCENTAGE PASSING AS PERCENTAGE OF TOTAL SOIL SAMPLE
	+ MASS OF CONTAINER						

**SIEVE ANALYSIS OF FRACTION PASSING 4.75-mm IS SIEVE
 BUT RETAINED ON 75-MICRON IS SIEVE**

Mass of partial sample taken for analysis

Water content

IS SIEVE DESIG- NATION	MASS OF SOIL RETAI- NED + MASS OF CONTAINER	MASS OF CON- AINER	MASS OF SOIL RETAI- NED	CUMULA- TIVE MASS RETAI- NED	SOIL RETAI- NED AS PER- CENTAGE OF PARTIAL SOIL TAKEN	SOIL PASSING AS PER- CENTAGE OF PARTIAL SOIL TAKEN	COMBINED PERCENTAGE PASSING AS PERCENTAGE OF TOTAL SOIL SAMPLE TAKEN FOR ANALYSIS

ANALYSIS OF SOIL PASSING 75-MICRON IS SIEVE

Mass of air dry soils (W_a)
 Water content of air dry soil (w)
 Mass of oven-dry soil after pre-treatment (W_b)
 Loss in mass in pre-treatment in percent

Pipette Analysis

Specific gravity of soil
 Volume of suspension taken in pipette (V_p)
 Depth at which sample was taken
 Mass of dispersing agent in the volume of suspension sampled

DATE	TIME ELAPSED BEFORE SAM- PLING	TEMPERA- TURE OF SUS- PENSION	MASS OF CON- TAI- NER + OVEN- DRY SOIL FRACTION	MASS OF BOT- TLE	MASS OF SOLID MATE- RIAL IN BOTTLE IN VOLUME	MASS OF SOLID MATE- RIAL IN BOTTLE IN VOLUME	COR- RECT MASS OF SOIL MATE- RIAL IN 500 ml	DIA- METER D OF SOIL GRAIN IN 500 ml	PERCEN- TAGE FINER THAN D AS PER- CENTAGE OF W_b	COMBINED PERCEN- TAGE FINER THAN D AS PER- CENTAGE OF TOTAL SOIL SAMPLE
------	--	--	---	---------------------------	--	--	---	--	---	---

Hydrometer Analysis

Hydrometer No.
 Meniscus correction (C_m)
 Temperature correction (M_t)
 Dispersing agent correction (x)
 Density of soil, G

$$W = \frac{100 G}{W_b (G - 1)} (R_h + M_t - x) \text{ (percent)}$$

DATE	TIME	TEM- PERA- TURE	ELAPSED TIME	HYDRO- METER R_h	CORREC- TED HYDRO- METER $R_h = R'_h$ + C_m	EQUIP- MENT DIA- METER. D (mm)	$R_h + M_t$ — x	PERCEN- TAGE OF PARTICLES FINER THAN D , W PERCENTAGE	COMBINED PERCEN- TAGE OF FINER THAN D AS PERCEN- TAGE OF TOTAL SAMPLE
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SECTION 7

Determination of Atterberg Limits

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Indian Standard

SPECIFICATION FOR LIQUID LIMIT APPARATUS FOR SOILS

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 The equipment covered in this standard is used for determination of liquid limit (mechanical method) covered in IS : 2720 (Part 5) - 1970.

0.2 This standard covers the minimum requirements for the apparatus. This apparatus may also be manufactured with a revolution counter to indicate the number of falls of cup automatically and/or a motorized driving arrangement to give approximately 120 rev/min.

1. SCOPE

1.1 This standard covers the requirements of liquid limit device, grooving tool and gauge block used for determination of liquid limit of soils by mechanical method.

2. DIMENSIONS

2.1 The dimensions with tolerances of different component parts of the liquid limit apparatus shall be as detailed in Fig. 1 to 3. The dimensions against which tolerances are not specifically mentioned shall be taken as nominal dimensions and the tolerances as given in IS : 2102 (Part 1)-1980 'General tolerances for dimensions and form and position: Part I General tolerances for linear and angular dimensions (*second revision*)' shall apply.

3. LIQUID LIMIT DEVICE

3.1 Materials — The materials of construction of different component parts of the liquid limit device shall be as given in Table 1. All parts made of brass shall be chrome-plated.

TABLE 1 MATERIALS FOR DIFFERENT COMPONENT PARTS OF LIQUID LIMIT DEVICE

SL No (1)	PART (2)	MATERIAL (3)	SPECIAL REQUIREMENT (4)	CONFORMING TO (5)
i)	Base	Vulcanized rubber	Hardness: 86 to 90 IRHD (see Note 1)	Grade 6, Type B of IS : 5192-1969*
ii)	Base feet}		Resilience : 30 to 40 percent (see Note 2)	
iii)	Cup	Sheet brass	—	IS : 410-1967†
iv)	Cam housing	Cast brass	—	IS : 292-1961‡
v)	Sliding carriage		—	
vi)	Cam	Brass	—	IS : 4170-1976§
vii)	Pin		—	
viii)	Handle		—	
ix)	Handle knob		—	

NOTE 1 — The hardness of the material shall be determined in accordance with IS : 3400 (Part 2)-1965 'Methods of test for vulcanized rubbers: Part 2 Hardness'.

NOTE 2 — The resilience of the material shall be determined in accordance with IS : 3400 (Part 11)-1969 'Methods of test for vulcanized rubbers: Part 11 Determination of rebound resilience'.

*Specification for vulcanized natural rubber based compounds (*first revision*).

†Specification for rolled brass plate, sheet, strip and foil (*second revision*).

‡Specification for brass ingots and castings (*revised*).

§Specification for brass rods for general engineering purposes.

3.2 Construction

3.2.1 The liquid limit device shall be constructed in accordance with Fig. 1. It shall consist of a base carrying a sliding carriage assembly to which a cup is hinged. The cup shall be suspended in such a way that it may be raised and dropped through a height of 10 mm with the help of a lead screw provided at the back of the sliding carriage. For ease of operation, the handle to rotate the cam shall be provided for right-hand operation. Rubber feet made of the same material shall be fixed to the base. The cup shall have the dimensions as detailed in Fig. 1. The inside of the cup shall be finished smooth. The cup shall have a brass follower block brazed to it for being suspended from the sliding carriage with the help of a brass pin. It shall be suspended from the top bracket with the help of the brass pin in such a way that it falls freely without having much play at its hinge. The sliding carriage shall have two grooves to facilitate adjustment of fall of the cup to 10 mm. The contact face of the cam shall be smoothly curved. The sliding carriage shall be secured to the top of the cam housing with two knurled head screws made of brass. The handle shall be fixed to the cam shaft. The handle knob shall have free rotating movement.

4. GROOVING TOOLS AND GAUGE BLOCK

4.1 The grooving tools shall be of three types, namely, Type A, Type B, Type C (see Fig. 2).

4.2 Materials — The materials of construction of the three different types of the grooving tools and of the gauge block shall be as given in Table 2.

4.3 Construction

4.3.1 The shapes and dimensions of the grooving tools shall be in accordance with Fig. 2. In the case of Type B grooving tool, the handle is of such a shape and dimension that it serves for the gauge block.

4.3.2 The shape and dimensions of the gauge block shall be in accordance with Fig. 3. The gauge block shall be finished smooth.

5. MARKING

5.1 The liquid limit device, the grooving tools and the gauge block shall be clearly marked with the following information:

- Name of the manufacturer or his registered trade-mark or both,
- Date of manufacture, and
- Type (where applicable).

TABLE 2 MATERIALS FOR GROOVING TOOLS AND GAUGE BLOCK

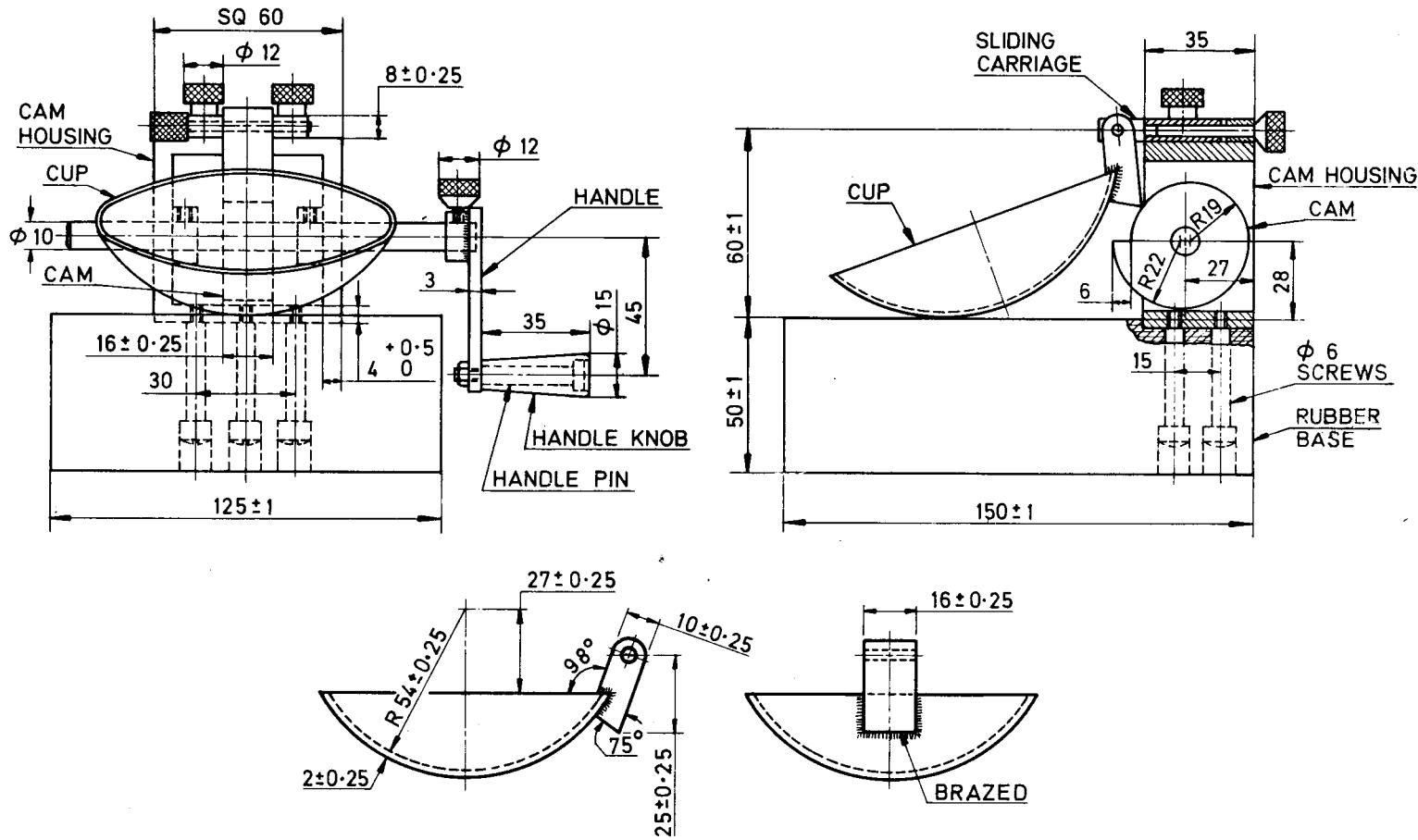
SL. No. (1)	PART (2)	MATERIAL (3)	SPECIAL REQUIREMENT (4)	CONFORMING TO (5)
i)	Grooving tool, Type A	Sheet brass or Cast brass	Smooth finish	IS : 410-1967* or IS : 292-1961†
ii)	Grooving tool, Type B: a) Handle b) Tool	Brass rod Cast brass	do do	IS : 4170-1967‡ IS : 292-1961†
iii)	Grooving tool, Type C: a) Tool b) Handle	Sheet brass Brass wire	do do	IS : 410-1967* IS : 4413-1967§
iv)	Gauge block	Cast brass	do	IS : 292-1961†

*Specification for rolled brass plate, sheet, strip and foil (*second revision*).

†Specification for brass ingots and castings (*revised*).

‡Specification for brass rods for general engineering purposes.

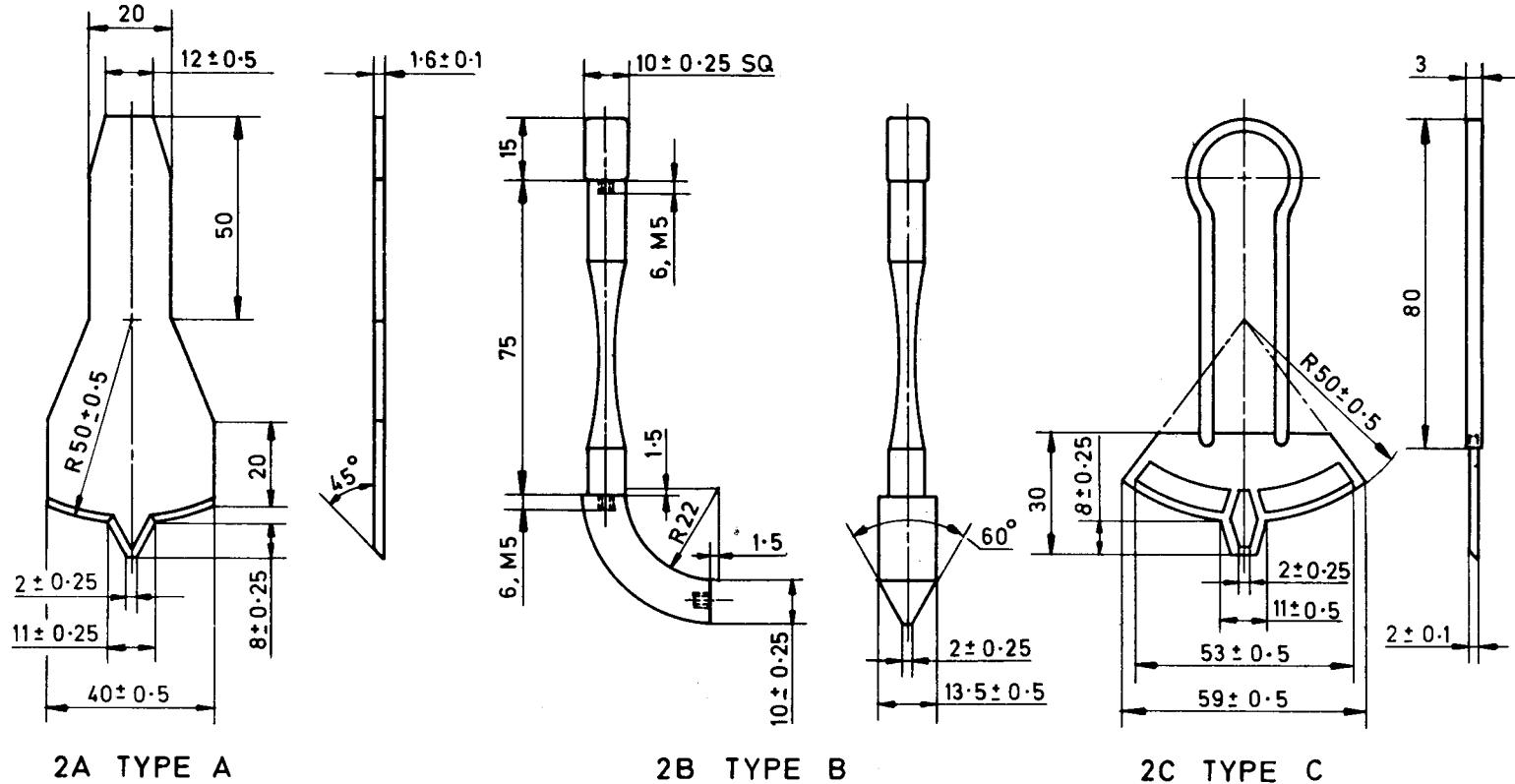
§Specification for brass wires for general engineering purposes.



DETAILS OF CUP

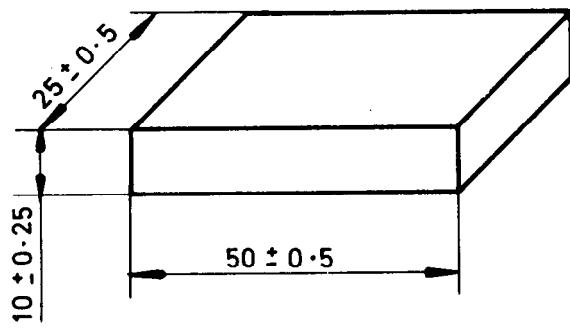
All dimensions in millimetres.

FIG. 1 LIQUID LIMIT DEVICE



All dimensions in millimetres.

FIG. 2 GROOVING TOOLS



All dimensions in millimetres.

FIG. 3 GAUGE BLOCK

5.1.1 The apparatus may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.

Indian Standard

SPECIFICATION FOR EQUIPMENT FOR DETERMINATION OF LIQUID LIMIT OF SOILS BY CONE PENETRATION METHOD

0. FOREWORD

0.1 The equipment covered in this standard is used for determination of liquid limit of soil by cone penetration method as covered in IS : 2720 (Part 5) - 1985.

1. SCOPE

1.1 This standard covers the details of apparatus for determination of liquid limit of soils by cone penetration method.

2. DIMENSIONS

2.1 Dimensions with tolerances of different component parts of the equipment shall be as detailed in Fig. 1 to 9. Except where tolerances are specially mentioned against the dimensions, all dimensions shall be taken as nominal tolerances of medium class as given in IS : 2101 (Part 1)-1980 shall apply.

3. MATERIALS

3.1 The materials of construction of various component parts of the equipment shall be as given in Table 1.

4. CONSTRUCTION

4.1 The base, pillar, bracket, plunger, release mechanism, dial rack and cone shall be according to details given in Fig. 1 to 9. The mass of plunger along with its components and cone as given in Fig. 5 and Fig. 9 shall be 80 ± 0.5 g (for this purpose thickness of weight given in Fig. 5E be adjusted) and when assembled the pin fixed at the bottom of the rack shall be in line and concentric with the plunger assembly.

5. MARKING

5.1 The following information shall be clearly and indelibly marked suitably on each part:

- Name of manufacturer, and
- Date of manufacture.

5.1.1 The equipment may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard convey the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.

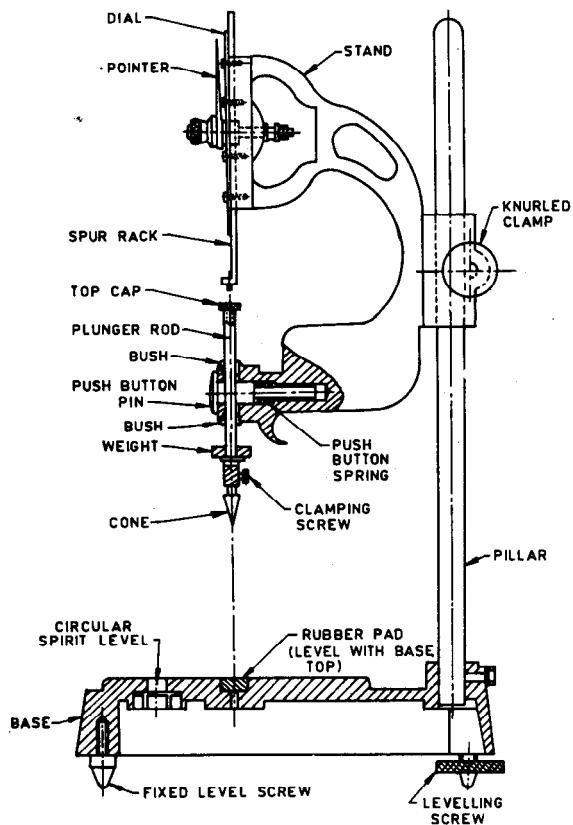
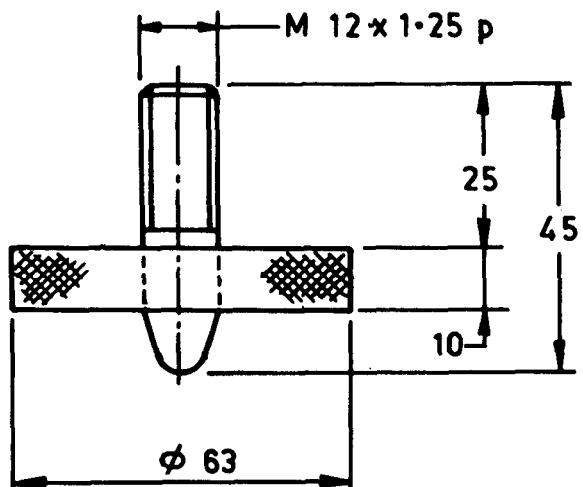
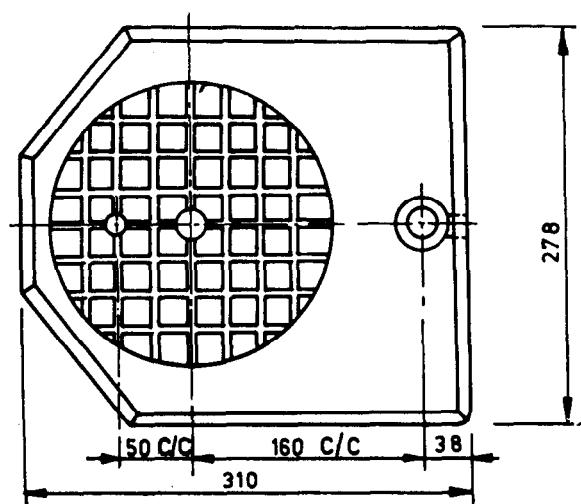
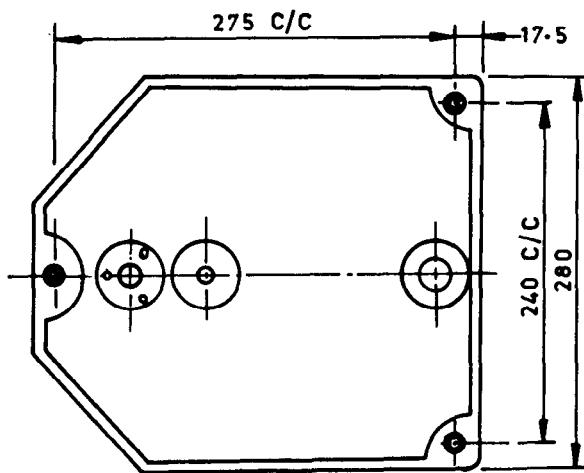
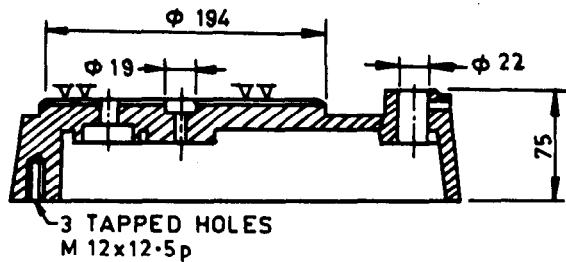


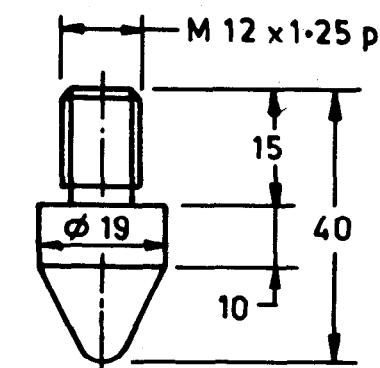
FIG. 1 GENERAL ASSEMBLY



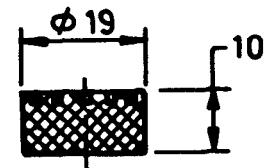
2B LEVELLING SCREW



2A BASE BODY



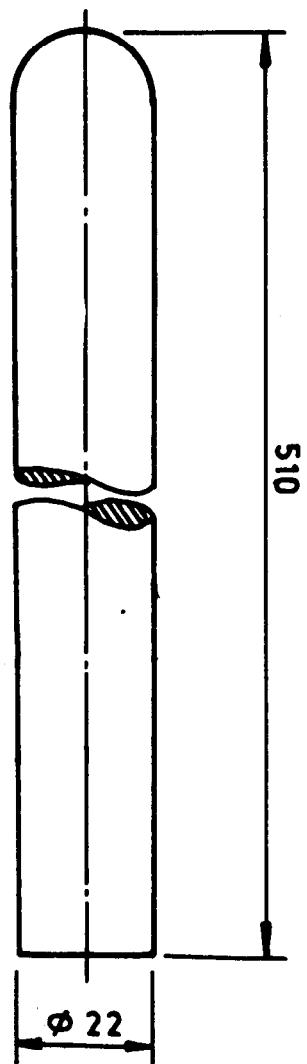
2C FIXED LEVEL SCREW



2D RUBBER PAD

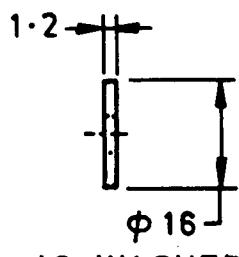
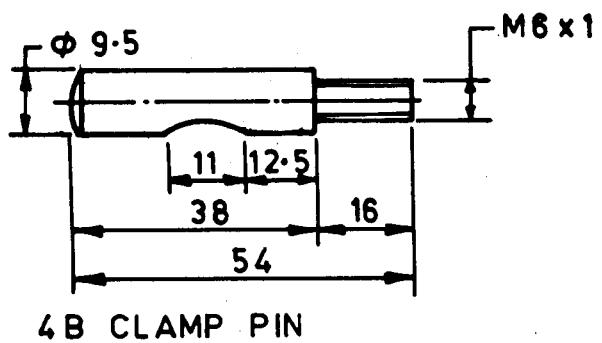
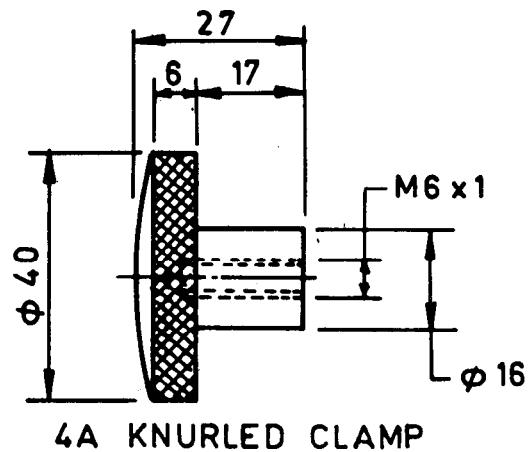
All dimensions in millimetres.

FIG. 2 BASE BODY



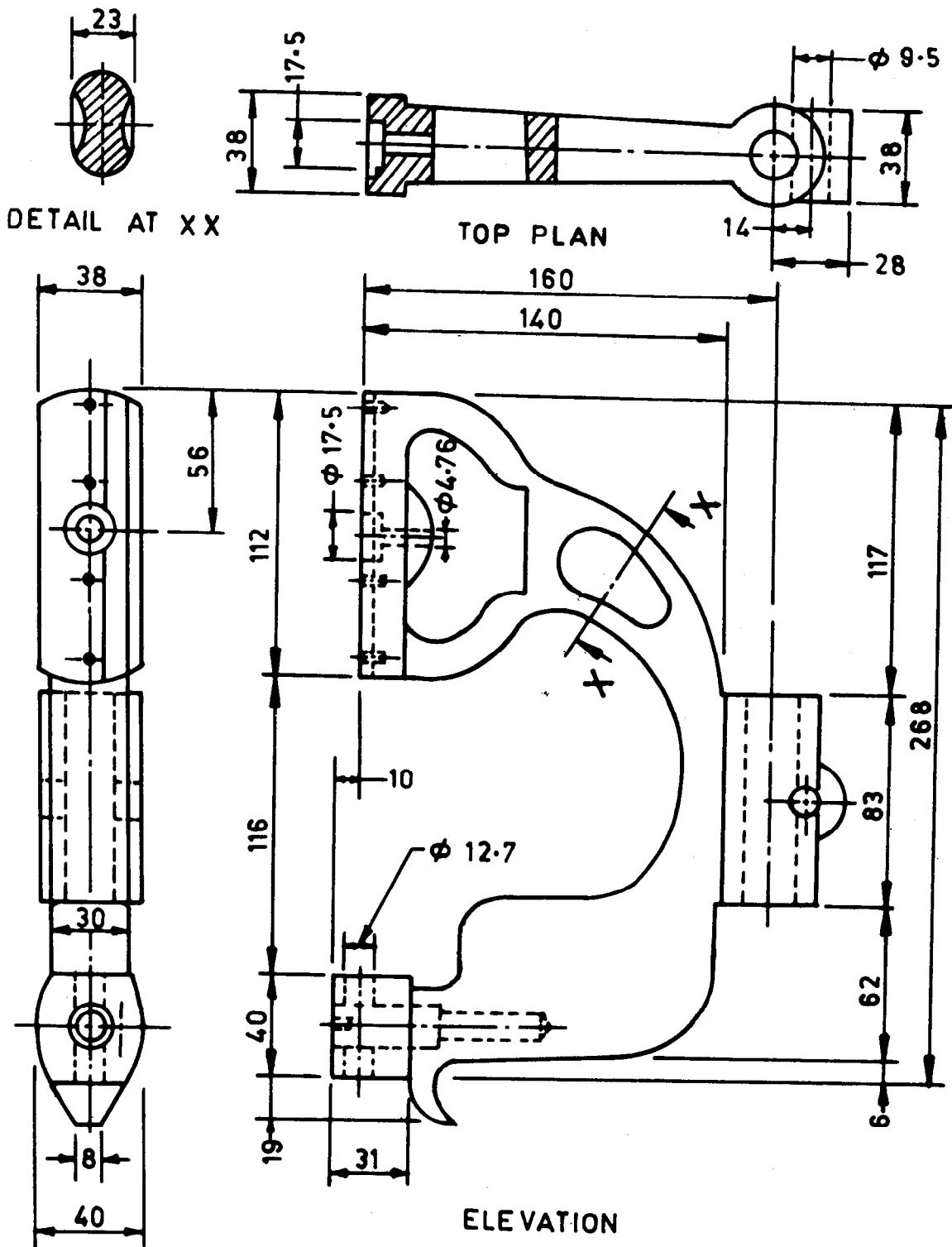
All dimensions in millimetres.

FIG. 3 PILLAR



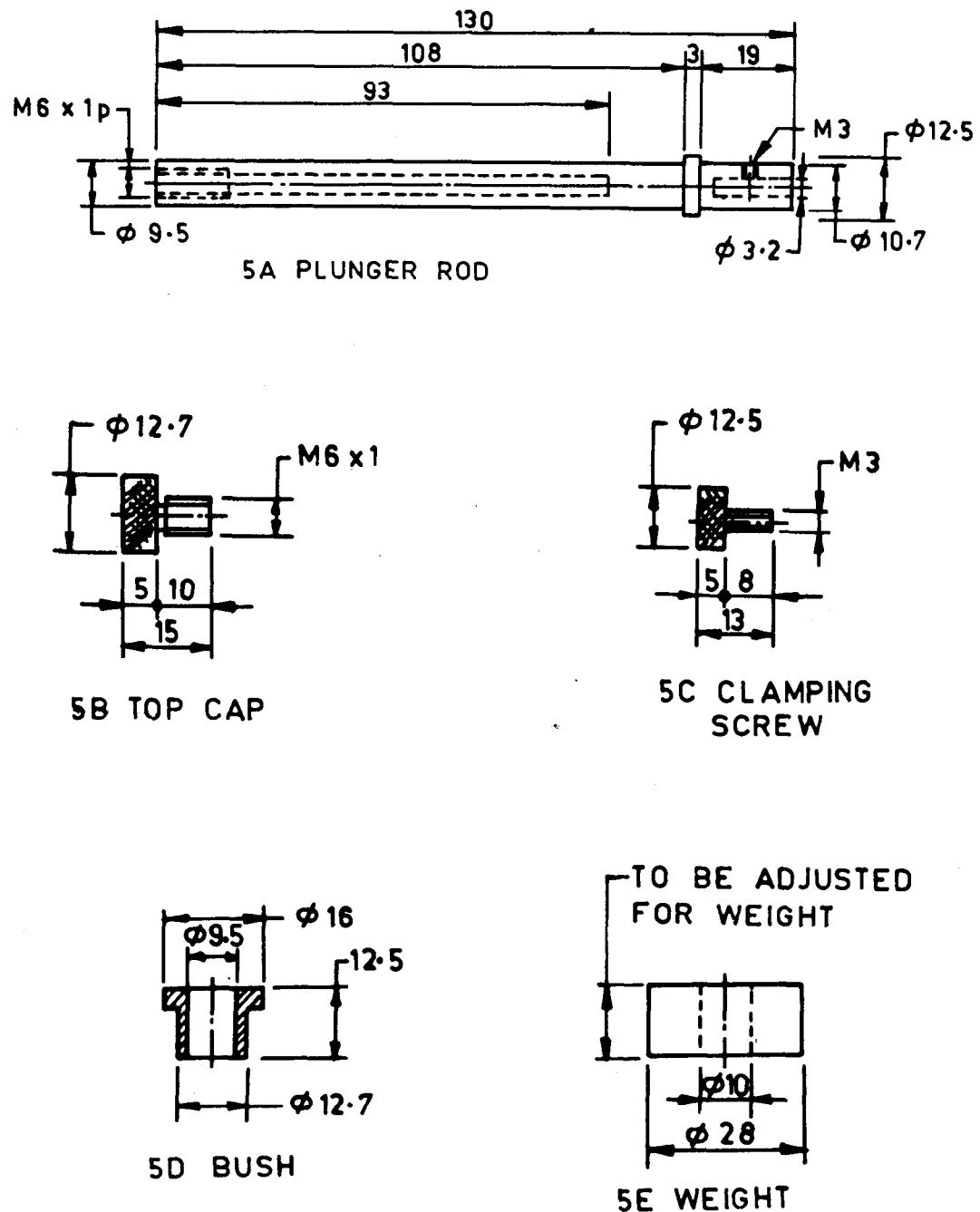
All dimensions in millimetres.

FIG. 4 BRACKET — *Contd*



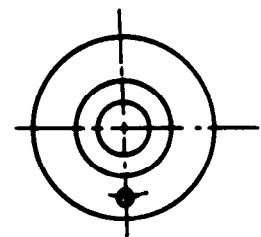
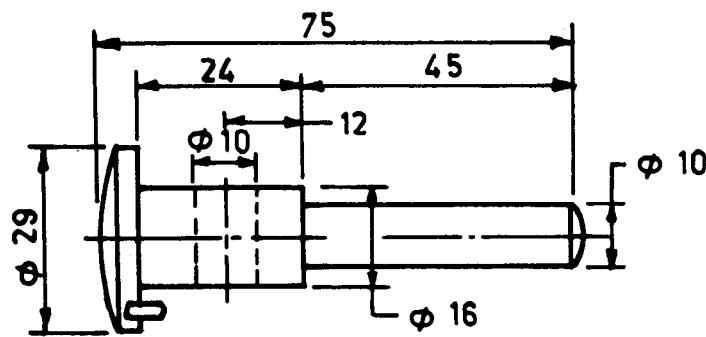
All dimensions in millimetres.

FIG. 4 BRACKET

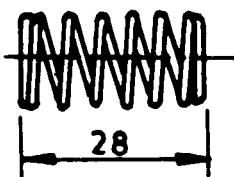


All dimensions in millimetres.

FIG. 5 PLUNGER



6A BUSH BUTTON PIN



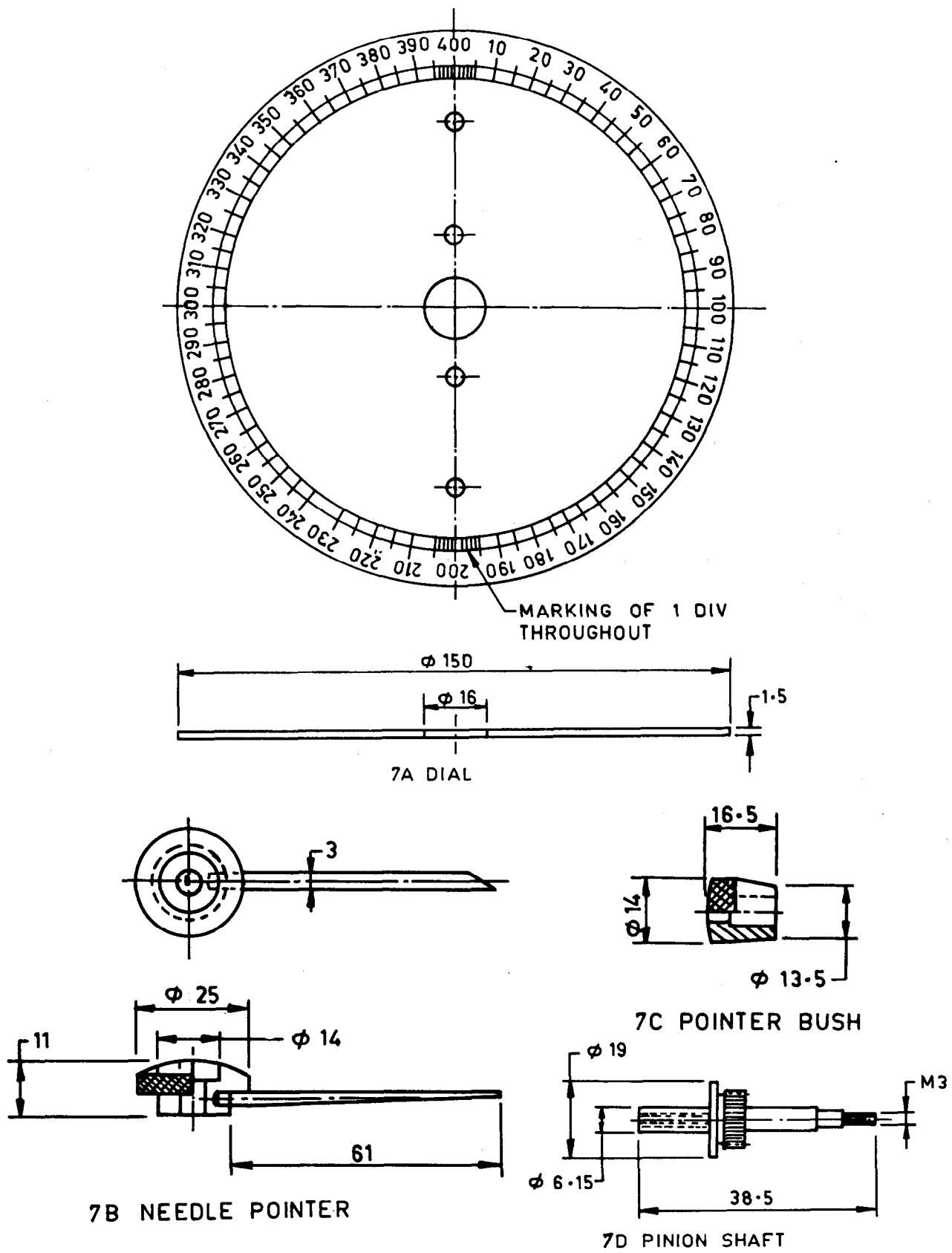
SPRING DATA

O.D. ϕ 15
 TOTAL LENGTH 28
 No OF COILS 8
 WIRE DIA 1.5

6B PUSH BUTTON SPRINGS

All dimensions in millimetres.

FIG. 6 RELEASE MECHANISM



All dimensions in millimetres.

FIG. 7 DIAL GAUGE

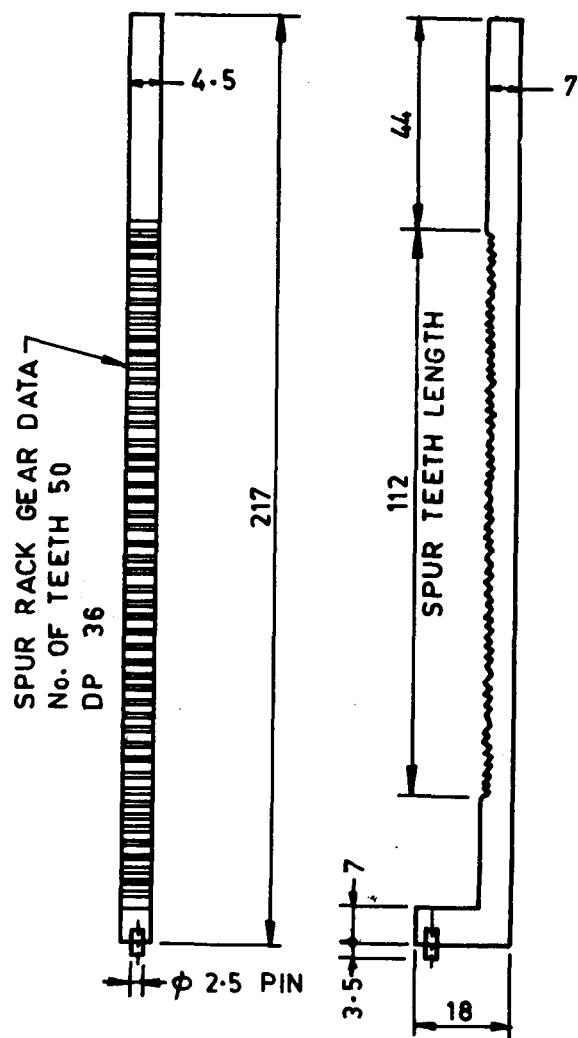


FIG. 8 SPUR RACK

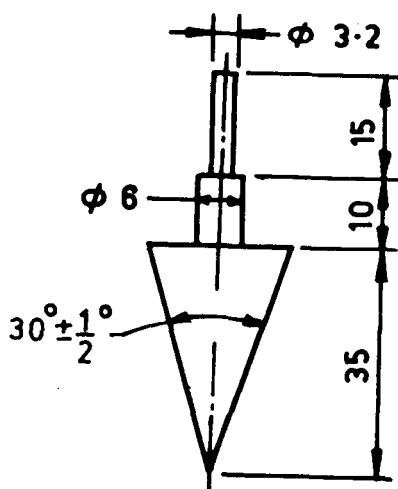


FIG. 9 CONE

**TABLE I MATERIALS OF CONSTRUCTION OF VARIOUS
COMPONENT PARTS**
(Clause 3.1)

Sl. No.	COMPONENTS PARTS	MATERIAL	SPECIAL REQUIREMENT	RELEVANT IS NUMBER
i)	Base body	Cast aluminium		IS : 617-1975 ¹
ii)	Levelling screws	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
iii)	Pillar	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
iv)	Bracket	Cast aluminium		IS : 617-1975 ¹
v)	Knurled clamp	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
vi)	Clamp pin	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
vii)	Plunger rod	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
viii)	Top cap	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
ix)	Clamping screw	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
x)	Bush	Brass	—	IS : 4170-1967 ³
xi)	Weight	Brass	—	IS : 4170-1967 ³
xii)	Push button pin	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
xiii)	Push button spring	Spring steel	Nickel/Chrome plated	IS : 4454 (Part 1)-1975 ⁴
xiv)	Dial	Aluminium	Anodized	IS : 7883-1975 ⁵
xv)	Needle pointer	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
xvi)	Pointer bush	Brass	—	IS : 4170-1967 ³
xvii)	Pinion shaft	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
xviii)	Spur rack	Mild steel	Nickel/Chrome plated	IS : 1875-1978 ²
xix)	Cone	Stainless steel	—	IS : 6603-1972 ⁶

¹ Specification for aluminium and aluminium alloy ingots and castings for general engineering purposes (*second revision*).

² Specification for carbon steel billets, blooms, slabs and bars for forgings (*fourth revision*).

³ Specification for brass rods for general engineering purposes.

⁴ Specification for steel wires for cold formed springs: Part I Patented and cold drawn steel wires — unalloyed (*second revision*).

⁵ Specification for aluminium-manganese alloy sheet and strip for aircraft purposes (alloy No. 31000).

⁶ Specification for stainless steel bars and flats.

Indian Standard

METHODS OF TEST FOR SOILS

PART 5 DETERMINATION OF LIQUID AND PLASTIC LIMIT

(Second Revision)

0. FOREWORD

0.1 This Part 5, which deals with the methods of test for the determination of liquid and plastic limits and other related indices of soils, was first published in 1965 and revised in 1970.

0.2 In this revision, cone penetration method has been revised based on the 'revised cone' which is now universally used in other countries. The conventional Casagrande apparatus has certain shortcomings, such as difficulty of cutting groove in soils of low plasticity and the tendency of soils to slip rather than flow. Cone penetrometer forms an alternative method to overcome the inherent shortcomings.

0.3 The liquid and plastic limits of soils are both dependent on the amount and type of clay in a soil and form the basis for the soil classification system for cohesive soils based on the plasticity tests. Besides their use for identification, the plasticity tests give information concerning the cohesion properties of soil and the amount of capillary water which it can hold. They are also used directly in specifications for controlling soil for use in fill. These index properties of soil have also been related to various other properties of the soil.

1. SCOPE

1.1 This standard (Part 5) lays down methods of test for the determination of the liquid limit and plastic limit of soils. Three methods, namely, mechanical method, one-point method and the cone method are given for the determination of liquid limit.

1.1.1 Liquid limits over about 120 percent shall be obtained by the procedure specified in 3 or 4. The one-point method shall not be used for highly organic soils (see Note).

Note — The one-point method may be applicable to the region for which the constants are obtained based upon results of tests on soils from that region. For all national and international reports, the results obtained by the method in 3 or 4 may be reported.

1.2 The methods for calculating the following indices which are related to the liquid and plastic limits are also given:

- a) Flow index (see 3.5.2),
- b) Plasticity index (see 8),
- c) Toughness index (see 9),
- d) Liquidity index (or water plasticity ratio) (see 10), and
- e) Consistency index (see 11).

2. TERMINOLOGY

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

3. TEST FOR THE DETERMINATION OF LIQUID LIMIT (MECHANICAL METHOD)

3.1 Apparatus

3.1.1 Mechanical Liquid Limit Device — It shall conform to IS: 9259-1979.

3.1.2 Grooving Tool — It shall conform to IS: 9259-1979.

3.1.3 Porcelain Evaporating Dish — about 12 to 15 cm in diameter.

3.1.4 Flat Glass Plate — 10 mm thick and about 45 cm square or larger (alternative to porcelain evaporating dish for mixing soil with water).

3.1.5 Spatula — flexible, with the blade about 8 cm long and 2 cm wide (for mixing soil and water in the porcelain evaporating dish).

3.1.6 Palette Knives — two, with the blade about 20 cm long and 3 cm wide (for mixing soil and water on the flat glass plate).

3.1.7 Balance — sensitive to 0.01 g.

3.1.8 Oven — thermostatically controlled with interior of non-corroding material to maintain the temperature between 105 and 110°C.

3.1.9 Wash Bottle or Beaker — containing distilled water.

3.1.10 Containers — air-tight and non-corrodible for determination of moisture content.

3.2 Soil Sample — A sample weighing about 120 g shall be taken from the thoroughly mixed portion of material passing 425-micron IS Sieve [see IS : 460 (Part 1)-1978] obtained in accordance with IS : 2720 (Part 1)-1983 (see Note and 6.2).

NOTE — When no stones are present in the soil and practically all of the soil passes 425-micron IS Sieve, there is sometimes a practice of testing samples without previously preparing them. When soils are tested in the natural condition, the results will usually differ from those obtained with air-dried samples. The test record shall state that soil in the natural condition was used.

If this is done and stones are present, only the material passing 425-micron IS Sieve shall be used for the test; this can be obtained by rubbing the wet soil through the sieve until a sufficient quantity of the size passing 425-micron IS Sieve is obtained.

3.3 Adjustment of the Mechanical Device

3.3.1 The liquid limit device shall be inspected to determine that it is clean, dry and in good working order, that the cup falls freely and it does not have too much side play at its hinge. The grooving tool shall also be inspected to determine that it is clean and dry.

3.3.2 Using the gauge on the handle of the grooving tool or a separate gauge and by means of the adjustment plate of the mechanical liquid limit device, the height through which the cup is lifted and dropped shall be adjusted so that the point on the cup which comes in contact with base falls through exactly one centimetre for one revolution of the handle. The adjustment plate shall then be secured by tightening the screw.

NOTE — If evenness of the base is not maintained in course of time, the base of the liquid limit device should be changed.

3.4 Procedure

3.4.1 About 120 g of the soil sample passing 425-micron IS Sieve shall be mixed thoroughly with distilled water in the evaporating dish or on the flat glass to form a uniform paste. The paste shall have a consistency that will require 30 to 35 drops of the cup to cause the required closure of the standard groove. In the case of clayey soils, the soil paste shall be left to stand for a sufficient time (24 hours) so as to ensure uniform distribution of moisture throughout the soil mass (*see Note 1 under 3.4.3*).

3.4.2 The soil should then be re-mixed thoroughly before the test. A portion of the paste shall be placed in the cup above the spot where the cup rests on the base, squeezed down and spread into position shown in Fig. 1, with as few strokes of the spatula as possible and at the same time trimmed to a depth of one centimetre at the point of maximum thickness, returning the excess soil to the dish. The soil in the cup shall be decided by firm strokes of the grooving tool along the diameter through the centre line of the cam follower so that a clean, sharp groove of the proper dimensions is formed (*see Note 2 under 3.4.3*). In case where grooving tool, Type A does not give a clear groove as in sandy soils, grooving tool Type B or Type C (*see Note 3 under 3.4.3*) should be used.



DIVIDED SOIL CAKE
BEFORE TEST



SOIL CAKE AFTER
TEST

FIG. 1 DIAGRAM ILLUSTRATING LIQUID LIMIT TEST

The cup shall be fitted and dropped by turning the crank at the rate of two revolutions per second until the two halves of the soil cake come in contact with bottom of the groove along a distance of about 12 mm (*see Note 4 under 3.4.3*). This length shall be measured with the end of the grooving tool or a ruler. The number of drops required to cause the groove close for the length of 12 mm shall be recorded.

3.4.3 A little extra of the soil mixture shall be added to the cup and mixed with the soil in the cup. The pat shall be made in the cup and the test repeated as in **3.4.2**. In no case shall dried soil be added to the thoroughly mixed soil that is being tested. The procedure given in **3.4.2** and in this clause shall be repeated until two consecutive runs give the same under of drops for closure of the groove (*see Notes 4 and 5*).

NOTE 1 — Light textured soils (of low clay content) may be tested immediately after thorough mixing of water.

NOTE 2 — To avoid tearing of the sides of the groove or slipping of the soil cake on the cup, up to six strokes, from front to back or from back to front counting as one stroke, shall be permitted. Each stroke penetrate a little deeper until the last stroke from back to front scrapes the bottom of the cup clean. The groove shall be made with as few strokes as possible.

NOTE 3 — With soils having low plasticity indices, it is sometimes difficult to cut a smooth groove in the soil with grooving tool, Type A. Grooving tool, Type B or Type C may be used in such cases. Grooving tool, Type B inserts a wedge into the pat of soil causing the two halves of the pat to slide at the cup-soil interface. During the test, the tendency is then for the soil of slide back again on this same face instead of flowing as it should do. It should, therefore, be used with caution.

NOTE 4 — Some soils tend to slide on the surface of the cup instead of the soil flowing. If this occurs, the results should be discarded and the test repeated until flowing does occur. If sliding still occurs, the test is not applicable and a note should be made that the liquid limit could not be obtained.

NOTE 5 — Care shall be taken to see that the soil paste does not dry out too rapidly between repeat tests as the number of blows for closure will increase gradually as the sample dries out.

3.4.4 A representative slice of soil approximately the width of the spatula, extending from about edge to edge of the soil cake at right angle to the groove and including that portion of the groove in which the soil flowed together, shall be taken in a suitable container and its moisture content expressed as a percentage of the oven-dry weight otherwise determined as described in IS : 2720 (Part 2)-1973. The remaining soil in the cup shall be transferred to the evaporating dish and the cup and the grooving tool cleaned thoroughly.

3.4.5 The operations specified in 3.4.2 to 3.4.4 shall be repeated for at least three more additional trials (minimum of four in all), with the soil collected in the evaporating dish or flat glass plate, to which sufficient water has been added to bring the soil to a more fluid condition. In each case, the number of blows shall be recorded and the moisture content determined as before. The specimens shall be of such consistency that the number of drops required to close the groove shall be not less than 15 or more than 35 and the points on the flow curve are evenly distributed in this range. The test should proceed from the drier (more drops) to the wetter (less drops) condition of the soil. The test may also be conducted from the wetter to the drier condition provided drying is achieved by kneading the wet soil and not by adding dry soil.

3.5 Determination of Liquid Limit and Flow Index

3.5.1 *Liquid Limit (w_L)* — ‘A flow curve’ shall be plotted on semi-logarithmic graph representing water content on the arithmetical scale and the number of drops on the logarithmic scale. The flow curve is a straight line drawn as nearly as possible through the four or more plotted points. The moisture content corresponding to 25 drops as read from the curve shall be rounded off to the nearest whole number and reported as the liquid limit of the soil.

3.5.2 *Flow Index (I_f)* — The flow curve (straight line) plotted on semi-logarithmic graph as in 3.5.1 shall be extended at either end so as to intersect the ordinates corresponding to 10 and 100 drops. The slope of this line expressed as the difference in water contents at 10 drops and at 100 drops shall be reported as the flow index.

NOTE — The flow index may be calculated from the following equation also:

$$I_f = \frac{w_1 - w_2}{\log_{10} \frac{N_2}{N_1}}$$

where

I_f = flow index,

w_1 = moisture content in percent corresponding to N_1 drops, and
 w_2 = moisture content in percent corresponding to N_2 drops.

3.6 Report

3.6.1 The results of the observations of the test shall be recorded suitably. A recommended proforma for the record of results is given in Appendix A.

3.6.2 The liquid limit should be reported to the nearest whole number. The history of the soil sample, that is, natural state, air-dried, oven-dried or unknown, the method used for the test reported and the period of soaking allowed after mixing of water to the soil shall also be reported.

4. TEST FOR THE DETERMINATION OF LIQUID LIMIT BY CONE PENETRATION METHOD

4.1 The basic principle is to observe depths of penetrations of soils at various initial moisture contents of a metal cone of certain weight and apex angle with the point barely touching the surface is allowed to drop into the surface. The standardization has been to identify liquid limit water content for a specified depth of penetration.

4.2 Apparatus

4.2.1 It shall conform to IS : 11196-1985 ‘Specification for equipment for determination of liquid limit of soils by cone penetration method’.

4.2.2 *Balance* — sensitive to 0.01 g.

4.2.3 *Containers* — non-corrodible and air-tight for moisture determination.

4.2.4 *Oven* — thermostatically controlled with interior non-corroding material to maintain the temperature between 105 and 110°C.

4.3 Soil Sample — A soil sample weighing about 150 g from thoroughly mixed portion of the soil passing 425-micron IS Sieve obtained in accordance to IS : 2720 (Part 1)-1983.

4.4 Procedure — About 150-g of soil sample obtained as in 4.3 shall be worked well into a paste with addition of distilled water. In the case of highly clayey soils, to ensure uniform moisture distribution, it is recommended that the soil in the mixed state is left for sufficient time (24 hours) in an air-tight container. The wet soil paste shall then be transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in this process. Finally the wet soil is levelled up to the top of the cup and placed on the base of the cone penetrometer apparatus. The penetrometer shall be so adjusted that the cone point just touches the surface of the soil paste in the cup clamped in this position. This initial reading is either adjusted to zero or noted down as is shown on the graduated

scale. The vertical clamp is then released allowing the cone to penetrate into the soil paste under its own weight. The penetration of the cone after 5 seconds shall be noted to the nearest millimetre. If the difference in penetration lies between 14 and 28 mm, the test is repeated with suitable adjustments to moisture either by addition of more water or exposure of the spread paste on a glass plate for reduction in moisture content. The test shall then be repeated at least to have four sets of values of penetration in the range of 14 to 28 mm. The exact moisture content of each trial shall be determined in accordance with IS : 2720 (Part 2)-1973.

4.5 Determination of Liquid Limit — A graph representing water content on the y-axis and the cone penetration on the x-axis shall be prepared. The best fitting straight line is then drawn. The moisture content corresponding to cone penetration of 20 mm shall be taken as the liquid limit of the soil and shall be expressed to the nearest first decimal place.

4.6 Report

4.6.1 The results of observations of the test shall be recorded suitably.

4.6.2 The liquid limit should be reported to the nearest first decimal place. The history of the sample, that is, natural state, air-dried, or unknown, the pretreatment, if any to the soil, shall be reported.

5. TEST FOR DETERMINATION OF LIQUID LIMIT BY ONE-POINT METHOD USING (CASAGRANDE APPARATUS)

5.1 Principle — It has been established by basic characteristics of soils and associated physico-chemical factors that critical shear strengths at liquid limit water contents arise out of force field equilibrium and are independent of soil type. This has lead to the formation of a scientific base for liquid limit determination by one-point method.

5.2 Apparatus — The requirements for apparatus are the same as specified in 3.1.

5.3 Soil Sample — The requirements for the soil sample are the same as specified in 3.2.

5.4 Adjustment of Mechanical Device — The requirements for mechanical device are the same as specified in 3.3.

5.5 Procedure — A sample of soil weighing at least 50 g from the soil sample passing 425-micron IS Sieve shall be mixed thoroughly with distilled water in the evaporating dish or on the flat glass plate to form a uniform paste with a moisture content as near as possible to that corresponding to the 25 drops value. The trial addition of water to give about 25 drops may be checked with the mechanical device until experience with the soil under test rend-

ers this step unnecessary. The procedure given in 3.4.1 to 3.4.4 should otherwise be followed, except that a moisture content sample shall be taken only for the accepted trial. For soils with liquid limits above 50 to 120 percent, the accepted range shall require between 20 and 30 drops to close the groove (see 1.1.1); for soils with liquid limit less than 50 percent, a range of 15 to 35 drops is acceptable. At least two consistent consecutive closures shall be observed before taking the moisture content sample for calculation of the liquid limit. The test shall always proceed from the wetter to the drier condition of the soil.

5.6 Computations — The water content w_N of the soil of the accepted trial shall be calculated. For the range of blows between 15 and 35, the liquid limit water content shall be calculated employing the formula:

$$w_L = \frac{w_N}{1.3215 - 0.23 \log N}$$

5.7 Report — See 4.6.

6. TEST FOR DETERMINATION OF LIQUID LIMIT BY ONE-POINT METHOD USING CONE PENETROMETER APPARATUS

6.1 Principle — Since the depth of penetration is an indirect reflection of shear strength at different water contents, it has been found, within the framework of a scientific base that w/w_L against $\log D$ or D is unique and is independent of soil type. The resulting linear relation enables to determine liquid limit water content corresponding to 20 mm penetration of the cone.

6.2 Apparatus — The requirements for apparatus are the same as in 4.3.

6.3 Soil Sample — The requirements for the soil sample are the same as in 4.4.

6.4 Procedure — Same as in 4.5. The accepted trial is such that the depth of cone penetration is between 16 and 26 mm.

6.5 Computations — The water content is determined for the accepted trial. The liquid limit water content is computed from any one of the following relationships:

$$w_L = w_N / 0.77 \log D$$

$$w = w_N / (0.65 + 0.0175 D)$$

6.6 Report — See 4.6.

7. TEST FOR THE DETERMINATION OF PLASTIC LIMIT

7.1 Apparatus

7.1.1 Porcelain Evaporating Dish — about 12 cm in diameter.

or

Flat Glass Plate — 10 mm thick and about 45 cm square or larger.

7.1.2 Spatula — flexible, with the blade about 8 cm long and 2 cm wide.

or

Palette Knives — two, with the blade about 20 cm long and 3 cm wide (for use with flat glass plate for mixing soil and water).

7.1.3 Surface for Rolling — ground-glass plate 20 × 15 cm.

7.1.4 Containers — air-tight to determine moisture content.

7.1.5 Balance — sensitive to 0.01 g.

7.1.6 Oven — thermostatically controlled with interior of non-corroding material to maintain the temperature between 105 and 110°C.

7.1.7 Rod — 3 mm in diameter and about 10 cm long.

7.2 Soil Sample — A sample weighing about 20 g from the thoroughly mixed portion of the material passing 425-micron IS Sieve, obtained in accordance with IS : 2720 (Part 1)-1983 shall be taken.

7.2.1 When both liquid limit and the plastic limit of a soil are to be determined, a quantity of soil sufficient for both the tests shall be taken for preparation of the soil. At a stage in the process of mixing of soil and water at which the mass becomes plastic enough to be easily shaped into a ball, a portion of the soil sample in the plastic state should be taken for the plastic limit test.

7.3 Procedure — The soil sample shall be mixed thoroughly with distilled water in an evaporating dish or on the flat glass plate till the soil mass becomes plastic enough to be easily moulded with fingers. In the case of clayey soils, the plastic soil mass shall be left to stand for a sufficient time (24 hours) to ensure uniform distribution of moisture throughout the soil (see 7.2.1). A ball shall be formed with about 8 g of this plastic soil mass and rolled between the fingers and the glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling shall be between 80 and 90 strokes/min counting a stroke as one complete motion of the hand forward and back to the starting position again. The rolling shall be done till the threads are of 3 mm diameter. The soil shall then be kneaded together to a uniform mass and rolled again. This process of alternate rolling and kneading shall be continued until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The crumbling may occur when the thread has a diameter greater than 3 mm. This shall be considered a satisfactory end point, provided the soil has been rolled into a thread 3 mm

in diameter immediately before. At no time shall an attempt be made to produce failure at exactly 3 mm diameter by allowing the thread to reach 3 mm, then reducing the rate of rolling or pressure or both, and continuing the rolling without further deformation until the thread falls apart. The pieces of crumbled soil thread shall be collected in an air-tight container and the moisture content determined as described in IS : 2720 (Part 2)-1973.

7.4 Report

7.4.1 The observations of the test should be recorded suitably. A recommended proforma for the record of results is given in Appendix A.

7.4.2 The moisture content determined as in 7.3 is the plastic limit of the soil. The plastic limit shall be determined for at least three portions of the soil passing 425-micron IS Sieve. The average of the results calculated to the nearest whole number shall be reported as the plastic limit of the soil.

7.4.3 The history of the soil sample (that is, natural state, air-dried, oven-dried or unknown) and the period of soaking allowed after mixing of water to the soil shall also be reported.

8. PLASTICITY INDEX

8.1 Calculation — The plasticity index is calculated as the difference between its liquid limit and plastic limit:

$$\text{Plasticity index } (I_p) = \text{liquid limit } (w_L) - \text{plastic limit } (w_p)$$

8.2 Report — The difference calculated as indicated in 8.1 shall be reported as the plasticity index, except under the following conditions:

- In the case of sandy soils, plastic limit should be determined first. When plastic limit cannot be determined, the plasticity index should be reported as N_p (non-plastic).
- When the plastic limit is equal to or greater than the liquid limit, the plasticity index shall be reported as zero.

9. TOUGHNESS INDEX

9.1 Calculation — The toughness index shall be calculated as follows:

$$\text{Toughness index } (I_T) = \frac{I_p}{I_f}$$

where

$$I_p = \text{plasticity index (see 8.1), and} \\ I_f = \text{flow index (see 3.5.2).}$$

10. LIQUIDITY INDEX

10.1 Calculation — The liquidity index shall be calculated as follows:

$$\text{Liquidity index } (I_L) = \frac{w_o - w_p}{I_p}$$

where

w_o = natural moisture content of the soil,
 w_p = plastic limit of the soil, and
 I_p = plasticity index of the soil.

$$\text{Consistency index } (I_c) = \frac{w_L - w_o}{I_p}$$

where

w_L = liquid limit of the soil,
 w_o = natural moisture content of the soil, and
 I_p = plasticity index of the soil.

11. CONSISTENCY INDEX

11.1 Calculation — The consistency index shall be calculated as follows:

12. GENERAL REPORT

12.1 The result of all the tests and calculations may be reported in the proforma given in Appendix A.

APPENDIX A

(Clauses 3.6.1, 7.4.1 and 12.1)

PROFORMA FOR TESTS AND CALCULATIONS

IS No. with year	Date
Details of soil sample	Room Temperature
Natural water content	
History of soil sample	
Period of soaking of soil sample before test	

LIQUID LIMIT						PLASTIC LIMIT				
Determination number	1	2	3	4	5	1	2	3	4	5
Number of drops										
Container number										
Weight of container + wet soil, g										
Weight of container + oven dry soil, g										
Weight of water, g										
Weight of container, g										
Weight of oven dry soil, g										
Moisture percent										

RESULT SUMMARY

Liquid Limit w_L	Flow Index I_f	Plastic Limit w_p	Plasticity Index I_p	Toughness Index I_T	Liquidity Index I_L	Consistency Index I_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)

REMARKS

Indian Standard

SPECIFICATION FOR EQUIPMENT FOR DETERMINATION OF SHRINKAGE FACTORS

0. FOREWORD

0.1 The equipment covered in this standard is used in the apparatus for determination of shrinkage factors of soils covered in IS : 2720 (Part 6)-1972.

1. SCOPE

1.1 This standard covers the requirement of equipments for the apparatus used for determination of shrinkage limit, shrinkage ratio, shrinkage index and volumetric shrinkage of soils.

2. DIMENSIONS

2.1 Dimensions and tolerances of different equipment shall be as detailed in Fig. 1 to 6 and in 4.6. Except where tolerances are specifically mentioned against the dimensions, all dimensions shall be taken as nominal dimensions and tolerances as given in IS : 2102-1969 'Allowable deviations for dimensions without specified tolerances (*first revision*)' shall apply.

3. MATERIALS

3.1 The materials of construction of various parts of the apparatus/equipment shall be as given in Table I and 4.6.

4. CONSTRUCTION

4.1 Evaporating Dish — The evaporating dish shall be as detailed in Fig. 1. The inside of the evaporating dish shall be smooth.

4.2 Spatula — The spatula shall be as detailed in Fig. 2. A wooden handle shall be fixed as shown in Fig. 2.

4.3 Shrinkage Dish — The shrinkage dish shall be as detailed in Fig. 3. The internal corner between the bottom and the vertical sides shall be rounded into a smooth concave curve of approximately 3 mm radius.

4.4 Glass Cup — It shall be as detailed in Fig. 4.

TABLE I MATERIALS OF CONSTRUCTION OF PARTS OF EQUIPMENTS

EQUIPMENT	MATERIAL	SPECIAL REQUIREMENT IF ANY	RELEVANT INDIAN STANDARD SPECIFICATION
Evaporating dish	Porcelain	—	IS : 2837 (Part 2)-1977 ¹
Spatula			
a) Blade	Steel	Polished	See IS : 2507-1975 ²
b) Handle	Wood	Painted	See IS : 620-1975 ³
Shrinkage dish	Stainless steel		Grade 07Cr18Ni9 of IS : 6911-1972 ⁴
Prong plate			
a) Prong	i) Brass ii) Stainless steel		See IS : 319-1974 ⁵ Grade 07Cr18Ni9 of IS : 6911-1972 ⁴
b) Plate	Acrylic plastic ⁶		
Plain plate	Acrylic plastic ⁶		
Glass cup	Glass		See IS : 878-1975 ⁶

¹ Specification for porcelain crucibles and basins: Part 2 Basins (*first revision*).

² Specification for cold rolled steel strip for springs (*first revision*).

³ General requirements for wooden tool handles (*third revision*).

⁴ Specification for stainless steel plate, sheet and strip.

⁵ Specification for free-cutting brass bars, rods and sections (*third revision*).

⁶ Specification for graduated measuring cylinders (*first revision*).

⁷ Relevant Indian Standard is under preparation.

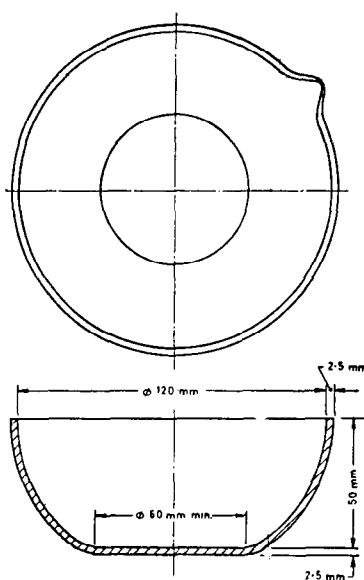
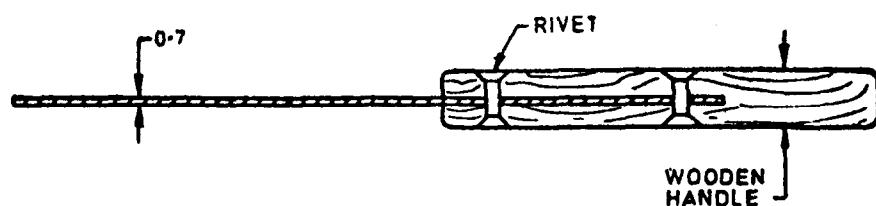
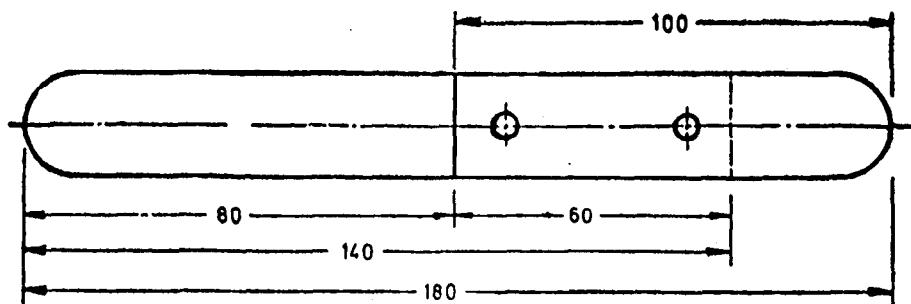
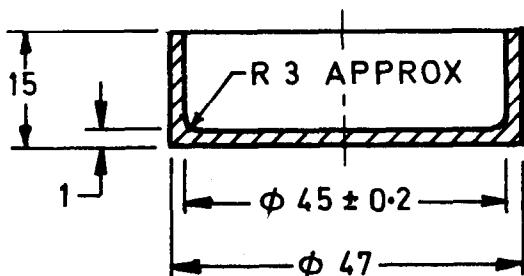


FIG. 1 EVAPORATION DISH



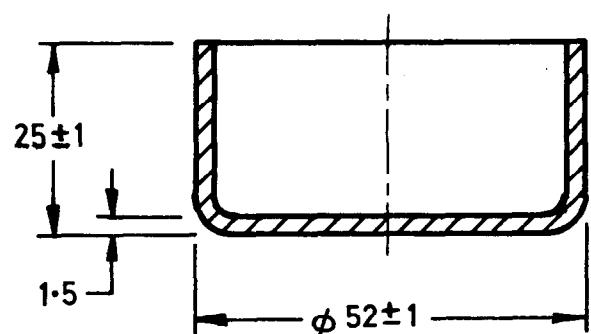
All dimensions in millimetres.

FIG. 2 SPATULA



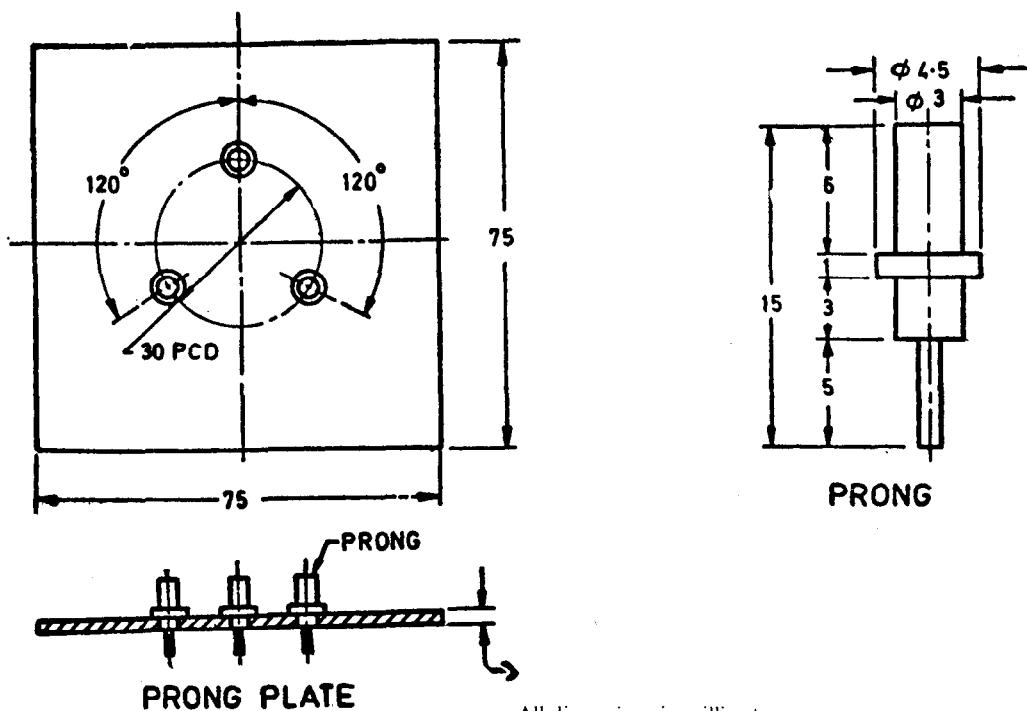
All dimensions in millimetres.

FIG. 3 SHRINKAGE DISH



All dimensions in millimetres.

FIG. 4 GLASS CUP



All dimensions in millimetres.
FIG. 5 DETAILS OF PRONG

4.5 Prong Plate — The prong plate shall be as detailed in Fig. 5. The plate shall be plain. Three prongs as detailed in Fig. 5 shall be fixed to the plate at 120° to each other and spacing of 30 mm (centre to centre).

4.6 Plain Plate — The plate shall be of size 75 mm square and of 3 mm thickness. The plate shall be plain (see Fig. 6).

4.7 Other Accessories — The equipment shall also have the following other accessories:

- Straight Edge* — 150 mm long and 25 mm wide as per IS : 2220-1962 'Specification for steel straight edges'.
- Measuring Cylinder* — of 25 ml capacity as per IS : 878-1975. 'Specification for graduated measuring cylinders (first revision)'.

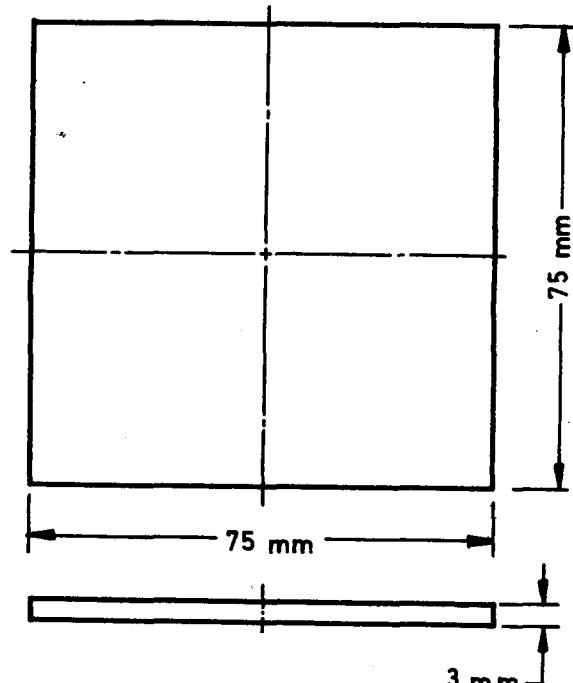
5. MARKING

5.1 The following information shall be clearly and indelibly marked suitably:

- Name of manufacturer or his registered trade-mark,
- Date of manufacture, and
- Type of material used.

5.1.1 The equipment may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard



All dimensions in millimetres.

FIG. 6 PLAIN PLATE

conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.

Indian Standard
METHODS OF TEST FOR SOILS
PART 6 DETERMINATION OF SHRINKAGE FACTORS
(First Revision)
(Incorporating Amendment No. 1)

0. FOREWORD

0.1 This part, first published in 1964, deals with the methods of test for the determination of shrinkage factors for soils. Factors, such as the shrinkage limit, shrinkage ratio, shrinkage index and volumetric shrinkage may be determined from the results of the test described. The method for determining the value of linear shrinkage on the basis of results of test conducted for obtaining the shrinkage limit has been found unsatisfactory and a direct method for determining this property has been covered in IS : 2720 (Part 20)-1966. Hence reference to linear shrinkage has been deleted from this revision. As weight measurements can be made more accurately than volume measurements, the former method has been specified in this revision for the determination of the volume of the soil pat. The inside edge of the shrinkage dish has been rounded so that air entrapped during the measurement of the volume of the pat is minimized. Recently it has been recognized that shrinkage upon drying is also indicative of the structure of the soil. The greater the shrinkage, the more dispersed the structure. It is possible, therefore, to study the shrinkage behaviour of undisturbed soil of natural or man-made deposits and get an idea of its structure. In this revision, the term shrinkage limit (undisturbed soil) has been introduced to define this property and a method included for its determination. Consequently, the term originally known as shrinkage limit has been re-designated as shrinkage limit (remoulded soil).

1. SCOPE

1.1 This standard (Part 6) lays down the method of test for obtaining data from which the shrinkage factors, namely, shrinkage limit (remoulded soil), shrinkage limit (undisturbed soil), shrinkage ratio, shrinkage index and volumetric shrinkage of soils may be calculated.

2. TERMINOLOGY

2.1 For the purpose of this standard, the following definitions shall apply. For definitions of terms not given below, reference may be made to IS : 2809-1972.

2.1.1 Shrinkage Index (I_s) — The numerical difference between the plastic limit and shrinkage limit (remoulded soil).

2.1.2 Shrinkage Limit (Undisturbed Soil) (w_{su}) — The maximum water content expressed as percentage of oven-dry weight at which any further reduction in water content will not cause a decrease in volume of the soil mass, the soil mass being initially of soil in its undisturbed state.

2.1.3 Shrinkage Limit (Remoulded Soil) (w_s) — The maximum water content expressed as percentage of oven-dry weight at which any further reduction in water content will not cause a decrease in volume of the soil mass, the soil mass being prepared initially from remoulded soil.

2.1.4 Shrinkage Ratio (R) — The ratio of a given volume change, expressed as a percentage of the dry volume, to the corresponding change in water content above the appropriate shrinkage limit, expressed as a percentage of the weight of the oven-dried soil.

2.1.5 Volumetric Shrinkage (Volumetric Change) (V_s) — The decrease in volume, expressed as a percentage of the soil mass when dried, of a soil mass when the water content is reduced from a given percentage to the appropriate shrinkage limit.

3. APPARATUS

3.1 The evaporating dish, spatula, shrinkage dish, straight edge, glass cup, prong plate, plain plate and measuring cylinder shall conform to IS : 10077-1982.

3.2 Oven — thermostatically controlled to maintain the temperature between 105 and 110°C, with interior of non-corroding material.

3.3 Sieve — 425-micron IS Sieves.

3.4 Balances — sensitive to 0.1 g and 0.01 g (see IS : 1433-1965).

3.5 Mercury — clean, sufficient to fill the glass cup to over-flowing.

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

4. SOIL SAMPLE FOR TEST

4.1 For shrinkage Limit (Remoulded Soil) Test (and Determination of Other Allied Properties) — Take a sample weighing about 100 g from the thoroughly mixed portion of the material passing the 425-micron IS Sieve which has been obtained in accordance with IS : 2720 (Part 1)-1983.

4.2 Shrinkage Index (Undisturbed Soil) Test

4.2.1 Preserve the undisturbed soil sample received from the field in its undisturbed state.

4.2.2 Trim from the undisturbed soil sample, soil pats approximately 45 mm in diameter and 15 mm in height. Round off their edges to prevent the entrapment of air during mercury displacement.

5. PROCEDURE FOR DETERMINATION OF SHRINKAGE LIMIT (REMOULDED SOIL) AND OTHER ALLIED PROPERTIES

5.1 Preparation of Soil Paste — Place about 30 g of the soil sample obtained in 4.1 in the evaporating dish and thoroughly mix with distilled water in an amount sufficient to fill the soil voids completely and to make the soil pasty enough to be readily worked into the shrinkage dish without entrapping air bubbles. In the case of friable soils, the amount of water required to obtain the desired consistency is equal to or slightly greater than the liquid limit; in the case of plastic soils, it may exceed the liquid limit by as much as 10 percent.

5.2 Weight and Volume of the Shrinkage Dish — Determine the weight of the clean empty shrinkage dish and record. Determine the capacity of the shrinkage dish in cubic centimetres, which is also the volume of the wet soil pat, by filling the shrinkage dish to overflowing with mercury, removing the excess by pressing the plain glass plate firmly over the top of the shrinkage dish in such a way that the plate is flush with the top of the dish and no air is entrapped, weighing the mercury held in the shrinkage dish to an accuracy of 0.1 g and dividing this weight by the unit weight of mercury to obtain the volume. Record this volume as the volume of the wet soil pat, V .

5.3 Filling the Shrinkage Dish — Coat the inside of the shrinkage dish with a thin layer of silicone grease or vaseline or some other heavy grease to prevent the adhesion of soil to the dish. Place in the

centre of the shrinkage dish an amount of the soil paste equal to about one-third the volume of the shrinkage dish, and allow the paste to flow to the edges by tapping the shrinkage dish on a firm surface cushioned by several layers of blotting paper, rubber sheet or similar material. Add an amount of the soil paste approximately equal to the first portion, and tap the shrinkage dish as before until the paste is thoroughly compacted and all included air has been brought to the surface. Add more soil paste and continue the tapping until the shrinkage dish is completely filled and excess soil paste stands out about its edge. Then strike off the excess soil paste with a straight edge, and wipe off all soil adhering to the outside of the shrinkage dish.

5.4 Weigh immediately the shrinkage dish as filled in 5.3 and record the weight as the weight of the shrinkage dish and wet soil pat. Allow the soil pat to dry in air until the colour of the pat turns from dark to light. Then oven-dry the pat in the shrinkage dish to constant weight at 105 to 110°C, cool in a desiccator and weigh immediately after removal from the desiccator. Record the weight as the weight of shrinkage dish and dry soil.

5.5 Volume of the Dry Soil Pat — Determine the volume of the dry soil pat by removing the pat from the shrinkage dish and immersing it in the glass cup full of mercury in the manner given in 5.5.1.

5.5.1 Fill the glass cup to overflowing with mercury and remove the excess mercury by pressing the glass plate with the three prongs (see Fig. 1) firmly over the top of the cup, collecting the excess mercury in a suitable container. Carefully wipe off any mercury which may be adhering to the outside of the cup. Place the cup, filled thus with mercury, in the evaporating dish taking care not to spill any mercury from the glass cup, and place the oven-dried soil pat on the surface of the mercury in the cup. Then carefully force the pat under the mercury by means of the glass plate with the same prongs (see Fig. 1) and press the plate firmly over the top of the cup, the displaced mercury being collected in the evaporating dish without spilling out of it. Care shall be taken to ensure that no air is trapped under the soil pat. Weigh the mercury so displaced by the dry soil pat to an accuracy of 0.1 g and determine its volume by dividing this weight by the unit weight of mercury. Record this volume as the volume of the oven-dry soil pat, V_0 .

6. PROCEDURE FOR DETERMINING SHRINKAGE LIMIT (UNDISTURBED SOIL)

6.1 Keep the specimen as prepared in 4.2 in a suitable small dish and air-dry it. Then dry the specimen in the dish to constant weight in an oven at 105 to 110°C. Remove the specimen from the oven and

smoothen the edges by sand papering. Brush off the soil dust from the specimen by a soft paint brush. Place the specimen again in the cleaned dish and dry it in an oven to constant weight. Cool the oven-dry specimen in a desiccator and weigh it with the dish. Determine the oven-dry weight of the specimen, W_{os} .

6.2 Determine the volume V_{os} of the oven-dry specimen of **6.1** as described in **5.5.1**.

6.3 Determine the specific gravity of the soil in accordance with IS : 2720 (Part 3/Sec 2)-1980.

7. CALCULATIONS

7.1 Moisture Content (w) — Calculate the moisture content of wet soil pat (see **5**) as a percentage of the dry weight of the soil as follows:

$$w = \frac{W - W_o}{W_o} \times 100$$

where

w = moisture content of the pat (see **5**),

W = weight of wet soil pat obtained by subtracting the weight of the shrinkage dish from the weight of the dish and wet pat, and

W_o = weight of dry soil pat obtained by subtracting the weight of the shrinkage dish from the weight of the dish and dry pat.

7.2 Shrinkage Limit (Remoulded Soil) (w_s) — Calculate the shrinkage limit using the following formula:

$$w_s = w - \left[\frac{V - V_o}{W_o} \right] 100$$

where

w_s = shrinkage limit in percent,

w = moisture content of wet soil pat (see **7.1**) in percent,

V = volume of wet soil pat in ml,

V_o = volume of dry soil pat in ml, and

W_o = weight of oven-dry soil pat in g.

NOTE — When the specific gravity of the soil is known, the shrinkage limit may also be calculated by the following formula (in this case, step indicated in **5.4** is not required):

$$w_s = \left[\frac{1}{R} - \frac{1}{G} \right] 100$$

where

w_s = shrinkage limit in percent,

R = shrinkage ratio (see **7.4**), and

G = specific gravity for the fraction used in the test determined in accordance with IS : 2720 (Part 3/Sec 2)-1980.

7.3 Shrinkage Index (I_s) — Calculate the shrinkage index using the following formula:

$$I_s = I_p - w_s$$

where

I_p = Plasticity index [determined in accordance with IS : 2720 (Part 5)-1970].

7.4 Shrinkage Ratio (R) — Calculate the shrinkage ratio using the following formula:

$$R = \frac{W_o}{V_o}$$

where

W_o = weight of oven-dry pat in g, and

V_o = volume of oven-dry soil pat in ml.

7.5 Volumetric Shrinkage (Volumetric Change) (V_s) — Calculate the volumetric shrinkage using the following formula:

$$V_s = (w_1 - w_s) R$$

Where

w_1 = given moisture content in percent,

w_s = shrinkage limit (see **7.2**), and

R = shrinkage ratio (see **7.4**).

7.6 Shrinkage Limit (Undisturbed Soil) (w_{su}) — Calculate the shrinkage limit (undisturbed soil) using the following formula (of sample referred in **6**):

$$w_{su} = \left[\frac{V_{os}}{W_{os}} - \frac{1}{G} \right] 100$$

where

w_{su} = shrinkage limit (undisturbed soil) in percent,

V_{os} = volume of oven-dry specimen in ml (see **6.2**),

W_{os} = weight of oven-dry specimen in g (see **6.1**), and

G = Specific gravity of soil determined in accordance with IS : 2720 (Part 3/Sec 2)-1980.

8. REPORT

8.1 The observations and results of the test shall be reported suitably. A recommended proforma for the record of results is given in Appendix A.

8.2 The tests shall be repeated at least three times for each soil sample and the average of the results thus obtained reported. If any individual value varies from the average by more than ± 2 percent, it shall be discarded and the test repeated.

A P P E N D I X A

(Clause 8.1)

PROFORMA FOR RECORD OF TEST RESULTS**a) Shrinkage Limit (Remoulded Soil)**

Project:

Name of work:

Laboratory number of sample:

Description of soil sample:

Soil fraction taken for the test:

Location	Bore/Trial Pit No.	Depth	Test No.
1. Determination No.			
2. Shrinkage dish No.			
3. Weight of shrinkage dish in g			
4. Weight of shrinkage dish + wet soil pat in g			
5. Weight of shrinkage dish + dry soil pat in g			
6. Weight of oven-dry soil pat (W_o) in g			
7. Weight of water in g			
8. Moisture content (w) of soil pat, percent			
9. Evaporating dish No. (dish into which mercury filling shrinkage dish is transferred for weighing) in g			
10. Weight of mercury filling shrinkage dish + weight of evaporating dish			
11. Weight of evaporating dish			
12. Weight of mercury filling shrinkage dish in g			
13. Volume of wet soil pat (V) in ml			
14. Evaporating dish No.			
15. Weight of mercury displaced by the dry soil pat + weight of evaporating dish in g			
16. Weight of evaporating dish in g			
17. Weight of mercury displaced by the dry soil pat in g			
18. Volume of dry soil pat (V_o) in ml			
19. $\left[\frac{V - V_o}{W_o} \right] \times 100$			
20. Shrinkage limit (remoulded soil)			
$w_s = w - \left[\frac{V - V_o}{W_o} \right] \times 100$			
21. Shrinkage ratio $R = \frac{W_o}{V_o}$			
22. Given moisture content w , percent			
23. $(W_1 - w_s)$			
24. Volumetric shrinkage $V_s = (W_1 - w_s) R$			

b) *Shrinkage Limit (Undisturbed Soil)*

Project:

Name of work:

Laboratory number of sample:

Description of soil sample

(including method of compaction
used in the field, sampling
method used, etc):

Location	Bore/Trial Pit No.	Depth	Test No.
1. Determination No.			
2. Dish No.			
3. Weight of dish + oven-dry soil specimen in g			
4. Weight of dish in g			
5. Weight of oven-dry soil specimen w_{os} in g			
6. Evaporating dish No.			
7. Weight of mercury displaced by the oven-dry specimen + weight of evaporating dish in g			
8. Weight of evaporating dish in g			
9. Weight of mercury displaced by the oven-dry soil specimen in g			
10. Volume of the oven-dry soil specimen V_{os} in ml			
11. $\frac{V_{os}}{W_{os}}$			
12. Specific gravity of the soil of the specimen G			
13. $1/G$			
14. Shrinkage limit (undisturbed soil)			
$w_{su} = \left[\frac{V_{os}}{W_{os}} - \frac{1}{G} \right] \times 100$			

Indian Standard
METHODS OF TEST FOR SOILS
PART 20 DETERMINATION OF LINEAR SHRINKAGE
(Incorporating Amendments No. 1 and 2)

0. FOREWORD

0.1 This part [IS : 2720 (Part 20)-1966] deals with the determination of the linear shrinkage of soils. The test is of value in indicating the plastic properties of soils having low clay contents.

1. SCOPE

1.1 This method covers the determination of the linear shrinkage of remoulded soils.

2. APPARATUS AND OTHER MATERIAL

2.1 Two Palette Knives — a convenient size is one having a blade about 10 cm long and 2 cm wide.

2.2 Flat Glass Plate — approximately 10 mm thick and 45 cm square, or an evaporating dish approximately 15 cm diameter.

2.3 Mould — of cast iron, brass or other suitable material of the type illustrated in Fig. 1.

NOTE — If moulds of essential dimensions and shape other than those specified in Fig. 1 are used, the value of shrinkage obtained may be different.

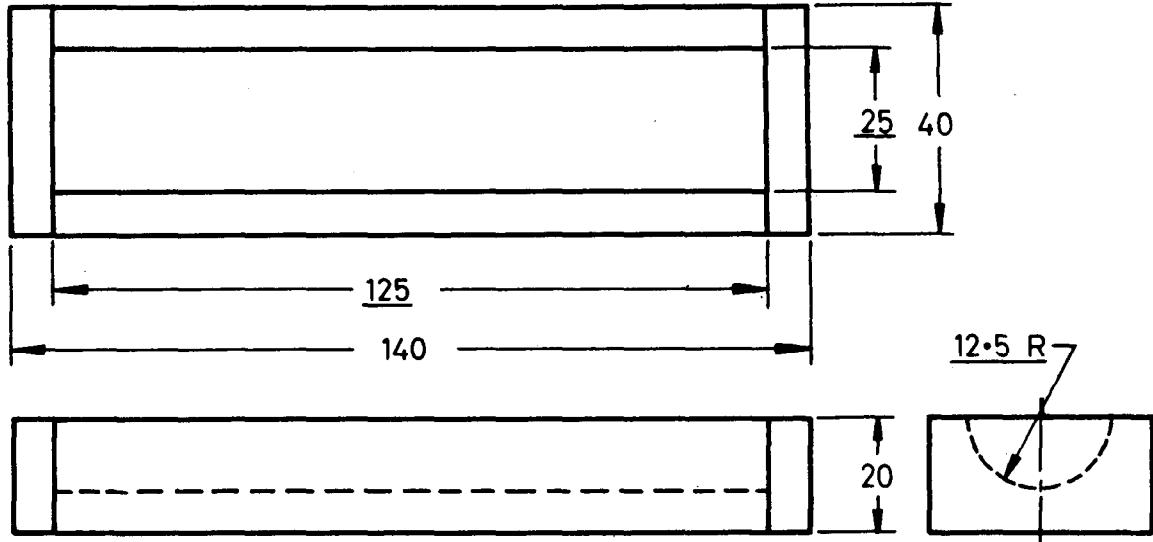
2.4 Oven — thermostatically controlled with interior of non-corroding material to maintain the constant temperatures between 60 to 65°C and 105 to 110°C.

2.5 Callipers — vernier gauge to measure 15 cm.

2.6 Silicone Grease or Any Other Suitable Grease

3. SOIL SPECIMEN

3.1 A specimen weighing about 150 g from the thoroughly mixed portion of the material passing 425-micron IS Sieve [see IS : 460 (Part 1)]-1978



Essential dimensions are underlined.
Tolerance on essential dimensions is ± 0.25 mm.
Other dimensions will depend on the material of the mould.

All dimensions in millimeters

FIG. 1 MOULD FOR LINEAR SHRINKAGE

obtained in accordance with IS : 2720 (Part 1)-1983 shall be taken for the test.

4. PROCEDURE

4.1 The mould shall be thoroughly cleaned and a thin film of grease shall then be applied to its inner walls in order to prevent the soil from adhering to the mould.

4.2 About 150 g of the soil sample passing 425-micron IS Sieve (*see 3.1*) shall be placed on the flat glass plate and thoroughly mixed with distilled water, using the palette knives, until the mass becomes a smooth homogeneous paste, with a moisture content approximately 2 percent above the liquid limit of the soil (*see Note 1 and Note 2*). In the case of clayey soils, the soil paste shall be left to stand for a sufficient time (24 h) to allow the moisture to permeate throughout the soil mass. The thoroughly mixed soil-water paste shall be placed in the mould such that it is slightly proud of the sides of the mould. The mould shall then be gently jarred to remove any air-pockets in the paste. The soil shall then be levelled off along the top of the mould with the palette knife. The mould shall be placed so that the soil-water mixture (paste) can air-dry slowly, until the soil has shrunk away from the walls of the mould (*see Note 3*). Drying should then be completed first at a temperature of 60 to 65°C until shrinkage has largely ceased and then at 105 to 110°C to complete the drying. The mould and soil

shall then be cooled and the mean length of the soil bar measured; if the specimen has become curved during drying, the measurement should be made along the mean arc (*see Note 4*).

NOTE 1 — The moisture content of the soil-water mixture at approximately 2 percent above the liquid limit of the soil is not critical to within a few percent.

NOTE 2 — The soil-water mixture should not be wet enough to allow segregation of the larger particles to the bottom of the mould.

NOTE 3 — With soils of low plasticity or shrinkage where there is no danger of cracking due to rapid drying, the moulds may be placed immediately in the high temperature oven.

NOTE 4 — Should a specimen crack badly, or break, such that measurement is difficult, the test should be repeated at a slower drying rate.

4.3 At least three determinations of linear shrinkage of the same soil shall be made and the average taken.

5. CALCULATIONS AND REPORT

5.1 The linear shrinkage of the soil shall be calculated as a percentage of the original length of the specimen from the following formula:

$$\text{Linear shrinkage} = \left[1 - \frac{\text{Length of oven-dry specimen}}{\text{Initial length of specimen}} \right] \times 100 \text{ percent}$$

5.2 The linear shrinkage of the soil shall be reported to the nearest whole number.

Indian Standard

METHODS OF TEST FOR SOILS

PART 40 DETERMINATION OF FREE SWELL INDEX OF SOILS

0. FOREWORD

0.1 This part deals with the method of test for the determination of free swell index of soils. Free swell is the increase in volume of a soil, without any external constraints, on submergence in water. The possibility of damage to structures due to swelling of expansive clays need be identified, at the outset, by an investigation of those soils likely to possess undesirable expansion characteristics. Inferential testing is resorted to reflect the potential of the system to swell under different simulated conditions. Actual magnitude of swelling pressures developed depends upon the dry density, initial water content, surcharge loading and several other environmental factors.

1. SCOPE

1.1 This standard (Part 40) covers a test for the determination of free swell index of soil which helps to identify the potential of a soil to swell which might need further detailed investigation regarding swelling and swelling pressures, under different field conditions.

2. APPARATUS

2.1 Sieve — 425-micron IS Sieve.

2.2 Glass Graduated Cylinders — Two, 100-ml capacity (see IS : 878-1956).

3. PROCEDURE

3.1 Take two 10 g (see Note) soil specimens of oven dry soil passing through 425-micron IS Sieve.

NOTE — In the case of highly swelling soils, such as sodium bentonites, the sample size may be 5 g or alternatively a cylinder of 250 ml capacity may be used.

3.2 Each soil specimen shall be poured in each of the two glass graduated cylinders of 100 ml capacity. One cylinder shall then be filled with kerosene oil and the other with distilled water up to the 100 ml (see Note under 3.1) mark. After removal of entrapped air (by gentle shaking or stirring with a glass rod), the soils in both the cylinders shall be allowed to settle. Sufficient time (not less than 24 h) shall be allowed for the soil sample to attain equilibrium state of volume without any further change in the volume of the soils. The final volume of soils in each of the cylinders shall be read out.

4. CALCULATION

4.1 The level of the soil in the kerosene graduated cylinder shall be read as the original volume of the soil samples, kerosene being a non-polar liquid does not cause swelling of the soil. The level of the soil in the distilled water cylinder shall be read as the free swell level. The free swell index of the soil shall be calculated as follows:

$$\text{Free swell index, percent} = \frac{V_d - V_k}{V_k} \times 100$$

where

V_d = the volume of soil specimen read from the graduated cylinder containing distilled water, and

V_k = the volume of soil specimen read from the graduated cylinder containing kerosene.

Indian Standard
METHODS OF TEST FOR SOILS
PART 41 MEASUREMENT OF SWELLING PRESSURE OF SOILS

0. FOREWORD

0.1 This part (Part 41) deals with the method of test for determination of swelling pressure of soils. The main purpose of swelling pressure test is to determine the intrinsic swelling pressure of the expansive soil tested. The expansive clays increase in their volume when they come in contact with water owing to surface properties of these clay types. Light structures founded on these type of clays—popularly known in India as black cotton soil, experience severe structural damage due to the swelling of the subsoil. Since the intrinsic swelling pressure is to be associated with the design of structures against such damages, measurement of swelling pressure assumes importance.

0.2 The swelling pressure is dependent upon several factors, namely, (a) the type and amount of clay in the soil and the nature of the clay mineral, (b) the initial water content and dry density, (c) the nature of pore fluid, (d) the stress history of the soil including the confining pressure, and (e) drying and wetting cycles to which the soils have been subjected to. Besides, the dependence of swelling pressure on volume change makes a precise measurement of swelling pressure difficult.

1. SCOPE

1.1 This standard covers the laboratory method of conducting one-dimensional swelling pressure test using either fixed or the floating rings on both undisturbed or remoulded soils in the partially saturated condition to determine the swelling pressure of the soil. Two methods, namely, consolidometer method in which the volume change of the soil is permitted and the corresponding pressure required to bring back the soil to its original volume is measured and the constant volume method in which the volume change is prevented and the consequent pressure is measured, are covered.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definition shall apply.

2.1 Swelling Pressure — The pressure which the expansive soil exerts, if the soil is not allowed to swell or the volume change of the soil is arrested.

SECTION 1 CONSOLIDOMETER METHOD

3. APPARATUS AND EQUIPMENT

3.1 Consolidometer — A device to hold the sample in a ring either fixed or floating with porous stones (or ceramic discs) 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 cantilevered 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 expansion of the specimen.

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

3.1.2 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.

3.1.3 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 thin coating of silicon grease or 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 maximum 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. The ring shall 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 central hole equal in diameter of the porous stone and should be perfectly concentric with the sample. The ring shall be provided with a collar of internal diameter same as that of the ring and of effective height 20 mm. The collar shall rest securely on the specimen ring.

3.1.4 Porous Stones — The stones shall be of silicon carbide or aluminium oxide 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 thickness of the stone shall be a minimum of 15 mm. The top stone shall be loaded through a corrosion-resistant plate of sufficient rigidity and of minimum thickness 10 mm to prevent breakage of the stone. The loading plate shall have suitable holes for free drainage of water.

3.2 Dial Gauge — accurate to 0.01 mm with a traverse of at least 20 mm.

3.3 Water Reservoir — To keep the soil sample submerged.

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 — Fine wire-saw knife, spatula, etc, for trimming sample to fit into the inside diameter of the consolidometer ring with minimum disturbance.

3.6 Oven — thermostatically controlled oven with interior of non-corroding material to maintain the temperature between 105 and 110°C.

3.7 Desiccator — With any desiccating agent other than sulphuric acid.

3.8 Balance — sensitive to 0.01 g.

3.9 Containers — for water content determination.

4. PREPARATION OF TEST SPECIMEN

4.1 Preparation of Specimen from Undisturbed Soil Samples — The container ring shall be cleaned and weighed empty. From one end of the undisturbed soil sample about 30 mm, or more if desired, of the soil sample, if desired shall be cut off and rejected. The specimen shall be cut off either from the undisturbed tube sample 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 10 mm 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 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 trimming shall be taken in moisture content cans and their moisture content

determined in accordance with IS : 2720 (Part 2)-1973.

4.2 Preparation of Specimen from Disturbed Soil Samples — In case, where it is necessary to use disturbed soil samples, the soil sample shall be compacted to the desired (field) density and water content in a standard compaction proctor mould. Samples of suitable sizes are cut from it as given in 4.1.

NOTE 1 — Since the swelling pressure of the soil is very much influenced by its initial water content and dry density, it shall be ensured that, in the case of undisturbed soil samples, the specimen shall be collected from the field for test during the driest season of the year, namely, April, May and June, so that the swelling pressure recorded shall be maximum.

In the case of remoulded soil samples, the initial water content shall be at the shrinkage limit or field water content so that the swelling pressure recorded shall be maximum.

NOTE 2 — The desiccated soil obtained from the field coupled with smaller thickness of consolidation ring make the undisturbed soil specimen always in danger of being disturbed during trimming; hence great care shall be taken to handle the specimen delicately with the least pressure applied to the soil.

5. PROCEDURE

5.1 Assembly

5.1.1 The porous stones shall be saturated. All surfaces 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 rendered wet (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.

5.1.2 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.

5.1.3 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.

5.1.4 The holder with the dial gauge to record the progressive vertical heave of the specimen under no load, shall then be screwed in place and adjusted in such a way that the dial gauge is near the end of its release run, allowing small margin for the compression of the soil, if any.

5.1.5 An initial setting load of 50 gf/cm² (this includes the weight of the porous stone and the loading pad) shall be placed on the loading hanger and the initial reading of the dial gauge shall be noted.

5.1.6 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 then be allowed to swell.

5.2 Procedure

5.2.1 The free swell readings shown by the dial gauge under the seating load of 5 kN/m² (0.05 kgf/cm²) shall be recorded at different time intervals. For the purpose of record, Form 1 given in Appendix A shall be used and the total readings noted at total elapsed time since starting shown therein.

5.2.2 The dial gauge readings shall be taken till equilibrium is reached. This is ensured by making a plot of swelling dial reading *versus* time in hours, which plot becomes asymptotic with abscissa (time scale). The equilibrium swelling is normally reached over a period of 6 to 7 days in general for all expansive soils.

5.2.3 The swollen sample shall then be subjected to consolidation under different pressures as given in Form 2 in Appendix A. The compression dial readings shall be recorded till the dial readings attain a steady state for each load applied over the specimen. The consolidation loads shall be applied till the specimen attains its original volume.

6. CALCULATIONS AND REPORT

6.1 The observations shall be recorded suitably. Two forms recommended for recording are given in Appendix A.

6.2 Calculations — The observed swelling dial reading recorded in Form 1 of Appendix A shall be plotted with elapsed time as abscissa and swelling dial reading as ordinates on natural scale. A smooth curve shall be drawn joining these points. If the curve so drawn becomes asymptotic with the abscissa, the swelling has reached its maximum and hence the swelling phase shall be stopped, and the consolidation phase shall be started. The compression readings shall be tabulated as in Form 2 of Appendix A and a plot of change in thickness of expanded specimen as ordinates and consolidation pressure applied as abscissa in semi-logarithmic scale shall be made. The swelling pressure exerted by the soil specimen under zero swelling condition shall be obtained by interpolation and expressed in kN/m² (kgf/cm²).

SECTION 2 CONSTANT VOLUME METHOD

7. APPARATUS AND EQUIPMENT

7.1 Consolidometer — The consolidometer shall conform to the requirements given in 3.1.

7.2 Dial Gauge — accurate to 0.002 mm with a traverse of at least 10 mm.

7.3 Moisture Room

7.4 Soil Trimming Tools — shall be in conformity with 3.5.

7.5 Balance — sensitive to 0.01 g.

7.6 Oven — thermostatically controlled oven with interior of non-corroding material to maintain temperature between 105 and 110°C.

7.7 Desiccator — With any desiccating agent other than sulphuric acid.

7.8 Moisture Content Cans

7.9 Loading Unit of 5 000 kg Capacity — Strain controlled type.

7.10 High Sensitive Proving Ring of 200 kg Capacity

8. PREPARATION OF SOIL SPECIMEN

8.1 Preparation of Specimen from Undisturbed Soil Samples — as specified in 4.1.

8.2 Preparation of Specimen from Disturbed Soil Samples — as specified in 4.2.

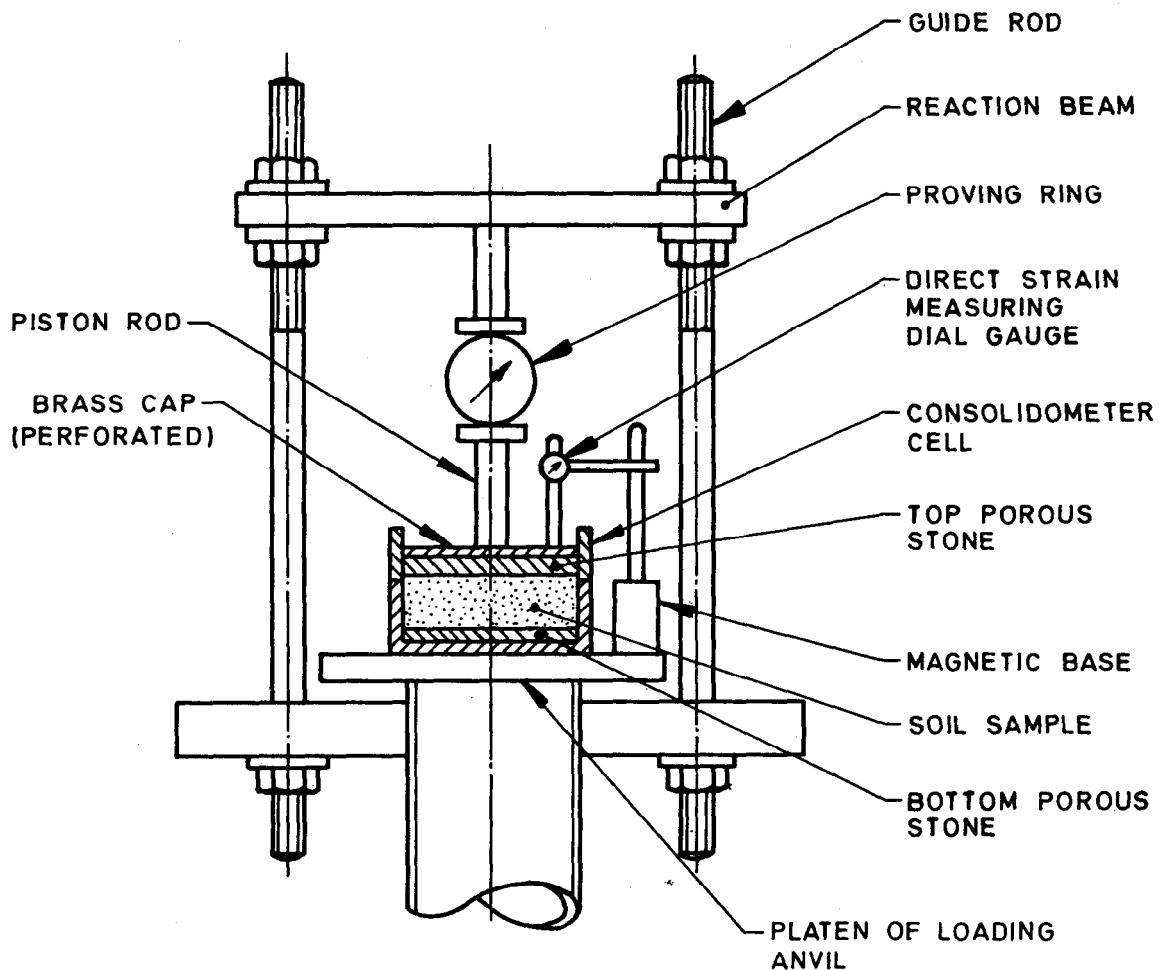
9. PROCEDURE

9.1 Assembly

9.1.1 The consolidation specimen ring with the specimen shall be kept in between two porous stones saturated in boiling water 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 of the porous stone.

9.1.2 This assembly shall then be placed on the platen of the loading unit as shown in Fig. 1. The load measuring proving ring tip attached to the load frame shall be placed in contact with the consolidation cell without any eccentricity. A direct strain measuring dial gauge shall be fitted to the cell. The specimen shall be inundated with distilled water and allowed to swell.

9.2 Detailed Procedure for the Test — The initial reading of the proving ring shall be noted. The swelling of the specimen with increasing volume shall be obtained in the strain measuring load gauge. To keep the specimen at constant volume, the platen shall be so adjusted that the dial gauge always show the original reading. This adjustment shall be done at every 0.1 mm of swell or earlier. The



NOTE — The above is only an illustrative set-up. Any suitable apparatus which minimises volume changes may be preferred.

FIG. 1 SET-UP FOR MEASURING SWELLING PRESSURE IN THE CONSTANT VOLUME METHOD

duration of test shall conform to the requirements given in 5.2.2. The assembly shall then be dismantled and the soil specimen extracted from the consolidation ring to determine final moisture content in accordance with IS : 2720 (Part 2)-1973.

10. CALCULATIONS AND REPORT

10.1 The observations shall be recorded suitably in the form given in Appendix B.

10.2 Calculations — The difference between the

final and initial dial readings of the proving ring gives total load in terms of division which when multiplied by the calibration factor gives the total load. This, when divided by the cross-sectional area of the soil specimen, gives the swell pressure expressed in kN/m² (kgf/cm²).

Swelling pressure in kN/M² (kgf/cm²)

$$= \frac{(\text{Final dial reading} - \text{Initial dial reading})}{\text{Area of the specimen}} \times \text{Calibration factor of proving ring}$$

A P P E N D I X A
(Clauses 5.2.1, 5.2.3, 6.1 and 6.2)

SWELLING PRESSURE TEST BY CONSOLIDOMETER METHOD

FORM 1

Project:

Dated:
Tested by:

1. Details of soils sample
 - i) Location
 - ii) Boring No.
 - iii) Depth
 - iv) Visual description of soil
 - v) Liquid limit
Plasticity index
 - vi) Percentage of soil fraction
below 0.002 mm
2. Details of soil specimen
 - i) Undisturbed or remoulded
 - ii) Specific gravity of the soil

NATURAL DENSITY			MOISTURE CONTENT		
Description	Test I	Test II	Description	Before Test	After Test
Weight of container ring + wet specimen			Weight of container + wet soil		
Weight of container			Weight of container + dry soil		
Diameter of container			Weight of container		
Initial thickness of soil sample			Weight of water		
Wet density in g/ml			Weight of dry soil		

Dry density in g/ml

Moisture content in
percent

Date

Time of starting

Elapsed time in hours	Swelling dial reading
0	
0.5	
1	
2	
4	
8	
12	
16	
20	
24	
36	
48	
60	
72	
96	
120	
144	

FORM 2

DATA SHEET FOR SWELL-COMPRESSION TEST

Pressure Increment		Compression	Change in Thick- ness of Expanded Specimen
in kgf/cm ²	in kN/m ²		
(0.0-0.05)	0-5		
(0.05-0.10)	5-10		
(0.10-0.25)	10-25		
(0.25-0.50)	25-50		
(0.50-1.00)	50-100		
(1.00-2.00)	100-200		
(2.00-4.00)	200-400		
(4.00-8.00)	400-800		
(8.00-16.00)	800-1600		

A P P E N D I X B
(Clause 10.1)

SWELL PRESSURE TEST BY CONSTANT VOLUME METHOD

Project	Dated: Tested by:
1. Details of soil samples	
i) Location	
ii) Boring No.	
iii) Depth	
iv) Visual description of soil	
v) Liquid limit	
Plasticity index	
vi) Percentage of soil fraction below 0.002 mm	
2. Details of the soil specimen	
i) Undisturbed or remoulded	
ii) Specific gravity of the soil	

NATURAL DENSITY			MOISTURE CONTENT		
Description	Test I	Test II	Description	Before Test	After Test
Weight of container ring + wet specimen			Weight of container + wet soil		
Weight of container			Weight of container + dry soil		
Diameter of container			Weight of container		
Initial thickness of sample			Weight of water		
Wet density in g/ml			Weight of dry soil		
Dry density in g/ml			Moisture content in percent		

SWELL PRESSURE DATA

Date	Time	Strain Dial Gauge Reading Before Adjustment	Proving Ring Reading	Difference	Load in kg	Swell Pressure in kg/cm ²	Remarks

SECTION 8
Determination of Permeability

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Indian Standard

SPECIFICATION FOR MOULD ASSEMBLY FOR DETERMINATION OF PERMEABILITY OF SOILS

0. FOREWORD

0.1 The equipment covered in this standard is used for determination of coefficient of permeability of soils as covered in IS : 2720 (Part 17)-1986.

1. SCOPE

1.1 This standard covers the details of mould, drainage base, drainage cap, extension collar, metal ring and rod used as the mould assembly for laboratory determination of the coefficient of permeability of soils.

2. DIMENSIONS

2.1 Dimensions with tolerances of different component parts of the equipment shall be as given in Fig. 1 to 6. Except where tolerances are specially mentioned against the dimensions, all dimensions shall be taken as nominal and tolerances as given in IS : 2102 (Part 1) - 1980 of medium class shall apply.

3. MATERIALS

3.1 The materials for construction of the various equipment parts shall be as given in Table 1.

4. CONSTRUCTION

4.1 The mould, drainage base and cap, metal ring,

tie rod, extension collar shall be constructed as per details given in Fig. 1 to 7. The complete assembly shall be leakproof and tested for an internal hydraulic pressure of 110 kPa.

5. MARKING

5.1 The following information shall be clearly and indelibly marked on each equipment:

- a) Name of the manufacturer or his registered trade-mark or both,
- b) Date of manufacture, and
- c) Type of material.

5.1.1 The equipment may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Mark) Act and the Rules and Regulations made there under. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as further safeguard. Details of conditions, under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standard Institution.

TABLE 1 MATERIALS FOR CONSTRUCTION OF DIFFERENT EQUIPMENT PARTS

SL. No.	EQUIPMENT	MATERIAL	SPECIAL REQUIREMENTS	RELEVANT INDIAN STANDARD
i)	Mould	Brass/ Gun Metal		IS : 292-1983* IS : 318-1981†
ii)	Drainage base	Brass/ Gun Metal		IS : 292-1983* IS : 318-1981†
iii)	Drainage cap	Brass/ Gun Metal		IS : 292-1983* IS : 318-1981†
iv)	Metal ring	Brass/ Gun Metal		IS : 292-1983* IS : 318-1981†
v)	Tie rod and fly nut	Mild Steel	Nickel/ Chromoplated	IS : 4367-1967‡
vi)	Extension collar	Brass/ Gun Metal		IS : 292-1983* IS : 318-1981†

*Specification for leaded brass ingots and castings (*second revision*).

†Specification for leaded tin bronze ingots and castings (*second revision*).

‡Specification for alloy and tool steel forgings for industrial use.

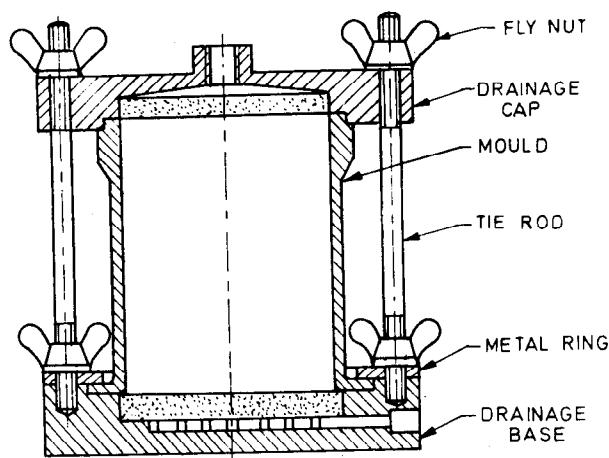
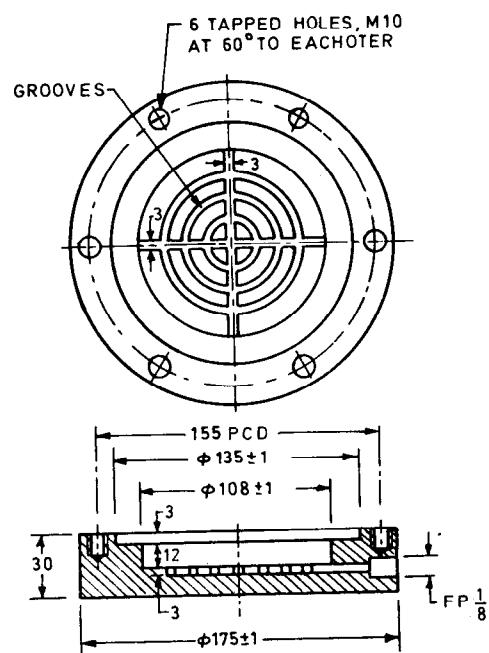
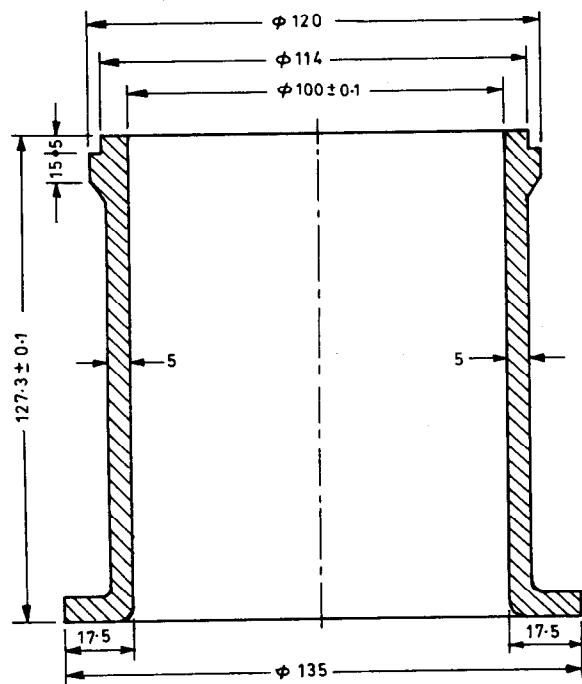


FIG. 1 PERMEABILITY CELL ASSEMBLY



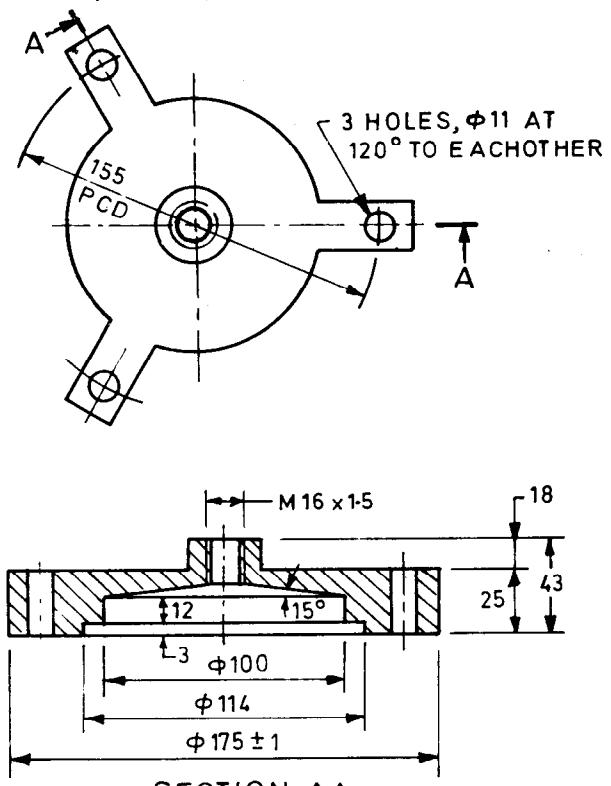
All dimensions in millimetres.

FIG. 3 DRAINAGE BASE



All dimensions in millimetres.

FIG. 2 MOULD



All dimensions in millimetres.

FIG. 4 DRAINAGE CAP

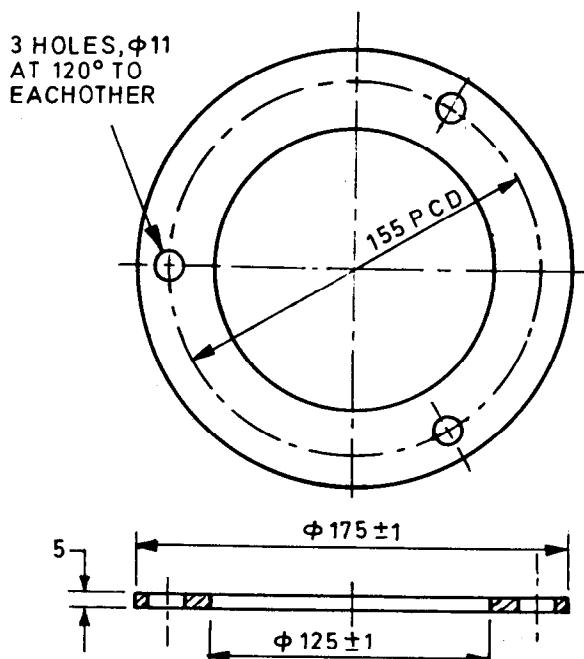


FIG. 5 METAL RING

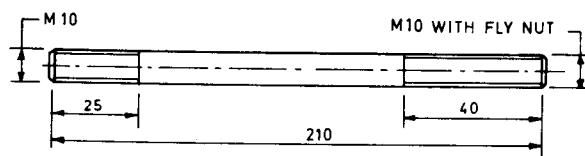


FIG. 6 TIE ROD

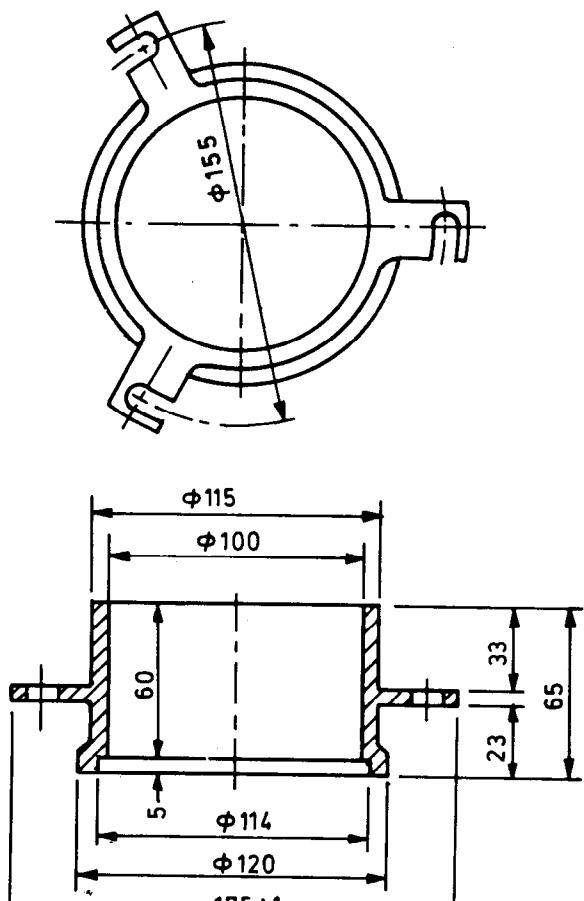


FIG. 7 EXTENSION COLLAR

Indian Standard

METHODS OF TEST FOR SOILS

PART 17 LABORATORY DETERMINATION OF PERMEABILITY

(First Revision)

0. FOREWORD

0.1 This part (Part 17) deals with the methods for the laboratory determination of the coefficient of permeability of soils.

0.2 The knowledge of the permeability is essential in the solution of many engineering problems involving flow of water through soils such as:

- a) Dewatering and drainage of excavations, back-fills and subgrades;
- b) Determining yield of water bearing strata;
- c) Assessing seepage through the body of earth dams; and
- d) Computing losses from canals.

0.3 In addition, since the soil may be used to inhibit flow of water, the permeability of soil governs the type of soil to be used.

0.4 This standard (Part 17) covers both constant head and falling head tests as used for most of the soil. The laboratory determination of permeability of granular soil by constant head method is covered in separate part (Part 36). This part was first published in 1966. Based on the experience gained in the use of this test in the past 20 years by various laboratories, this standard has been revised. The principal modifications made are deletion of details of the equipment for testing for which separate Indian Standard has been formulated (*see IS : 11209 - 1985*), giving detailed procedures for the record of the observations as well as calculations for two types of the test and revising the proforma for the record of test by enlarging to cover more details.

1. SCOPE

1.1 This standard (Part 17) covers the methods for laboratory determination of coefficient of permeability of soils using falling head and the constant head methods. This test is recommended for soils with coefficient of permeability in the range 10^{-3} to 10^{-7} cm/s and maximum particle size of 9.5 mm.

2. TERMINOLOGY

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

3. APPARATUS

3.1 The mould assembly (including drainage base and drainage cap) shall conform to IS : 11209-1985.

3.2 The compaction rammer shall conform to IS : 9198-1979.

3.3 Set of Stand Pipes — Glass stand pipes for falling head (variable head) test arrangement, varying in diameter from 5 to 20 mm, suitably mounted on stand or otherwise fixed on wall.

3.4 Constant Head Tank — A suitable water reservoir capable of supplying water to the permeater under constant head for constant head test arrangement.

3.5 Vacuum Pump

3.6 Miscellaneous Apparatus — Such as IS sieves, mixing pan, graduated cylinder, metre scale, stop watch, 75-micron wire gauge, thermometer and a source of de-aired water.

4. PREPARATION OF TEST SPECIMEN

4.1 Disturbed Soil Sample

4.1.1 A 2.5-kg sample shall be taken from a thoroughly mixed air-dried or oven-dried material which has been obtained in accordance with IS : 2720 (Part 1)-1983.

4.1.2 The moisture content of the 2.5-kg sample shall be determined as described in IS : 2720 (Part 2)-1973. The sample shall be placed in an airtight container. The quantity of water to be added to the stored sample to give the desired moisture content shall be computed and spread evenly over the sample, and after thoroughly mixing, the material shall again be placed in the storage container. The moisture content of the sample shall again be determined and the entire process repeated until the actual moisture content is within 0.5 percent of that desired.

4.1.3 The permeameter mould shall be weighed empty to the nearest gram. After greasing lightly the inside of the mould, it shall be clamped between the compaction base plate and the extension collar. The assembly shall be kept on a solid base.

4.1.4 The dry density for remoulding of soil samples shall be either the field density or the value of the maximum dry density estimated by the compaction tests [see IS : 2720 (Part 7)-1980 and IS : 2720 (Part 8)-1983] or any other density at which the permeability is desired. The moisture content used for compaction should be the optimum moisture content or the field moisture as the case may be. The compactive effort may be varied to simulate field conditions. Static compaction may also be used where necessary. After completion of compaction, the collar, if attached, shall be removed and excess soil trimmed level with the top of the mould. The base shall be detached and the mould full of the compacted specimen shall be weighed.

4.1.5 The mould with the specimen inside shall be assembled to the drainage and cap having porous discs. The porous discs shall be saturated before assembling the mould.

4.2 Undisturbed Soil Sample — For testing undisturbed soils, undisturbed specimen shall be trimmed in the form a cylinder not larger than about 85 mm in diameter and having a height equal to that of the mould. The specimen shall be placed centrally over the porous disc of the drainage base fixed to the mould. The annular space between the mould and the specimen shall be filled with an impervious material such as cement slurry, or a mixture of 10 percent dry powdered bentonite and 90 percent fine sand by weight to provide sealing between the soil specimen and the mould against leakage from the sides. When using the cement slurry, the mould shall be kept on a flat surface other than the porous discs. The mixture shall be compacted using a small tamping rod. The drainage cap shall then be fixed over the top of the mould.

4.3 Saturation — In the case of soils of medium to high permeability, the specimen shall be subjected to sufficient head, flow or immersion so as to obtain full saturation. Soils of low permeability require flow under a high head for periods ranging from a day to a week depending upon the permeability and the head. Alternatively, in the case of soils of low permeability, the specimen shall be subjected to a gradually increasing vacuum with bottom outlet closed so as to remove to form the soil voids. The vacuum shall be increased to at least 70 cm of mercury which shall be maintained for 15 minutes or more depending upon the soil type. The evacuation shall be followed by a very slow saturation of the specimen with de-aired water from the bottom upwards under full vacuum. When the specimen is saturated, both the top and bottom outlets shall be closed.

5. CONSTANT HEAD TEST

5.1 For a constant head test arrangement, the specimen shall be connected through the top inlet to the

constant head water reservoir. The bottom outlet shall be opened and when the steady state of flow has been established, the quantity of flow for a convenient time interval shall be collected and weighed or measured. Alternatively, the inlet may be at the bottom and water may be collected from the outlet at the top. The collection of the quantity of flow for the same time interval shall be repeated thrice.

5.2 The linearity (of Darcy's law) between the hydraulic gradient and the average velocity of flow for the soil under test should be established by performing the test over a range of hydraulic gradients. The hydraulic gradients in the permeability test should preferably include the hydraulic gradient likely to occur in the field and deviation from linearity observed should be noted.

5.3 Record of Observation

5.3.1 The inside diameter and the height of the permeameter are measured and recorded as diameter D and length L of the specimen in Appendix A. The heights H_1 and H_2 are measured to determine the head loss h . The temperature of water T is also measured and recorded.

5.3.2 During the test, observations are made of volume of water, Q collected in a graduated jar in time t and are recorded in col 2 and 3 of Appendix A respectively. The permeability is calculated and recorded in col 4 of Appendix A. Remarks, if any, are entered in col 5 of Appendix A.

5.3.3 For the purpose of getting a quantitative description of the state of the sample, after the test, the weight of wet soil specimen W_t is measured and recorded. Its dry weight W_s is measured after drying for 24 hours. The water content, w is computed and noted. From the knowledge of the specific gravity G_s of specimen and water content w , void ratio e and degree of saturation S are determined.

5.4 Calculations

5.4.1 The permeability k_T at temperature T is calculated as:

$$k_T = \frac{Q}{Ait}$$

$$k_{27} = k_T \frac{\gamma_T}{\gamma_{27}}$$

in which

k_{27} = permeability at 27°C ,

γ_T = coefficient of viscosity at $T^\circ\text{C}$,

γ_{27} = coefficient of viscosity at 27°C ,

Q = quantity in cm^3 ,

A = area of specimen in cm^2 ,

i = hydraulic gradient, and

t = time in seconds.

5.4.2 The parameters water content, void ratio and degree of saturation shall be calculated according to IS : 2720 (Part 2)-1973.

5.4.3 A data sheet with observed data, calculation and result is presented in Appendix A.

5.5 Presentation of Results — The values of permeability at $T^{\circ}\text{C}$ and 27°C are reported as a number with units of cm/s. Also reported are corresponding void ratio, degree of saturation and water content.

6. FALLING HEAD TEST

6.1 For a falling head test arrangement, the specimen shall be connected through the top inlet to selected stand-pipe. The bottom outlet shall be opened and the time interval required for the water level to fall from a known initial head to a known final head as measured above the centre of the outlet shall be recorded. The stand-pipe shall be refilled with water and the test repeated till three successive observations give nearly same time interval; the time intervals being recorded for the drop in head from the same initial to final values, as in the first determination. Alternatively, after selecting the suitable initial and final heads h_1 and h_2 respectively, time intervals shall be noted for the head to fall from h_1 to $\sqrt{h_1 h_2}$ and similarly from $\sqrt{h_1 h_2}$ to h_2 . The time intervals should be the same; otherwise the observation shall be repeated after refilling the stand-pipe.

6.2 Record of Observation — See Appendix B.

6.2.1 The dimensions of specimen, length L and diameter D , are measured and recorded in Appendix B. Area a of stand-pipe is recorded. The temperature T , of water is also measured and recorded.

6.2.2 During the test, observations are made of

initial time t_i , final time t_f , initial head h_1 , final head h_2 in stand-pipe and are recorded in col 2 to 5 of Appendix B respectively. h_1/h_2 and $\log_{10}(h_1/h_2)$ are calculated and recorded in col 6 and 7 of Appendix B respectively. The permeability k_T is calculated and recorded in col 8 of Appendix B. Remarks, if any, are entered in col 9 of Appendix B.

6.2.3 At the end of the test, the weight of wet soil specimen W_t is measured and recorded. Then the sample is dried in the oven for 24 hours and the dry weight W_s is measured and recorded. The water content, W is computed and noted. Void ratio, e , and degree of saturation S are calculated using specific gravity G_s of the specimen and water content, W .

6.3 Calculations

6.3.1 At temperature T of water, the permeability k_T is calculated as:

$$k_T = 2.303 \frac{aL}{A(t_f - t_i)} \log_{10} \frac{h_1}{h_2}$$

and the permeability at 27°C is given by

$$k_{27} = K_T \frac{\gamma_T}{\gamma_{27}}$$

Other parameters to be calculated are the water content, w , void ratio, e and degree of saturation s , shall be determined according to IS : 2720 (Part 2)-1973.

6.3.2 A data sheet with observation data, calculation and result is presented in Appendix B.

6.4 Presentation of Results

6.4.1 The permeability values at temperatures T and 27°C are reported as numbers with units as cm/s. The state of the sample is also reported in terms of water content, void ratio and degree of saturation.

APPENDIX A

(Clauses 5.3 and 5.4.2)

RECORD OF OBSERVATION WITH EXAMPLE FOR CALCULATION OF PERMEABILITY BY CONSTANT HEAD METHOD

Project _____
 Sample No. _____
 Soil identification _____
 Diameter of specimen (D) _____ cm
 Length of specimen (L) _____ cm
 Area of specimen (A) _____ cm^2
 Volume of specimen (V) _____ cm^3
 Head Loss $h = H_1 - H_2 =$ _____ cm
 Hydraulic Gradient $i = h/L$ _____
 Temperature of water $T =$ _____ $^\circ\text{C}$

Test No. _____
 Date _____
 Tested by _____

Sl No.	Quantity Q cm^3	Time, t seconds	Permeability $k_T = \frac{Q}{Ait}$ cm/s	Remarks
(1)	(2)	(3)	(4)	(5)

Weight of wet soil specimen after test, $W_t =$ _____ gWeight of dry soil specimen, $W_s =$ _____ gWater content, $W = \frac{W_t - W_s}{W_s} \times 100 =$ _____ percentSpecific gravity of specimen, $G_s =$ _____Void ratio, $e = \frac{VG_s - W_s}{W_s} =$ _____Degree of saturation, $S = \frac{G_s \cdot W}{e} =$ _____ percentPermeability at 27°C , $k_{27} = \frac{k_T \gamma_T}{\gamma_{27}} =$ _____ cm/s

A P P E N D I X B
(Clauses 6.2 and 6.3.2)

**RECORD OF OBSERVATION WITH EXAMPLE FOR CALCULATION OF
PERMEABILITY BY FALLING HEAD METHOD**

Project _____

Test No. _____

Sample No. _____

Date _____

Soil identification _____

Tested by _____

Diameter of specimen (D) _____ cmLength of specimen (L) _____ cmArea of specimen (A) _____ cm²Volume of specimen [V] = AL = _____ cm³Area of stand-pipe (a) = _____ cm²

$$C = 2.303 \frac{aL}{A} = \text{_____ cm}$$

Temperature of water, $T = 34^\circ\text{C}$

Sl No.	Initial t_i (seconds)	Final t_f (seconds)	Initial Head h_1 (cm)	Final Head h_2 (cm)	h_1/h_2	$\log_{10} \frac{h_1}{h_2}$	$K_T =$ $\log_{10} \frac{h_1}{h_2}$ $C \frac{h_1}{(t_f - t_i)}$ cm/s	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Weight of wet soil specimen after test, W_t = _____ gWeight of dry soil specimen, W_s = _____ gWater content, $W = \frac{W_t - W_s}{W_s} \times 100$ = _____ percentSpecific gravity of specimen, G_s = _____Void ratio, $e = \frac{VG_s - W_s}{W_s} = \text{_____}$ Degree of saturation, $S = \frac{G_s \cdot W}{e} = \text{_____ percent}$ Permeability at 27°C , $k_{27} = \frac{k_T \gamma_T}{\gamma_{27}} = \text{_____ cm/s}$

Indian Standard

METHODS OF TEST FOR SOILS

PART 36 LABORATORY DETERMINATION OF PERMEABILITY OF GRANULAR SOILS (CONSTANT HEAD)

(First Revision)

0. FOREWORD

0.1 With a view to establish uniform procedures for determination of different characteristics of soils and also for facilitating comparative studies of the results, an Indian Standard on methods of test for soils (IS : 2720) is being published in various parts. This part describes the method for determination of coefficient of permeability of granular soils by a constant head method and under conditions of laminar flow of water. The knowledge of this property is essential in a solution of problems involving de-watering, yield of water bearing strata, seepage through earth dams, etc. A reliable determination of permeability can be made only when the conditions for the validity of Darcy Law are fulfilled, that is, when the flow is steady and laminar and the soil is saturated and the rate of flow is proportional to the hydraulic gradient. Part 17 of this standard covers the general method but this part covers the disturbed granular materials containing less than 10 percent soil passing through 75 micron IS Sieve which are used in embankments, earth dams base courses, etc, and thus has different test apparatus. This standard was first published in 1975. Based on the experience gained in conducting this test in the past 13 years, the procedures have been updated and figures have been modified. The opportunity has also been taken to make references of latest Indian Standards which have been published or revised in this period.

1. SCOPE

1.1 This standard (Part 36) describes the method for determining coefficient of permeability of granular soils by a constant head method and under conditions of laminar flow of water. This method is suitable for disturbed granular soil containing less than 10 percent soil passing 75-micron IS Sieve, the type of material used for construction of embankments and base courses under pavements.

1.1.1 Pre-requisite for laminar flow of water through granular soils is that, water shall flow below critical velocity so that there is no movement or disturbance of soil particles; moreover water shall flow through saturated soil voids without having bubbles in them, and there shall be no change in soil volume nor any change in hydraulic gradient during the performance of the test.

2. EQUIPMENT

2.1 Permeameter — As shown in Fig. 1, the permeameter shall have specimen cylinders with minimum diameters approximately 8 or 12 times the maximum particle size in accordance with Table 1. The permeameter shall be fitted with:

- a) A porous disc or suitable reinforced screen at the bottom with a permeability greater than that of the soil specimen, but with openings sufficiently small (not larger than 10 percent of finer size of the soil to be tested) to prevent the movement of particles;

TABLE I CYLINDER DIAMETER

MAXIMUM PARTICLE SIZE BETWEEN IS SIEVE OPENINGS	MINIMUM CYLINDER DIAMETER				
	Not more than 35 Percent of Total Soil Retained on Sieve Opening		More than 35 Percent of Total Soil Retained on Sieve Opening		
	2.00 mm	10.00 mm	2.00 mm	10.00 mm	
(1)	(2)	(3)	(4)	(5)	
2.00 mm and 10.00 mm	80	—	120	—	
10.00 mm and 20.00 mm	—	160	—	230	

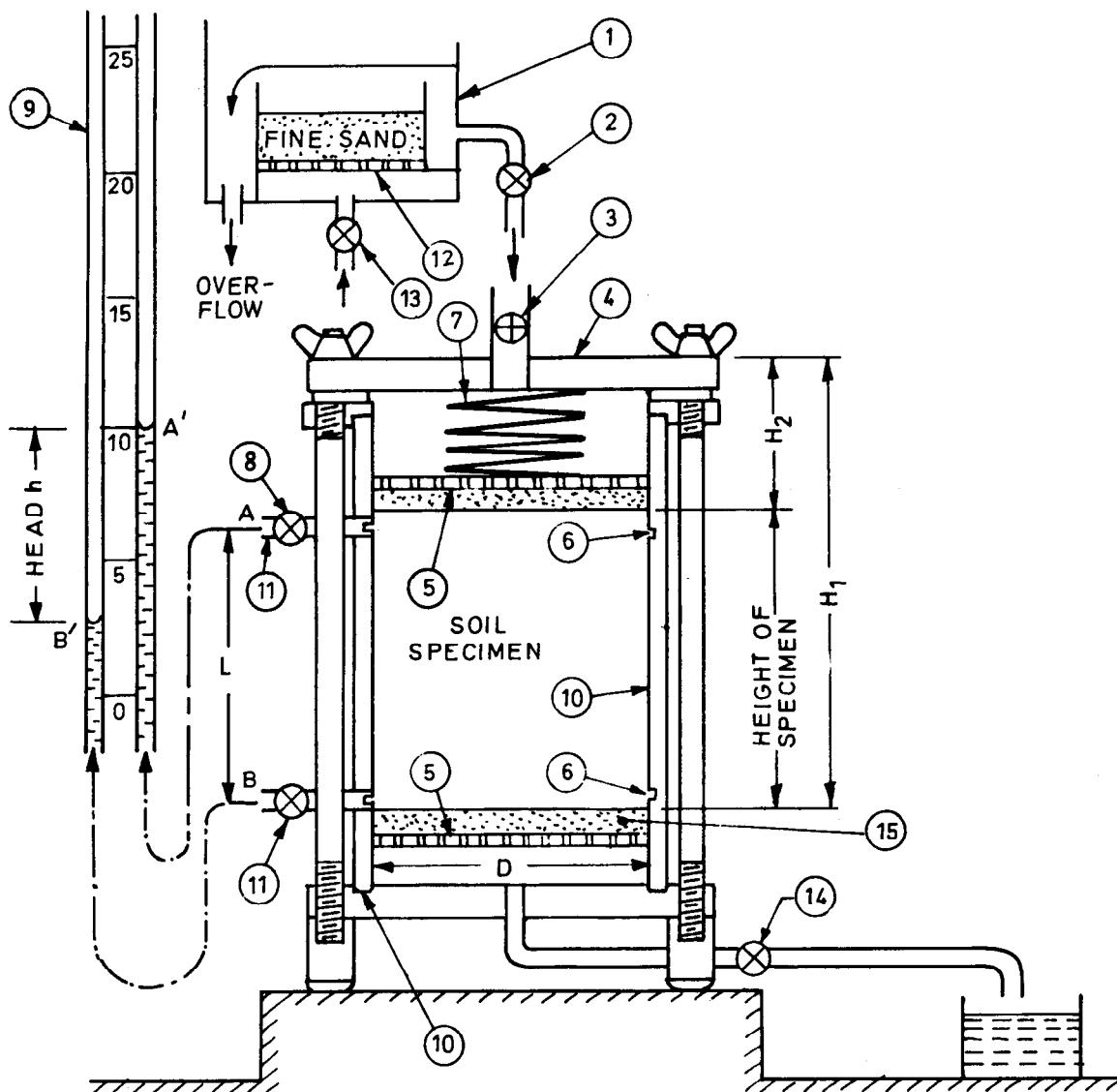
NOTE — The diameter to length ratio may be about 1 : 2

- b) Manometer outlets for measuring the loss of head, h over a length, L , equivalent to at least the diameter of the cylinder; and
- c) A porous disc or suitable reinforced screen with spring attached to the top, or any other device for applying a light spring pressure of 2 to 4 kg total load when the top plate is attached in place. This will hold the placement

density and volume of soil without significant change during the saturation of the specimen and the permeability testing to satisfy the requirement that there should be no soil volume change during a test.

NOTE — Perforated metal disc may also be used for the test.

2.2 Constant-Head Filter Tank — This shall be as shown in Fig. 1, to supply water and shall be fitted



- | | |
|------------------------------------|---|
| 1) Constant-head filter tank (NTC) | 9) Manometer tubes |
| 2) Filter tank valve | 10) Metal or transparent acrylic plastic cylinder |
| 3) Inlet valve | 11) Manometer outlet |
| 4) Top plate | 12) Screen |
| 5) Porous disc or screen | 13) Tap water valve |
| 6) Screened manometer groove | 14) Outlet valve |
| 7) Spring | 15) Gravel filter |
| 8) Manometer valve | |

FIG. 1 CONSTANT HEAD PERMEAMETER

with suitable control valves to prevent formation of air bubbles in the soil voids. The size of the constant head filter tank shall be large enough to meet the demand depending upon the permeability of the specimen.

NOTE — There are several methods of reducing air content of water, such as: (a) by boiling, (b) by spraying water into a partial vacuum, (c) to use water having higher temperature, at least 5°C more than that of the soil specimen under test, and (d) by running water before use through a porous fine grained material so that the air is entrapped in the interstices of the material. Out of all these methods of de-airing water, the last method of passing tap water through filter is less expensive and more suitable specially when large quantities of de-airated water are required to be used. It will be essential that the filter material should be of finer grade than that of the soil to be tested otherwise air may come out of the solution in water while passing through the soil mass. But still, if preferred, the de-aired water prepared by boiling or spraying through partial vacuum may be used.

2.3 Large Funnels — These shall be fitted with special cylindrical spout, 25 mm in diameter for 10.00 mm maximum size particles and 13 mm in diameter for 2.00 mm maximum size particles. The length of the spout should be greater than the full length of the permeability chamber at least by 160 mm.

2.4 Specimen Compaction Equipment — Compaction equipment as deemed desirable may be used. The following are suggested:

- A vibrating tamper fitted with a tamping foot 50 mm in diameter;
- A sliding tamper with a tamping foot 50 mm in diameter and a rod for sliding weights of 100 g (for sands) to 1 kg (for soils with a large

gravel content), having an adjustable height of drop to 100 mm for sands and 200 mm for soils with large gravel contents.

2.5 Vacuum Pump or Water Faucet Aspirator — for evacuating and for saturating soil specimen under full vacuum (see Fig. 2).

2.6 Balance — It shall be of 2 kg capacity and sensitive to 1 g.

2.7 Scoop — With a capacity of 100 g of soil.

2.8 Miscellaneous Apparatus — Thermometers, clock with sweep second hand, 250 ml graduated cylinder and mixing pan.

3. SAMPLE

3.1 A representative sample of air-dried granular soil containing less than 10 percent of the material passing 75-micron IS Sieve and equal to an amount sufficient to satisfy the requirements prescribed in 3.2 and 3.3 shall be selected by the method of quartering.

3.2 A sieve analysis [in accordance with IS : 2720 (Part 4)-1986] shall be made on a representative sample of the complete soil prior to the permeability test. All particles larger than 20 mm IS Sieve shall be separated out by sieving. This oversize material shall not be used for the permeability test but the percentage of the oversize material shall be recorded. The grading analysis data thus obtained shall also be utilized for determining the required grading for sand or gravel filter to be used at the bottom and top of the compacted sample in the

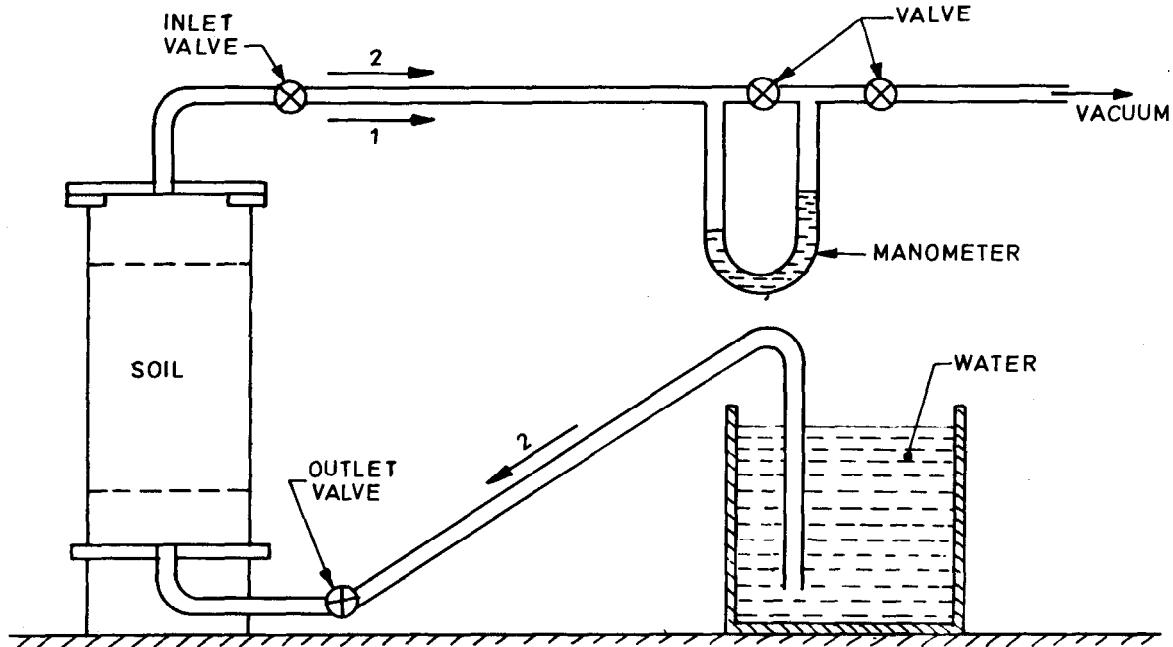


FIG. 2 DEVICE FOR EVACUATING AND SATURATING SPECIMEN

permeameter. From the grading curve, the particle sizes corresponding to 85 percent and 15 percent points shall be noted and the filter designed accordingly.

NOTE — In order to establish representative values of coefficient of permeabilities for the range which may exist in the soil at site being investigated, samples of the finer, average and coarser soils should be obtained for testing.

3.3 From the material, from which the oversize has been removed (see 3.2), select by the method of quartering a sample for testing equal to an amount approximately twice that required for filling the permeameter chamber.

4. PREPARATION OF SPECIMEN

4.1 The size of permeameter to be used shall be as prescribed in Table 1.

4.2 Make the following initial measurements and record on the data sheet (Appendix A), the inside diameter, D , of the permeameter; the length, L , between manometer outlets; and the depth H_1 measured at four symmetrically spaced points from the upper surface of the top plate of the permeability cylinder to the top of the upper porous stone or screen temporarily placed on the lower porous plate or screen. This automatically deducts the thickness of the upper porous plate or screen from the height measurements used to determine the volume of soil placed in the permeability cylinder. A duplicate top plate, containing four large symmetrically spaced openings through which the necessary measurements can be made, shall be employed to determine the average value for H_1 . Calculate the cross-sectional area A of the specimen.

4.3 A small portion of the sample selected as prescribed in 3.2 and 3.3 shall be taken for water content determinations. Record the weight of the remaining air-dried sample (see 3.3), W_1 , for unit weight determinations.

4.4 Place the prepared soil by one of the following procedures in uniform thin layers approximately 15 to 20 mm.

NOTE — In case of granular soils there is every likelihood that water would separate through between the specimen and the wall of the cylinder. In order to prevent this, special precautions are suggested to be observed. For fine sands, a water-pump grease should be applied to the cylinder wall to prevent flow of water between the specimen and the wall. For coarse sand, a 7-mm thickness of sponge rubber cemented to the cylinder wall is found to be satisfactory.

4.4.1 For soils having a maximum size of 10 mm or less, place the appropriate size of funnel, as prescribed in 2.3, in the permeability device with the spout in contact with the lower porous plate or screen or previously formed layer, and fill the funnel with sufficient soil to form a layer, taking soil from different areas of the sample in the pan. Lift the funnel by 15 mm or approximately the unconsoli-

dated layer thickness to be formed, and spread the soil with a slow spiral motion, working from the perimeter of the device towards the centre so that a uniform layer is formed. Remix the soil in the pan for each successive layer to reduce segregation caused by taking soil from the pan.

4.4.2 For soils with a maximum size greater than 10.00 mm, spread the soil from a scoop. Uniform spreading can be obtained by sliding a scoopful of soil in a nearly horizontal position down along the inside surface of the device to the bottom or to the formed layer, then tilting the scoop and drawing it towards the centre with a single slow motion, this allows the soil to run smoothly from the scoop in a windrow without segregation. Turn the permeability cylinder sufficiently for the next scoopful, thus progressing around the inside perimeter to form a uniform compacted layer of a thickness equal to the maximum particle size.

4.5 Compact successive layers of soil to the desired relative density by appropriate procedure, as follows, to a height of about 20-mm above the upper manometer outlet.

4.5.1 Minimum Density (Zero Percent Relative Density) — Continue placing layers of soil in succession by one of the procedures described in 4.4.1 until the device is filled to the proper level.

4.5.2 Maximum Density (100 Percent Relative Density).

4.5.2.1 Compaction by vibrating tamper — Compact each layer of soil thoroughly with the vibrating tamper, distributing the light tamping action uniformly over the surface of the layer in a regular pattern. The pressure of contact and the length of time of the vibrating action at each spot should not cause soil to escape from beneath the edges of the tamping foot, thus tending to loosen the layer. Make a sufficient number of coverages to produce maximum density, as evidenced by practically no visible motion of surface particles adjacent to the edges of the tamping foot.

4.5.2.2 Compaction by sliding weight tamper — Compact each layer of soil thoroughly by tamping blows uniformly distributed over the surface of the layer. Adjust the height of drop and give sufficient coverages to produce maximum density, depending on the coarseness and gravel content of the soil.

4.5.2.3 Compaction by other methods — Compaction may be accomplished by other approved methods, such as deposition under water, by vibratory packer equipment where care is taken to obtain a uniform specimen without segregation of particle sizes.

4.5.3 Relative Density Intermediate Between Zero and 100 Percent — By trial in a separate container of the same diameter as the permeability

cylinder, adjust the compaction to obtain reproducible values of relative density. Compact the soil in the permeability cylinder by these procedures in thin layers to a height of about 20 mm above the upper manometer outlet.

NOTE — In order to cover systematically and representatively, the relative density conditions that may govern in natural deposits or in compacted embankments, a series of permeability tests should be made to cover the range of field relative densities.

4.6 Preparation of Specimen for Permeability Test

4.6.1 Level the upper surface of the soil by placing the upper porous plate or screen in position and by rotating it gently clockwise and anti-clockwise.

4.6.2 Measure and record the final height of specimen, $H_1 - H_2$, by measuring the depth, H_2 , from the upper surface of the perforated top plate employed to measure H_1 to the top of the upper porous plate or screen at four symmetrically spaced points after compressing the spring lightly to seat the porous plate or screen during the measurements; the final weight of air-dried soils used in the test ($W_1 - W_2$) by weighing the remainder of soil W_2 left in the pan. Compute and record the unit weights, void ratio, and relative density of the test specimen.

4.6.3 With its gasket in place, press down the top plate against the spring and attach it securely to the top of the permeameter cylinder, making an airtight seal. This satisfies the condition of no volume change during testing for holding the initial density.

4.6.4 Connect the inlet tube of the top plate of the permeameter to vacuum pump or suitable aspirator capable of evacuating the air content from the specimen and the outlet tube in the base plate to the water container as shown in Fig. 2. Close the manometer outlets [see 2.1 (b)] and the outlet valve at the base plate of the permeameter. Using a vacuum pump or aspirator, evacuate the specimen under 500 mmHg, minimum for 15 minutes to remove air adhering to soil particles and from the voids. Follow the evacuation by a slow saturation of the specimen from the bottom upward under full vacuum in order to force any remaining air in the specimen. Continued saturation of the specimen can be maintained more adequately by the use of de-aired water, or water maintained at an in-flow temperature sufficiently high to cause a decreasing temperature gradient in the specimen during the test. Native water or water of low mineral content (see Note) should be used for the test, but in any case the fluid should be described on the report form (Appendix A). This satisfies the conditions of laminar flow through saturated soil voids.

NOTE — Native water is water occurring in the rock or soil *in-situ*. It should be used if possible, but it (as well as de-aired water) may need a refinement not ordinarily feasible for large scale production testing in which case available water may be used and so stated in the report.

4.6.5 After the specimen has been saturated and the permeameter is full of water, close the bottom valve on the outlet tube (see Fig. 2) and disconnect the vacuum. Care should be taken to ensure that the permeability flow system and the manometer system are free of air and are working satisfactorily. Fill the inlet tube with water from the constant-head tank by slightly opening the filter tank valve. Then connect the inlet tube to the top of the permeameter, open the inlet valve slightly and open the manometer outlet cocks slightly, to allow water to flow, thus freeing them of air. Connect the water manometer tubes to the manometer outlets and fill with water to remove the air. Close the inlet valve and open the outlet valve to allow the water in the manometer tubes to reach their stable water level under zero head.

5. PROCEDURE

5.1 Open the inlet valve from the filter tank slightly for the first run, delay measurements of quantity of flow and head until a stable head condition without appreciable drift in water manometer level is attained. Measure and record the time t , head h (the difference in level in the manometers), quantity of flow Q and water temperature T .

5.2 Repeat the test runs at heads, increasing by 5 mm in order to establish accurately the region of laminar flow with velocity v (where $v = Q/At$), directly proportional to hydraulic gradient i (where $i = h/L$). When departures from the linear relation become apparent, indicating the initiation of turbulent flow conditions, 10 mm intervals of head may be used to carry the test run sufficiently along in the region of turbulent flow to define this region if it is significant for field conditions.

NOTE — Much lower values of hydraulic gradient h/L are required than generally recognized, in order to ensure laminar flow conditions. The following values are suggested; loose compactness ratings h/L from 0.2 to 0.3; and dense compactness ratings h/L from 0.3 to 0.5; the lower values of h/L apply to coarser soils and the higher values to finer soils.

5.3 At the completion of the permeability test, drain the specimen and inspect it to establish whether it was essentially homogenous and isotropic in character. Any light and dark alternating horizontal streaks or layers are evidence of segregation of fines.

6. RECORD OF OBSERVATION

6.1 The inside diameter D of the permeameter, the length L between manometer outlets and depth H_1 (Fig. 1) are measured and recorded in Appendix A. For the given soil, water content is determined and recorded. The weight W_s , of air-dried soil used in preparing soil specimen is also recorded. The final height of specimen after compression by spring, $H_1 - H_2$, is measured and recorded. Dry unit weight

and void ratio are calculated. The temperature of water, T is measured and recorded.

6.2 During the test, observations are made of manometer readings h_1 and h_2 , quantity of flow Q collected in a graduated jar in the time t and are recorded in columns (2) to (5) respectively. Head h ($= h_1 - h_2$) is calculated to column (6) and gradient i ($= h/L$) is calculated and recorded in column (7). Finally, permeability k_T is calculated and recorded in column (8). Remarks, if any, are entered in column (9).

7. CALCULATIONS

7.1 Permeability k_T at temperature T is calculated by:

$$K_T = \frac{Q}{Ait}$$

and permeability at 27°C by using the expression

$$k_{27} = k_T \frac{\gamma_T}{\gamma_{27}}$$

where

γ_T = coefficient of viscosity at $T^\circ\text{C}$, and
 γ_{27} = coefficient of viscosity at 27°C .

Void ratio e is calculated as

$$e = \frac{G_s \gamma_w}{\gamma} - 1$$

in which γ_w is the density of water and is taken as 1 g/cm^3 , γ is dry unit weight of specimen and G_s is the specific gravity.

7.2 A data sheet with observation data calculation and result is presented in Appendix A.

8. PRESENTATION OF RESULTS

8.1 The values of permeability, calculated at T and 27°C are reported as numbers with units of cm/s . Also reported are the dry density and void ratio of the sample.

APPENDIX A

(Clauses 4.2, 4.6.4, 6.1 and 7.2)

Project _____

Test _____

Sample No. _____

Date _____

Soil identification _____

Tested by _____

Diameter of specimen, D _____ cm

Spacing between manometer outlets, L = _____ cm

Length of specimen ($H_1 - H_2$) = _____ - _____ = _____ cm

Area of specimen, $A = \frac{\pi D^2}{4} =$ _____ cm^2

Volume of specimen, $V = A (H_1 - H_2) =$ _____ cm^3

Water content, $W =$ _____ %

Dry weight of soil specimen, $W_s =$ _____ g

Dry unit weight $\gamma = \frac{W_s}{V} =$ _____ g/cm^3

Specific gravity, $G_s =$ _____

Void ratio, $e = \frac{G_s \gamma_w}{\gamma} - 1 =$ _____

Temperature of water, $T =$ _____ $^\circ\text{C}$

SL No	MANOMETER READINGS	QUANTITY OF FLOW	TIME, t SECONDS	HEAD $h = h_1 - h_2$	$i = h/L$	$k_T = \frac{Q}{Ait}$	REMARKS	
							(1)	(2)
	h_1 cm	h_2 cm	Q cm^3				(3)	(4)

$$k_{27} = K_T \frac{\gamma_T}{\gamma_{27}} =$$
 _____ cm/sec

SECTION 9

Determination of Compactness and Density

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Indian Standard

SPECIFICATION FOR COMPACTION MOULD ASSEMBLY FOR LIGHT AND HEAVY COMPACTION TEST FOR SOILS

0. FOREWORD

0.1 The equipment covered in this standard is used for determination of water content : dry density relation as covered in IS : 2720 (Part 7)-1980 and IS : 2720 (Part 8)-1974.

1. SCOPE

1.1 This standard covers the requirements of compaction mould assembly used for determination of water content : dry density relation of soils using light and heavy compaction.

2. MATERIALS

2.1 The materials of construction of the different component parts of compaction mould assembly shall be as given in Table 1.

3. TYPES AND DIMENSIONS

3.1 The compaction mould assembly shall be of two types (Types 1 and 2). Dimensions of component parts of compaction mould assembly shall be as detailed in Fig. 1 to 6. Except where tolerances are specifically mentioned against the dimensions, all dimensions shall be taken as nominal dimensions and tolerances as given in IS : 2102 (Part 1)-1980 shall apply.

4. CONSTRUCTION

4.1 Compaction Mould — The compaction mould

shall be of two types as detailed in Fig. 2. It shall be cylindrical in shape and finished smooth inside. The mould shall have two eyes either cast integral with the body or welded. It shall have suitable seatings at the top end for positioning the collar.

4.2 Collar — The collar shall be made from the same material as that of the mould. It shall be made as detailed in Fig. 3. The collar shall be cylindrical in shape and finished smooth inside. Two eyes either cast or welded to the collar to secure it with the mould and base plate shall be provided. It shall have a suitable seating at the lower end for sitting flush with the mould.

4.3 Base Plate — The base plate shall be made from the same material as that of the mould. The base plate shall have a seating 3 mm deep on top face for proper seating of mould. It shall be square in shape and shall be as detailed in Fig. 4. Alternatively, the base plate shall be made circular in shape as detailed in Fig. 5. It shall have two tapped and two plain holes. The tapped holes across the corners or diameter shall be used for fixing the stay rods (as shown in Fig. 6A) and the plain holes shall be used to fix the base plate to the base of an automatic compactor. The stay rods shall be fixed to suit the eyes on the mould and collar, and four wing nuts (as shown in Fig. 6B) shall be used to tighten the mould and collar with the base plate.

TABLE 1 MATERIALS OF CONSTRUCTION OF DIFFERENT COMPONENT PARTS OF COMPACTION MOULD ASSEMBLY

PART	MATERIAL	SPECIFIC REQUIREMENTS, IF ANY	REFERENCE TO INDIAN STANDARD
Mould, Collar, Base plate	a) Copper alloy b) Brass c) Mild steel‡	— —	IS : 318-1981* IS : 292-1983†
Stay rods	Mild steel	Cadmium plated	IS : 513-1973§
Wing nuts	Cast steel/Forged steel	Chromium plated Cadmium plated	— —

*Specification for leaded tin bronze ingots and castings (*second revision*).

†Specification for leaded brass ingots and castings (*second revision*).

‡For short term use.

§Specification for cold rolled carbon steel sheets (*second revision*).

5. MARKING

5.1 The following information shall be clearly and indelibly marked on each part of equipment:

- Name of the manufacturer or his registered trade-mark;
- Type of material used; and
- Date of manufacture.

5.1.1 The equipment may also be marked with the ISI Certification Mark.

NOTE — The use of ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.

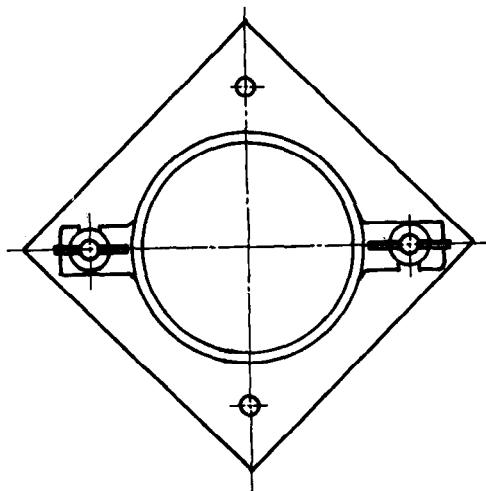
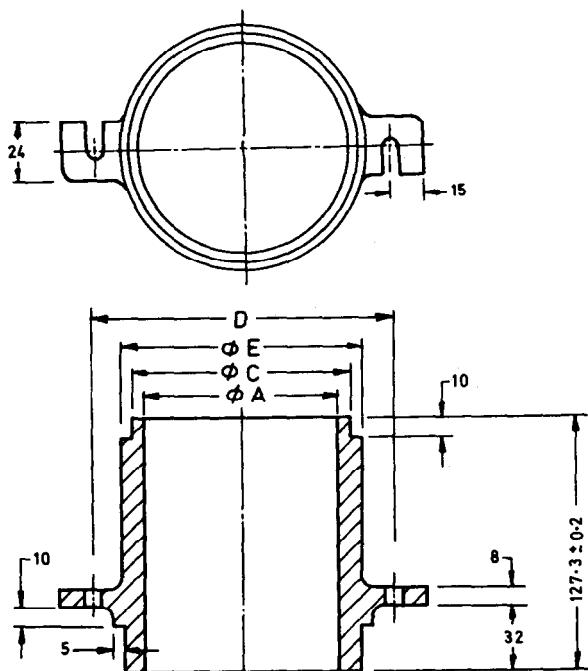
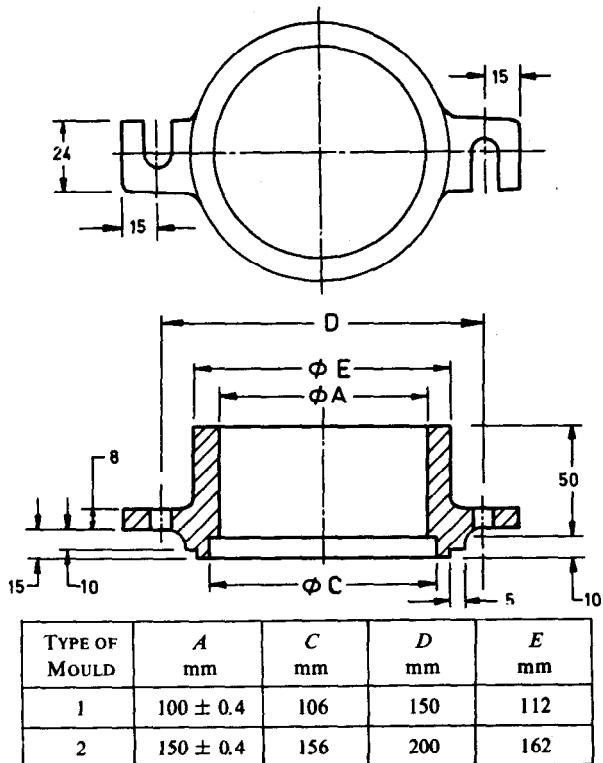


FIG. 1 ASSEMBLY



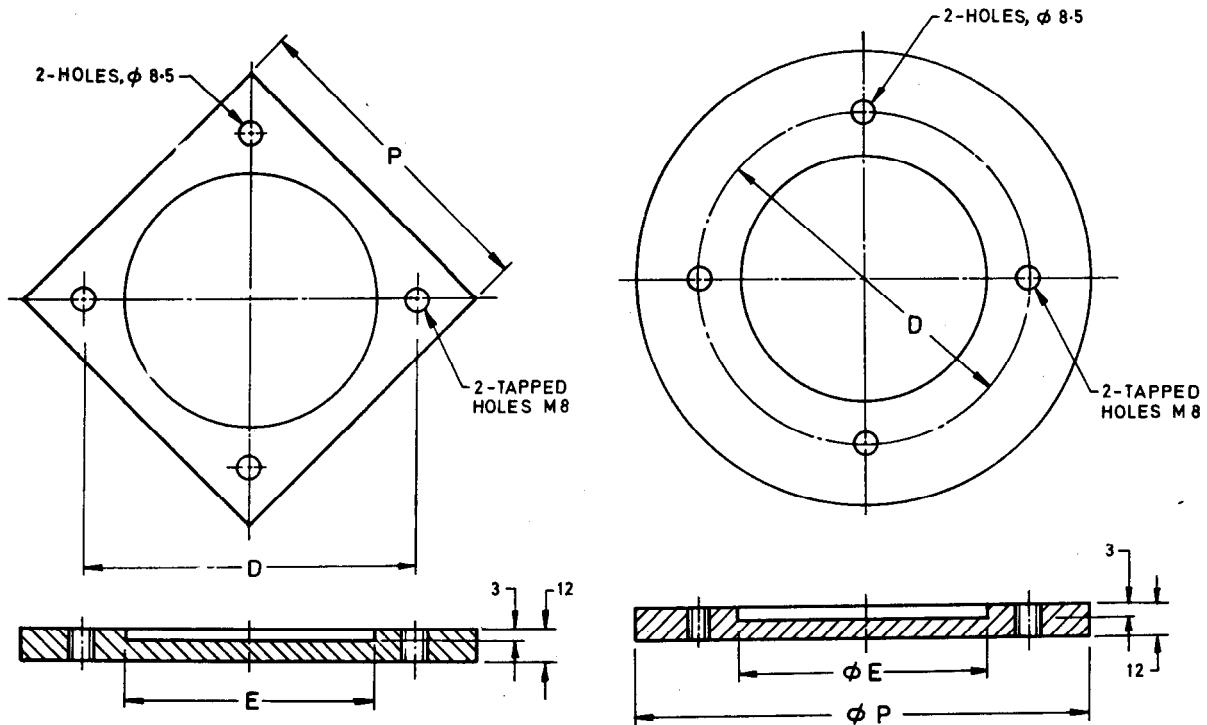
All dimensions in millimetres.

FIG. 2 MOULD



All dimensions in millimetres.

FIG. 3 COLLAR

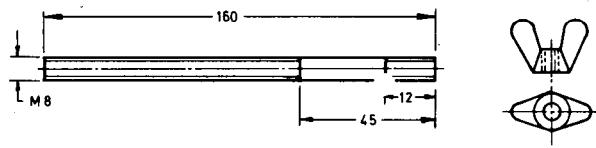


TYPE OF MOULD	D mm	E mm	P mm
1	150	112.5	150
2	200	162.5	200

All dimensions in millimetres.
FIG. 4 BASE PLATE (SQUARE)

TYPE OF MOULD	D mm	E mm	P mm
1	150	112.5	180
2	200	170.5	230

All dimensions in millimetres.
FIG. 5 BASE PLATE (CIRCULAR)



6 A Stay Rod 6 B Wing Nut

All dimensions in millimetres.

FIG. 6 STAY ROD AND WING NUT

Indian Standard

SPECIFICATION FOR COMPACTION RAMMER FOR SOIL TESTING

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 The equipment covered in this standard is used for the determination of water content dry density relation of soil covered in IS : 2720 (Part 7)-1980 and IS : 2720 (Part 8)-1983.

1. SCOPE

1.1 This standard covers the requirements of compaction rammer both for light and heavy compaction used for the determination of the water content dry density relation of soils.

2. MATERIALS

2.1 The materials of construction of the different component parts of the compaction rammer, both light and heavy, shall be as given in Table 1.

3. DIMENSIONS

3.1 Dimensions with tolerances of different component parts of compaction rammer shall be as detailed in Fig. 1 to 4. Except where tolerances are specifically mentioned against the dimensions, all dimensions shall be taken as nominal dimensions and tolerances as given in IS : 2102 (Part 1)-1980 shall apply.

4. COMPACTION RAMMER, LIGHT

4.1 The light compaction rammer shall be as shown in Fig. 1 to 3. The mass of the moving parts of the rammer shall be $2.6 \text{ kg} \pm 25 \text{ g}$. The length of guide pipe shall be such as to give a fall of $310 \pm 0.5 \text{ mm}$. The free end of the rammer foot shall be square with the sides and shall be finished smooth. Provision shall also be made to secure this to the shaft with a pin to prevent it from unscrewing while on use. It shall be chrome plated. It shall be provided with air vents at both ends as shown in Fig. 3 and a suitable guide for the shaft of the rammer shall be screwed on to the pipe at the top end. The washer shall be as shown in Fig. 2. It shall be of minimum 1.5 mm thick

5. COMPACTION RAMMER, HEAVY

5.1 The heavy compaction rammer shall be as shown in Fig. 1, Fig. 2 and Fig. 4. The mass of the moving parts of the rammer shall be $4.9 \text{ kg} \pm 50 \text{ g}$. The length of the guide pipe shall be such as to give a fall of $450 \pm 0.5 \text{ mm}$. The free end of the rammer foot shall be square with the sides and shall be finished smooth. Provision shall also be made to secure it to the shaft with a pin to prevent it from unscrewing while on use. It shall be chrome plated. The washer shall be as shown in Fig. 4. It shall be minimum 1.5 mm thick.

TABLE 1 MATERIALS OF CONSTRUCTION OF DIFFERENT COMPONENT PARTS OF COMPACTION RAMMER (LIGHT AND HEAVY)

PART	MATERIAL	SPECIFIC REQUIREMENTS. IF ANY	REF TO INDIAN STANDARD
(1)	(2)	(3)	(4)
Rammer foot	Mild steel or brass	Smooth finish and chrome plated	IS : 226-1975* and IS : 4170-1967†
Shaft	Mild steel	—	IS : 226-1975*
Handle knob	Mild steel	—	IS : 226-1975*
Guide pipe	Mild steel drawn pipe	—	IS : 1239 (Part 1)-1979‡
Washer	Gasket rubber vulcanized	—	Vulcanized rubber IS : 5832-1969§

*Specification for structural steel, standard quality (*first revision*).

†Specification for brass rods for general engineering purposes.

‡Specification for mild steel tubes, tubulars and other wrought steel fittings: Part 1 Mild steel tubes (*fourth revision*).

§Specification for rubber sealing rings for gas mains, water mains and sewers.

6. MARKING

6.1 The following information shall be clearly and indelibly marked on each component of the apparatus in such a way that it does not interfere with the performance of the apparatus:

- Name of manufacturer or his registered trademark or both,
- Date of manufacture,
- Whether the rammer foot is of mild steel or brass, and
- Type of rammer.

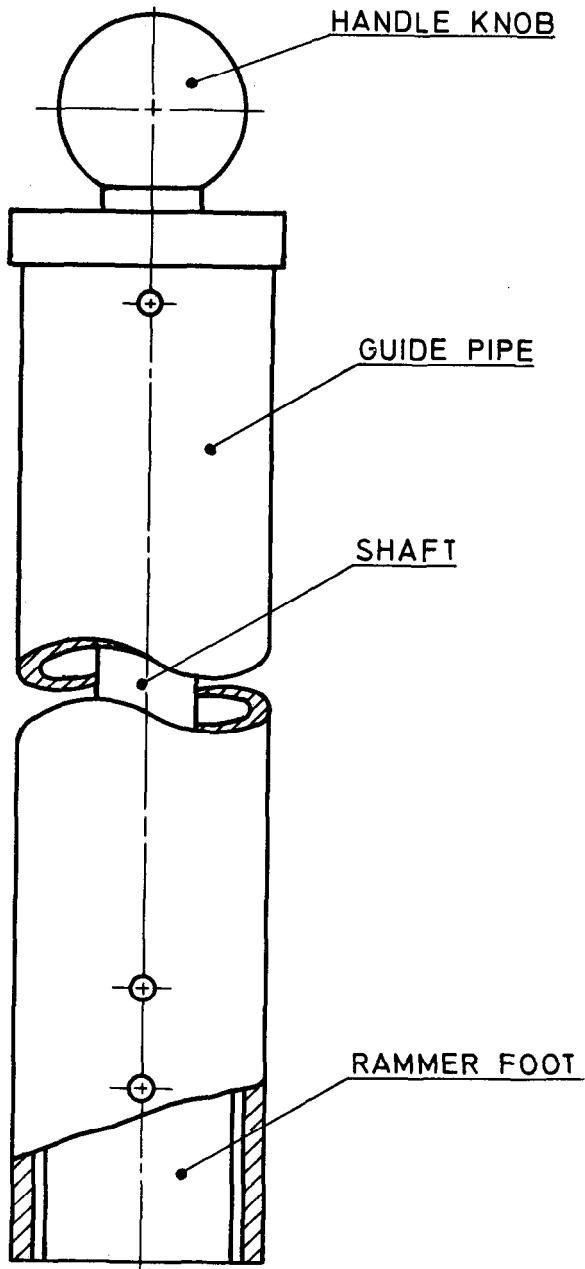
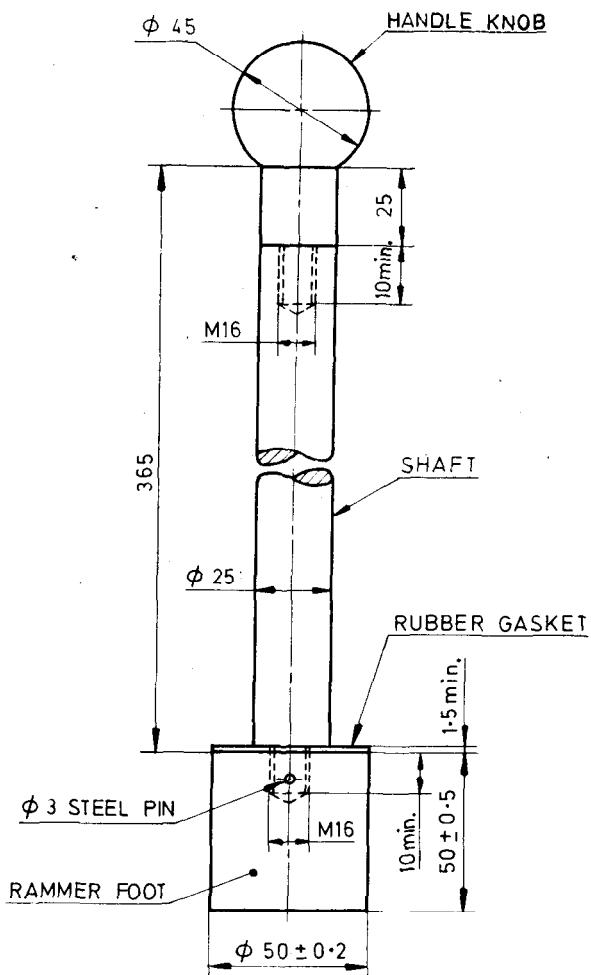


FIG. 1 ASSEMBLY OF COMPACTION RAMMER

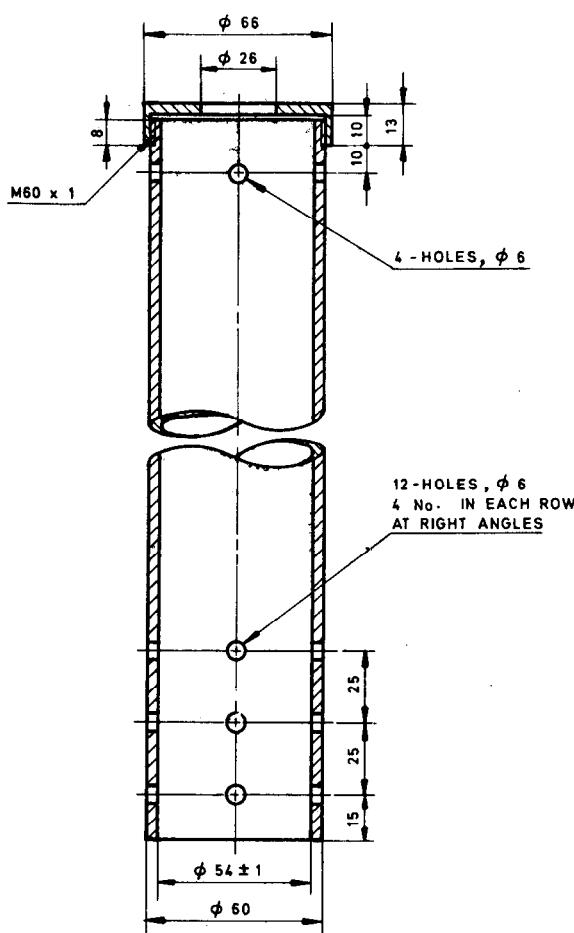
6.1.1 The equipment may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.



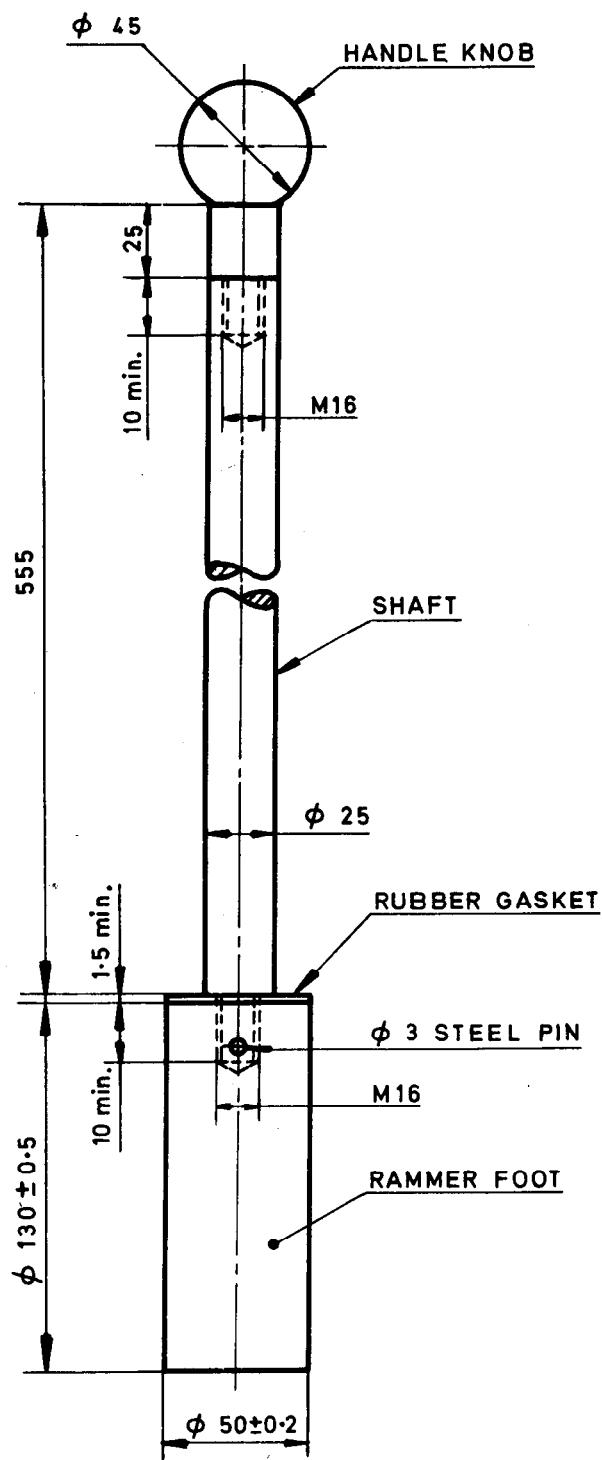
All dimensions in millimetres.

FIG. 2 DETAILS OF LIGHT RAMMER FOOT, SHAFT AND KNOB



All dimensions in millimetres.

FIG. 3 DETAILS OF GUIDE PIPE



All dimensions in millimetres.

FIG. 4 DETAILS OF HEAVY RAMMER FOOT, SHAFT
AND KNOB

Indian Standard

SPECIFICATION FOR MOULDS AND ACCESSORIES FOR DETERMINATION OF DENSITY INDEX (RELATIVE DENSITY) OF COHESIONLESS SOILS

0. FOREWORD

0.1 The equipment covered in this standard is used in the apparatus for determination of density index of cohesionless of soils covered in IS : 2720 (Part 14)-1983 using vibratory table.

1. SCOPE

1.1 This standard covers the details of two types of moulds, guide sleeves surcharge base plate with handle and surcharge weights used for the laboratory determination of density index (relative density) of cohesionless free draining soils using vibratory table.

2. DIMENSIONS

2.1 Dimensions with tolerances of different equipment shall be as detailed in Fig. 1 to 5. Except where tolerances are specifically mentioned against the dimensions, all dimensions shall be taken as nominal dimensions and tolerances as given IS : 2102 (Part 1)-1980 (medium class).

3. MATERIALS

3.1 The materials of construction of the various equipment shall be as given in Table 1.

4. CONSTRUCTION

4.1 Mould — The mould shall be smooth from inside and shall have two handles either cast integral with the body or welded. The moulds shall be of capacity 3 000 cm³ as detailed in Fig. 1.

4.2 Guide Sleeve — The inside of the sleeve shall be finished smooth and one is provided with each mould. Two of the three set screws on the clamp assembly shall be provided with lock nuts. The details of guide sleeve for two capacities of mould are given in Fig. 2.

4.3 Surcharge Base Plates with Handles — The surcharge base plate is provided with each mould as detailed in Fig. 3. The details of handle for both sizes are given in Fig. 4.

4.4 Surcharge Weight — The surcharge weight, as

TABLE 1 MATERIALS OF CONSTRUCTION OF DIFFERENT COMPONENTS

SL No. (1)	EQUIPMENT (2)	MATERIAL (3)	SPECIAL REQUIRE- MENTS, IF ANY (4)	RELEVANT INDIAN STANDARD (5)
i)	Mould	Copper alloy or Brass or Aluminium or Mild Steel	—	IS : 318-1981*
ii)	Guide sleeve	Mild Steel	Cadmium plated	IS : 513-1973§
iii)	Surcharge base plate with handle	Mild Steel	Cadmium plated	IS : 513-1973§
iv)	Surcharge weight: Body Filling	Mild Steel Lead	Cadmium plated	IS : 513-1973§ IS : 782-1978//

*Specification for leaded in bronze ingots and castings (*second revision*).

†Specification for leaded brass ingots and castings (*second revision*).

‡Specification for aluminium and aluminium alloy ingots and castings for general engineering purposes (*second revision*).

§Specification for cold rolled carbon steel sheets (*second revision*).

//Specification for caulking lead (*third revision*).

detailed in Fig. 5, is provided with each mould. The body shall be filled with lead from bottom to have a specified weight as mentioned in Fig. 5.

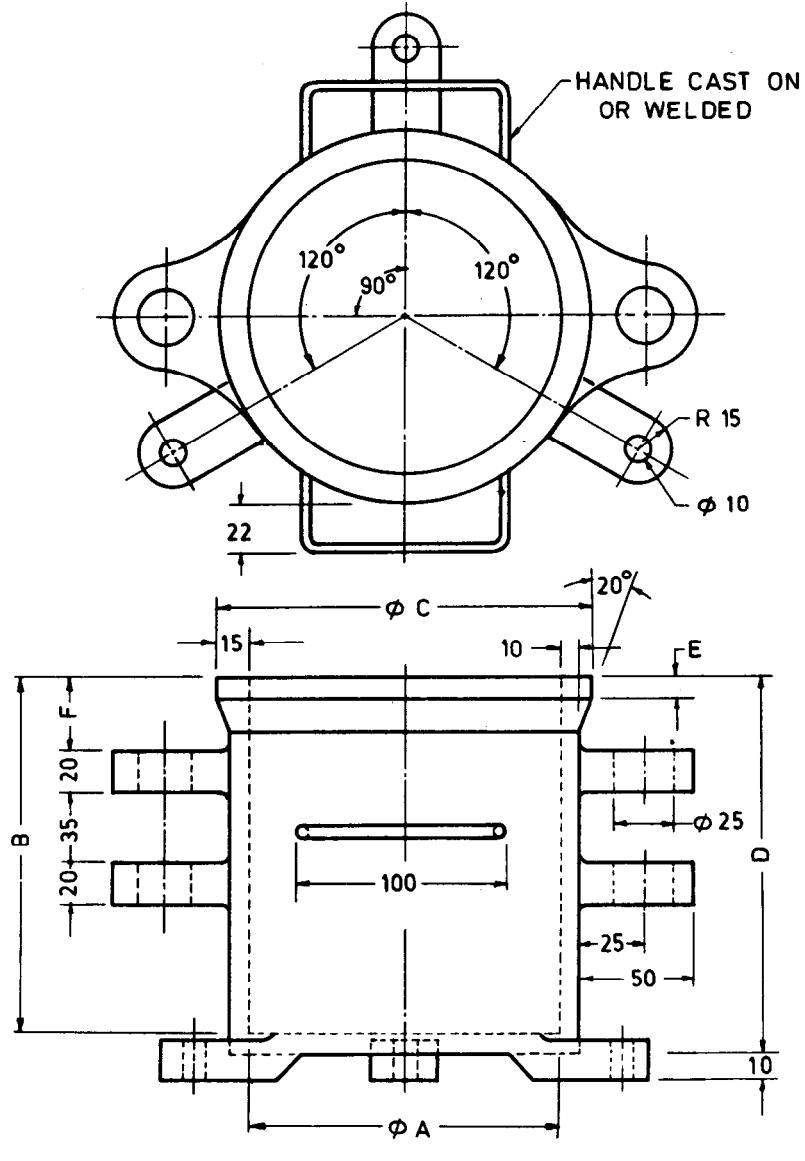
5. MARKING

5.1 The following information shall be clearly and indelibly marked on each part of equipment:

- Name of the manufacturer or his registered trade-mark;
- Type of material used; and
- Date of manufacture.

5.1.1 The equipment may also be marked with the ISI Certification Mark.

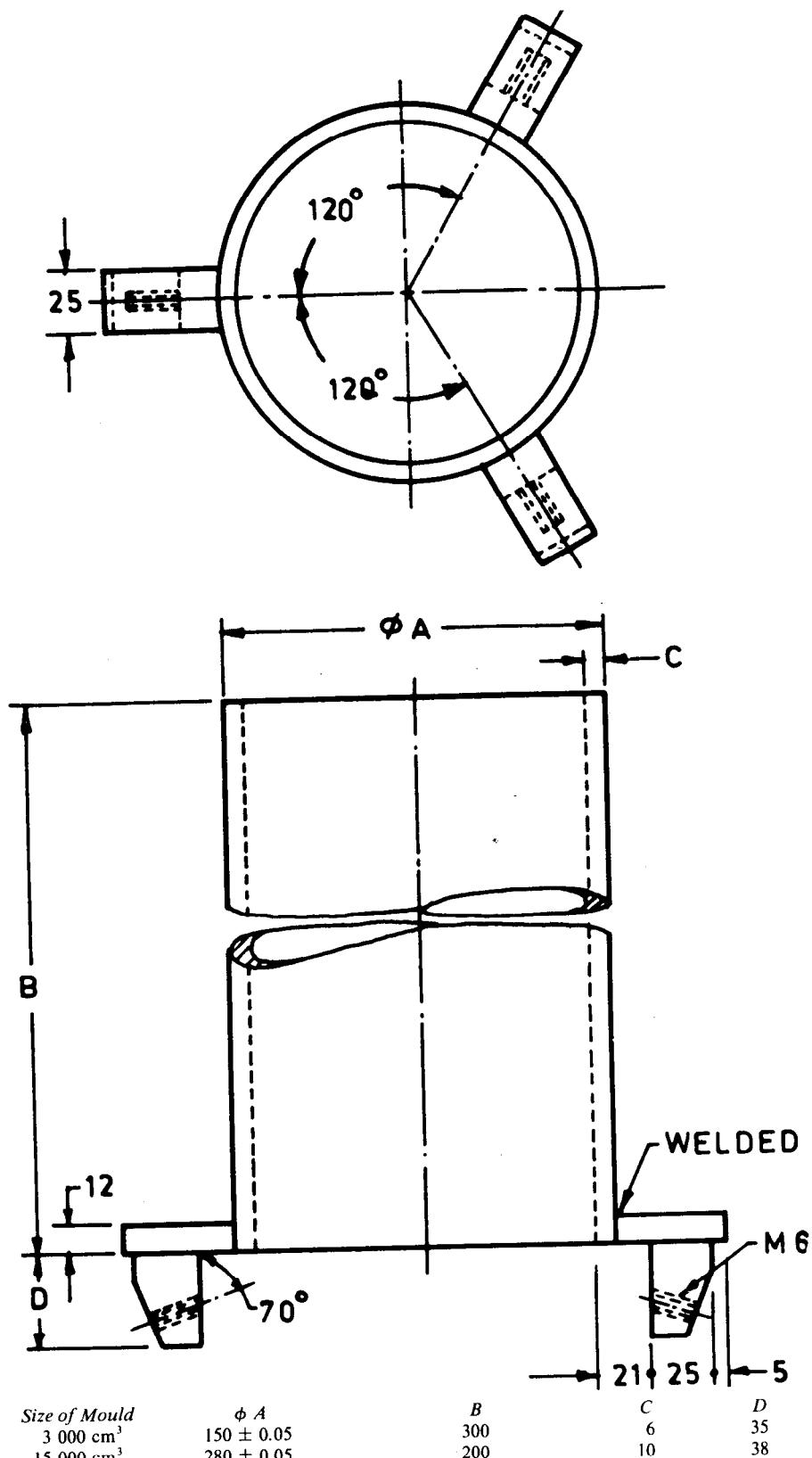
NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.



Size of Mould cm ³	A	B	C	D	E	F
3 000	150 ± 0.05	169.77 ± 0.05	180	180	10	30
15 000	280 ± 0.05	243.60 ± 0.05	310	225	15	50

All dimensions in millimetres.

FIG. 1 MOULD



All dimensions in millimetres.

FIG. 2 GUIDE SLEEVE

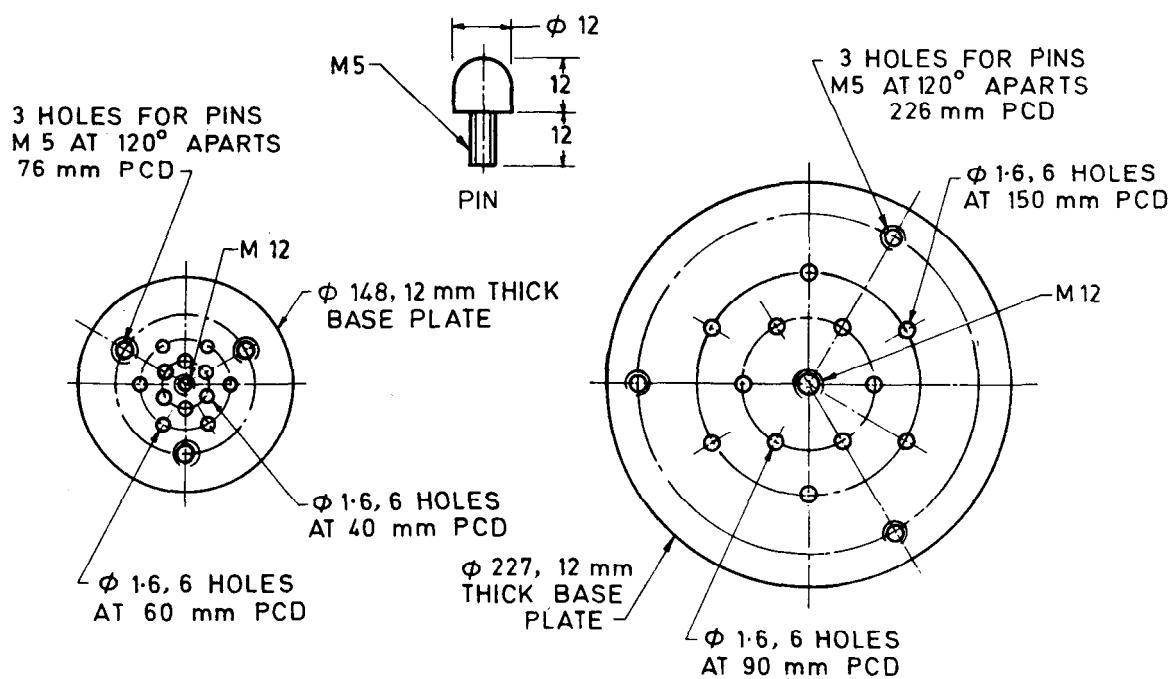
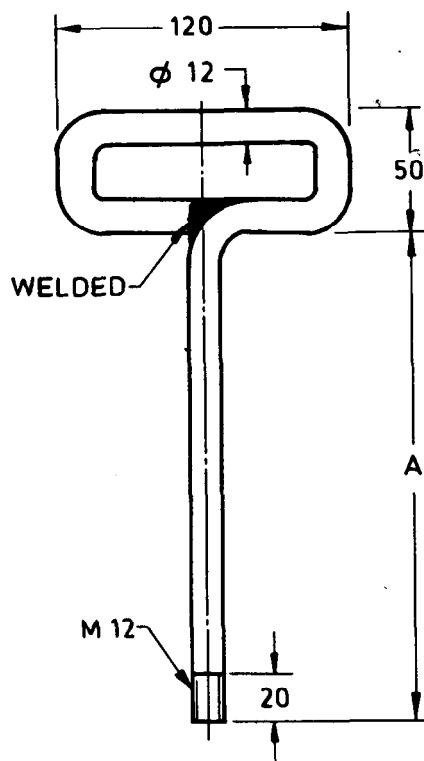


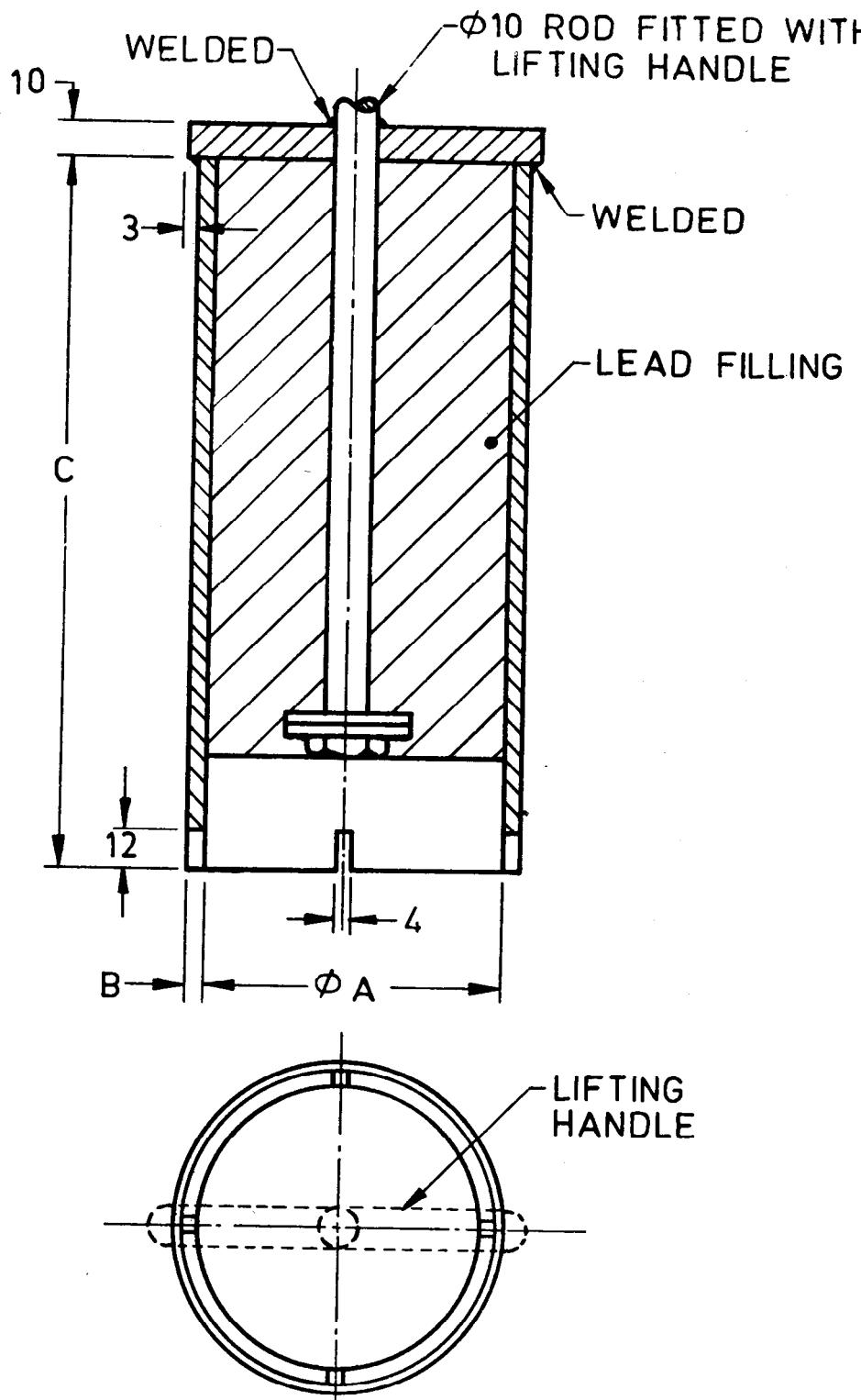
FIG. 3 SURCHARGE BASE PLATE



$A = 275$ mm for mould of capacity $3\ 000 \text{ cm}^3$
 $A = 200$ mm for mould of capacity $15\ 000 \text{ cm}^3$

All dimensions in millimetres.

FIG. 4 LIFTING HANDLE



Size of Mould
3 000 cm³
15 000 cm³

A
 100 ± 0.05
 250 ± 0.05

B
6
10

C
225
150

Total Wt. Reqd, kg
 24.7 ± 0.2
 86.0 ± 0.5

All dimensions in millimetres.

FIG. 5 SURCHARGE WEIGHT

Indian Standard

METHODS OF TEST FOR SOILS

PART 7 DETERMINATION OF WATER CONTENT-DRY DENSITY RELATION USING LIGHT COMPACTION

(Second Revision)

(Incorporating Amendments No. 1 and 2)

0. FOREWORD

0.1 This part (Part 7) (first published in 1965 and revised in 1974) deals with the method of test for the determination of water content-dry density relation of soil using light compaction (*see Note*). The purpose of a laboratory compaction test is to determine the proper amount of mixing water to be used, when compacting the soil in the field and the resulting degree of denseness which can be expected from compaction at optimum moisture content. To accomplish this, a laboratory test which will give a degree of compaction comparable to that obtained by the field method used is necessary. This procedure is satisfactory for cohesive soils but does not lend itself well to the study of the compaction characteristics of clean sands or gravels which displace easily when struck with the rammer. Some nearly-cohesionless soils compact satisfactorily in the standard test although in many cases the water density curve is not well defined. Frequently, too in these cases indicated, maximum density is not as great as can be achieved readily in the field under available compaction methods. With a knowledge of the water density relation as determined by this test, better control of the field compaction of soil fill is possible because the optimum moisture content and the density which should be obtained are known by using this test procedure and these can be checked by field control tests.

NOTE — The method of test based on heavy compaction is covered in IS : 2720 (Part 8)-1983.

0.2.1 This revision is prepared so as to cover such cases when soil could be susceptible to crushing during compaction.

1. SCOPE

1.1 This standard (Part 7) lays down the method for the determination of the relation between the water content and the dry density of soils using light compaction. In this test, a 2.6-kg rammer falling through a height of 310 mm is used.

2. TERMINOLOGY

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

3. APPARATUS

3.1 Moulds — It shall conform to IS : 10074-1982.

3.2 Sample Extruder (Optional) — It consists of a jack, lever frame or other device adopted for the purpose of extruding compacted specimens from the mould.

3.3 Balances — one, of capacity 10 kg sensitive to 1 g and other of capacity 200 g sensitive to 0.01 g.

3.4 Oven — thermostatically controlled with interior of non-corroding material to maintain temperature between 105 and 110°C.

3.5 Container — any suitable non-corroding airtight container to determine the water content for tests conducted in the laboratory.

3.6 Steel Straightedge — a steel straightedge about 30 cm in length and having one bevelled edge.

3.7 Sieve — 4.75-mm and 19-mm IS sieves conforming to the requirements of IS : 460 (Part 1)-1978.

3.8 Mixing Tools — miscellaneous tools, such as tray or pan, spoon, trowel and spatula, or a suitable mechanical device for thoroughly mixing the sample of soil with additions of water.

3.9 Metal Rammer — It shall conform to IS : 9198-1979.

4. SOIL SPECIMEN

4.1 A representative portion of air-dried soil material and large enough to provide about 6 kg of material passing a 20-mm IS Sieve (for soils not susceptible to crushing during compaction), or about 15 kg of material passing a 19-mm IS sieve (for soils susceptible to crushing during compaction), shall be taken (*see Note 1*). This portion shall be sieved on a 19-mm IS Sieve and the coarse

fraction rejected after its proportion of the total sample has been recorded.

NOTE 1 — The soil should be considered susceptible to crushing during compaction if the sample contains granular material of a soft nature, such as soft limestone, sandstone, etc, which is reduced in size by the action of the 2.6 kg rammer. The procedure given in 5.2 for soils susceptible to crushing during compaction can be applied to all soils, if it is convenient to do so.

4.1.1 Aggregations of particles shall be broken down so that, if the sample was sieved on a 4.75-mm IS sieve, only separated individual particles would be retained.

5. PROCEDURE

5.1 Soil not Susceptible to Crushing During Compaction (see Note 1)

The procedure is as follows.

5.1.1 A 5-kg sample of air-dried soil passing the 19-mm IS test sieve shall be taken (see Note 2). The sample shall be mixed thoroughly with a suitable amount of water depending on the soil type (see Notes 3 and 4).

5.1.2 The mould, with baseplate attached, shall be weighed to the nearest 1 g (m_1). The mould shall be placed on a solid base, such as a concrete floor or plinth and the moist soil shall be compacted into the mould, with the extension attached, in three layers of approximately equal mass, each layer being given 25 blows from the 2.6-kg rammer dropped from a height of 310 mm above the soil. The blows shall be distributed uniformly over the surface of each layer. The operator shall ensure that the tube of the rammer is kept clear of soil so that the rammer always falls freely. The amount of soil used shall be sufficient to fill the mould, leaving not more than about 6 mm to be struck off when the extension is removed (see Note 5). The extension shall be removed and the compacted soil shall be levelled off carefully to the top of the mould by means of the straightedge. The mould and soil shall then be weighed to 1 g (m_2).

5.1.3 The compacted soil specimen shall be removed from the mould and placed on the mixing tray. The water content of representative samples of the specimen shall be determined as in IS : 2720 (Part 2)- 1973.

5.1.4 The remainder of the soil specimen shall be broken up, rubbed through the 19-mm IS test sieve, and then mixed with the remainder of the original sample. Suitable increments of water (see Note 6) shall be added successively and mixed into the sample, and the above procedure from operations 5.1.2 to 5.1.4 shall be repeated for each increment of water added. The total number of determinations made shall be at least five, and the range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range.

5.2 Soil Susceptible to Crushing During Compaction (see Note 1)

The procedure is as follows:

- a) Five or more 2.5-kg samples of air-dried soil passing the 19-mm IS test sieve, shall be taken (see Note 2). The samples shall each be mixed thoroughly with different amounts of water to give a suitable range of moisture contents (see Notes 3 and 4). The range of moisture content, at which the maximum dry density occurs, is within that range (see Note 6).
- b) Each sample shall be treated as in 5.1.2.
- c) Each compacted specimen shall be treated as in 5.1.3.
- d) The remainder of each soil specimen shall be discarded.

5.3 Compaction in Large Size Mould

For compacting soil containing coarse material up to 37.5 mm size, the 2 250 ml mould should be used. A sample weighing about 6 kg and passing the 40-mm IS sieve is used for the test. Soil is compacted in three layers, each layer being given 55 blows of the 2.6-kg rammer. The rest of the procedure is same as in 5.1 or 5.2.

NOTE 2 — The removal of small amounts of stone (up to 5 percent.) retained on a 19-mm IS Sieve will affect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density. The exclusion of a large proportion of stone coarse than 19-mm may have a major effect on the density obtained compared with that obtainable with the soil as a whole, and on the optimum moisture content. There is at present no generally accepted method of test or of calculation for dealing with this difficulty in comparing laboratory compaction test results with densities obtained in the field. For soils containing larger proportions of gravel, the use of a bigger mould (2 250 ml) will avoid major errors.

NOTE 3 — The amount of water to be mixed with air-dried soil at the commencement of the test will vary with type of soil under test. In general, with sandy and gravelly soils, a moisture content of 4 to 6 percent would be suitable, while with cohesive soils a moisture content about 8 to 10 percent below the plastic limit of the soil (plastic limit minus 10 to plastic limit minus 8) usually be suitable.

NOTE 4 — It is important that the water is mixed thoroughly and adequately with the soil, since inadequate mixing gives rise to variable test results. This is particularly important with cohesive soils when adding a substantial quantity of water to the air-dried soil. With clays of high plasticity or where hand mixing is employed, it may be difficult to distribute the water uniformly through the air-dried soil by mixing alone, and it may be necessary to store the mixed sample in a sealed container for a minimum period of about 16 hours before continuing with the test.

NOTE 5 — It is necessary to control the total volume of soil compacted, since it has been found that if the amount of soil struck off after removing the extension is too great, the test results will be inaccurate.

NOTE 6 — The water added for each stage of the test should be such that a range of moisture contents is obtained which includes the optimum moisture. In general, increments of 1 to 2 percent are suitable for sandy and gravelly soils and of 2 to 4 percent for cohesive soils. To increase the accuracy of the test, it is often advisable to reduce the increments of water in the region of the optimum moisture content.

6. CALCULATIONS

6.1 Bulk Density — γ_m in g/ml, of each compacted specimen shall be calculated from the equation:

$$\gamma_m = \frac{m_2 - m_1}{V_m}$$

where

m_1 = mass in g of mould and base;

m_2 = mass in g of mould, base and soil; and

V_m = volume in ml of mould.

6.2 The dry density, γ_d in g/ml, shall be calculated from the equation:

$$\gamma_d = \frac{100 \gamma_m}{100 + w}$$

where

w = water content of soil in percent.

6.3 The dry densities γ_d obtained in a series of determinations shall be plotted against the corresponding moisture contents w . A smooth curve shall be drawn through the resulting points and the position of the maximum on this curve shall be determined.

7. REPORTING OF RESULTS

7.1 The experimental points and the smooth curve drawn through them showing the relationship

between moisture content and dry density shall be reported.

7.2 The dry density in g/ml corresponding to the maximum point on the moisture content/dry density curve shall be reported as the maximum dry density to the nearest 0.01.

7.3 The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the optimum moisture content and quoted to the nearest 0.2 for values below 5 percent to the nearest 0.5 for values from 5 to 10 percent, and to the nearest whole number for value exceeding 10 percent (see Note 7).

7.4 The amount of stone retained on the 19-mm IS Sieve shall be reported to the nearest 1 percent.

7.5 The method of obtaining the result shall be stated (2.6-kg rammer method). The procedure used shall also be stated, that is, single sample or separate sample and size of the mould used.

NOTE 7 — For some highly permeable soils such as clean gravels; uniformly graded and coarse clean sands, the results of the laboratory compaction test (2.6-kg rammer method) may provide only a poor guide for specifications on field compaction. The laboratory test often indicates higher values of optimum moisture content than would be desirable for field compaction and the maximum dry density is often much lower than the state of compaction that can readily be obtained in the field.

Indian Standard

METHODS OF TEST FOR SOILS

PART 8 DETERMINATION OF WATER CONTENT-DRY DENSITY RELATION USING HEAVY COMPACTION

(Second Revision)

0. FOREWORD

0.1 Purpose of a laboratory compaction test is to determine the proper amount of mixing water to be used when compacting the soil in the field and the resulting degree of denseness which can be expected from compaction at optimum moisture content. To accomplish this, a laboratory test which will give a degree of compaction comparable to that obtained by the field method used is necessary. This procedure is satisfactory for cohesive soils but does not lend itself well to the study of the compaction characteristics of clean sands or gravels which displace easily when struck with rammer. Some nearly cohesionless soils compact satisfactorily in the standard test although in many cases the water density curve is not well defined. Frequently, too in these cases indicated, maximum density is not as great as can be achieved readily in the field under available compaction methods. With a knowledge of the water density relation as determined by this test, better control of the field compaction of soil fill is possible because the optimum moisture content and the density which should be obtained are known by using this test procedure and these can be checked by field control tests. This part, which was first published in 1965 and revised in 1974, covers the method of test based on heavy compaction. The method of test based on light compaction is covered in IS : 2720 (Part 7)-1980. This revision is prepared so as to cover such cases when soil could be susceptible to crushing during compaction.

1. SCOPE

1.1 This standard (Part 8) lays down the method for the determination of the relation between the water content and the dry density of soils using heavy compaction.

2. TERMINOLOGY

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

3. APPARATUS

3.1 Cylindrical Metal Mould — It shall be either of 100 mm diameter and 1 000 cm³ volume or 150 mm diameter and 2 250 cm³ volume and shall conform to IS : 10074-1982.

3.2 Sample Extruder (Optional) — It consists of jack, lever frame or other device adopted for the purpose of extruding compacted specimens from the mould.

3.3 Balances — One of 10 kg capacity sensitive to 1 g, and other of 200 g capacity and sensitive to 0.01 g.

3.4 Oven — Thermostatically controlled, with interior of non-corroding material to maintain temperature between 105 and 110°C.

3.5 Container — Any suitable non-corrodible airtight container to determine the water content for tests conducted in the laboratory.

3.6 Steel Straightedge — A steel straightedge about 30 cm in length and having one bevelled edge.

3.7 Sieve — 4.75-mm, 19-mm and 37.5-mm IS sieves conforming to IS : 460 (Part 1)-1978.

3.8 Mixing Tools — Miscellaneous tools, such as tray or pan, spoon, trowel and spatula or a suitable mechanical device for thoroughly mixing the sample of soil with additions of water.

3.9 Metal Rammer — Heavy compaction rammer conforming to IS : 9189-1979.

4. SOIL SPECIMEN

4.1 A representative portion of air-dried soil material and large enough to provide about 6 kg of material passing a 19-mm IS sieve (for soils not susceptible to crushing during compaction) or about 15 kg of material passing a 19-mm IS sieve (for soils susceptible to crushing during compaction) shall be taken (see Note). This portion shall be sieved on 19-mm IS sieve and the coarse fraction rejected after its proportion of the total sample has been recorded.

NOTE — The soil should be considered susceptible to crushing during compaction if the sample contains granular material of a soft nature, such as soft lime stone, sandstone, etc. which is reduced in size by the action of the 4.9-kg rammer. The procedure given in 5.2 for soils susceptible to crushing during compaction can be applied to all soils if it is convenient to do so.

4.1.1 Aggregations of particles shall be broken down so that, if the sample was sieved on a 4.75-mm IS sieve, only separated individual particles would be retained.

5. PROCEDURE

5.1 Soil Not Susceptible to Crushing During Compaction (see Note under 4.1) — The procedure is as follows.

5.1.1 A 5-kg sample of air-dried soil passing the 19-mm IS test sieve shall be taken (*see Note 1*). The sample shall be mixed thoroughly with a suitable amount of water depending on the soil type (*see Notes 2 and 3*).

5.1.2 The mould, of 1000 cm³ capacity with baseplate attached, shall be weighed to the nearest 1 g (m_1). The mould shall be placed on a solid base, such as a concrete floor or plinth and the moist soil shall be compacted into the mould, with the extension attached, in five layers of approximately equal mass, each layer being given 25 blows from the 4.9-kg rammer dropped from a height of 450 mm above the soil. The blows shall be distributed uniformly over the surface of each layer. The operator shall ensure that the tube of the rammer is kept clear of soil so that the rammer always falls freely. The amount of soil used shall be sufficient to fill the mould, leaving not more than about 6 mm to be struck off when the extension is removed (*see Note 4*). The extension shall be removed and the compacted soil shall be levelled off carefully to this top of the mould by means of the straightedge. The mould and soil shall then be weighed nearest to 1 g (m_2).

5.1.3 The compacted soil specimen shall be removed from the mould and placed on the mixing tray. The water content of a representative sample of the specimen shall be determined as in IS : 2720 (Part 2)-1973.

5.1.4 The remainder of the soil specimen shall be broken up, rubbed through the 19-mm IS test sieve, and then mixed with the remainder of the original sample. Suitable increments of water (*see Note 5*) shall be added successively and mixed into the sample, and the above procedure from operations 5.1.2 to 5.1.4 shall be repeated for each increment of water added. The total number of determinations made shall be at least five, and the moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range.

5.2 Soil Susceptible to Crushing During Compaction (see Note under 4.1) — The procedure is as follows.

5.2.1 Five or more 2.5 kg samples of air-dried soil passing the 19-mm IS sieve shall be taken (*see Note 1*). The samples shall each be mixed thoroughly with different amounts of water to give a suitable range of moisture contents (*see Notes 2 and 3*). The range of moisture content, at which the maximum dry density occurs, is within that range (*see Note 5*).

5.2.2 Each sample shall be treated as in 5.1.2.

5.2.3 Each specimen shall be treated as in 5.1.3.

5.2.4 The remainder of each soil specimen shall be discarded.

5.3 Compaction in Large Size Mould — For compacting soil containing coarse material up to 37.5 mm size, the 2 250 cm³ mould should be used. A sample weighing about 30 kg and passing the 37.5-mm IS sieve is used for the test. Soil is compacted in five layers, each layer being given 55 blows of the 4.9-kg rammer. The test of the procedure is the same as in 5.1 or 5.2.

NOTE 1 — The removal of small amounts of stone (up to 5 percent) retained on a 19-mm IS sieve will effect the density obtainable only by amounts comparable with the experimental error involved in measuring the maximum dry density. The exclusion of a large proportion of stone coarser than 19-mm may have a major effect on the density obtained compared with that obtainable with soil as a whole, and on the optimum moisture content. There is at present no generally accepted method of test of calculation for dealing with this difficulty in comparing laboratory compaction test results with densities obtained in the field. For soils containing larger proportions of gravel, the use of a bigger mould (2 250 cm³) will avoid major errors.

NOTE 2 — The amount of water to be mixed with air-dried soil at the commencement of the test will vary with the type of soil under test. In general, with sandy and gravelly soils a moisture content of 3 to 5 percent would be suitable, while with cohesive soils a moisture content about 12 to 16 percent below the plastic limit of the soil should usually be suitable.

NOTE 3 — It is important that the water is mixed thoroughly and adequately with the soil, since inadequate mixing gives rise to variable test results. This is particularly important with cohesive soils when adding a substantial quantity of water to the air-dried soil. With clays of high plasticity or where hand mixing is employed, it may be difficult to distribute the water uniformly through the air-dried soil by mixing alone, and it may be necessary to store the mixed sample in a sealed container for a minimum period of about 16 hours before continuing with the test.

NOTE 4 — It is necessary to control the total volume of soil compacted, since it has been found that if the amount of soil struck off after removing the extension is too great, the test results will be inaccurate.

NOTE 5 — The water added for each stage of the test should be such that a range of moisture contents is obtained which includes the optimum moisture. In general, increments of 1 to 2 percent are suitable for sandy and gravelly soils and of 2 to 4 percent for cohesive soils. To increase the accuracy of the test, it is often advisable to reduce the increments of water in the region of the optimum moisture content.

6. CALCULATIONS

6.1 Bulk Density — Bulk density, γ_m , in g/cm³ of each compacted specimen shall be calculated from the equation:

$$\gamma_m = \frac{m_2 - m_1}{V_m}$$

where

m_1 = mass in g of mould and base;

m_2 = mass in g of mould, base and soil; and

V_m = volume in cm³ of mould.

6.2 Dry Density — The dry density, γ_d , in g/cm³, shall be calculated from the equation:

$$\gamma_d = \frac{100 \gamma_m}{100 + w}$$

where

w = moisture content of soil in percent.

6.3 The dry densities, γ_d obtained in a series of determinations shall be plotted against the corresponding moisture contents w . A smooth curve shall be drawn through the resulting points and the position of the maximum on this curve shall be determined.

7. REPORTING OF RESULTS

7.1 The experimental points and the smooth curve

drawn through them showing the relationship between moisture content and dry density shall be reported.

7.2 The dry density in g/cm³ corresponding to the maximum point on the moisture content/dry density curve shall be reported as the maximum dry density to the nearest 0.01.

7.3 The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the optimum moisture content and quoted to the nearest 0.2 for values below 5 percent, to the nearest 0.5 for values from 5 to 10 percent and to the nearest whole number for value exceeding 10 percent (see Note under 7.5).

7.4 The amount of stone retained on the 19-mm IS sieve shall be reported to the nearest 1 percent.

7.5 The method of obtaining the result shall be stated (4.9-kg rammer method). The procedure used shall also be stated, that is, single sample or separate sample and the size of the mould used.

NOTE — For some highly permeable soils such as clean gravels, uniformly graded and coarse clean sands, the results of the laboratory compaction test (4.9 kg rammer method) may provide only a poor guide for specifications on field compaction. The laboratory test often indicates higher values of optimum moisture content than would be desirable for field compaction and the maximum dry density is often much lower than the state of compaction that can readily be obtained in the field.

Indian Standard
METHODS OF TEST FOR SOILS

**PART 9 DETERMINATION OF DRY DENSITY-MOISTURE CONTENT RELATION BY
CONSTANT WEIGHT OF SOIL METHOD**

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 This part (Part 9) deals with the determination of moisture content-dry density relation of soil using a constant weight of dry soil. This is a rapid method and is essentially useful as a field control method. It may be used as a rapid laboratory test also. However, it shall not be used as a substitute for the tests covered by IS : 2720 (Part 7)-1980 and IS : 2720 (Part 8)-1983.

1. SCOPE

1.1 This standard (Part 9) lays down the method for the determination of the dry density-moisture content relation of soil passing 4.75-mm IS Sieve, using constant weight of soil on oven-dry basis in the compacted mass.

2. TERMINOLOGY

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

3. APPARATUS

3.1 A Cylindrical Metal Tube with Base Plate — having an internal diameter of 50 mm and height of 435 mm. The tube shall be fitted with a detachable base plate. A suitable design of the tube with flange and base plate is shown in Fig. 1. The internal surface of the tube shall be smooth. At a height of about 100 mm from the bottom, 8 holes of 1.5 mm dia, equally spaced, shall be provided in the wall of the tube.

3.2 A Metal Rammer — 48 mm in diameter and about 48.5 mm in height attached to a metallic rod and a knob so as to have a combined height of about 550 mm and a total weight of 2.6 kg. The rod shall also carry a cap for the tube. The rammer shall be adjusted for a drop of 310 mm. When the rammer is resting on the base plate without the specimen, the position of the rod touching the cap of the tube shall be marked zero. The rod shall then be marked in cm and mm up to 8 cm, downwards from zero.

3.3 Balances — One of capacity of 10 kg sensitive to 2 g, and another of capacity of 200 g sensitive to 0.01 g.

3.4 Oven — thermostatically controlled with interior of non-corroding material to maintain temperature between 105 and 110°C.

3.5 Container — any suitable non-corroding air-tight container to determine the moisture content of soils for tests conducted in the laboratory.

3.6 Sieve — 4.75-mm IS Sieve conforming to the requirements of IS : 460 (Part-1)-1978.

3.7 Pipette

3.8 Mixing Tools — Miscellaneous tools like mixing pan, spoon, trowel, spatula, etc, or a suitable mechanical device for thoroughly mixing the sample of soil with additions of water.

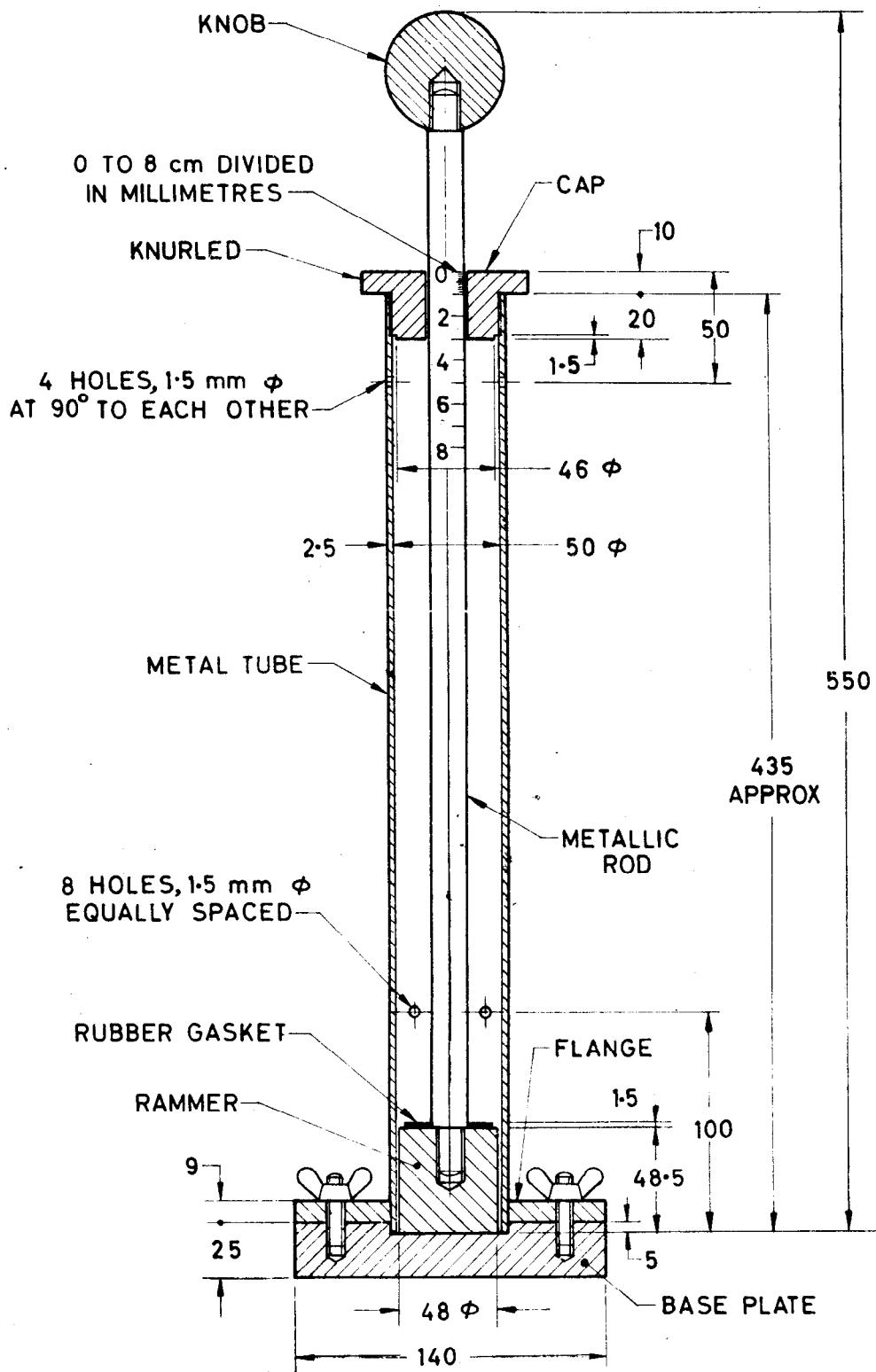
4. SOIL SPECIMEN

4.1 Soil specimen obtained as indicated in 4.2 shall be used for the test.

4.2 A representative thoroughly mixed air-dried soil sample passing 4.75-mm IS Sieve and weighing about 2 kg obtained in accordance with the procedure laid down in IS : 2720 (Part 1)-1983 shall be taken for the test. This sample shall be put into an air-tight container. The moisture content of this sample shall be determined in accordance with IS : 2720 (Part-2)-1973.

5. PROCEDURE

5.1 The empty tube shall be cleaned, dried and assembled with the base plate. A known exact weight of the air-dried soil equivalent to 200 g of oven-dried soil shall be taken. If w percent is the moisture content of the air-dried soil sample obtained in accordance with 4.2, then for 200 g of oven-dried soil for each test the weight of air-dried soil to be taken will be $(200 + 2w)$ g. Water shall be added in measured quantities so as to have a known moisture content on the oven-dry weight of soil. This shall be thoroughly mixed with a spatula and



All dimensions in millimetres.

FIG. 1 APPARATUS FOR COMPACTION BY CONSTANT WEIGHT METHOD

then poured into the mould. The wet soil shall be given 8 blows of the rammer (for light compaction tests) and 36 blows of the rammer (for heavy compaction tests) falling through a height of 310 mm. The height of the compacted mass shall be read from the calibration on the rod. Similar tests shall be carried out with increasing percentage of moisture, each time using a fresh specimen obtained from the sample in 4.2 so as to have enough points even after the volume has started increasing after decreasing initially.

6. CALCULATIONS

6.1 The dry density in g/cm³ shall be calculated by dividing the factor 10.2 by the reading on the rod of the rammer in cm (see 5.1).

NOTE — As the internal diameter of the tube is 50 mm and dry weight of soil for each stage in the test is 200 g, if R is the reading on the rod of the rammer (height of compacted soil in the tube) in centimetres.

$$\text{Dry density} = \frac{200}{\frac{\pi}{4} (5^2) R} = \frac{10.2}{R} \text{ g/cm}^3$$

6.2 The moisture content at each test shall be calculated from the water added and moisture already present in the air-dried soil. If w_a ml of water is added in one test, the moisture content in terms of percent of dry weight of soil will be $(w + 0.5 w_a)$ where w is the percent moisture already present in the soil sample taken for the test.

7. REPORT

7.1 The results of the test shall be recorded suitably. A recommended proforma for the record of results is given in Appendix A.

7.2 The dry density-moisture content relationship curve shall then be drawn, and the maximum dry density and the corresponding moisture content shall be reported.

A P P E N D I X . A

(Clause 7.1)

COMPACTATION TEST DATA SHEET (CONSTANT WEIGHT OF SOIL METHOD)

Weight of oven-dried soil = 200 g

Moisture content or air-dried soil taken for test = w percent

Test No.	1	2	3	4	5	6
Water added w_a , ml						
Reading on rod R , cm						
Moisture content, percent ($w + 0.5 w_a$)						
Dry density in g/cm ³ = $\frac{10.2}{R}$						

Indian Standard

METHODS OF TEST FOR SOILS

PART 14 DETERMINATION OF DENSITY INDEX (RELATIVE DENSITY) OF COHESIONLESS SOILS

(First Revision)

0. FOREWORD

0.1 This part deals with the method for the determination of density index (relative density) of cohesionless soils. For cohesionless soils in the natural or artificially compacted state, neither the actual density (or void ratio) nor the actual density expressed as a percentage of the maximum density give an exact idea of the compactness of the soil. The concept of density index (relative density) gives a practically useful measure of compactness of such soils. The compactive characteristics of cohesionless soils and the related properties of such soils are dependent on factors like grain size distribution and shape of individual particles. Density index (relative density) is also affected by these factors and serves as a parameter to correlate properties of soils. Various soil properties, such as penetration resistance, compressibility, compaction friction angle, permeability and California bearing ratio are found to have simple relationships with density index (relative density).

0.2 This standard was first published in 1968. This revision has been prepared so as to give more details of vibratory table, deletions of specifications of moulds and its assembly, which are being published separately in detail, and adding an alternative method using vibratory hammer.

1. SCOPE

1.1 This part (Part 14) covers the principal and alternative laboratory methods for the determination of the density index (relative density) of cohesionless free draining soils.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definition shall apply.

2.1 Density Index, I_d (or Relative Density D_r) — The ratio of the difference between the void ratio of a cohesionless soil in the loosest state and any given void ratio to the difference between its void ratios in the loosest and the densest states.

3. PRINCIPAL METHODS USING VIBRATORY TABLE

3.1 Apparatus

3.1.1 Vibratory Table — a steel table with a cushioned steel vibrating deck about 75×75 cm. The vibrator should have a net mass of over 45 kg. The vibrator shall have frequency of 3 600 vibrations per minute, a vibrator amplitude variable between 0.05 and 0.65 mm in steps of 0.05 to 0.25 mm, 0.25 to 0.45 mm and 0.45 to 0.65 mm under a 11-kg load and shall be suitable for use with a 415-V three-phase supply.

3.1.2 Moulds — With Guide Sleeves — cylindrical metal unit mass moulds of 3 000 and 15 000 cm^3 capacity conforming to the requirements as given in IS : 10837 - 1984.

3.1.3 Surcharge Base Plates with Handle — one surcharge base plate 10 mm in thickness for each size mould conforming to requirements given in IS : 10837-1984.

3.1.4 Surcharge Masses — one surcharge mass for each size mould conforming to requirements given in IS : 10837-1984.

3.1.5 Dial Gauge Holder — conforming to requirements given in IS : 10837-1984.

3.1.6 Dial Gauge — 50 mm travel with 0.025 mm graduations (see IS : 2092-1962 'Specification for dial gauges').

3.1.7 Calibration Bar — of metal and $75 \times 300 \times 3$ mm in size.

3.1.8 Pouring Devices — consisting of funnels 12 mm and 25 mm in diameter and 15 cm long, with cylindrical spouts and lipped brims for attaching to 15 cm diameter and 30 cm high metal cans.

3.1.9 Mixing Pans — suitable sizes are 60×90 cm and 10 cm deep, and 40×40 cm and 5 cm deep.

3.1.10 Weighing Scale — portable platform scale, 100 kg capacity with sensitivity of 20 g in accordance with IS : 1435-1960 'Specification for platform weighing machines'.

3.1.11 Hoist — suitable hoist of at least 135 kg capacity.

3.1.12 Metal Hand Scoop

3.1.13 Bristle Brush

3.1.14 Timing Device — indicating in minutes and seconds.

3.1.15 Metal Straight Edge — about 40 cm long.

3.1.16 Micrometer — 0 to 25 mm, accurate to 0.025 mm.

3.2 Calibration — The volume of the mould should be determined by direct measurement (3.2.1) and checked by filling with water (3.2.2). The initial dial reading for computing the volume of the specimen should be determined as provided in 3.2.3.

3.2.1 Determination of Volume by Direct Measurement — The average inside diameter and height of the mould should be measured to 0.025 mm. Volume of the 3000 cm³ mould should be calculated to the nearest 3 cm³ and that of 15 000 cm³ mould to the nearest 30 cm³. The average inside cross-sectional area of the mould should also be calculated in square centimetres.

3.2.2 Determination of Volume by Filling with Water — The mould should be filled with water and a glass plate should be slid carefully over the top surface of the mould in such a manner as to ensure that the mould is completely filled with water. The temperature of the water should be measured and the mass in grams of the water filling the mould should be determined. The volume of the mould should be calculated in cubic centimetres by multiplying the mass of water by the volume of water per gram at the measured temperature.

3.2.3 Determination of Initial Dial Reading for Computing the Volumes of the Specimen — The thickness of the surcharge base plate and the calibration bar should be measured to 0.025 mm using a micrometer. The calibration bar should then be

placed across a diameter of the mould along the axis of the guide brackets. The dial gauge holder should be inserted in each of the guide brackets on the mould with the dial gauge stem on top of the calibration bar and on the axis of the guide brackets. The dial gauge holder should be placed in the same position in the guide brackets each time by means of matchmarks on the guide brackets and the holder. Six dial gauge readings should be obtained, three on the left side and three on the right side, and these six readings averaged. The initial dial reading should be computed by adding together the surcharge base plate thickness and the average of the six dial gauge readings and subtracting the thickness of the calibration bar. The initial dial reading is constant for a particular mould and surcharge base plate combination.

3.3 Soil Sample

3.3.1 A representative sample of soil should be selected. The mass of soil sample to be taken depends upon the maximum size particle in the soil as given in Table 1.

3.3.2 The soil sample should be dried in an oven at a temperature of 105 to 110°C. The soil sample should be pulverized without breaking the individual soil particles and sieved through the required sieve.

3.4 Procedure for the Determination of Minimum Density

3.4.1 The pouring device and mould should be selected according to the maximum size of particle as indicated in Table 1. The mould should be weighed and the mass recorded. Oven-dry soils should be used.

3.4.2 Soil containing particles smaller than 9.50 mm should be placed as loosely as possible in the mould by pouring the soil through the spout in a steady stream. The spout should be adjusted so that the height of free fall of the soil is always 25 mm.

TABLE 1 MASS OF SOIL SAMPLE TO BE TAKEN FOR THE TEST

MAXIMUM SIZE OF SOIL PARTICLE	MASS OF SOIL SAMPLE REQUIRED	POURING DEVICE TO BE USED IN TEST FOR THE DETERMINATION OF MINIMUM DENSITY	SIZE OF MOULD TO BE USED
(1) mm	(2) kg	(3)	(4) cm ³
75	45	Shovel or extra large scoop	15 000
37.5	12	Scoop	3 000
19	12	Scoop	3 000
9.50	12	Pouring device (25 mm dia spout)	3 000
4.75	12	Pouring device (12 mm dia spout)	3 000

While pouring the soil the pouring device should be moved in a spiral motion from the outside towards the centre to form a soil layer of uniform thickness without segregation. The mould should be filled approximately 25 mm above the top and levelled with top by making one continuous pass with the steel straightedge. If all excess matter is not removed, an additional continuous pass should be made. Great care shall be exercised to avoid jarring the mould during the entire pouring and trimming operation. The mould and the soil should be weighed and the mass recorded.

3.4.3 Soil containing particles larger than 9.50 mm should be placed by means of a large scoop (or shovel) held as close as possible to and just above the soil surface to cause the material to slide rather than fall into the previously placed soil. If necessary, large particles may be held by hand to prevent them from rolling off the scoop. The mould should be filled to overflowing but not more than 25 mm above the top. The surface of the soil should be levelled with the top of the mould using the steel straightedge (and the fingers, if necessary) in such a way that any slight projections of the larger particles above the top of the mould shall approximately balance the larger voids in the surface below the top of the mould. The mould and the soil should be weighed and the mass recorded.

3.5 Procedure for the Determination of Maximum Density

3.5.1 The maximum density may be determined by either the dry or wet method.

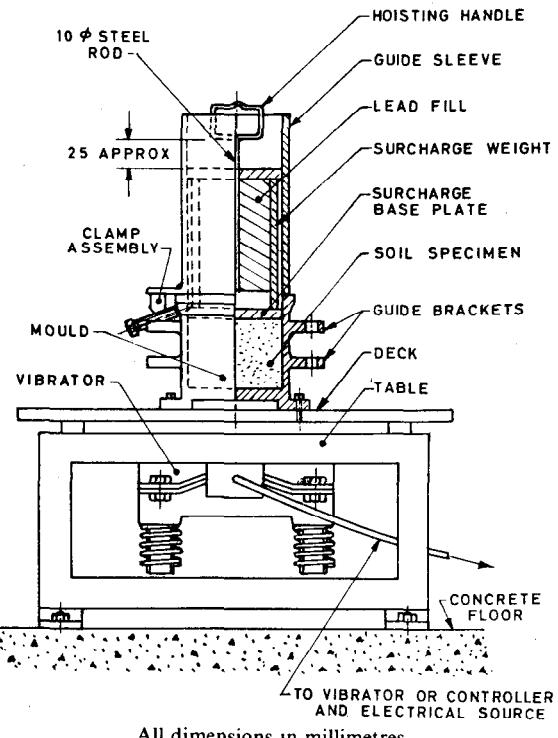
3.5.2 Dry Method

3.5.2.1 The guide sleeve should be assembled on top of the mould and the clamp assemblies tightened so that the inner surface of the walls of the mould and the sleeve are in line. The lock nuts on the two set screws equipped with them should be tightened. The third clamp should be loosened, the guide sleeve removed, the empty mould weighed and its mass recorded.

3.5.2.2 The mould should then be filled with the thoroughly mixed oven-dry soil by the procedure explained in 3.4.2 or 3.4.3. The mould filled for the determination of minimum density may also be used for this test.

3.5.2.3 The guide sleeves should be attached to the mould and the surcharge base plate should be placed on the soil surface. The surcharge weight should then be lowered on the base plate using the hoist in the case of the 15 000 cm³ mould.

3.5.2.4 The mould should be fixed to the vibrator deck (see Fig. 1) for assembly. The vibrator control should be set at maximum amplitude and the loaded soil specimen should be vibrated for 8 minutes.



All dimensions in millimetres.

FIG. 1 ASSEMBLY OF THE APPARATUS

The surcharge weight and guide sleeves should be removed from the mould. The dial gauge readings on two opposite sides of the surcharge base plate should be obtained and the average recorded. The mould with the soil should be weighed and its mass recorded.

3.5.3 Wet Method

3.5.3.1 The wet method (see Note) may be conducted on dry soil or wet soil from the field.

NOTE — While the dry method is preferred from the standpoint of securing results in a shorter period of time, the highest maximum density is obtained from some soils in a saturated state. At the beginning of a laboratory testing programme, or when a radial change of materials occurs, the maximum density test should be performed on both wet and dry soils to determine which method results in higher maximum density. If the wet method produces higher maximum densities (in excess of one percent), it shall be followed in succeeding tests.

3.5.3.2 The mould should be filled with wet soil. Sufficient water should be added to the soil to allow a small quantity of free water to accumulate on the surface of the soil during filling. During and just after filling the mould, it should be vibrated for a total of 6 minutes. During this period, the amplitude of the vibrator should be reduced as much as necessary to avoid excessive boiling and fluffing of the soil, which may occur in some soils. During the final minutes of vibration, any water appearing above the surface of the soil should be removed.

3.5.3.3 The guide sleeve, surcharge base plate and surcharge weight should be assembled as described in 3.5.2.3.

3.5.3.4 The specimen with the surcharge weight should be vibrated for 8 minutes. After the vibration, the surcharge weight and the guide should be removed from the mould. Dial gauge readings should be obtained on two opposite sides of the surcharge base plate and recorded. The entire wet specimen should be carefully removed from the mould, dried to constant mass, weighed and the mass recorded.

3.6 Calculations

3.6.1 Minimum Density — The minimum density, γ_{min} , in g/cm³ should be calculated as follows:

$$\gamma_{min} = \frac{W_{sm}}{V_c}$$

where

W_{sm} = mass of dry soil in the minimum density test in g; and

V_c = calibrated volume of the mould in cm³.

3.6.2 Maximum Density — The maximum density, γ_{max} , in g/cm³ should be calculated as follows:

$$\gamma_{max} = \frac{W_s}{V_s}$$

where

W_s = mass of dry soil in the maximum density test in g;

V_s = volume of soil in maximum density test in cm³;

$$= V_c - (D_i - D_f) A;$$

D_i = initial dial gauge reading in cm;

D_f = final dial gauge reading on the surcharge base plate after completion of the vibration period in cm; and

A = cross-sectional area of mould in cm³.

3.6.3 Density of Soil In-Place — The dry density of soil in-place, γ_d should be determined in accordance with IS : 2720 (Part 28)-1966.

3.6.4 Density Index (Relative Density) — The density index, I_d (relative density, D_r) expressed as a percentage should be calculated as follows:

$$I_d \text{ (or } D_r) = \frac{\gamma_{max} (\gamma_d - \gamma_{min})}{\gamma_d (\gamma_{max} - \gamma_{min})} \times 100$$

or in terms of void ratio

$$I_d \text{ (or } D_r) = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

where

e_{max} = void ratio of the soil in loosest state,

e = void ratio of the soil in the field, and

e_{min} = void ratio of the soil in its densest state obtainable in the laboratory.

4. ALTERNATE METHOD USING VIBRATORY HAMMER

4.1 Apparatus

4.1.1 Moulds — A cylindrical metal with an internal diameter of 152 mm and an internal effective height of 127 mm, with a detachable base plate and a collar 50 mm deep, conforming to IS : 9669-1980. 'Specification for CBR moulds and accessories'.

4.1.2 Vibratory Hammer — An electric vibrating hammer having a power consumption between 600 and 750 W and operating at a frequency between 25 and 45 Hz.

4.1.3 Tamper — A steel tamper attached to the vibrating hammer; the tamper shall have a circular foot of 145 mm diameter and shall not exceed 3 kg in mass.

4.1.4 Balance — readable and accurate to 5 g.

4.1.6 Straightedge — a steel strip 300 mm long, 25 mm wide and 3 mm thick.

4.1.7 Depth Gauge or Steel Rule

4.1.8 Metal Tray — 600 mm × 500 mm and with sides 80 mm deep.

4.1.9 Stop-Watch or Stop Clock

4.2 Procedure

4.2.1 Soil not Susceptible to Crushing During Compaction

4.2.1.1 The sample shall be mixed thoroughly with a suitable amount of water depending on the soil type.

4.2.1.2 The mould, together with its 50 mm collar and base plate fixed firmly, shall be weighed (m_1), and then stood on a solid base, of a concrete floor. A quantity of the moist soil, sufficient to give a specimen 127 to 133 mm deep after compaction in the mould, shall be compacted in the mould in three layers of approximately equal mass, using the vibrating hammer fitted with the circular steel tamper. Each layer shall be compacted for a period of 60 seconds and throughout this period a firm downward pressure shall be applied to the vibrating hammer so that the total downward force, including that resulting from the mass of the hammer and tamper, shall be 300 to 400 N.

4.2.1.3 When the final layer has been compacted, any loose material around the sides of the mould shall be removed from the surface of the specimen. The straightedge shall be laid across the top of the collar of the mould and the depth of the specimen below the top of the collar measured to an accuracy of 0.5 mm. Readings shall be taken at four points spread evenly over the surface of the specimen, all at least 15 mm from the side of the mould,

and the mean height, h , of the specimen calculated. If the specimen is more than 133 mm or less than 127 mm in height, it shall be rejected and a further test carried out.

4.2.1.4 The mould, together with the collar, base plate and soil shall be weighed to the nearest 5 g (m_2).

4.2.1.5 The compacted soil specimen shall be removed from the mould and placed on the large metal tray. A representative sample of the specimen shall be taken and its moisture content w , shall be determined as in IS : 2720 (Part 8)-1983.

4.2.1.6 The remainder of the soil specimen shall be broken up and then mixed with remainder of the original sample. Suitable increments of water shall be added successively and mixed into the sample, and the above procedure from operations shall be repeated for each increment of water added. The total number of determinations made shall be at least five, and the range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range.

4.2.2 Soil Susceptible to Crushing During Compaction

4.2.2.1 The sample shall be mixed thoroughly with different amounts of water to give a suitable range of moisture contents. The range of moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range.

4.2.2.2 Each sample shall be treated as in 4.2.1.2 to 4.2.1.5 and the remainder of each specimen shall be discarded.

4.3 Calculations

4.3.1 The bulk density, γ_b in t/m³, of each compacted specimen shall be calculated from the equation:

$$\gamma_b = \frac{m_2 - m_1}{18.15h}$$

where

m_1 = mass of the mould + base + collar (g);

m_2 = mass of the mould + base + collar
+ compacted specimen (g); and

h = height of specimen (mm).

4.3.2 The dry density, γ_d in t/m³, shall be calculated from the equation:

$$\gamma_d = \frac{100\gamma_d}{100 + w}$$

where

w = the moisture content of the soil (percent).

4.3.3 The dry densities, γ_d , obtained in a series of determinations, shall be plotted against the corresponding moisture contents, w . A smooth curve shall be drawn through the resulting points and the position of the maximum on this curve determined, and the zero, 5 and 10 percent air voids lines plotted for comparison.

5. REPORT

5.1 The experimental points and the smooth curve drawn through them showing the relationship between moisture content and dry density shall be reported.

5.2 The dry density corresponding to the maximum point on the moisture content/dry density curve shall be reported as the maximum dry density to the nearest 0.01.

5.3 The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve shall be reported as the optimum moisture content, and quoted to the nearest 0.2 for values below 5 percent to the nearest 0.5 for values from 5 to 10 percent and to the nearest whole number for values exceeding 10 percent.

5.4 The amount of soil retained on the 37.5 mm IS Sieve shall be reported to the nearest 1 percent.

5.5 The method of obtaining the result shall be stated. The procedure used shall also be stated, that is, single sample or separate samples.

Indian Standard
METHODS OF TEST FOR SOILS
PART 38 COMPACTATION CONTROL TEST (HILF METHOD)

0. FOREWORD

0.1 The field density tests covered in IS : 2720 (Part 28)-1974, IS : 2720 (Part 29)-1975, IS : 2720 (Part 33)-1971 and IS : 2720 (Part 34)-1972 determine the dry density and the water content of the compacted fill. For control purposes, these values should be compared with the maximum dry density and optimum moisture content obtained in the laboratory using methods specified in IS : 2720 (Part 7)-1974 and IS : 2720 (Part 8)-1974. The rapid control procedure covered in this standard gives the exact percentage of laboratory maximum dry density and a close approximation of the difference between optimum moisture content and fill water content of a field density sample, without requiring determinations of water contents. This procedure enables to effect compaction control within one hour from the time the field test is made. Only the field water content is measured and, after it is available, the values of field dry density, cylinder dry density at fill water content, laboratory maximum dry density and optimum moisture content are determined.

0.1.1 This method of evaluating quickly and accurately the compaction of cohesive soils such as earth-fill materials used in the construction of impervious and semi-impervious zones of embankment type dams, is essentially the method developed by Dr J. W. Hilf of US Bureau of Reclamation. (Ref. Water Resources Technical Publication, Engineering Monograph No. 26, 1966, 'A rapid method of construction control for embankments of cohesive soil' by J. W. Hilf, published by United States Department of the Interior). Although most commonly used in controlling the placement of earth-fill in dam construction, the method is also applicable to controlling earth-fill placement in the construction of highway embankments, canal embankments and similar structures build of cohesive soils.

1. SCOPE

1.1 This standard (Part 38) describes the procedure for determining the relative compaction and/or the difference between the optimum moisture content and the field water content of a soil by relating 'converted' wet density and 'added' water, without the immediate need to determine the water content. It is a rapid method based on tests covered by IS :

2720 (Part 7)-1974 and IS : 2720 (Part 8)-1974 using a 1 000 cm³ mould. Usually, the results of only three compacted test specimens are required and both the test and the calculations can be done in less than an hour.

1.1.1 The control parameters are determined either for the total material or for the material finer than a specified IS Sieve (*see Note*).

NOTE — In construction control of coarse earth-fill, it is often necessary to determine the field dry density of a certain fraction of the soil after excluding the mass and volume of all particles coarser than a specified sieve (usually 20-mm or 40-mm IS Sieve) in accordance with tests covered in IS : 2720 (Part 38)-1974 and IS : 2720 (Part 39)-1975. The rapid compaction test is performed on that fraction of the soil which is finer than the specified sieve. The size of the sieve should ensure that not less than 85 percent by mass of the total material is tested.

1.1.2 Because it is a rapid method, the refinement of proper curing is necessarily omitted. There is also some relaxation in the maximum particle size to allow compaction of material up to 25 mm size. These relaxations may result in minor differences between results obtained from tests covered in IS : 2720 (Part 28)-1974 and IS : 2720 (Part 29)-1975, especially in more cohesive soils and soils with a rock fraction.

1.1.3 The test may be used for checking material before placement to ensure that the water content is within specified limits (*see Note*).

NOTE — Samples which have been taken for testing before placement of the material may require pretreatment to simulate the effects of excavation and construction operations on particle breakdown and other physical properties. When previous tests have shown that significant changes in soil properties will occur during construction, pretreat the sample for the appropriate time by the method adopted in the laboratory to simulate the effects of the construction operations. One suitable method of pretreatment may be by mixing in a mechanical mixer.

2. APPARATUS

2.1 Cylindrical Metal Mould — as described in IS : 2720 (Part 7)-1974, or IS : 2720 (Part 8)-1974 of volume 1 000 cm³ (*see Note*).

NOTE — Alternatively, a larger mould may be used for soil compaction tests needed for the construction control of earth-fill in dam embankments. A tapered metal mould, having internal diameter at base of mould of 1100.00 ± 0.05 mm and at top of mould of 105.00 ± 0.05 mm and internal effective height of 165.20 ± 0.05 mm (a volume of 1 500 cm³), fitted with a detachable base plate and a removable collar assembly approximately 60 mm high, both of which may be firmly attached to the mould, may be used.

2.2 Metal Rammer — as described in IS : 2720 (Part 7)-1974 or IS : 2720 (Part 8)-1974 (*see Notes 1 and 2*).

NOTE 1 — The metal rammer used in the rapid compaction test for compacting soil in a mould of the dimensions given in Note under 2.1 is similar to that used in the method given in IS : 2720 (Part 7)-1974 except that it should be equipped with a device to control the height of drop to a free fall of 465 mm.

NOTE 2 — A mechanical form of ramming apparatus may be used provided that the essential dimensions are adhered to and the rammer has a free fall of the correct height. It is also essential that the design of the machine is such that the machine rests on a solid base.

2.3 Rigid Foundation — A rigid foundation on which to compact the specimen, for example, concrete floor or concrete block of at least 90 kg mass.

2.4 Balance — of 10 kg capacity readable and accurate to 5 g (*see Note*).

NOTE — For test using 1 500 cm³ mould, use a balance of approximately 15 kg capacity readable and accurate to 5 g.

2.5 Apparatus for Water Content Determination — as described in IS : 2720 (Part 2)-1973.

2.6 Sieves — 25-mm, 20-mm and 10-mm IS Sieves; 300-mm in diameter and conforming to IS : 460 (Part 1)-1962 with lid and pan.

2.7 Spatula — strong spatula with a 100-mm blade or a suitable knife.

2.8 Steel Straight edge — about 300-mm long, 25-mm wide and 3-mm thick, preferably with one bevelled edge.

2.9 Miscellaneous Mixing Apparatus — such as a pan or bowl, spoon, scoop, trowels, water spray, etc, suitable for thoroughly mixing increments of water with soil and drying apparatus (*see Note*).

NOTE — For soil samples which are close to or wetter than optimum moisture content, it is usually necessary to dry out soil for at least one specimen. To accelerate the drying process, a special sample drier may be used. This usually consists of a 450-mm diameter sieve mounted over a fan-assisted heater with a metal cone between them (alternatively, a fan blowing air across the soil which is turned from time to time to assist evaporation, may be used). The sieve in the special drier has, preferably 40-mm openings which are covered with successive layers of 2.36-mm and 75-micron IS Sieve mesh. When the sample of moist soil has almost reached the predetermined required mass, the heater is switched off but the fan continues to blow cool air through the soil. This reduces it to room temperature so that the tendency to lose moisture, after the final weighing, is minimized. Care should be taken to prevent loss of soil, particularly when handling the loaded sieve of the special drier since portion of the soil fines which have become dusty may be lost through the apertures of 75-micron IS Sieve mesh.

Where the soil is close to optimum moisture content and the difference between the converted wet densities of point (1) and point (2) is 0.05 g/cm³ or less, the drying process can be eliminated by a procedure given in the reference in 0.1.1.

2.10 Rule — 250-mm long.

2.11 Airtight Containers — suitable for transporting moistened soil samples.

2.12 Sample Extruder — a jack, lever, frame or other device suitable for extruding compacted soil specimens from the moulds.

3. PROCEDURE

3.1 Obtain the bulk sample for the rapid compaction control test immediately after completing the field work for the field density test (*see Notes 1 and 2*). When using the test only for checking the water content of the soil before placement, no density test is required but pretreatment (*see Note under 1.1.1*) may be necessary.

NOTE 1 — A sample yielding 10 kg mass (minimum) passing the specified IS Sieve is usually required when using a mould of 1 000 cm³ capacity, or 15 kg mass (minimum) when using a mould of 1 500 cm³ capacity.

NOTE 2 — The sample should be taken from the area immediately around the density hole to a depth not exceeding the depth of the field density hole. Also, as the validity of the test depends on the water content of the soil at the time of sampling, samples should always be collected, transported and stored in airtight containers to prevent loss of moisture. To prevent excessive loss of moisture in hot weather, it may be advisable to perform the test in a humidified room. For certain types of soil and climate conditions, a humidified room is essential.

3.2 Obtain the first point on the 'added moisture-wet density' plot by compacting, at field water content, a sample (*see Note 1*) of the soil passing the specified sieve by the appropriate method of laboratory compaction test given in IS : 2720 (Part 7)-1974 or IS : 2720 (Part 8)-1974 (*see also Note under 2.1 and Note 1 under 2.2*). Plot the resulting wet density of this specimen, calculated as in IS : 2720 (Part 7)-1974 as point (1) on the 0 percent 'added water' ordinate of a suitable graph, for example, Fig. 1. Take a water content sample (*see Note 2*) for the determination of water content in accordance with IS : 2720 (Part 2)-1973 (*see Note 3*).

NOTE 1 — Weigh out 2.5 kg of soil at field water content for each compacted specimen for moulds of 1 000 cm³ capacity and 3.7 kg of soil for moulds of capacity 1 500 cm³. Use of such standardized masses allows water additions to be made by using standardized measures—50 ml of water for 2.5 kg of soil or 74 ml for 3.7 kg, increases water content by 2 percent (by wet mass).

NOTE 2 — Cut a diametral slice for the full height of the compacted specimen after extracting it from the mould and trim all edges. The water content sample for material passing the 10-mm IS Sieve should not be less than 400 g. For coarser materials, a minimum of 1 500 g should be taken. However, with coarse soils, particularly those containing particles up to 25 mm maximum size, it may be advisable to dry the whole specimen.

NOTE 3 — Only one water content, namely, the field water content, is measured. When the field water content is available, usually the following day, the values of field dry density, cylinder dry density at a field water content, laboratory maximum dry density and optimum moisture content are determined for record purposes.

3.3 Obtain the record point on the plot by weighing out the appropriate amount of soil at field water content (*see Note 1 under 3.2*). Add 2 percent of water (by mass of wet soil) (*see Note*), compact into

a cylinder in the appropriate manner and determine the wet density. Reduce the wet density to converted wet density (wet density at the same water content as the first point in 3.2) by dividing the wet density by

$$\frac{(100 + \text{percent change in water content})}{100}$$

For example, if the water content change is +2 percent, that is, the soil has been made wetter, then converted wet density is equal to

$$\frac{\text{wet density}}{1.02}$$

If, on the other hand, the water content change is -2.5 percent, that is, the soil has been made drier, then converted wet density is equal to

$$\frac{\text{wet density}}{0.975}$$

Alternatively, a graphical method of division employing the diagonal lines of Fig. 1 may be used (interpolating, if necessary) or, provided water content increments of 2 percent are used, Table 1 may be employed.

Plot the converted wet density on the +2 percent ordinate of the graph as point (2).

NOTE — Vigorously rub and blend the soil between the hands to facilitate even distribution of added moisture throughout the material, before compaction. Also treat all soil which has been dried for compacting specimens at water content less than field water content in a similar manner, before compaction. The use of mechanical mixers as a means of saving time and ensuring even distribution of water is not recommended since further changes in soil properties, such as optimum moisture content and maximum dry density can occur with certain soils, for example, residual soils.

3.4 Obtain the third point on the plot by the procedure given in 3.4.1, 3.4.2 or 3.4.3 depending on the relative positions of points (1) and (2).

3.4.1 Point (2) Higher Than Point (1) — Weigh the appropriate amount of soil at field water content (see Note 1 under 3.2). Add 4 percent of water (by mass of wet soil) (see Note 1 under 3.3), compact into a cylinder in the appropriate manner and determine the wet density. Reduce this wet density to converted wet density (see 3.3). Plot the converted wet density on the +4 percent ordinate of the graph as point (3).

3.4.2 Point (2) Lower Than Point (1) — Weigh the appropriate amount of soil at field water content (see Note 1 under 3.2) and permit the soil to dry by 2 percent (see Note under 2.9) without loss of soil, then reweigh. Table 2 gives the percentage of water loss corresponding to the mass of the partly

dried soil. Remove the partly dried soil from the drying sieve and remix thoroughly (see Note under 3.3) before compacting it in the mould in the appropriate manner. Determine the wet density of the compacted specimen. Reduce this wet density to converted wet density (see 3.4.1). Plot the converted wet density on the -2 percent ordinate of the graph as point (3).

NOTE — Table 2 is based on the following equations:

$$\text{Percentage of water loss} = \frac{(\text{Dried mass of soil} - 2.50) \times 40}{\text{when moist soil taken is } 2.50 \text{ kg.}}$$

$$\text{Percentage of water loss} = \frac{\text{Dried mass of soil} \times 3.70}{3.70} \times 100,$$

when moist soil taken is
3.70 kg.

3.4.3 Point (1) Level with Point (2) — Weigh the appropriate amount of soil at field water content (see Note 1 under 3.2) and compact into a cylinder in the appropriate manner at a water content 4 percent wet of field water content. Proceed as in 3.4.1 to plot point (3).

Alternatively, compact a specimen to which one percent water content has been added. The converted wet density of this point is then the maximum, and the use of Table 3 or the parabola solution (see 4.2) is unnecessary.

NOTE — Table 3 is based on the following equations:

$$X_m = \frac{4 Y_2 - Y_4}{2 Y_2 - Y_4}$$

$$Y_m = \frac{(4 Y_2 - Y_4)^2}{8(2 Y_2 - Y_4)}$$

(Explanations of symbols are as in 4.1 and figure in Table 3B)

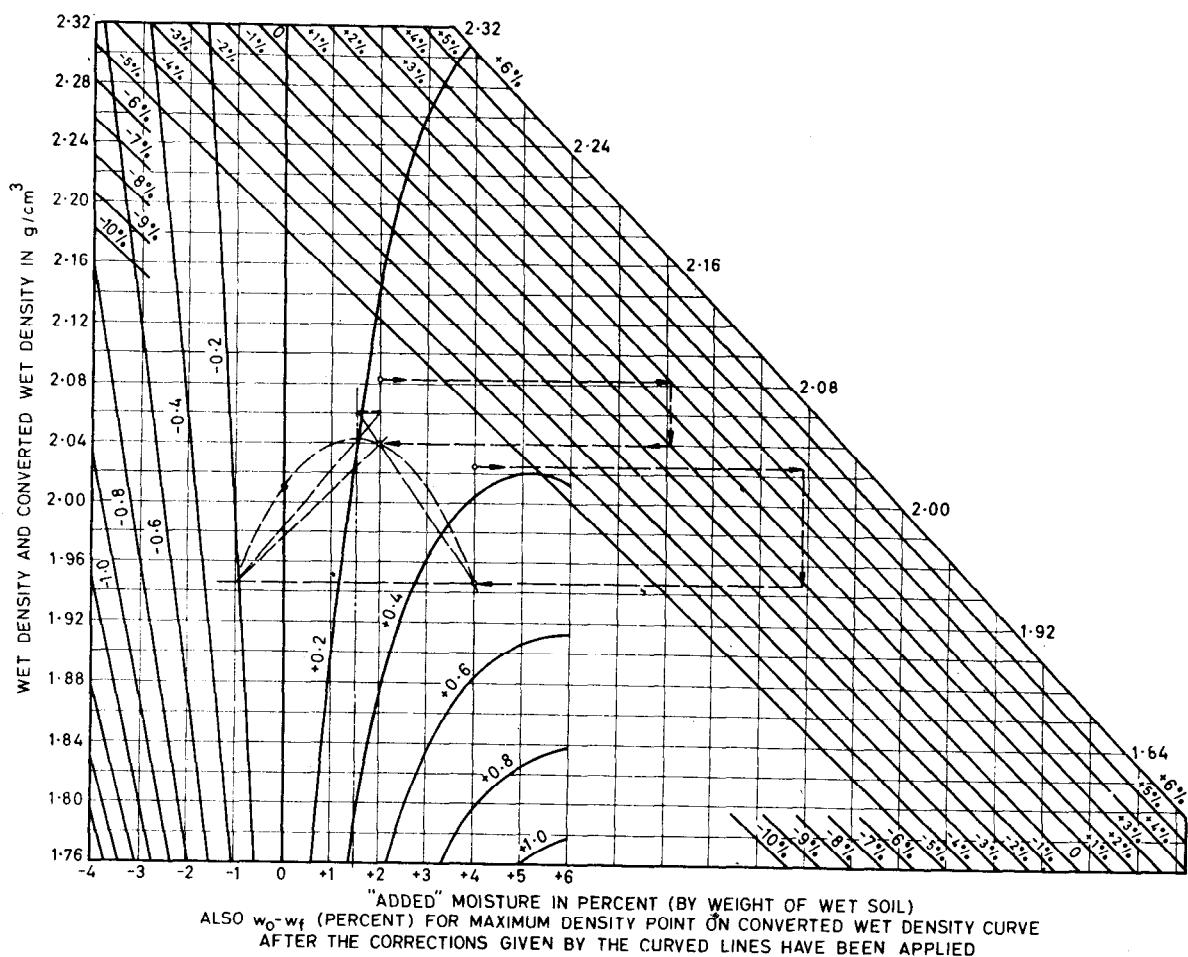
3.5 Three plotted points are sufficient if both the left and the right points are lower in ordinate than the centre point, if not, obtain one or more additional points as required (see Note).

NOTE — For pavement construction, where the water content range is usually wider than in dam construction, it may be necessary to use more than three points or the increments (plus and minus) may need to be more than 2 percent.

4. CALCULATIONS

4.1 Solutions Using Table 3 (see Note 1) — Where the points obtained are spaced 2 percent apart, the coordinates of the maximum density point of the converted wet density curve may be obtained from Table 3 as follows (interpolating, as necessary):

- Designate each point successively from left to right as A, B and C.
- Subtract the converted wet density of point A from the corresponding values for point B and point C, paying attention to the sign of the



Example:

$$RC = 99.3\%$$

$$C = 101.0\%$$

$$w_o - w_f = 1.7\% \quad (1.5 \text{ from the plot} + 0.2 \text{ from the moisture correction curves})$$

$$\text{Field moisture content, } w_f = 16.5\%$$

$$\text{Field dry density*} = 1.74 \text{ g/cm}^3$$

$$\text{Lab. maximum dry density} = 1.76 \text{ "}$$

$$\text{Cylinder dry density} = 1.72 \text{ "}$$

$$\text{Optimum moisture content, } w_o = 18.2\% \dagger$$

* Of material passing the specified IS Sieve.

† As calculated from the formula:

$$w_o = w_f + Z_m \left[1 + \frac{w_f}{100} \right]$$

(Explanations of symbols are as in 4.1 and figure in Table 3B)

FIG. 1 WET DENSITY AND CONVERTED WET DENSITY *versus* 'ADDED' MOISTURE

- differences. These differences are termed Y_2 and Y_4 respectively.
- c) Find the values of X_m and Y_m at the intersection of the values for Y_2 and Y_4 . Y_4 can be positive or negative (negative values of Y_4 appear in Table 3A and positive values in Table 3B). The values X_m and Y_m are the coordinates of the maximum density point of the converted wet density curve. The origin of the coordinates is at point A , the extreme left point of the curve.

- d) Calculate the maximum converted wet density by adding Y_m to the converted wet density of point A .
- e) Calculate the water content difference (Z_m) for the maximum density point by adding X_m to the water content difference of point A . Obtain the water content correction from the nearest correction curve (see Note 2), interpolating to 0.1 percent.
- f) Calculate the difference between the optimum moisture content (w_o) and the field water

content (w_f) by adding the water content correction to the water content difference (Z_m) for the maximum density point. Record the value as $w_o - w_f$.

- g) Calculate the relative compaction (RC) by dividing the field wet density by the peak converted wet density.
- h) Calculate the compaction ratio (C) (also known as roller or compaction efficiency) by dividing the wet density of the soil (field density) by the wet density of the specimen compacted at the field water content (first cylinder).
- j) If the water content of the first cylinder is known (w_f) (see Note 3 under 3.2), as determined in accordance with IS: 2720 (Part 2)-1973, calculate the field dry density, the cylinder dry density, the laboratory maximum dry density and the optimum moisture content as follows:

1) Field dry density =
field wet density

$$\left[1 + \frac{w_f}{100} \right]$$

2) Cylinder dry density =
wet density of first specimen

$$\left[1 + \frac{w_f}{100} \right]$$

3) Laboratory maximum dry density =
maximum converted wet density

$$\left[1 + \frac{w_f}{100} \right]$$

4) Optimum moisture content (OMC) =

$$= w_f + \left[1 + \frac{w_f}{100} \right] Z_m$$

where

w_f and Z_m are expressed as percentages.

NOTE 1 — The method given in 4.1 cannot be used for finding the maximum point of the parabolic converted wet density *versus* 'added' water content curve when:

- a) water is 'added' in other than 2 percent increments; and
- b) the differences in wet density between the driest point and each of the other two exceeds 0.08 g/cm³, that is, when the values of Y_2 and Y_4 exceed 0.08 g/cm³. (For greater differences, use the table or mathematical formulae given in the reference mentioned in 0.1.1.)

NOTE 2 — Because 'added' water is calculated as a percentage of the wet weight of the soil, the water actually added or subtracted is not water content as defined in IS : 2720 (Part 2)-1973. Hence,

a correction is needed to allow for this fact. The correction curves plotted in Fig. 1 are employed for making necessary adjustments. These curves are for standard compaction and cover a wide range of soils.

For modified compaction or for soils with very high or low values of laboratory maximum dry density and corresponding optimum water contents, the preparation of special curves may be required. If $w_o - w_f$ is consistently different from the difference between w_o [as calculated by the relationship in 4.1 (j) (1)] and the water content of the first cylinder, calculate the positions of appropriate new correction curves as described in the reference given in 0.1.1.

4.2 Solution Using Graphical Methods — Because the determination of the maximum ordinate of the converted wet density *versus* 'added' water content curve is similar to determining the maximum dry density from a dry density *versus* water content curve, graphical methods may be used in all circumstances, and are particularly applicable when the water content differences are not exactly 2 percent. In many instances, the peak point may be found with sufficient accuracy by drawing a smooth curve approximating a parabola through the plotted points. The use of a true parabolic curve, although not essential, nevertheless provides a unique value for the peak point without sketching and interpretation of the curve. Graphical procedures for determining the peak points of true parabolic curves through three points are given in Appendix A.

5. REPORTING

5.1 When the Test is Moisture Control Only — Report the difference between optimum moisture content and field water content ($w_o - w_f$) to the nearest 0.5 percent or less, if required.

5.2 When the Test is for Both Density and Water Content Control — Report the following:

- a) The difference between optimum moisture content and field water content ($w_o - w_f$) rounded to the first place of decimal.
 - b) The relative compaction (RC) and the compaction ratio (C) rounded to the first place of decimal.
- When the field water content is available (usually the next day), report this result, and also
- c) The optimum moisture content (OMC) rounded to the first place of decimal.
 - d) The field dry density, the cylinder dry density and the laboratory maximum dry density rounded to two decimal places in g/cm³.

5.3 When the Test is for Density Control Only — Report the relative compaction (RC) rounded to the first place of decimal.

APPENDIX A

(Clause 4.2)

GRAPHICAL METHOD FOR THE DETERMINATION OF PEAK POINTS OF TRUE PARABOLIC CURVES THROUGH THREE POINTS**A-1. GRAPHICAL SOLUTION FOR PEAK POINT OF PARABOLA (THE MAXIMUM DENSITY POINT ON THE CONVERTED WET DENSITY CURVE) GIVEN THREE POINTS EQUALLY SPACED HORIZONTALLY****A-1.1** Proceed as follows (see Fig. 2):

- Draw a horizontal base line through the right point *C*.
 - Find *G*, the mid-point on the vertical between the base line and the left point *A*.
 - Find *H*, the intersection of the base line and the extension of *BG*. Find *X*, the mid-point of *CH*. The vertical through *X* is the axis of the parabola.
 - Find *J*, the intersection of the axis and the extension of *CB*. Project *J* horizontally to *K* on the vertical through *B*.
 - Find *O*, the intersection of *HK* and the axis. *O* is the peak point of the parabola.
- Alternatively, draw the base line through the left point *A*. Continue as above but from the reverse side.

A-2. GRAPHICAL SOLUTION FOR PEAK POINT OF PARABOLA (THE MAXIMUM DENSITY POINT ON THE CONVERTED WET DENSITY CURVE) GIVEN THREE POINTS UNEQUALLY SPACED HORIZONTALLY**A-2.1** Proceed as follows (see Fig. 3):

- Draw a horizontal base line through the left point *A*. Find *D* on the base line vertically below *B*.
- Draw *DE* parallel to *AB*. *E* is on the vertical through *C*. Project *E* horizontally to *F* on the vertical through *B*.
- Draw *DG* parallel to *AC*. *G* is on the vertical through *C*.
- Find *H*, the intersection of the base line and the extension of *FG*. Find *X*, the mid point of *AH*. The vertical through *X* is the axis of the parabola.
- Find *J*, the intersection of the axis and the extension of *AB*. Project *J* horizontally to *K* on the vertical through *B*.
- Find *O*, the intersection of *HK* and the axis. *O* is the peak point of the parabola.

If *A*, *B* and *C* are equally spaced horizontally, as they are when moisture changes are exactly 2 percent, *F* coincides with *B* and *G* is midway between *C* and the base line. The construction is then the simple reverse of Fig. 2.

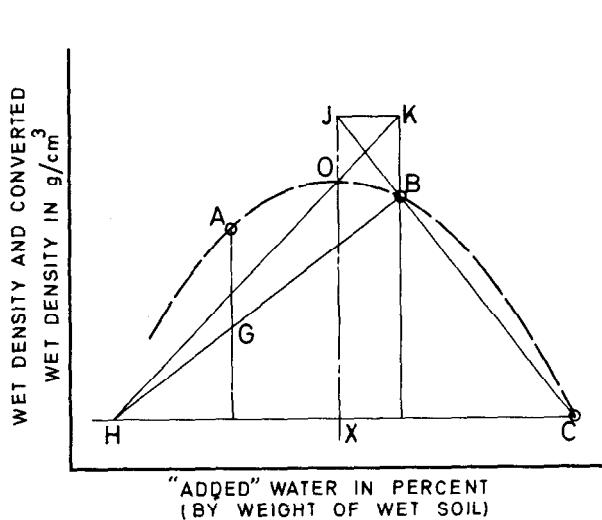


FIG. 2 GRAPHICAL SOLUTION GIVEN THREE POINTS EQUALLY SPACED HORIZONTALLY

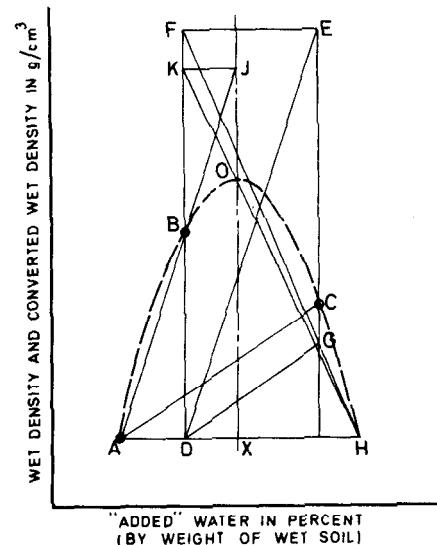


FIG. 3 GRAPHICAL SOLUTION GIVEN THREE POINTS UNEQUALLY SPACED HORIZONTALLY

TABLE 1 CONVERTED WET DENSITY, GIVEN WET DENSITY AND 'ADDED' MOISTURE
(Clause 3.3)

Use of Table : Locate the wet density value in column marked 'x'. Depending on whether the 'added' moisture is -4, -2, +2 or +4 percent, find the 'converted wet density' within the appropriate section of the table at the intersection of either the 96, 98, 102 or 104 column, respectively and the row in which the wet density value appears.

x	96	98	102	104
(1)	(2)	(3)	(4)	(5)
1.500	1.563	1.531	1.471	1.442
1.505	1.568	1.536	1.475	1.447
1.510	1.573	1.541	1.480	1.452
1.515	1.578	1.546	1.485	1.457
1.520	1.583	1.551	1.490	1.462
1.525	1.589	1.556	1.495	1.466
1.530	1.594	1.561	1.500	1.471
1.535	1.599	1.566	1.505	1.476
1.540	1.604	1.571	1.510	1.481
1.545	1.609	1.577	1.515	1.486
1.550	1.615	1.582	1.520	1.490
1.555	1.620	1.587	1.525	1.495
1.560	1.625	1.592	1.529	1.500
1.565	1.630	1.597	1.534	1.505
1.570	1.635	1.602	1.539	1.510
1.575	1.641	1.607	1.544	1.514
1.580	1.646	1.612	1.549	1.519
1.585	1.651	1.617	1.554	1.524
1.590	1.656	1.622	1.559	1.529
1.595	1.661	1.628	1.564	1.534
1.600	1.667	1.633	1.569	1.538
1.605	1.672	1.638	1.574	1.543
1.610	1.677	1.643	1.578	1.548
1.615	1.682	1.648	1.583	1.553
1.620	1.686	1.653	1.588	1.558
1.625	1.693	1.658	1.593	1.593
1.630	1.698	1.663	1.598	1.567
1.635	1.703	1.668	1.603	1.572
1.640	1.708	1.673	1.608	1.577
1.645	1.714	1.679	1.613	1.582
1.650	1.719	1.684	1.618	1.587
1.655	1.724	1.689	1.623	1.591
1.660	1.729	1.694	1.627	1.596
1.665	1.734	1.699	1.632	1.601
1.670	1.740	1.704	1.637	1.606
1.675	1.745	1.709	1.642	1.611
1.680	1.750	1.714	1.647	1.615
1.685	1.755	1.719	1.652	1.620
1.690	1.760	1.724	1.657	1.625
1.695	1.766	1.730	1.662	1.630
1.700	1.771	1.735	1.667	1.635
1.705	1.776	1.740	1.672	1.639
1.710	1.781	1.745	1.676	1.649
1.715	1.786	1.750	1.681	1.649
1.720	1.792	1.755	1.686	1.654
1.725	1.797	1.760	1.691	1.659
1.730	1.802	1.765	1.696	1.663
1.735	1.807	1.770	1.701	1.668

(Continued)

TABLE 1 CONVERTED WET DENSITY, GIVEN WET DENSITY AND 'ADDED' MOISTURE — *Contd*

x	96	98	102	104
(1)	(2)	(3)	(4)	(5)
1.740	1.813	1.776	1.706	1.673
1.745	1.818	1.781	1.711	1.678
1.750	1.823	1.786	1.716	1.683
1.755	1.828	1.791	1.721	1.688
1.760	1.833	1.796	1.725	1.692
1.765	1.834	1.801	1.730	1.697
1.770	1.844	1.806	1.735	1.702
1.775	1.849	1.811	1.740	1.707
1.780	1.854	1.816	1.745	1.712
1.785	1.859	1.821	1.750	1.716
1.790	1.865	1.827	1.755	1.721
1.795	1.870	1.832	1.760	1.726
1.800	1.875	1.837	1.765	1.731
1.805	1.880	1.842	1.770	1.736
1.810	1.885	1.847	1.775	1.740
1.815	1.891	1.852	1.779	1.745
1.820	1.896	1.857	1.784	1.750
1.825	1.901	1.862	1.789	1.755
1.830	1.906	1.867	1.794	1.760
1.835	1.911	1.872	1.799	1.764
1.840	1.917	1.878	1.804	1.769
1.845	1.922	1.883	1.809	1.774
1.850	1.927	1.888	1.814	1.779
1.855	1.932	1.893	1.819	1.784
1.860	1.938	1.898	1.824	1.788
1.865	1.943	1.903	1.828	1.793
1.870	1.948	1.908	1.833	1.798
1.875	1.953	1.913	1.838	1.803
1.880	1.958	1.918	1.843	1.808
1.885	1.963	1.923	1.848	1.813
1.890	1.969	1.929	1.853	1.817
1.895	1.974	1.934	1.858	1.822
1.900	1.979	1.939	1.863	1.827
1.905	1.984	1.944	1.868	1.832
1.910	1.990	1.949	1.872	1.837
1.915	1.995	1.954	1.877	1.841
1.920	2.000	1.959	1.882	1.846
1.925	2.005	1.964	1.887	1.851
1.930	2.010	1.969	1.892	1.856
1.935	2.016	1.974	1.897	1.861
1.940	2.021	1.980	1.902	1.865
1.945	2.026	1.985	1.907	1.870
1.950	2.031	1.990	1.912	1.875
1.955	2.036	1.995	1.917	1.880
1.960	2.042	2.000	1.922	1.885
1.965	2.047	2.005	1.926	1.889
1.970	2.052	2.010	1.931	1.894
1.975	2.057	2.015	1.936	1.899
1.980	2.063	2.020	1.941	1.904
1.985	2.068	2.026	1.946	1.909
1.990	2.073	2.031	1.951	1.913
1.995	2.078	2.036	1.956	1.918

(Continued)

TABLE 1 CONVERTED WET DENSITY, GIVEN WET DENSITY AND 'ADDED' MOISTURE — *Contd*

<i>x</i>	96	98	102	104
(1)	(2)	(3)	(4)	(5)
2.000	2.083	2.041	1.961	1.923
2.005	2.089	2.046	1.996	1.928
2.010	2.094	2.051	1.971	1.933
2.015	2.099	2.056	1.975	1.938
2.020	2.104	2.061	1.980	1.942
2.025	2.109	2.066	1.985	1.947
2.030	2.115	2.071	1.990	1.952
2.035	2.120	2.077	1.995	1.957
2.040	2.125	2.082	2.000	1.962
2.045	2.130	2.087	2.005	1.966
2.050	2.135	2.092	2.010	1.971
2.055	2.141	2.097	2.015	1.976
2.060	2.146	2.102	2.020	1.981
2.065	2.151	2.107	2.025	1.986
2.070	2.156	2.112	2.029	1.990
2.075	2.161	2.117	2.034	1.995
2.080	2.167	2.122	2.039	2.000
2.085	2.172	2.128	2.044	2.005
2.090	2.177	2.133	2.049	2.010
2.095	2.182	2.138	2.053	2.014
2.100	2.188	2.143	2.059	2.019
2.105	2.193	2.148	2.064	2.024
2.110	2.198	2.153	2.069	2.029
2.115	2.203	2.158	2.074	2.034
2.120	2.208	2.163	2.078	2.038
2.125	2.214	2.168	2.083	2.043
2.130	2.219	2.173	2.088	2.048
2.135	2.224	2.179	2.093	2.053
2.140	2.229	2.184	2.098	2.058
2.145	2.234	2.189	2.103	2.063
2.150	2.240	2.194	2.108	2.067
2.155	2.245	2.199	2.113	2.072
2.160	2.250	2.204	2.118	2.077
2.165	2.255	2.209	2.123	2.082
2.170	2.260	2.214	2.127	2.087
2.175	2.266	2.219	2.132	2.091
2.180	2.271	2.224	2.137	2.096
2.185	2.276	2.230	2.142	2.101
2.190	2.281	2.235	2.147	2.106
2.195	2.286	2.240	2.152	2.111
2.200	2.292	2.245	2.157	2.115
2.205	2.292	2.245	2.162	2.120
2.210	2.302	2.255	2.167	2.125
2.215	2.307	2.260	2.172	2.130
2.220	2.313	2.265	2.176	2.135
2.225	2.318	2.270	2.181	2.139
2.230	2.323	2.276	2.186	2.144
2.235	2.328	2.281	2.191	2.149
2.240	2.333	2.286	2.196	2.154
2.245	2.339	2.291	2.201	2.159
2.250	2.344	2.296	2.206	2.163

TABLE 2 PERCENTAGE WATER LOSS CORRESPONDING TO MASS OF DRIED SOIL
(Clause 3.4.2)

A. For 2.50 kg of moist soil		B. For 3.70 kg of moist soil	
DRIED MASS (1)	PERCENT (2)	DRIED MASS (1)	PERCENT (2)
2.495	-0.20	2.405	-3.80
2.490	-0.40	2.400	-4.00
2.485	-0.60	2.395	-4.20
2.480	-0.80	2.390	-4.40
2.475	-1.00	2.385	-4.60
2.470	-1.20	2.380	-4.80
2.465	-1.40	2.375	-5.00
2.460	-1.60	2.370	-5.20
2.455	-1.80	2.365	-5.40
2.450	-2.00	2.360	-5.60
2.445	-2.20	2.355	-5.80
2.440	-2.40	2.350	-6.00
2.435	-2.60	2.345	-6.20
2.430	-2.80	2.340	-6.40
2.425	-3.00	2.335	-6.60
2.420	-3.20	2.330	-6.80
2.415	-3.40	2.325	-7.00
2.410	-3.60		
B. For 3.70 kg of moist soil			
3.695	-0.14	3.600	-2.70
3.690	-0.27	3.595	-2.84
3.685	-0.41	3.590	-2.97
3.680	-0.54	3.585	-3.11
3.675	-0.68	3.580	-3.24
3.670	-0.81	3.575	-3.38
3.665	-0.95	3.570	-3.51
3.660	-1.08	3.565	-3.65
3.655	-1.22	3.560	-3.78
3.650	-1.35	3.555	-3.92
3.645	-1.49	3.550	-4.05
3.640	-1.62	3.545	-4.19
3.635	-1.76	3.540	-4.32
3.630	-1.89	3.535	-4.46
3.625	-2.03	3.530	-4.59
3.620	-2.16	3.525	-4.73
3.615	-2.30	3.520	-4.86
3.610	-2.43	3.515	-5.00
3.605	-2.57		

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TABLE 3 COORDINATES OF MAXIMUM DENSITY POINT ON CONVERTED WET DENSITY CURVE
(Clause 4.1)

		A. Negative Values of γ_4																			
Values of γ_4	X_m γ_m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
		0.010	0.009	0.009	0.008	0.008	0.007	0.006	0.006	0.005	0.004	0.004	0.003	0.003	0.002	0.001	0.001	0.001	0.001	0.001	
0.005	X_m γ_m	1.11 0.014	1.12 0.013	1.13 0.013	1.13 0.012	1.14 0.011	1.15 0.011	1.17 0.010	1.18 0.010	1.20 0.009	1.22 0.008	1.25 0.008	1.29 0.007	1.33 0.007	1.36 0.007	1.40 0.012	1.44 0.012	1.50 0.011	1.57 0.011	1.67 0.010	1.50 0.010
		1.20 0.018	1.21 0.017	1.22 0.017	1.24 0.016	1.25 0.016	1.27 0.015	1.29 0.014	1.31 0.014	1.33 0.013	1.36 0.013	1.40 0.012	1.44 0.012	1.48 0.012	1.52 0.012	1.57 0.012	1.62 0.012	1.67 0.012	1.73 0.012	1.80 0.012	1.89 0.012
0.010	X_m γ_m	1.27 0.022	1.29 0.022	1.30 0.021	1.32 0.021	1.33 0.020	1.35 0.019	1.38 0.019	1.40 0.018	1.43 0.018	1.46 0.017	1.50 0.017	1.55 0.016	1.60 0.016	1.67 0.016	1.75 0.016	1.80 0.015	1.86 0.015	1.86 0.015	1.80 0.015	1.80 0.015
		1.33 0.027	1.35 0.026	1.36 0.026	1.38 0.025	1.40 0.025	1.42 0.024	1.44 0.023	1.47 0.023	1.50 0.023	1.53 0.022	1.57 0.022	1.62 0.022	1.67 0.022	1.73 0.022	1.80 0.022	1.89 0.022	1.89 0.022	1.80 0.022	1.80 0.022	1.80 0.022
0.015	X_m γ_m	1.38 0.031	1.40 0.031	1.42 0.030	1.43 0.030	1.45 0.029	1.48 0.029	1.50 0.028	1.53 0.028	1.56 0.027	1.59 0.027	1.63 0.026	1.67 0.026	1.71 0.026	1.77 0.025	1.83 0.025	1.91 0.025	1.88 0.025	1.88 0.025	1.88 0.025	1.88 0.025
		1.43 0.036	1.44 0.035	1.46 0.035	1.48 0.034	1.50 0.034	1.52 0.033	1.55 0.033	1.57 0.032	1.60 0.032	1.63 0.032	1.67 0.031	1.71 0.031	1.75 0.031	1.80 0.030	1.86 0.030	1.92 0.030	1.92 0.030	1.92 0.030	1.92 0.030	1.92 0.030
0.020	X_m γ_m	1.47 0.040	1.48 0.040	1.50 0.039	1.52 0.039	1.54 0.038	1.56 0.038	1.58 0.038	1.61 0.037	1.64 0.037	1.67 0.036	1.70 0.036	1.74 0.036	1.78 0.036	1.82 0.035	1.88 0.035	1.93 0.035	1.88 0.035	1.88 0.035	1.88 0.035	1.88 0.035
		1.50 0.045	1.52 0.045	1.53 0.044	1.55 0.044	1.57 0.043	1.59 0.043	1.62 0.042	1.64 0.042	1.67 0.042	1.70 0.041	1.73 0.041	1.76 0.041	1.80 0.040	1.84 0.040	1.89 0.040	1.94 0.040	1.94 0.040	1.94 0.040	1.94 0.040	1.94 0.040
0.025	X_m γ_m	1.53 0.050	1.55 0.049	1.56 0.049	1.58 0.048	1.60 0.048	1.62 0.048	1.64 0.047	1.67 0.047	1.69 0.047	1.72 0.046	1.75 0.046	1.78 0.046	1.82 0.045	1.86 0.045	1.90 0.045	1.95 0.045	1.95 0.045	1.95 0.045	1.95 0.045	1.95 0.045
		1.56 0.054	1.57 0.054	1.59 0.054	1.61 0.053	1.63 0.053	1.65 0.052	1.67 0.052	1.69 0.052	1.71 0.051	1.73 0.051	1.77 0.051	1.80 0.050	1.83 0.050	1.87 0.050	1.91 0.050	1.95 0.050	1.95 0.050	1.95 0.050	1.95 0.050	1.95 0.050
0.030	X_m γ_m	1.58 0.059	1.59 0.059	1.61 0.058	1.63 0.058	1.65 0.058	1.67 0.057	1.69 0.057	1.71 0.057	1.73 0.057	1.75 0.056	1.78 0.056	1.81 0.055	1.85 0.055	1.89 0.055	1.92 0.055	1.95 0.055	1.95 0.055	1.95 0.055	1.95 0.055	1.95 0.055
		1.60 0.064	1.62 0.064	1.63 0.063	1.65 0.063	1.67 0.062	1.69 0.062	1.71 0.062	1.73 0.062	1.75 0.061	1.77 0.061	1.80 0.061	1.83 0.061	1.86 0.060	1.89 0.060	1.92 0.060	1.96 0.060	1.96 0.060	1.96 0.060	1.96 0.060	1.96 0.060
0.035	X_m γ_m	1.62 0.069	1.63 0.068	1.65 0.068	1.67 0.068	1.68 0.067	1.70 0.067	1.72 0.067	1.74 0.067	1.76 0.066	1.79 0.066	1.81 0.066	1.84 0.065	1.87 0.065	1.90 0.065	1.93 0.065	1.96 0.065	1.96 0.065	1.96 0.065	1.96 0.065	1.96 0.065
		1.64 0.074	1.65 0.073	1.67 0.073	1.68 0.073	1.70 0.072	1.72 0.072	1.74 0.072	1.76 0.072	1.78 0.071	1.80 0.071	1.82 0.071	1.85 0.070	1.88 0.070	1.90 0.070	1.93 0.070	1.97 0.070	1.97 0.070	1.97 0.070	1.97 0.070	1.97 0.070
0.040	X_m γ_m	1.65 0.078	1.67 0.078	1.68 0.078	1.70 0.077	1.71 0.077	1.73 0.077	1.75 0.077	1.77 0.076	1.79 0.076	1.81 0.076	1.83 0.075	1.86 0.075	1.88 0.075	1.91 0.075	1.94 0.075	1.97 0.075	1.97 0.075	1.97 0.075	1.97 0.075	1.97 0.075
		1.67 0.083	1.68 0.083	1.70 0.083	1.71 0.082	1.73 0.082	1.74 0.082	1.76 0.081	1.78 0.081	1.80 0.081	1.82 0.081	1.84 0.081	1.86 0.080	1.88 0.080	1.91 0.080	1.94 0.080	1.97 0.080	1.97 0.080	1.97 0.080	1.97 0.080	1.97 0.080
		-0.080	-0.075	-0.070	-0.065	-0.060	-0.055	-0.050	-0.045	-0.040	-0.035	-0.030	-0.025	-0.020	-0.015	-0.010	-0.005				

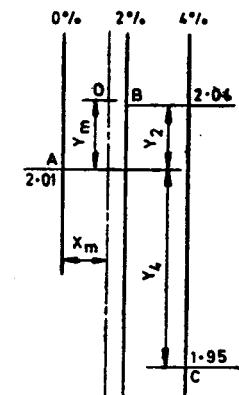
Values of γ_4 (Negative values)

(Continued)

TABLE 3 COORDINATES OF MAXIMUM DENSITY POINT ON CONVERTED WET DENSITY CURVE — Contd.

B. Positive Values of γ

Values of γ_1	X_m	Y_m											
	X_m	Y_m											
0	—	—											
0.005	X_m	Y_m	2.00	3.00									
			0.005	0.006									
0.010	X_m	Y_m	2.00	2.33	3.00								
			0.010	0.010	0.011								
0.015	X_m	Y_m	2.00	2.20	2.50	3.00							
			0.015	0.015	0.016	0.017							
0.020	X_m	Y_m	2.00	2.14	2.33	2.60	3.00						
			0.020	0.020	0.020	0.021	0.023						
0.025	X_m	Y_m	2.00	2.11	2.25	2.43	2.67	3.00					
			0.025	0.025	0.025	0.026	0.027	0.028					
0.030	X_m	Y_m	2.00	2.09	2.20	2.33	2.50	2.71	3.00				
			0.030	0.030	0.030	0.031	0.031	0.032	0.034				
0.035	X_m	Y_m	2.00	2.08	2.17	2.27	2.40	2.56	2.75	3.00			
			0.035	0.035	0.035	0.036	0.036	0.037	0.038	0.039			
0.040	X_m	Y_m	2.00	2.07	2.14	2.23	2.33	2.45	2.60	2.78	3.00		
			0.040	0.040	0.040	0.040	0.041	0.041	0.042	0.043	0.045		
0.045	X_m	Y_m	2.00	2.06	2.13	2.20	2.29	2.38	2.50	2.64	2.80	3.00	
			0.045	0.045	0.045	0.045	0.046	0.046	0.047	0.048	0.049	0.051	
0.050	X_m	Y_m	2.00	2.05	2.11	2.18	2.25	2.33	2.43	2.54	2.67	2.82	3.00
			0.050	0.050	0.050	0.050	0.051	0.051	0.052	0.052	0.053	0.055	0.056
0.055	X_m	Y_m	2.00	2.05	2.10	2.16	2.22	2.29	2.38	2.47	2.57	2.69	2.83
			0.055	0.055	0.055	0.055	0.056	0.056	0.056	0.057	0.058	0.059	0.062
0.060	X_m	Y_m	2.00	2.04	2.09	2.14	2.20	2.26	2.33	2.41	2.50	2.60	2.71
			0.060	0.060	0.060	0.060	0.061	0.061	0.061	0.062	0.063	0.063	0.068
0.065	X_m	Y_m	2.00	2.04	2.08	2.13	2.18	2.24	2.30	2.37	2.44	2.53	2.63
			0.065	0.065	0.065	0.065	0.065	0.066	0.066	0.067	0.067	0.068	0.073
0.070	X_m	Y_m	2.00	2.04	2.08	2.12	2.17	2.22	2.27	2.33	2.40	2.47	2.56
			0.070	0.070	0.070	0.070	0.070	0.071	0.071	0.071	0.072	0.073	0.074
0.075	X_m	Y_m	2.00	2.03	2.07	2.11	2.15	2.20	2.25	2.30	2.36	2.43	2.50
			0.075	0.075	0.075	0.075	0.075	0.076	0.076	0.076	0.077	0.078	0.079
0.080	X_m	Y_m	2.00	2.03	2.07	2.10	2.14	2.19	2.23	2.28	2.33	2.39	2.45
			0.080	0.080	0.080	0.080	0.080	0.081	0.081	0.081	0.082	0.083	0.084



Tabulated values are coordinates (upper value X_m , lower value Y_m) of the peak point (maximum density point on converted wet density curve) of a parabola whose axis is vertical, given three points A , B , and C spaced 2 percent apart horizontally. The origin of coordinates is at point A , the extreme left point.

γ_2 is the ordinate of point B minus ordinate of point A . γ_4 is the ordinate of point C minus ordinate of point A . γ_4 may be negative.

Example:

$$Y_3 = 2.04 - 2.01 = 0.03$$

$$Y_4 = 1.95 - 2.01 = -0.06$$

From table, $X_m = 1.5$; $\gamma_m = 0.034$

$$\begin{aligned}\text{Ordinate of point } O &= \text{Ordinate of point } A + Y_m \\ &= 2.01 + 0.034 \\ &= 2.044 \approx 2.04\end{aligned}$$

$$\text{Abscissa of point } O, \zeta_m = \text{Abscissa of point } A + X_m \\ = 0 + 1.5 = 1.5\%$$

NOTE — If abscissa of point A were -2% , Z_m would be $-2.0 + 1.5 = -0.5\%$.

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tive values)

SECTION 10

Determination of Shear Strength Parameter Using
(a) Direct Shear Test, (b) Triaxial Apparatus, and
(c) Vane Shear Test

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Indian Standard

SPECIFICATION FOR SHEAR BOX FOR TESTING OF SOILS

0. FOREWORD

0.1 The Indian Standards Institution has already published a series of standards on methods of testing soils. It has been recognized that reliable and intercomparable test results can be obtained only with standard testing equipment capable of giving the desired level of accuracy. The Sectional Committee has, therefore, decided to bring out a series of specifications covering the requirements of equipment used for testing soils to encourage its development and manufacture in the country.

0.2 The equipment covered in this standard is used as a part of the assembly for the equipment used for the determination of shear strength of the soil covered in IS : 2720 (Part 13)-1986.

1. SCOPE

1.1 This standard covers specification for shear box used as an assembly for the determination of shear strength of the soil with a maximum particle size of 4.75 mm.

2. GENERAL REQUIREMENTS

2.1 The shear box shall consist of the following (see Fig. 1):

- a) Upper and lower parts of shear box coupled together with two pins,
- b) Grid plates — 2 pairs,
- c) Stone plates,
- d) Base plate,
- e) Top plate,
- f) Loading pad, and
- g) Water jacket.

3. MATERIALS

3.1 The materials of the construction of the different components of shear box shall be as given in Table 1.

4. DIMENSIONS

4.1 The dimensions of the component parts of shear box shall be as detailed in Fig. 2 to 7. The tolerance to the dimensions shall be as given in IS : 2102 (Part 1)-1980 and shall be of medium class.

5. MARKING

5.1 The following information shall be clearly and indelibly marked on each part of the component:

- a) Name of the manufacturer or his registered trade-mark,
- b) Type of material, and
- c) Date of manufacture.

5.1.1 The equipment may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors may be obtained from the Indian Standards Institution.

TABLE 1 MATERIAL OF CONSTRUCTION OF DIFFERENT COMPONENT PARTS OF SHEAR BOX
(Clause 3.1)

PART	MATERIAL	REFERENCE TO INDIAN STANDARD
Upper and lower parts of shear box coupled together with two pins	Mild steel/Brass	IS : 513-1973*/IS : 292-1983‡
Grid plates — two pairs	Mild steel/Brass	IS : 513-1973*/IS : 292-1983‡
Stone plates	Sand stone	IS : 3622-1977† of size 60 × 60 × 6 mm
Base plate	Mild steel/Brass	IS : 513-1973*/IS : 292-1983‡
Top plate	Mild steel/Brass	IS : 513-1973*/IS : 292-1983‡
Loading pad	Mild steel/Brass	IS : 513-1973*/IS : 292-1983‡
Water jacket	Mild steel/Brass	IS : 513-1973*/IS : 292-1983‡

*Specification for cold rolled carbon steel sheets (second revision).

†Specification for sandstone (slabs and tiles) (first revision).

‡Specification for brass ingots and castings (second revision).

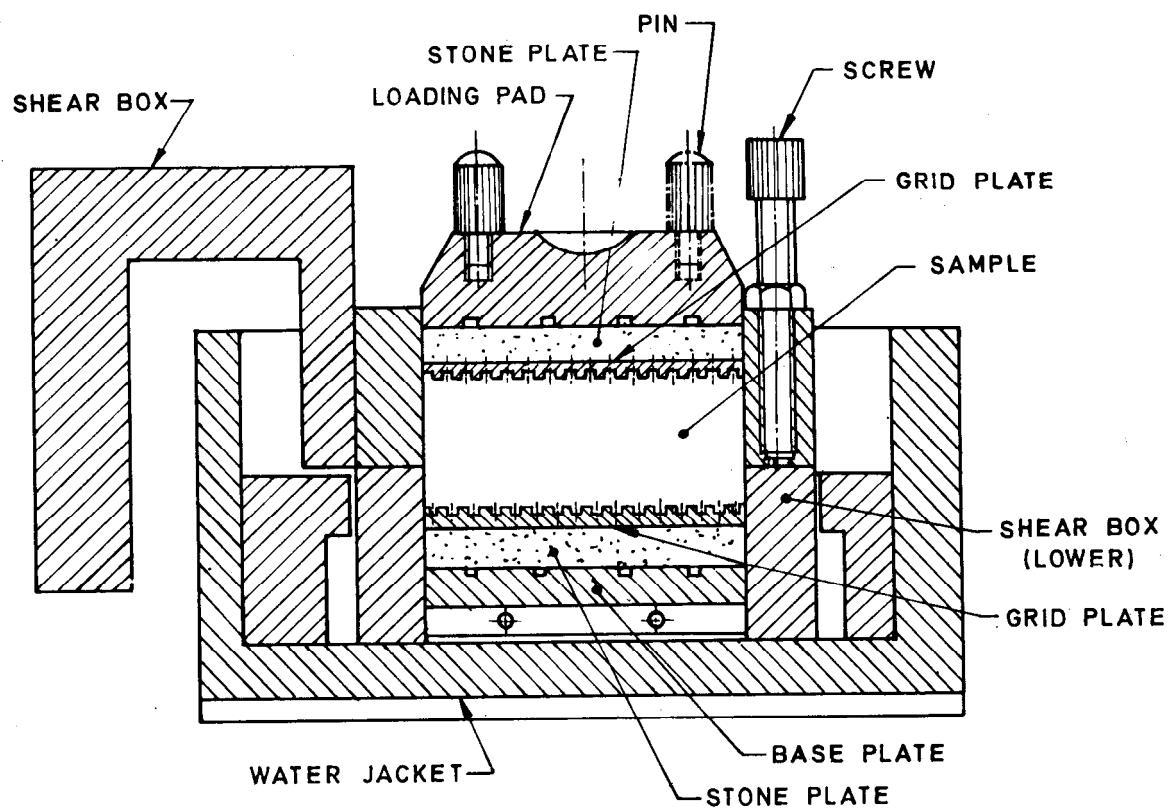
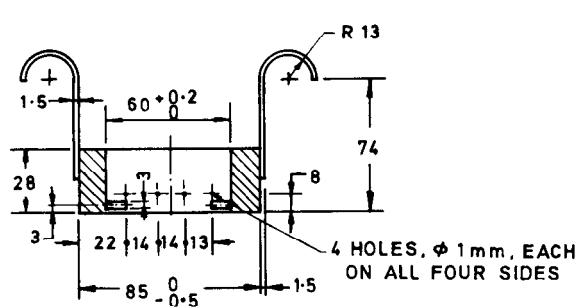
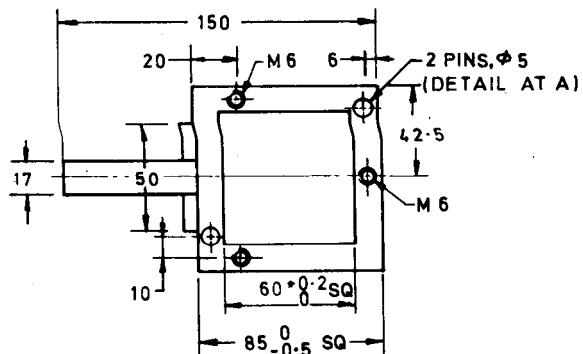
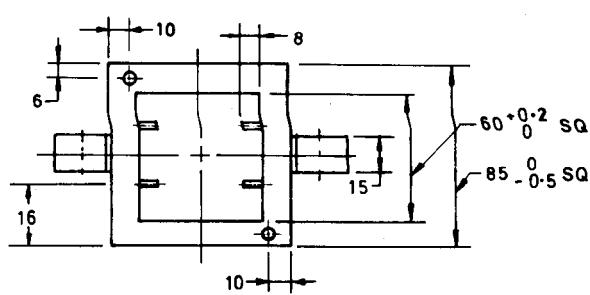
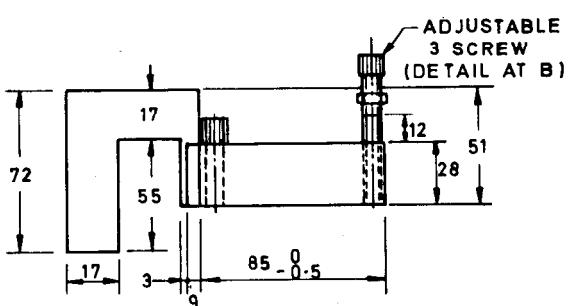
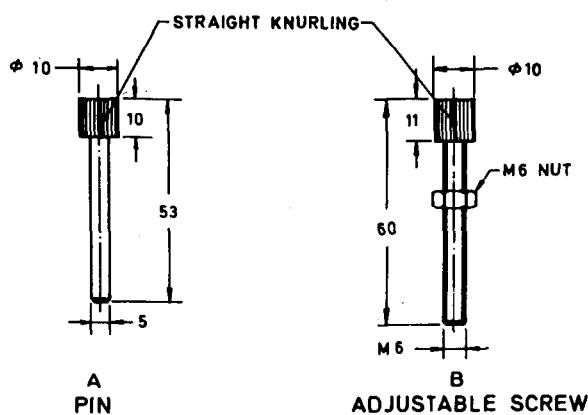
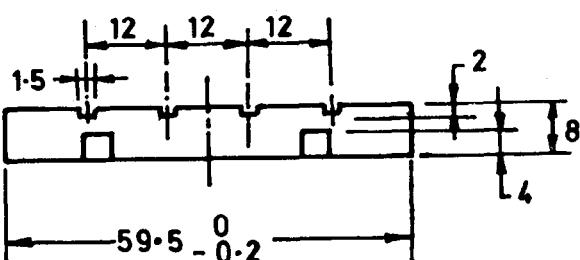
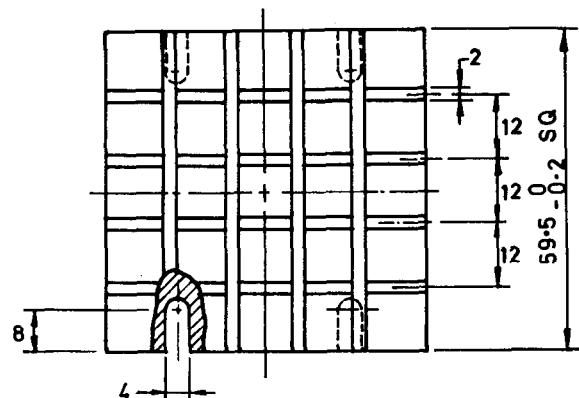


FIG. 1 SHEAR BOX ASSEMBLY

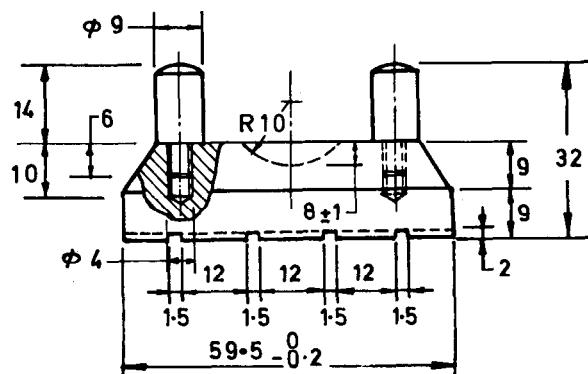
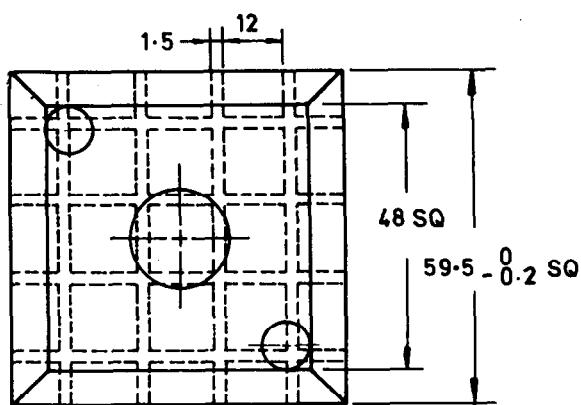
All dimensions in millimetres.
FIG. 2 SHEAR BOX - LOWER HALF WITH BOXAll dimensions in millimetres.
FIG. 3 SHEAR BOX - UPPER HALF (Continued)



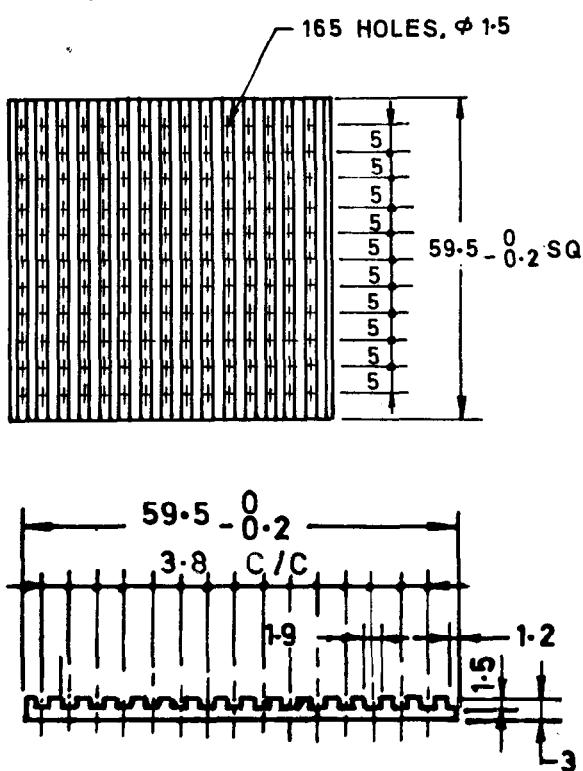
All dimensions in millimetres.
FIG. 3 SHEAR BOX—UPPER HALF



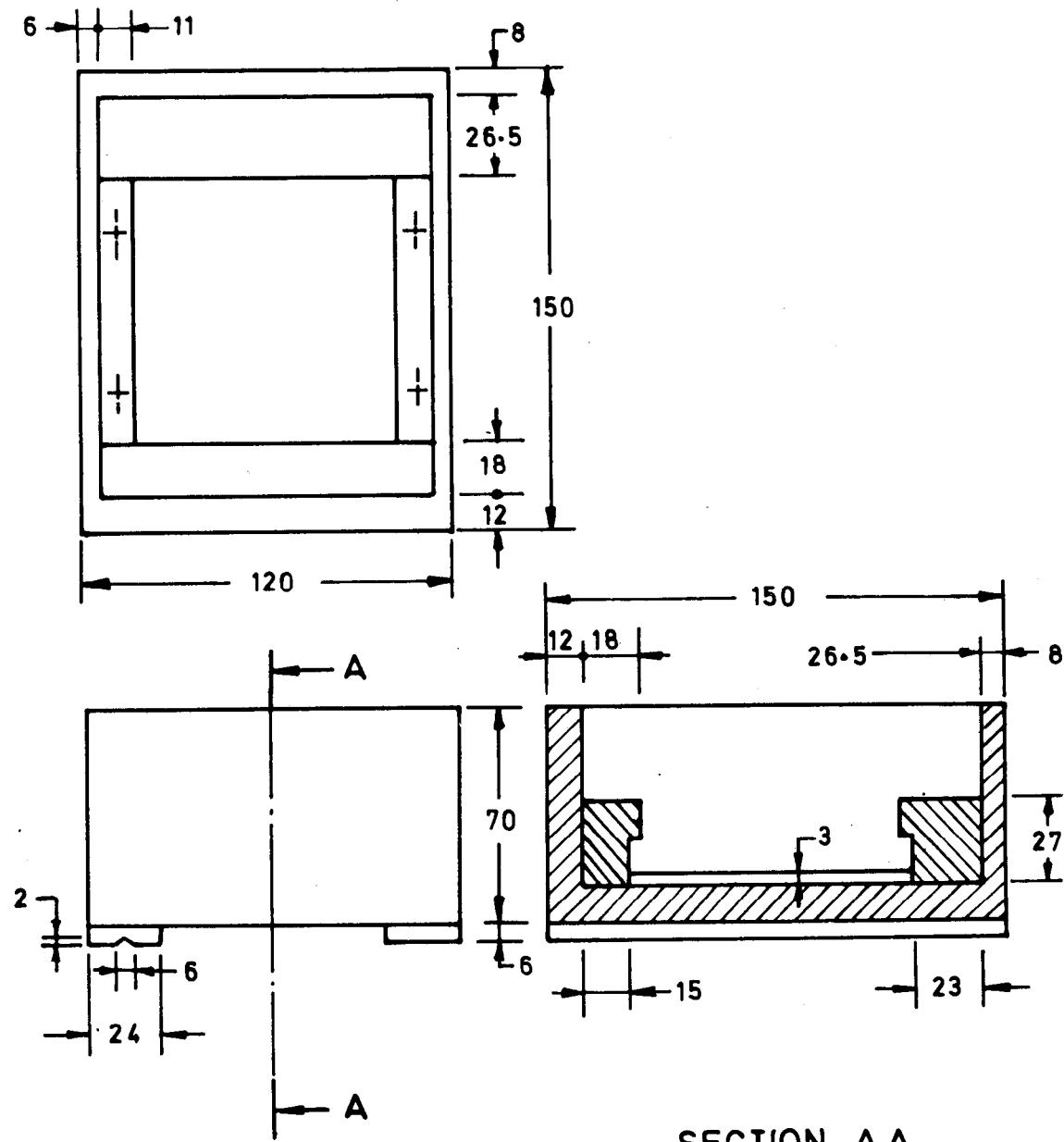
All dimensions in millimetres.
FIG. 5 BASE PLATE



All dimensions in millimetres.
FIG. 4 LOADING PAD



All dimensions in millimetres.
FIG. 6 GRID PLATE



SECTION A-A

All dimensions in millimetres.

FIG. 7 WATER JACKET

Indian Standard
METHODS OF TEST FOR SOILS
PART 13 DIRECT SHEAR TEST

(Second Revision)

0. FOREWORD

0.1 This Part 13 deals with the method for the determination of direct shear test of soils. Depending upon the application of shear load, the direct shear test is of two types, controlled stress and controlled strain. The controlled strain test is simpler and provides accurate results and is, therefore, recommended.

0.2 This standard was first published in 1965 and revised in 1972. In this revision, provisions regarding the requirements for equipment have been deleted as these have been now covered in detail in IS : 11229-1985. Opportunity has also been taken to make requirements up-to-date in respect of procedure for the test based on the experience gained in the use of this test by various laboratories in the past years.

1. SCOPE

1.1 This part (Part 13) covers the methods for determination of shear strength of soil with a maximum particle size of 4.75 mm in undrained, consolidated undrained and consolidated drained conditions.

NOTE — The undrained test can be performed only for high impermeable clays. When silty clays and silts are involved, partial drainage is inevitable. This fact should be recognized while interpreting results.

2. TERMINOLOGY

2.0 For the purpose of this standard, definition of terms given in IS : 2809-1972 shall apply.

3. APPARATUS

3.1 The shear box grid plates, porous stones, base plates, and loading pad and water jacket shall conform to IS : 11229-1985.

3.2 Loading Frame — It shall satisfy the following requirements :

- a) The vertical stress on the sample shall remain vertical and stand during the test and there shall be arrangement to measure compression.

- b) The shear stress or strain can be applied in the dividing plane of the two parts of the shear box.
- c) It shall be possible to maintain a constant rate of increase in stress during the test (irrespective of the strained rate) with arrangement to get different rates of stress increase.
- d) In case of a strain-controlled apparatus, the strain rate should remain constant irrespective of the stress. Suitable arrangement shall be provided to obtain different strain rates.
- e) No vibrations should be transmitted to the sample during the test and there should not be any loss of shear force due to friction between the loading frame and the shear box container assembly.

3.3 Weights (If Necessary) — for providing the required normal loads.

3.4 Proving Ring — Force measuring of suitable capacity, fitted with a dial-gauge accurate to 0.002 mm to measure the shear force.

NOTE — For normal testing, proving rings of 100 to 250 kg capacity, depending on the type of soil and the normal load on the sample during test, may be needed.

3.5 Micrometer Dial Gauges — Accurate to 0.01 mm. One suitably mounted to measure horizontal movement and the other suitably mounted to measure the vertical compression of the specimen.

3.6 Sample Trimmer or Core Cutter

3.7 Stop Clock

3.8 Balance — Balance of 1 kg capacity sensitive to 0.1 g.

3.9 Spatula and a Straightedge

4. PREPARATION OF SPECIMEN

4.1 Undisturbed Specimens — Specimens of required size (*see 5.1*) shall be prepared in accordance with IS : 2720 (Part 1)-1983.

4.2 Remoulded Specimens

- a) Cohesive soils may be compacted to the required density and moisture content, the

sample extracted and then trimmed to required size. Alternatively, the soil may be compacted to the required density and moisture content directly into the shear box after fixing the two halves of the shear box together by means of the fixing screws.

- b) Cohesionless soils may be tamped in the shear box itself with the base plate and grid plate or porous stone as required in place at the bottom of the box.

4.3 The cut specimen shall be weighed and trimmings obtained during cutting shall be used to obtain the moisture content. Using this information, the bulk dry density of the specimen in the shear box shall be determined.

5. PROCEDURE

5.1 Undrained Test — The shear box with the specimen, plain grid plate over the base plate at the bottom of the specimen and plain grid plate at the top of the specimen should be fitted into position in the load frame. The serrations of the grid plates should be at right angles to the direction of shear (see Note). The loading pad should be placed on the top grid plate. The water jacket should be provided so that the sample does not get dried during the test. The required normal stress should be applied and the rate of longitudinal displacement/shear stress application so adjusted that no drainage can occur in the sample during the test. The upper part of the shear box should be raised such that a gap of about 1 mm is left between the two parts of the box. The test may now be conducted by applying horizontal shear load to failure or to 20 percent longitudinal displacement, whichever occurs first. The shear load readings indicated by the proving ring assembly and the corresponding longitudinal displacements should be noted at regular intervals. If necessary, the varmical compression, if any, of the soil specimen may be measured to serve as check to ensure that drainage has not taken place from the soil specimen. At the end of the test, the specimen should be removed from the box and the final moisture content measured. A minimum of three (preferably four) tests shall be made on separate specimens of the same density.

NOTE — As porous stones are not used for the undrained tests, plain plates of equal thickness should be substituted in their place so as to maintain the shear plane in the sample in the middle of its thickness.

5.2 Consolidated Undrained Test — The apparatus should be assembled in a way similar to that given in 5.1 except that, instead of the plain grid plates, perforated grid plates and saturated porous stones should be used at the top and bottom of the specimen. The procedure is same as in 5.1 except that, after the application of normal stress, the vertical compression of the soil with time should be

recorded [see IS : 2720 (Part 15)]-1985. The shear test should be conducted only after complete consolidation has occurred under the particular normal stress. The rate of shear should be such that water does not drain from the specimen at the time of application of the shear load. At the end of the test, the specimen should be removed form the box and the final moisture content measured. A minimum of three (preferably four) tests should be made on separate specimens of the same density at different normal stresses.

5.3 Consolidated Drained Test — The shear box with sample and perforated grid plates and porous stones should be fitted into the load frame as in 5.2. After application of normal stress, which is done in increments [see IS : 2720 (Part 15)-1985], the sample should be allowed to consolidate. When the consolidation has completely occurred, the shear test should be done at such a slow rate so that at least 95 percent pore pressure dissipation occurs during the test in this calculated time factor (see Appendix A). At the end of the test, the specimen should be removed from the box and the final moisture content measured. A minimum of three (preferably four) tests should be made on separate specimens of the same density at different normal stresses.

5.4 The normal stresses to be selected for the test should correspond to the field conditions and design requirements.

6. CALCULATIONS AND REPORT

6.1 All Tests

6.1.1 Results of tests shall be recorded suitably. A recommended proforma for recording the results is given in Appendix B.

6.1.2 From the calibration chart of the proving ring, the loads corresponding to the load dial readings obtained during the test should be calculated. The loads so obtained divided by the corrected cross-sectional area of the specimen gives the shear stress in the sample. The corrected cross-sectional area shall be calculated from the following equation:

$$\text{Corrected area} = A_o \left(\frac{\delta}{3} \right)$$

where

A_o = initial area of the specimen in cm^2 , and
 δ = displacement in cm.

6.1.2.1 The longitudinal displacement at a particular load may be either noted directly from the strain dial readings or calculated as the product of the corresponding time reading and the strain rate, allowing for the compression of the proving ring, where applicable. The stress-longitudinal displacement readings should be plotted and the maximum stress and corresponding longitudinal displacement

together with the normal load applied during the test recorded (see Note).

NOTE — In general, failure in direct shear may be considered to take place either at maximum shear or at the maximum obliquity of the Mohr failure envelope. If the failure is assumed to take place at maximum shear and not at maximum obliquity, the angle of shearing resistance thus obtained will be smaller, giving an error, if any, on the safe side. It should, however, be noted that differences in the values of the angle of shearing resistance obtained by using the two criteria mentioned above are more important for sands than for clays.

6.1.2.2 The maximum shear stress and the corresponding longitudinal displacement and applied normal stress should be recorded for each test, and the results should be presented in the form of a graph in which the applied normal stress is plotted as abscissa and the maximum shearing stress is plotted

as ordinate to the same scale. The angle which the resulting straight line makes with the horizontal axis and the intercept which the straight line makes with the vertical axis shall be reported as the angle of shearing resistance and cohesion-intercept, respectively (see Note).

NOTE — The normal stress-maximum shear stress relationship may not be a straight line in all cases. In such cases, the shear parameters may be obtained by drawing a tangent to the normal stress expected in the field.

6.1.3 In the case of the consolidated undrained and consolidated drained tests, the load at which the specimen is consolidated and the consolidation characteristics as determined during the consolidation part of the test should also be reported.

APPENDIX A (Clause 5.3)

RATE OF SHEAR FOR CONSOLIDATED DRAINED TEST

A-1. RATE OF STRAIN

A-1.1 For sandy soils, a rate of strain 0.2 mm/min may be suitable. For clayey soils, a rate of strain of 0.01 mm/min or slower may be used but actual rate of strain suitable for the soil under test may be ascertained as in A-1.1.1.

A-1.1.1 From the consolidation data collected, the compression dial readings should be plotted against the log of time and from this curve, the value of coefficient of consolidation, C_v should be computed from the formula:

$$C_v = \frac{0.197 h^2}{t_{50}}$$

where

h = initial thickness of the specimen, and

t_{50} = time corresponding to 50 percent consolidation.

A-1.1.2 The requisite time to failure, when theoretically 95 percent dissipation is ensured, may be obtained from the following equation:

$$t_f = \frac{h^2}{n C_v (1 - U_c)} = \frac{20 h^2}{3 C_v}$$

where

t_f = time to failure,

h = initial thickness of the specimen,

n = a constant for drainage from both ends = 3, and

U_c = degree of pore pressure dissipation.

From a knowledge of approximate strain expected at failure, the rate of strain for the test may be calculated. In the case of cohesive soils, the failure may be assumed as taking place at 5 percent deformation.

A P P E N D I X B.

(Clause 6.1.1)

PROFORMA FOR RECORDING TEST RESULTS

Project _____

Location of samples _____

*Rate of strain _____

Bore hole No. _____ Sample No. _____

Proving ring/Load cell No. _____

Calibration curve _____

Load-hanger lever ratio _____

Soil Specimen Measurements

Dimensions _____

Area of specimen _____

Thickness _____

Volume of specimen _____

Initial wet weight of specimen _____

Moisture content _____

(Average of _____ tests)

Bulk density _____

Final wet weight of the specimen _____

Moisture content at shear zone _____

Consolidation

Hanger load _____

Applied load _____

Normal stress _____

Date and Time	Vertical Dial Reading	Vertical Dial Difference	Thickness of Specimen
<hr/>			

Shearing Stage
 *Rate of shearing _____ mm/min

DATE AND TIME	DISPLACEMENT READING	DISPLACEMENT DIAL	AREA CORRECTION	CORRECTED AREA	STRESS DIAL	SHEAR FORCE	SHEAR STRESS	VERTICAL CAL DIAL	VERTICAL DIAL	THICKNESS OF SPECIMEN
<hr/>										

Plot — shear stress-shear displacement curve and find:

- a) Maximum shear stress, and
- b) Corresponding shear displacement.

Summary of Results

TEST NO.	NORMAL STRESS	SHEAR STRESS AT FAILURE	SHEAR DISPLACEMENT AT FAILURE	INITIAL WATER CONTENT	FINAL WATER CONTENT	REMARKS
<hr/>						

Plot — shear stress-normal stress curve and find:

- a) Cohesion intercept, and
- b) Angle of shearing resistance.

*Should be decided after analyzing consolidation-time data in the case of drained tests.

Indian Standard

METHODS OF TEST FOR SOILS

PART 39 DIRECT SHEAR TEST FOR SOILS CONTAINING GRAVEL

Section 1 Laboratory Test

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 This part deals with the laboratory determination by direct shear, the shear strength of soils containing gravel with particle size more than 4.75 mm or with disturbed specimen. The test is of two kinds depending upon the state of samples, namely, laboratory test and *in-situ* test. The *in-situ* test is being covered separately.

1. SCOPE

1.1 This standard (Part 39/Sec 1) covers the method for the laboratory determination by direct shear of the shear strength of soils containing gravel (with particle size more than 4.75 mm).

NOTE — It is recommended that the 300-mm box shall be used for soils containing gravel up to 30 mm size.

1.2 The test shall be carried out at natural moisture content. In case, the deposit is likely to get saturated, the test shall be carried out in the saturated condition.

2. APPARATUS

2.1 The shear box and its assembly shall conform to IS : 11593-1986 'Specification for shear box (large) for testing of soils'.

2.7 Loading Device — The major requirements of the loading device are the following:

- a) The vertical stress on the sample shall remain vertical and constant during test. The normal load shall be applied uniformly on the soil specimen in the shear box without eccentricity;
- b) The shear stress or strain shall be applied in the same plane as the dividing plane of the two parts of the shear box;
- c) In case of a stress controlled apparatus, it should be possible to maintain a constant rate of stress increase during the test irrespective of the strain rate; proper arrangement shall be provided to get different rates of stress increase;

- d) In case of strain controlled apparatus, the strain rate shall remain constant irrespective of the stress. Suitable arrangement shall be provided to provide different strain rates; and
- e) No vibrations shall be transmitted to the sample during the test and there shall not be any loss of shear force due to friction between the loading frame and the shear box container assembly.

2.3 Weights (If Necessary) — For providing the normal load through a normal loading device.

2.4 Proving Ring — of suitable capacity fitted with dial gauge accurate to 0.002 mm to measure the shear force.

2.5 Micrometer Dial Gauges — Accurate to 0.01 mm. Two, suitably mounted to measure the horizontal movement and the other two suitably mounted to measure the compression or expansion of the specimen.

2.6 Stop Clock

2.7 Balance — of 50 kg capacity sensitive of 1 kg.

3. PREPARATION OF SPECIMEN

3.1 Specimen may be compacted in layers to the required density by a suitably hammer into the shear box after fixing the two halves of the shear box together by means of fixing screws.

4. PROCEDURE

4.1 The shear box with the soil specimen should be fitted into position as shown in Fig. 1. The required normal load shall be applied. After the required normal load is applied, the shear strain shall be applied. Before the application of shear strain, the upper half of the box should be lifted up slightly to eliminate friction between the parts of the shear box. The shear strain should be applied at a constant rate of 0.2 mm/min on the upper half of the box till the failure of the specimen. The final shear shall be recorded through the calibrated proving ring. At the end of the test, the specimen should be

removed from the box and the water content at the shear zone should be determined. The process shall be repeated for the next higher normal load. A minimum of 4 sets of readings shall be taken.

5. CALCULATION AND REPORT

5.1 Results of tests shall be recorded suitably. A recommended proforma for recording the result is given in Appendix A.

5.2 The longitudinal displacement at a particular load shall be recorded from the shear displacement dial readings.

5.3 The maximum shear force shall be the peak load from load-displacement curve or where the tangent of flatter portion of later part of the curve leaves in case the curve does not give peak point.

5.4 The maximum shear stress and the corresponding longitudinal displacement (shear displacement) and applied normal stress should be recorded for each test and the result should be presented in the form of a graph in which the applied normal stress is plotted as abscissa and the maximum shear stress is plotted as ordinate. The angle which the resulting straight line makes with horizontal axis and the intercept which the straight line makes with the vertical axis shall be reported as the angle of shearing resistance and cohesion intercept, respectively.

NOTE — The normal stress *versus* maximum shear stress relationship may not be straight line in all cases. In such cases, the shear parameter shall be obtained by drawing a tangent to the normal stress and maximum shear-stress curve at the point of normal stress expected in the field.

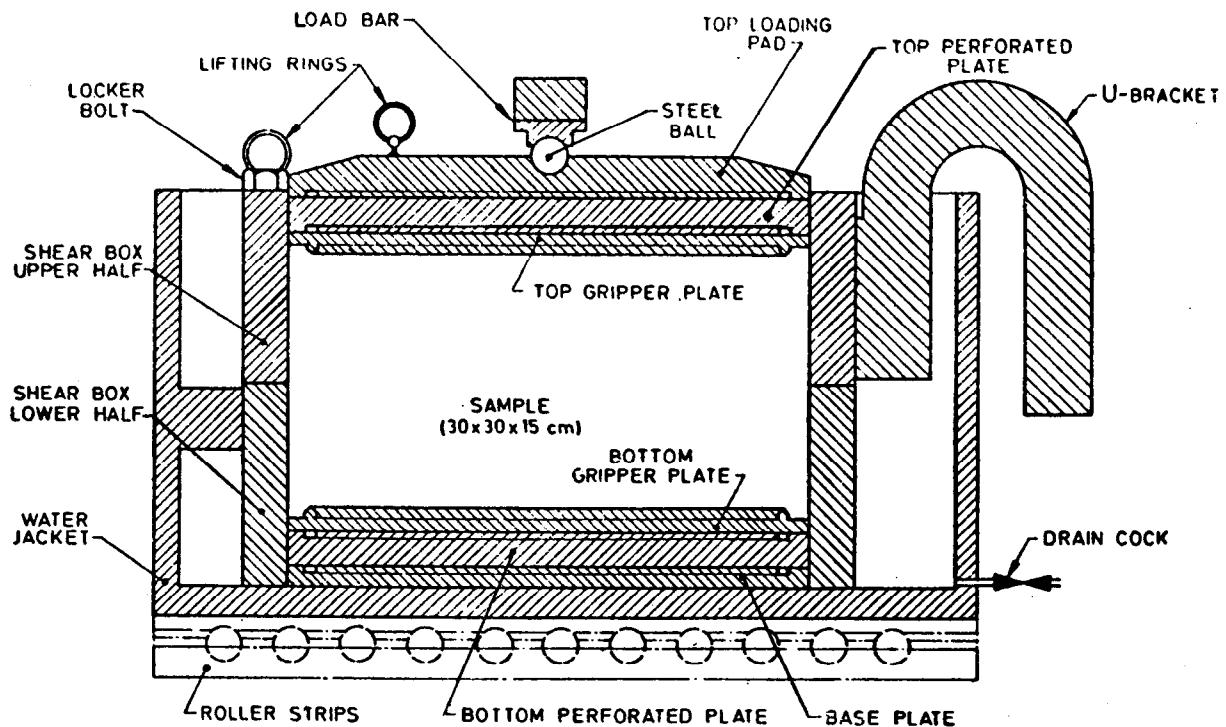


FIG. 1 SHEAR BOX ASSEMBLY

A P P E N D I X A
(Clause 5.1)

PROFORMA FOR RECORDING TEST RESULTS

Project _____

Location of sample _____

Rate of shear strain _____

Sample No. _____

Proving ring No. _____

Proving ring constant _____

Weight of loading frame _____

Normal load applied _____

Soil Specimen Measurements

Dimensions _____

Area of specimen _____

Initial wet mass of specimen _____

Volume of specimen _____

Water content _____

Bulk density _____

Final wet mass of specimen _____

Water content at the shear zone _____

Proforma for Recording Shear Stage

- | | |
|------------------------------------|--|
| i) Thickness of specimen _____ mm | ii) Area of cross-section
of specimen _____ cm ² |
| iii) Rate of shearing _____ mm/min | iv) Normal stress applied _____ kg/cm ² |

DATE AND TIME	SHEAR DISPLACE- MENT DIAL READING	SHEAR DISPLACE- MENT	PPROVING RING READING	SHEAR FORCE	SHEAR STRESS	VERTICAL DIAL READINGS	VERTICAL DISPLACE- MENT
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)

Plot—shear stress *versus* shear displacement and find:

- a) Maximum shear stress at the peak of curve, and
- b) Corresponding shear displacement.

Proforma for Recording Summary fo Results

TEST NO.	NORMAL STRESS	SHEAR STRESS AT FAILURE	SHEAR DISPLACEMENT AT FAILURE	INITIAL WATER CONTENT	FINAL WATER CONTENT	REMARK
(1)	(2)	(3)	(4)	(5)	(6)	(7)

Plot—shear stress *versus* normal stress relationship to obtain:

- a) Cohesion intercept, and
- b) Angle of shearing resistance.

Indian Standard

METHODS OF TEST FOR SOILS

PART 10 DETERMINATION OF UNCONFINED COMPRESSIVE STRENGTH

(First Revision)

0. FOREWORD

0.1 This Part 10 deals with the method of test for determination of unconfined compressive strength of soils. The maximum load that can be transmitted to the sub-soil by a foundation depends upon the resistance of the underlying soil or rock to shearing deformations or compressibility. Therefore, it is of prime importance to investigate the factors that control the shearing strength of these materials. The shearing strength is commonly investigated by means of compression tests in which an axial load is applied to the specimen and increased until failure occurs. The use of compression tests to investigate the shearing strength of materials depends upon the fact that failure in such tests takes place by shear on one or more inclined planes and that it is possible to compute the normal pressure and the shearing stress on such a plane at the instant of failure. The specimen may or may not be subjected to a lateral pressure during the test. When it is not, the test is known as unconfined compression test.

1. SCOPE

1.1 This standard (Part 10) describes the method for determining the unconfined compressive strength of clayey soil, both undisturbed and remoulded, using controlled strain. The purpose of this test is to obtain a quantitative value of compressive and shearing strength of such soils in an undrained state.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Unconfined Compressive Strength, q_u — It is the load per unit area at which an unconfined cylindrical specimen of soil will fail in a simple compression test.

NOTE — If the unit axial compression force per unit area has not reached a maximum value up to 20 percent, axial strain, q_u shall be considered the value obtained at 20 percent axial strain.

3. APPARATUS

3.1 Compression Device — The compression device may be any of the following types:

- a) Platform weighing scale equipped with a screw jack activated yoke,
- b) Hydraulic loading device,
- c) Screw jack with spring load measuring device, or
- d) Any other loading device.

All these loading devices shall have sufficient capacity and strain control, and shall be suitably calibrated.

NOTE — The calibration of spring load measuring device especially should be checked frequently.

3.1.1 The selection of the apparatus shall depend on the following:

- a) For relatively weak soil with q_u less than 1 kg/cm^2 , load shall be measurable to 0.01 kg/cm^2 . For soils with q_u equal to or greater than 1 kg/cm^2 , load shall be measurable to the nearest 0.05 kg/cm^2 ; and
- b) The axial deformation shall be measurable to 0.01 mm with a convenient dial indicator or a suitable measuring device.

3.2 Sample Ejector — When samples are pushed from the drive sampling tube, the ejecting device shall be capable of ejecting the soil core from the sampling tube in the same direction of travel in which the sample entered the tube and with negligible disturbance of the sample. Conditions at the time of removal of the sample may dictate the direction of removal, but the principal concern should be to keep the degree of disturbance negligible.

NOTE 1 — Three specimens obtained by trimming and carving from undisturbed soil samples shall be tested.

NOTE 2 — When the sample is ejected horizontally, a curved plate may be provided to butt against the sampling tube such that the ejecting specimen slips over it freely. This will avoid bending of the specimen and facilitate bringing the specimen to vertical position in many cases.

3.3 Deformation Dial Gauge — a dial gauge with 0.01 mm graduations and specific travel to permit 20 percent axial strain.

NOTE — A dial gauge of 20 mm travel will suffice for the test on 38 mm diameter specimen.

3.4 Vernier Calipers — suitable to measure physical dimensions of the test specimen to the nearest 0.1 mm.

3.5 Timer — timing device to indicate the elapsed testing time to the nearest second shall be used for establishing the rate of strain application prescribed in 5 and 6.

3.6 Oven — thermostatically controlled, with interior of non-corroding material, capable of maintaining the temperature at $110 \pm 5^\circ\text{C}$.

3.7 Balances — suitable for weighing soil specimens specially. Specimens of less than 100 g shall be weighed to the nearest 0.01 g, whereas specimens of 100 g or larger shall be weighed to the nearest 0.1 g.

3.8 Miscellaneous Equipment — Specimen trimming and carving tools, remoulding apparatus, water content cans, data sheets, etc, as required.

4. PREPARATION OF TEST SPECIMEN

4.1 The soil specimen to be used for test may be either undisturbed, compacted or remoulded.

4.2 Specimen Size — The specimen for the test shall have a minimum diameter of 38 mm and the largest particle contained within the test specimen shall be smaller than 1/8 of the specimen diameter. If, after completion of test on undisturbed sample, it is found that larger particles are present than permitted for the particular specimen size tested, it shall be noted in the report of test data under remarks. The height to diameter ratio shall be 2. Measurements of height and diameter shall be made with vernier calipers or any other suitable measuring device to the nearest 0.1 mm.

4.3 Undisturbed Specimens — Undisturbed specimens shall be prepared from large undisturbed samples or samples secured in accordance with IS : 2132-1987 'Code of practice for thin-walled tube sampling of soils (first revision)'.

4.3.1 The specimen shall be handled carefully to prevent disturbance, change in cross-section or loss of water. If any type of disturbance is likely to be caused by the ejection device, the sample tube shall be split lengthwise or be cut off in small sections to facilitate removal of the specimen without disturbance. If possible, carved specimen should be prepared in a humid room to prevent, as far as possible, change in water content of the soil.

4.3.2 The specimen shall be uniform circular cross-section with ends perpendicular to the long axis of the specimen.

4.3.3 Specimens of required size may be carved from large undisturbed specimens. When sample condition permits a vertical lathe, which will accommodate the total sample, may be used as an aid in carving the specimen to the required diameter. Tube

specimens may be tested without trimming except for squaring of ends.

4.3.4 Where the prevention of the possible development of appreciable capillary forces is required, the specimens shall be sealed with rubber membranes, thin plastic coatings or with a coating of grease or sprayed plastic immediately after preparation and during the entire testing cycle.

4.3.5 Representative sample cuttings shall be used for the determination of water content.

4.4 Remoulded Specimen — The specimen may be prepared either from a failed undisturbed specimen or from a disturbed soil sample.

4.4.1 Remoulded Specimen — In the case of failed undisturbed specimen, the material shall be wrapped in a thin rubber membrane and thoroughly worked with the fingers to assure complete remoulding. Care shall be taken to avoid entrapped air to obtain a uniform density, to remould to the same void ratio as that of the undisturbed specimen, and to preserve the natural water content of the soil.

4.4.2 Compacted Specimen — When compacting disturbed material, it shall be done using a mould of circular cross-section with dimensions corresponding to those given in 4.3. Compacted specimen may be prepared at any predetermined water content and density.

4.4.3 After the specimen is formed, the ends shall be trimmed perpendicular to the long axis and removed from the mould. Representative sample cuttings shall be obtained or the entire specimen shall be used for the determination of water content after the test.

5. PROCEDURE

5.1 The initial length, diameter and weight of the specimen shall be measured and the specimen placed on the bottom plate of the loading device. The upper plate shall be adjusted to make contact with the specimen.

5.2 The deformation dial gauge shall be adjusted to zero. Force shall be applied so as to produce axial strain at a rate of 1/2 to 2 percent per minute. Force and deformation readings shall be recorded at suitable intervals; the frequency of the readings shall be more at the initial stages; the frequency may be reduced at higher percentage of strain (see Note).

NOTE — Up to 6 percent strain, the readings may be taken at every 30 s; after 6 percent, the frequency may be halved and beyond 12 percent, it may be decreased further.

5.3 The specimen shall be compressed until failure surfaces have definitely developed or the stress-strain curve is well past its peak or until an axial strain of 20 percent is reached.

5.4 The failure pattern shall be sketched carefully and shown on the data sheet or on the sheet presenting the stress-strain plot. The angle between the failure surface and the horizontal may be measured, if possible, and reported.

5.5 The water content of the specimen shall be determined in accordance with IS : 2720 (Part 2)-1973 using samples taken from the failure zone of the specimen.

6. CALCULATIONS AND PLOTTING

6.1 Stress-strain values shall be calculated as follows:

- a) The axial strain, ϵ , shall be determined from the following relationship:

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

where

ΔL = the change in the specimen length as read from the strain dial indicator, and

L_o = the initial length of the specimen.

- b) The average cross-sectional area, A , at a particular strain shall be determined from the following relationship:

$$A = \frac{A_0}{1 - \epsilon}$$

where

A_o = the initial average cross-sectional area of the specimen.

- c) Compressive stress, σ_c , shall be determined from the relationship:

$$\sigma_c = \frac{P}{A}$$

where

P = the compressive force, and

A = average cross-sectional area [see 6.1 (b)].

6.2 Values of stress σ_c and strain, ϵ , obtained from 6.1 shall be plotted. The maximum stress from this plot gives the value of the unconfined compressive strength, q_u . In case no maximum occurs within 20 percent axial strain, the unconfined compressive strength shall be taken as the stress at 20 percent axial strain.

6.3 In the case of soils which behave as if the angle of shearing resistance $\phi = 0$ (as in the case of saturated or nearly saturated clays in an undrained test), the shear strength or cohesion of the soil may be taken to be equal to half the unconfined compressive strength obtained from 6.2.

7. REPORT

7.1 The observations of the test shall be suitably recorded giving details indicated in Appendix A. A recommended proforma for the record of observations is given in Appendix A.

APPENDIX (Clause 7.1)

PROFORMA FOR RECORD OF OBSERVATIONS OF UNCONFINED COMPRESSION TEST

Project :

Date :
Tested by :

1. Details of soil samples:
 - i) Location
 - ii) Boring No.
 - iii) Depth
 - iv) Visual description of soil
 - v) Date of sampling
2. Details of apparatus used:
3. Details of load measuring device:
4. Details of the soil specimen:
 - i) Undisturbed or remoulded or compacted
 - ii) Specific gravity of the soil
 - iii) Initial diameter, D_o _____ mm
 - iv) Initial length, L_o _____ mm

- v) Initial area, A_o _____ cm²
 vi) Initial mass of the specimen _____ g
 vii) Initial density _____ g/cm²
 viii) Initial water content _____ percent
 ix) Initial degree of saturation _____ percent
 x) Whether test has been performed at *in-situ* density and water content/maximum dry density—optimum water content.

5. Observations of compression test:

Rate of strain

Sl No.	Elapsed Time in mm	Force in kg	Deformation in mm	Strain in %	Area A in cm ²	Stress in kg/cm ²	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$A = \frac{A_o}{1 - \epsilon}$							

6. Sketch of failed specimen and description of failure:

7. Water content of the specimen after test (determined from water content samples taken from the failure zone of the specimen)

8. Unconfined compressive strength (q_u) _____ kg/cm²
Undrained shear strength (if applicable) _____ kg/cm²9. Remarks:
(see Note)

NOTE — Remarks should include observations with reference to 4.2 regarding the maximum particle size in the specimen.

Indian Standard

METHODS OF TEST FOR SOILS

PART 11 DETERMINATION OF THE SHEAR STRENGTH PARAMETERS OF A SPECIMEN TESTED IN UNCONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION WITHOUT THE MEASUREMENT OF PORE WATER PRESSURE

(Incorporating Amendments No. 1 to 3)

0. FOREWORD

0.1 This Part 11 covers the determination of the compressive strength of a specimen of saturated cohesive soil in the triaxial compression apparatus under conditions in which the cell pressure is maintained constant and there is no change in the total water content of the specimen.

1. SCOPE

1.1 This standard (Part 11) describes the test for the determination of the compressive strength of a specimen of saturated cohesive soil in the triaxial compression apparatus under conditions in which the cell pressure is maintained constant and there is no change in the total water content of the specimen (see Notes 1 and 2).

NOTE 1 — In this standard, the term 'sample' is used to denote the soil submitted to the laboratory for testing and the term 'specimen' refers to a portion of the sample upon which the test is performed.

NOTE 2 — The result of any test made in accordance with this standard requires interpretation in relation to the nature of the soil, and the way in which the specimen was obtained and prepared.

1.1.1 The test is limited to specimens in the form of right cylinders of nominal diameter 38, 50, 70 and 100 mm and of height approximately equal to twice the nominal diameter (see Note). In case of remoulded samples, ratio of diameter of specimen to maximum size of particle in the soil should not be less than 5.

NOTE — The diameter of the specimen is to be selected having regard to the character of the soil and the maximum size of the particles present in the sample. Generally, a diameter of 37.5 mm will be suitable for homogeneous fine-grained soils.

2. APPARATUS

2.1 Apparatus required for the preparation of a test specimen is listed in 2.2 and 2.3 to cover the three possible following procedures:

a) *Procedure 1* — For obtaining a specimen from a sampler tube of the same internal diameter as the required specimen.

- b) *Procedure 2* — For obtaining a specimen from a sampler tube of larger diameter than the required specimen.
- c) *Procedure 3* — For obtaining a specimen from a block sample.

2.2 Articles Common to Sample Preparation by All Three Procedures

2.2.1 *Split Mould* — of diameter and length to suit the test specimen.

2.2.2 *Trimming Knife* — sharp-bladed, for example, a spatula or pallet knife.

2.2.3 *Piano Wire Saw*

2.2.4 *Metal Straightedge*

2.2.5 *Metal Scale*

2.2.6 *Non-Corrodible Metal or Plastic End-Caps* — of the same diameter as the test specimen. The upper end cap is to have a central spherical seating to receive the loading ram (see Note).

NOTE — A plastic upper end cap, 20 mm thick, is normally satisfactory for use on soft or very soft soils. Metal end caps are considered preferable for use on stiff soils. A metal upper end cap 12 to 20 mm thick is normally satisfactory.

2.2.7 *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 to be tested. A thickness of 0.2 to 0.3 mm is normally satisfactory.

2.2.8 *Membrane Stretcher* — to suit the size of the specimen.

2.2.9 *Rubber Rings* — of circular cross-section to suit the diameter of the end caps.

2.2.10 *Apparatus for Moisture Content Determination* — as described in IS : 2720 (Part 2)-1973.

2.2.11 *Balance* — readable and accurate to 0.5 g.

2.3 Additional Items for the Specific Procedures

2.3.1 *For Procedures (a) and (b) of 2.1 Extruders* — to suit the size of sample and specimen tubes.

2.3.2 For Procedure (b) of 2.1 Thin-walled Tubes — for obtaining test specimens. The tubes shall be smooth inside and out and turned at one end to form a cutting edge at the inner surface of the tube. The area ratio (see Note) shall be kept as low as possible consistent with the strength requirements of the specimen tubes and its value shall not exceed 10 percent. The length of the tubes shall be somewhat (at least 50 mm) greater than the required length of the specimens.

NOTE — The area ratio is defined as the volume of soil displaced by the sampler in proportion to the volume of the sample and is defined as:

$$\text{Area ratio} = \frac{D_o^2 - D_c^2}{D_c^2} \times 100 \text{ percent}$$

where

D_o = outside diameter of the tube, and

D_c = inside diameter of the cutting edge.

2.3.3 For Procedures (b) and (c) of 2.1 Soil Lathe — for preparing test specimens.

2.3.4 For Procedure (c) of 2.1 Mitre Box — for cutting the ends of the specimens perpendicular to their axes.

2.4 Apparatus Required for Triaxial Test

2.4.1 A Triaxial Test Cell — of dimensions appropriate to the size of the specimen, capable of being opened for the insertion of the specimen, suitable for use with the fluid selected for use at internal pressures up to 10 kg/cm² and provided with a means of applying additional axial compressive load to the specimen by means of a loading ram. A transparent chamber is recommended. The base of the cell shall be provided with a suitable central pedestal with drainage outlets with valves.

2.4.2 An Apparatus for Applying and Maintaining the Desired Pressure on the Fluid Within the Cell — to an accuracy of 0.1 kg/cm² (preferably 0.05 kg/cm²) with a gauge for measuring the pressure. The gauge shall be regularly calibrated.

2.4.3 A Machine Capable of Applying Axial Compression to the Specimen — at convenient speeds to cover the range 0.05 to 7.5 mm per minute. The machine should have a capacity of 5 000 kg. A means of measuring the axial compression of the specimen to an accuracy of 0.01 mm shall be provided and the machine shall be capable of applying an axial compression of about one-third the height of the specimen tested.

NOTE — In case the travel of the dial gauges is not sufficient to measure the compression, a magnetic spacer of known thickness may be used.

2.4.4 Provision shall be made for measuring the additional axial load on the specimen. Proving ring of 100 kg capacity with sensitivity of 0.2 kg for low strength soils and one of 1 000 kg capacity with

sensitivity of 1 kg for high strength soils are found suitable.

3. PREPARATION OF SPECIMENS

3.1 Undisturbed Specimens

3.1.1 The object of specimen preparation is to produce cylindrical specimens of height twice the specimen diameter with plane ends normal to the axis and with the minimum change of the soil structure and moisture content.

The method of preparation will depend on whether the sample is received in the laboratory in a tube or as a block sample and any one of the procedures given in 3.1.1.1, 3.1.1.2 or 3.1.1.3 may be used.

3.1.1.1 A specimen from a sampler tube of the same internal diameter as the required specimen may be obtained as given in (a) to (e).

- a) When the ends of the sampling tube are not flat and normal to the axis of the tube, a length of the sample sufficient to form a specimen shall be extruded from the tube and cut off. This specimen shall then be placed in the split mould and the ends trimmed flat and normal to its axis.
- b) As an alternative to (a) when the tube enclosing the sample is in good condition and the ends are plane and normal to the axis of the tube, the specimen may be prepared in the tube and extracted.
- c) Any wax, used for sealing, shall be removed and the cutting edge end of the sample smoothed so that it is approximately normal to the axis of the tube. The extruder shall then be used to push the sample through the tube so that the other end may be cut normal to the axis and finally smoothed with the metal straight edge. The sample should be extruded from the tube pushing from the cutting edge side and cut to the required length. During this operation, the sample tube shall be held vertical. Precautions shall be taken to prevent adhesion between the soil and the extruder, for example, by interposing oiled paper discs or lightly oiling the face of the extruder.
- d) The length, diameter and weight of the specimen shall be measured to an accuracy enabling the bulk density to be calculated to an accuracy of ± 1.0 percent.
- e) The specimen shall be placed on one of the end caps and the other end cap shall be put on top of the specimen. The rubber membrane shall then be placed around the specimen using the membrane stretcher and the membrane sealed to the end caps by means of rubber rings. The specimen is then ready to be placed on the pedestal in the triaxial cell. The pedestal

should be either covered with a solid end cap or the drainage valve should be kept closed.

3.1.1.2 For obtaining a specimen from a sample tube of larger diameter than the required specimen — Two methods are available. Either the specimens may be cut to size by means of thin walled tubes or by hand trimming on a soil lathe. Specimens of sensitive clays and, in some cases, of stiff fissured, clays, may be best prepared by the latter method. The preparation of specimens on the soil lathe is dealt with in 3.1.1.3. To prepare specimens by means of thin-walled tubes, the sample shall be extruded from the sampling tube directly into a number of thin-walled specimen tubes rigidly clamped with their cutting ends short distance from the end of the sampling tube. Test specimens shall be prepared from the thin-walled specimen tubes in the manner described in 3.1.1.1.

3.1.1.3 A specimen from a block sample — may be obtained as given in (a) to (c):

- A rectangular prism slightly larger than the required final dimensions of the specimen shall be cut from the block sample. The rectangular prism shall be cut either on a required orientation or an orientation as best suited to the sample. The ends of the prism shall be made plane and parallel using the mitre box and the prism shall be placed in the soil lathe. The excess soil shall be cut off in thin layers. The trimming operation, rotating the sample between each cutting operation, shall be continued until a cylindrical specimen results.
- The specimen shall be removed from the soil lathe, placed in the split mould and cut to the correct length and the ends made plane and normal to the axis of the specimen.
- The remainder of the preparation shall be as described in 3.1.1.1.

3.2 Remoulded Samples — Remoulded samples prepared at the desired moisture and density by static and dynamic methods of compaction or by any other suitable methods may also be used where necessary.

4. TESTING

4.1 The specimen prepared as described in 3 shall be placed centrally on the pedestal of the triaxial cell. The cell shall be assembled with the loading ram initially clear of the top cap of the specimen and the cell containing the specimen shall be placed in the loading machine. The operating fluid shall be admitted to the cell and the pressure raised to the desired value.

4.2. The loading machine shall be adjusted to bring the loading ram a short distance away from the seat

on the top cap of the specimen and the initial reading of the load measuring gauge shall be recorded. The loading machine shall then be further adjusted to bring the loading ram just in contact with the seat on the top cap of the specimen and the initial reading of the gauge measuring the axial compression of the specimen shall be recorded.

A rate of axial compression shall be selected such that failure is produced within a period of approximately 5 to 15 minutes. The test shall be commenced, a sufficient number of simultaneous readings of the load and compression measuring gauges being taken to define the stress-strain curve (see Note). The test shall be continued until the maximum value of the stress has been passed or until an axial strain of 20 percent has been reached. The specimen shall then be unloaded and the final reading of the load measuring gauge shall be recorded as a check on the initial reading.

NOTE — It is often convenient to make a plot of load *versus* compression as the test proceeds, to enable the point of failure to be determined.

4.3 The cell shall be drained of fluid and dismantled, and the specimen taken out. The rubber membrane shall be removed from the specimen and the mode of failure shall be noted (see Note 1). The specimen shall be weighed (see Note 2) and samples for the determination of the moisture content of the specimen shall be taken [see IS : 2720 (Part 2)-1973]. If there is a moisture change in the specimen, it should be recorded and discretion used with regard to acceptability of the test.

NOTE 1 — The most convenient method of recording the mode of failure is by means of a sketch indicating the position of the failure planes. The angle of the failure plane (s) to the horizontal may be recorded, if required. These records should be completed without undue delay to avoid loss of moisture from the specimen.

NOTE 2 — Comparison with the recorded weight of the specimen before testing provides a check on the impermeability of the rubber membrane if water has been used as the operating fluid in the cell.

5. CALCULATIONS

5.1 According to the procedure given in this standard, the difference between the initial reading and any subsequent reading of the load measuring device is the axial load applied to the specimen in addition to that due to cell pressure.

5.1.1 The area A of the specimen normal to its axis at any stage of the test shall be computed on the assumption that the sample deforms as a right cylinder. This area at any strain e is given by:

$$A = A_0 / (1 - e)$$

where

A_0 = initial area of the specimen normal to the

axis, and

$$e = (L_0 - L) / L_0$$

where

L_0 = initial length of the specimen, and
 L = length of the specimen at the stage of the test at which area A is to be determined.

5.1.1.1 The principal stress difference ($\sigma_1 - \sigma_3$) for any stage of the test shall be determined by dividing the additional axial load by the corresponding area A .

5.1.1.2 A correction to allow for the restraining effect of the rubber membrane* shall be made as given below:

$$\text{Correction} = 4 M \frac{(1 - \epsilon)}{D}$$

where

M = the compression modulus of the rubber membrane in kg/cm of width (see 5.1.1.4),

ϵ = the axial strain at the maximum principal stress difference, and

D = initial diameter of the sample in cm.

5.1.1.3 The value of the correction calculated as given in 5.1.1.2 shall be deducted from the measured maximum principal stress difference to give the corrected value of the maximum principal stress difference.

5.1.1.4 The compression modulus of the rubber membrane cannot be measured directly but may be assumed to be equal to the modulus measured in extension. The extension modulus of a circumferential strip (25 mm) wide cut from the membrane may be determined by means of the arrangement shown in Fig. 1. The contact faces between the rubber and the glass rods should be dusted with French chalk (talc powder) to reduce friction.

6. REPORTING OF RESULTS

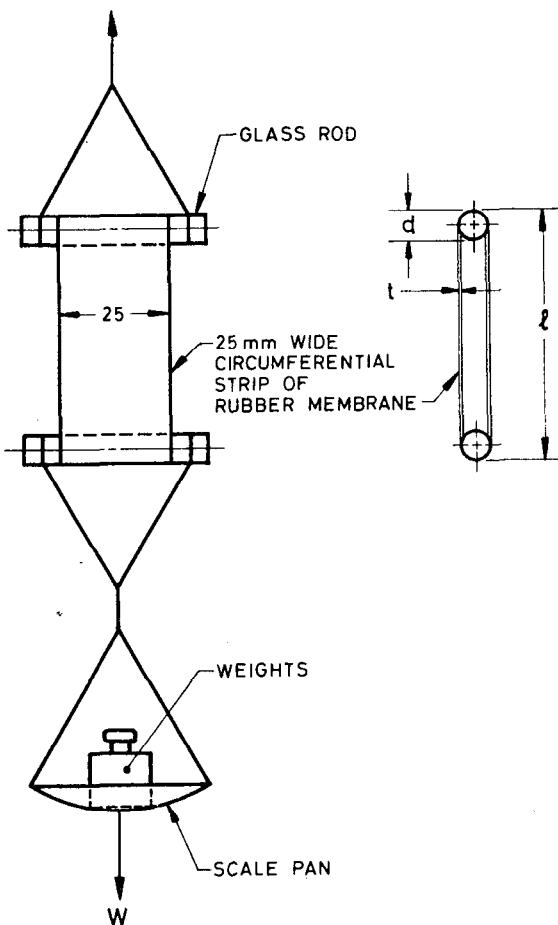
6.1 The dimensions of each test specimen, the bulk density, the moisture content, the cell pressure, the value of the maximum principal stress difference ($\sigma_1 - \sigma_3$), and the corresponding strain and time to failure and the rate of strain at which the test was conducted shall be reported.

6.1.1 When required, the stress-strain curve of the test shall be plotted with the axial strain as abscissa and the principal stress difference as ordinate.

6.1.2 The type of sampler and method of sampling in the field shall be reported.

6.2 The shear parameters shall be obtained from a plot of Mohr circles for which purpose peak values of principal stress difference or principal stress ratio or the ultimate value as desired may be used.

6.3 A proforma for the record of test results is given in Appendix A.



$$\text{Mean Length of Membrane} = 2(l - d - 2t) + \pi(d + t)$$

$$\text{Load per } 25 \text{ mm} = \frac{W}{2}$$

$$\text{Extension Modulus } (M) = \frac{\text{Load per cm}}{\text{Strain}}$$

$$\text{Strain} = \frac{\text{Extension}}{\text{Mean length}}$$

FIG. 1 APPARATUS FOR MEASURING THE EXTENSION MODULUS OF RUBBER MEMBRANE

*D. J. Henkel and G. D. Gilbert (1952). 'The effect of the rubber membrane on the measured triaxial compression strength of clay samples', Geotechnique, 3, 20.

A P P E N D I X A
(Clause 6.3)

**UNCONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST WITHOUT THE
MEASUREMENT OF PORE WATER PRESSURE**

Operator	Date	Depth
	Borehole No.	
Site	Sample No.	
Specimen preparation procedure		
Initial length of specimen		
Initial diameter of specimen	Bulk density	
Initial weight of specimen	Moisture content	
Load gauge No.	Load gauge constant	
Cell pressure (σ_1) =	Rate of strain	
Description of sample	Sketch of specimen after failure	
Mode of failure		
Angle of shear plane with vertical axis		

Compression Gauge Reading	Load Gauge Reading	Compression of Sample	Strain	Corrected Area	Load	Vertical Stress σ_1	$\sigma_1-\sigma_2$	$\frac{\sigma_1}{\sigma_2}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Indian Standard

METHODS OF TEST FOR SOILS

PART 12 DETERMINATION OF SHEAR STRENGTH PARAMETERS OF SOIL FROM CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST WITH THE MEASUREMENT OF PORE WATER PRESSURE

(First Revision)

0. FOREWORD

0.1 This standard was first published in 1975. Based on the experience gained in the use of this standard in the past five years, this part has been revised. The principal modifications being made are in regard to permitting the other types of apparatus also which meet the basic requirements given in the standard and also other sizes of specimen.

1. SCOPE

1.1 This standard (Part 12) lays down the method of determining the shear strength parameters of saturated soils from triaxial compression shear tests conducted under consolidated undrained conditions with measurements of pore water pressures. It also describes a procedure.

1.2 The test is limited to specimens in the form of right cylinders of nominal diameter 38, 50, 70 or 100 mm with height twice its diameter. The ratio of diameter of the sample to the maximum size of the particle in the soil shall not be less than five.

2. TERMINOLOGY

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

3. APPARATUS

3.1 For conducting the CU test, the testing system consists of the following five major functional components:

- A system to house the sample, that is, a triaxial cell;
- A system to apply cell pressure and maintain it at a constant magnitude;
- A system to apply additional axial stress;
- A system to measure pore water pressure; and
- A system to measure changes of volume of the soil sample.

3.2 Any of the apparatus which can achieve the five functions listed above can be used. One of the suggested variety of the apparatus and the alternate variety suitable are given below. The general set up of apparatus is given in Fig. 1.

<i>Functional Component (See 3.1)</i>	<i>Suggested Variety</i>	<i>Alternate Variety</i>
a)	A triaxial cell with two valves providing access to cell and two to pedestal. Operation of valves shall not produce a change of volume in the lines in which the valves exist. The cell has one air vent and one oil inlet. It has a stainless steel loading ram running in a lapped or honed bush lubricated with oil. The triaxial cell considered can be subjected to a maximum pressure of 10 kgf/cm ²	Variation in number of valves and vents acceptable. Triaxial cells with higher pressure capacity may be used. The bush through which the loading ram passes should not have a 'O' ring seal which will increase the ram friction
b)	Self-compensating mercury pot system able to keep pressure at a constant level with a variation of less than 0.01 kgf/cm ²	Any system employing air or hydraulic pressure so long as it can be maintained at a constant level with a precision of ± 0.01 kgf/cm ²

- c) Loading frame able to subject soil sample to axial deformation at constant rates in the range from 0.50 to 0.02 mm/min
- d) Mechanical null indicator system able to measure pore water pressure with an accuracy of 0.01 kgf/cm²
- e) Burette of 10 ml capacity with a least count of 0.05 ml
- Any device to effect incremental loading for conducting tests under stress control conditions
- 1) Electrical null systems
2) Pressure transducers actuated by insignificantly little flow of water
- The systems shall be such as to measure pore water pressure with an accuracy of 0.01 kgf/cm²
- Burette of larger capacity but with a least count of at least 0.05 ml

3.3 The details of the suggested variety except the loading frame and its accessories are shown in Fig. 1. The details of the alternate varieties will depend on their types.

3.4 Components — The suggested variety shall consist of the components given in 3.4.1 to 3.4.14. The components of the other varieties will depend upon their types.

3.4.1 The Triaxial Cell — See (11) to (25) in Fig. 1.

3.4.2 A System to Fill Water in Cell — See (7), (I) and (II) in Fig. 1. The water reservoir (7) can be filled with de-aired water by connecting lead (I) to a vacuum pump and lead (II) to a sump of de-aired water with valves *W1* and *W2* open and valves *G1*, *G2* and *G3* closed. After reservoir (7) is filled, disconnect vacuum pump from lead (I). For filling cell with water, open valves *W1*, *G2*, *C3* and *C2* and air vent (12), and keep all other valves closed.

3.4.3 A System to Apply Cell Pressure and Maintain it at Constant Pressure — See (1) to (6) in Fig. 1. With valves *M2* and *M3* closed and valves *M1*, *C3* and *C2* open, cell pressure can be applied on account of the difference in elevation of the level of mercury in the top movable mercury pot (3) and its corresponding bottom mercury pot (4). The movable bracket (1) can be moved up or down as necessary to apply any desired pressure. The maximum amount of pressure that can be thus applied is controlled by the floor to ceiling height of the laboratory. The range of cell pressure that can be applied as noted above can be doubled by using two pairs of mercury pots in series by closing valves *M2*, *M3*, *C3* and *C2*. Pressure from mercury pots (3) and (4) is conveyed via valve *M3* to top of mercury pot (5) fixed at the ceiling and is thus added to the pressure contribution from mercury pots (5) and (6) before it is conveyed to the cell via valves *M2*, *C3* and *C2*.

3.4.3.1 The cell pressure is maintained at a constant level by hanging the top mercury pots on

specially designed springs (2). The spring constant of the springs is given by the formula:

$$k = \frac{A_p \gamma_m}{2 - \frac{\gamma_w}{\gamma_m}} - W$$

where

k = spring constant,

A_p = the cross-sectional area of the inside of the mercury pot,

γ_m = the unit weight of mercury

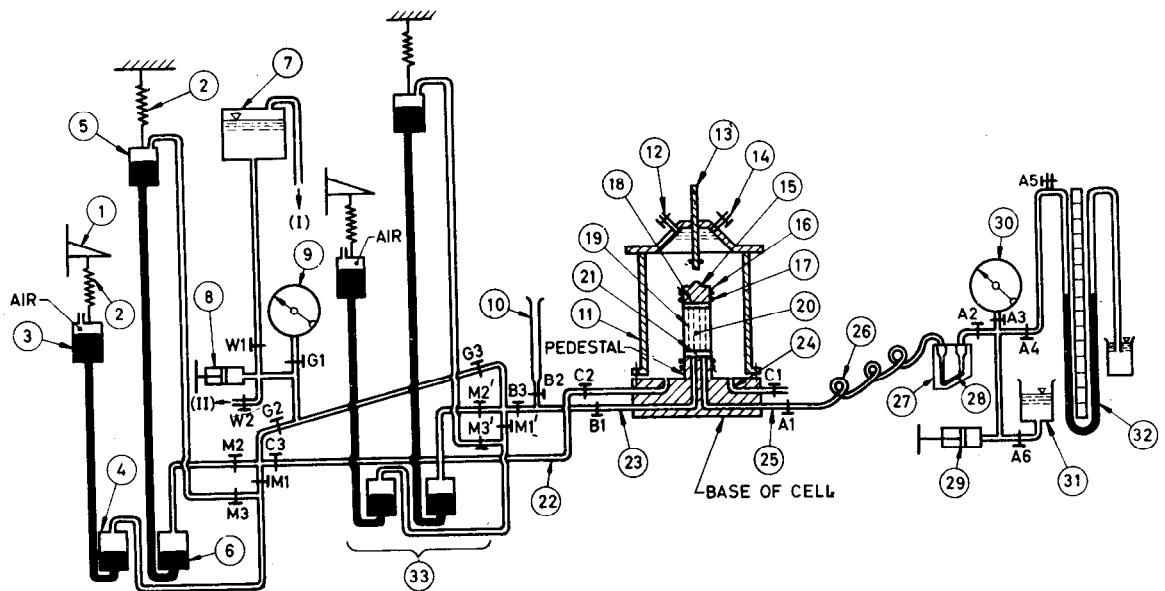
γ_w = the unit weight of water, and

W = the weight per unit length of the flexible pressure tubing filled with mercury connected to the mercury pot. (*W* shall include the weight of mercury in the tubing).

3.4.4 A System to Measure Drainage of Water from the Sample During the Consolidation Phase of the Test — See (10) in Fig. 1. With valves *B1* and *B2* open and valve *B3* closed, water flows out of the sample and into burette (10).

3.4.5 A System to Apply Back Pressure to the Sample in Order to Saturate it — See (33) in Fig. 1. With valves *B1* and *B3* open and valve *B2* closed, pressure can be raised in the pore water of the sample through the mercury pot system connected to valves *M1'*, *M2'*, and *M3'* (with valves *M2'* and *M3'* closed and valve *M1'* open, pressure will be applied by single pair of mercury pots; with valve *M1'* open, pressure will be applied by a single pair of mercury pots; with valve *M1'* closed and valves *M2'* and *M3'* open, higher pressure will be applied by two pairs of mercury pots connected in series).

3.4.6 A System to Measure Cell Pressure and Back Pressure — See (9) in Fig. 1. Cell pressure can be read on the pressure gauge (9) with valves *C2*, *C3*, *G2* and *G1* open and valves *W1*, *W2* and *G3* closed. Back pressure can be read on the pressure gauge (9) with valves *B1*, *B3*, *G3* and *G1* open and valves *W1*, *W2*, *G2* and *B2* closed. The pressure gauge (9) which



- | | | | |
|------|---|------|------------------------------------|
| (1) | Movable bracket | (21) | Coarse porous stone |
| (2) | Spring with specified spring constant | (22) | Cell pressure line |
| (3) | Top movable mercury pot | (23) | Drainage and back pressure line |
| (4) | Bottom mercury pot connected to the top movable mercury pot | (24) | Top drainage line |
| (5) | Top fixed mercury pot | (25) | Pore pressure measurement line |
| (6) | Bottom mercury pot connected to the top fixed mercury pot | (26) | Non-expansive tube (annealed tube) |
| (7) | Reservoir of de-aired water | (27) | Null indicator |
| (8) | Screw control cylinder | (28) | Mercury |
| (9) | Pressure gauge | (29) | Screw control cylinder |
| (10) | Burette | (30) | Pressure gauge |
| (11) | Triaxial cell | (31) | Reservoir of de-aired water |
| (12) | Air vent | (32) | Manometer |
| (13) | Loading ram | (33) | System to apply back pressure |
| (14) | Oil inlet | (I) | Connection to vacuum pump |
| (15) | Loading cap | (II) | Connection to de-aired water sump |
| (16) | Rubber membrane | | VALVES |
| (17) | Rubber "O" rings | | <i>A1 to A6 M1' to M3'</i> |
| (18) | Coarse porous stone | | <i>B1 to B3 M1 to M3</i> |
| (19) | Filter paper strips | | <i>C1 to C3 W1 and W2</i> |
| (20) | Soil sample | | <i>G1 to G3</i> |

NOTE — All tubes, cell, etc. filled with water; shaded portions filled with mercury; dashed portion filled with oil.

FIG. 1 GENERAL SET UP OF APPARATUS WITH DETAILS OF SUGGESTED VARIETY

should have a least count of at least 0.1 kgf/cm² shall be so mounted in the system that it is at about the same elevation as the mid-height of the soil sample.

3.4.7 A System to Push Water into or to Withdraw Water from Zones in the Cell Pressure Application System and in the Back Pressure Application System — See (8) in Fig. 1. Clockwise rotation of the handle of the screw control cylinder (8) pushes water out of the cylinder and into the zone determined by valve positions anti-clockwise rotation of the handle draws water into the cylinder.

3.4.8 A System to Measure Pore Water Pressure — See (26) to (32) in Fig. 1. Pore water pressure measurement is made with valves *B1*, *A4*, *A5* and *A6* closed and valves *A1*, *A2* and *A3* open if pressure is to be read in the pressure gauge (30). If pressure is to be measured on the manometer (32) then valves *B1*, *A3*, *A5* and *A6* are closed and valves *A1*, *A2* and *A4* are opened. The pressure gauge (30) which should have a least count of at least 0.1 kgf/cm² and the manometer (32) shall be so mounted in the system that they are at about the same elevation as the mid height of the sample. The crucial requirement for the pore water pressure measuring system is that it shall be able to measure the pore water pressure under undrained condition, that is, water should neither flow out of the soil sample nor flow into it during the process of measurement. This is ensured by:

- using a tube which expands a negligible amount when stressed internally (for example, annealed tube) between the valve *A1* and the null indicator;
- completely de-airing the drainage and back pressure line (23), the pore pressure measurement line (25), the tubing (26) and the null indicator (27); and
- using the null indicator.

NOTE — For the purpose of understanding how this equipment works, the null indicator may be considered to be narrow bore U-tube with mercury filled in the bottom of the U-tube, and also partially filling a vertical limb of the U-tube. Before beginning to make a measurement, the pore water pressure measuring system shall be brought to the same pressure which exists in the pore water of the sample and which is determined by the position of valves *B2* and *B3* in the drainage and back pressure line (23). This is achieved by opening valves *A2*, *A3* and *A4* but keeping valve *A6* closed and using screw control cylinder (29) to build up pressure in the pore pressure measuring system to approximately equal the pore water pressure in the soil sample and then by connecting the pore pressure measurement line (25) and the drainage and back pressure line (23) together by keeping open valve *B1* and opening valve *A1*. With pressure in the measuring system now equal to the initial pore water pressure in the sample and recorded by pressure gauge (30), the position of the mercury-water interface in the left limb of the U-tube is set at a convenient height by using the screw control cylinder (29). Valve *B1* is closed. The external stress conditions on the soil sample are changed which induce changes in pore water pressure. If the induced pore water pressure is positive, there will be a tendency

for the pore water to move out of the sample, travel through the tubing (26) and push the mercury-water meniscus in the left limb of the U-tube down from its initially set position. The movement of the meniscus is prevented by operating the screw control cylinder (29) and raising pressure on the right limb of the U-tube. When the pressure built up by the screw control cylinder equals the induced pore water pressure there will be no tendency for the meniscus to move. By keeping the meniscus at its initially set position, the null condition or the undrained condition is maintained and the increase in pore water pressure is obtained by observing the increase in the pressure reading in the gauge (30). If the induced pressure in the pore water had been negative, there would have been a tendency for the mercury-water meniscus to rise which can be countered by operating the screw control cylinder (29) and reducing the pressure on the right limb. The induced reduction in pressure can then be obtained by observing the decrease in the pressure reading in the gauge (30).

3.4.9 The Membrane Stretcher — See Fig. 2. To mount the membrane and the rubber 'O' rings on the soil sample and loading cam/pedestal.

3.4.10 Rubber Membrane — See (16) in Fig. 1. The soil sample is enclosed in a rubber membrane impermeable to water, to isolate the sample from the water in the cell. The membrane should be about 140 mm long. Its thickness should be about 0.2 mm.

3.4.11 Rubber 'O' Rings — See (17) in Fig. 1. Seamless rubber 'O' rings should be used to seal the rubber membrane to the loading cap and pedestal. The unstretched inside diameter of the 'O' ring should be 31 ± 1 mm. At least two, usually more, 'O' rings, are used both for sealing with the loading cap and with the pedestal.

3.4.12 Coarse Porous Stones — See (18) and (21) in Fig. 1. Coarse porous stones should be placed at the top and bottom of the sample to provide a free draining surface to the pore water. The stones should be about 3 mm thick and should be made of material whose particle size is between 180 and 150 micron IS Sieves.

3.4.13 Filter Paper for Strips [See (19) in Fig. 1] and Discs — Filter paper strips should be provided along the height of the sample at its circumference to induce radial drainage. In lieu of strips, a rectangular paper of appropriate size with parallel slits may be wrapped around the sample after soaking the paper in water. Filter paper discs should be placed between the sample ends and the coarse porous stones to prevent the stones from becoming clogged due to migration of fine soil particles with the pore water. The filter paper to be used for this purpose should be such that it does not soften in water (for example, Whatman's No. 54 or equivalent).

3.4.14 Accessories — Also required are accessories for soil sample preparation, extrusion, trimming and for measurement of size, weight, water content, etc.

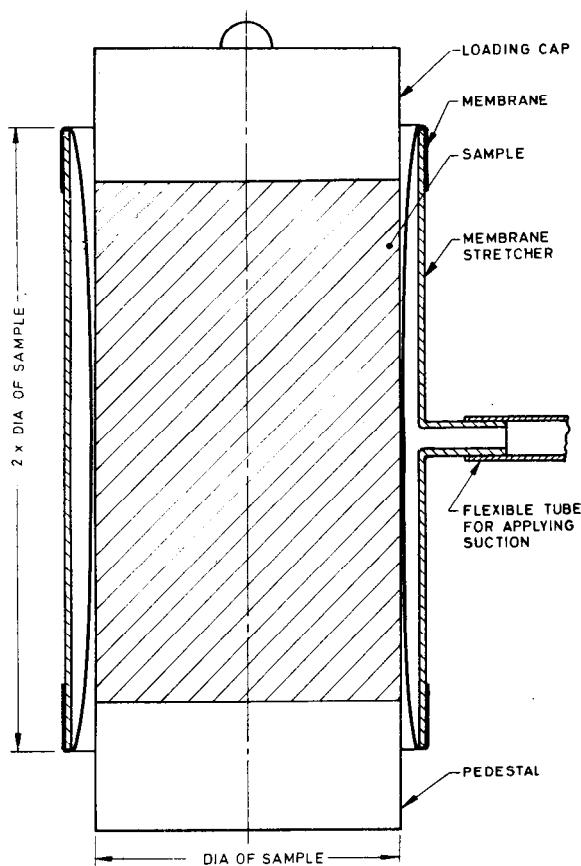


FIG. 2 TYPICAL APPARATUS FOR MEMBRANE STRETCHER

4. PROCEDURES FOR COMMISSIONING APPARATUS

4.1 De-airing of Pore Pressure Measurement Line

To make accurate measurements of pore water pressure, the pore pressure measurement line shall be completely de-aired and shall contain de-aired water from the line's outlet in the pedestal of the base of the triaxial cell to the mercury-water meniscus in the null indicator. This is achieved as described in 4.1.1 to 4.1.5. The description assumes that all valves are initially closed, and the top of the triaxial cell is lying on a table separated from the base.

4.1.1 Open valve *A6* and fill de-aired water in screw control cylinder (29) from reservoir of de-aired water (31) by moving the handle of the screw control cylinder in the anti-clockwise direction. Close valve *A6* when cylinder is more than three quarters full.

4.1.2 Open valves *A2* and *A3*, and adjust pressure so that pressure gauge reads zero. Open valve *A1* and by operating the handle of the screw control cylinder bring the mercury down to the horizontal

part of U-tube in the null indicator. Tilt the null indicator such that the mercury settles at the bottom part of the horizontal limb of the U-tube and such that when the water is pushed from the screw control cylinder, it passes over the mercury to the tubing (26). Mercury shall always be prevented from coming in contact with brass and copper fittings since it reacts with these materials. By operating the screw control cylinder, push water from the cylinder to pass over the mercury in the null indicator through the tubing (26) and let it overflow at the pedestal on the base of the triaxial cell. Flush water thus through the pore pressure measurement line until screw control cylinder is empty. Close valve *A2*, open valve *A6*, refill screw control cylinder, then close valve *A6*, open valve *A2* and flush the pore pressure measurement line again until screw control cylinder is half empty. This flushing will push out most of the air from the pore pressure measurement line. Close valve *A1*, build up pressure of about 6 kgf/cm^2 in the tubing (26) and null indicator by rotating the handle of the screw control cylinder in the clockwise direction. Leave the system under pressure for one to two hours. Open valve *A1* and flush out some more water through the pore pressure measurement line. The line is most likely de-aired.

4.1.3 To check whether the pore pressure line has been de-aired or not, proceed as follows. This check, however, tests the line from the null indicator to valve *A1* only and not beyond valve *A1* to the pedestal.

With valves *A1*, *A4* and *A6* closed and valves *A2* and *A3* open, tilt null indicator so that mercury shifts to the left side of the horizontal part of the U-tube. Build up pressure by operating the screw control cylinder (29). As pressure is built up, mercury will rise in the left limb of the U-tube. If the pore pressure line from the null indicator to valve *A1* has a lot of air, it will compress as pressure builds up and lot of mercury will be pushed into the left limb of the U-tube. On the other hand, if the above mentioned portion of the pore pressure line has been de-aired, the rise of the mercury in the left limb of the U-tube, when pressure is built up, will be insignificant and only due to the slight expansion of the tubing (26). The rise should be less than 10 mm for an increase in pressure of 8.0 kgf/cm^2 .

4.1.4 Apart from de-airing, there shall be no leaks in the pore pressure measuring apparatus. This may be checked visually as well as by subjecting different segments of the apparatus to pressure by operating the screw control cylinder (29) and seeing, by observing the pressure gauge (30), if pressure is maintained in the segment; if the pressure drops to zero with time, some leak in the segment under study is indicated, and this shall be isolated and eliminated.

4.1.5 When the pore pressure measuring apparatus has been de-aired and systematically checked to ensure that no leaks exist, the mercury in the null indicator is again brought to the horizontal part of the U-tube as described in 4.1.2, water is pushed from the screw control cylinder through valve *A*2 over the mercury, through valve *A*1 until the pedestal is covered with water. Valve *A*1 is then closed and pressure built up in the apparatus to about 6 kgf/cm² by operating the screw control cylinder (29). The apparatus is left thus under pressure until required.

NOTE — During the consolidation phase of the CU test, the pore pressure measuring unit is not required. The unit may be used elsewhere in the laboratory. For such purpose, close valves *A*1 and *A*2, and disconnect the unit where the tubing (26) meets valve *A*1. Prior to applying back pressure, this connection shall be remade and to avoid any air getting trapped in the line during connection, the following procedure shall be observed; the connection shall be made under water: (a) while water is flowing out from the tubing (26) which can be arranged by keeping mercury in the horizontal limb of the null indicator, valve *A*2 open and moving the screw control cylinder (29) clockwise, and (b) while water is flowing out from valve *A*1 which can be arranged by opening valves *A*1, *B*1 and *B*2 and letting water flow from burette (10) through the pedestal and out at valve *A*1.

4.2 De-airing of Drainage and Back Pressure Line (see Fig. 1) — There shall be no air in the drainage and back pressure line (23) (see 3.4.8). The de-airing is achieved as in 4.2.1 to 4.2.3 and the description with reference to Fig. 1 assumes that initially all valves associated with this line are closed.

4.2.1 Open valves *B*2 and *B*1 and let de-aired water flow from burette (10) to overflow at top of pedestal on the base of the triaxial cell. Keep the burette supplied with de-aired water and let water flow until no air bubbles are observed to emerge at the pedestal. Close valve *B*2.

4.2.2 Open valves *W*1, *G*1, *G*3 and *B*3 and let de-aired water flow from water reservoir (7) to overflow at top of the pedestal on the base of the triaxial cell until no air bubbles are observed to emerge at the pedestal. Close valves *W*1 and *B*1.

4.2.3 Operate screw control cylinder (8) and build up pressure in the back pressure and drainage line (23) to 6 kgf/cm². Leave the system under pressure for one to two hours. Open valve *B*1 and flush out some more water through the drainage and back pressure line by operating the screw control cylinder. Let some water stand on the pedestal and close valve *B*1.

4.2.4 Check for leaks in the line in a manner similar to that described in 4.1.4 and systematically eliminate leaks.

4.3 Commissioning Self-Compensating Mercury Pot Systems — The mercury pot systems apply pressure on account of the difference in the elevation of levels of mercury in the top and the corres-

ponding bottom mercury pots. For applying pressure, it is necessary, therefore, that there be mercury in both the top and the corresponding bottom mercury pots. Mercury can be moved from one pot to another as in 4.3.1 to 4.3.4. The description with reference to Fig. 1 assumes that all valves associated with the system are initially closed.

4.3.1 To Bring Mercury Down from Movable Pot (3) to Bottom Pot (4) — Open valves *M*1, *G*2 and *W*1; mercury will thus flow from movable pot (3) to bottom pot (4) and water from pot (4) will be pushed up into water reservoir (7). When required amount of mercury has come down to pot (4), close valve *W*1.

4.3.2 To Push Mercury Up from Bottom Pot (4) to Movable Pot (3) — With valves *M*1 and *G*2 open, operate screw control cylinder (8) and push water from screw control cylinder to bottom pot (4), which will push mercury up to movable pot (3).

4.3.3 To Bring Mercury Down from Fixed Pot (5) to Bottom Pot (6) — This can be accomplished only by simultaneously bringing down mercury from movable pot (3) to bottom pot (4). Open valves *M*2, *M*3, *G*2 and *W*1, and valve *M*1 closed, mercury will flow from movable pot (3) to bottom pot (4) which will push water up through valve *M*3 to top fixed pot (5) and mercury from pot (5) will then flow down to bottom pot (6) which, in turn, will push water up through valves *M*2, *G*2 and *W*1 to water reservoir (7). When required amount of mercury has come down from top pots to corresponding bottom ones, close valve *W*1.

4.3.4 To Push Mercury Up from Bottom Pot (6) to Top Fixed Pot (5) — This too can be accomplished only by simultaneously pushing mercury up from bottom pot (4) to movable top pot (3). With valves *M*2, *M*3 and *G*2 open, operate screw control cylinder (8) and push water from screw control cylinder to bottom pot (6) which will push mercury up to pot (5) and simultaneously mercury from pot (4) will go up to pot (3).

4.4 De-airing of Filter Paper and Discs and Porous Stones — For rapid drainage of water from soil sample during consolidation and for rapid equalization of pore water pressure during shear, it is necessary to place two coarse porous stones and two filter paper discs, one set of stone and disc at top of the sample (18) in Fig. 1 and one set at the bottom of the sample (21) and to place about 8 filter paper strips of suitable dimensions vertically along the exposed surface of the sample (see Note). The filter paper strips should be placed so that they are in contact with the top and bottom porous stones and so that they do not protrude out from under the rubber 'O' rings. The filter paper strips and discs and the porous stones should also be de-aired. The de-airing is achieved by immersing them in a pan of water and

boiling the water. After the water has boiled for about 10 minutes, let the water cool keeping the strips, discs and stones immersed.

NOTE — Alternately a filter paper of length $(\pi D_o + 5)$ mm and width equal to $(L_o + 6)$ mm with slits of 5 mm width leaving 5 mm width of filter paper cut with a sharp blade or knife, may be wrapped around the sample (where D_o is the diameter of the sample and L_o is the height of the sample).

4.5 The Rubber Membrane — See (16) in Fig. 1. The membrane shall be checked for leaks, by pinching one end and filling the membrane with water, then pinching the other end and building up pressure by squeezing the water into small zones in turn. After checking for leaks, the rubber membrane should be dried and some french chalk applied to it.

4.6 The Loading Ram — See (13) in Fig. 1. The ram should move freely in its bush at the top of the triaxial cell. If it does not, it should be cleaned with a soft and absolutely clean cloth and lightly oiled. The loading ram, when fully lifted, should fall freely and smoothly under its own weight.

4.7 The Pedestal and Loading Cap — The pedestal at the base of the cell (see Fig. 1), and the loading cap (15) should be carefully cleaned and their vertical sides lightly greased with high vacuum silicon grease.

5. SOIL SAMPLES FOR TEST

5.1 Number of Sample — Normally a minimum of three samples of the soil are required to be able to determine the strength parameters. The three samples are then tested under three different effective confining stresses in the stress range of interest for the investigation in hand.

5.2 Type of Sample and Soil — The method described herein is equally valid for disturbed or undisturbed samples obtained by sampling from the field as well as for samples prepared in the laboratory by compaction, remoulding or any other process. Cohesionless soil samples are unable to stand on their own without lateral support. Samples of such soil are formed directly on the pedestal at the base of the triaxial cell. The procedures relevant to cohesionless soils are described in Appendix A. The procedure described in 6 is for soil samples which are cohesive enough to stand on their own and which can be handled. The samples shall be brought to a diameter equal to the diameter of the pedestal of the triaxial cell and they shall have a height equal to twice their diameter.

5.3 Pre-sample Handling Operations — Prior to handling the soil for preparation of soil samples, the equipment should be commissioned and thoroughly checked as described in 4.

5.4 Control Measurements — For control purposes, the initial diameter, length and weight of the

sample shall be measured before setting it up for test; the measurements shall be recorded in the proforma given in Appendix B. The water content of the soil sample which may be ascertained by determining the water content of the parent soil from which the sample has been trimmed or shaped should also be recorded in the proforma.

6. TEST PROCEDURE

6.1 The test should be conducted in an environment in which ambient temperature is constant.

6.2 Setting Up of Sample — See Fig. 1. All valves are assumed to be closed and it is also assumed that the pedestal at the base of triaxial cell is covered with water as described in 4.1.5.

6.2.1 Gently slide one de-aired coarse porous stone on to the top of the pedestal and blow off any excess water from the pedestal. Place a filter paper disc on the stone and then place the soil sample on the disc. Place the second de-aired disc and then the coarse porous stone on top of the sample and the loading cap on top of the second porous stone. Ensure that the sample, the stones, the discs, and the loading cap are all concentrically placed on the pedestal.

6.2.2 Envelope the sample with eight de-aired filter paper strips placing each strip in turn so that it touches the top and bottom porous stones and arranging them so that they are placed at regular intervals around the entire circumference of the sample. Alternately wrap the filter paper with slits, around the sample.

6.2.3 Mount the rubber membrane on the membrane stretcher (see Fig. 2). Suck out the air between the membrane and the stretcher wall, and lower the stretcher on to the soil sample. Release the vacuum between the membrane and the stretcher wall and let the membrane cling on to the soil sample. Unfold the membrane from the top and bottom of the stretcher, and loading cap and the pedestal.

6.2.4 Mount rubber 'O' rings at the edge of the membrane stretcher and by again lowering the stretcher on the sample, slip off two 'O' rings to seal the membrane to the pedestal and then two 'O' rings to seal the membrane to the loading cap.

6.2.5 Place the top of the triaxial cell on its base and screw the two together. While placing the top, make sure loading ram is pulled sufficiently out of the top so that it does not hit the soil sample when the cell is being assembled.

6.2.6 Fill up cell with water as described in 3.4.2 until the cell is almost full. Fill the remaining space in the top of cell by injecting oil through the oil inlet (14). When excess oil begins to spill out through the air vent (12), close both the air vent and the oil inlet.

6.2.7 With valves *C1*, *A1* and *B1* closed and valve *C2* open, apply cell pressure as described in 3.4.3

equal to the desired amount of effective confining pressure and record it in the proforma given in Appendix B. The sample is now set up.

6.3 Consolidation of Sample — The sample will begin to consolidate as soon as valves *B1* and *B2* are opened (valves *B3*, *A1* and *C1* are still closed). Before opening valves *B1* and *B2*, ensure the following:

- That the water level in burette (10) is at an appropriate level so that water draining from or into the sample can be observed and recorded. The burette should be so positioned that the water level in it is approximately at the same elevation as the mid-height of the sample.
- That the initial reading of water level in the burette (10) is recorded in the proforma in Appendix B.
- That the observer is ready to record data time *versus* flow of water into or out of the burette (10).

6.3.1 Recording Data — Immediately upon opening valves *B1* and *B2*, data or burette reading *versus* time and elapsed time should be recorded in the proforma in Appendix B. Readings may be taken for elapsed times which have a whole number for their square root, that is, for 1, 4, 9, 16, 25, 36, 49 and 64 minutes, etc, and continued until essentially complete consolidation has occurred or for a maximum of 24 hours.

6.3.2 Computation of Post-Consolidation Dimensions of Sample — On account of volume change occurring in the soil during consolidation, the length and diameter of the sample alter. The dimensions after consolidation may be estimated on the assumption that the sample remains a cylinder and that the soil behaves isotropically as follows:

$$L = L_o \left(1 - \frac{\Delta V}{3V_o}\right)$$

$$D = D_o \left(1 - \frac{\Delta V}{3V_o}\right)$$

where

L = post-consolidation length,

L_o = original length,

ΔV = change in volume during consolidation and is positive if volume has decreased,

V_o = original volume,

D = post-consolidation diameter, and

D_o = original diameter.

These dimensions should be recorded in the proforma in Appendix B.

6.3.3 Computing Coefficient of Consolidation

— From data recorded as in 6.3.1, the coefficient of

consolidation, *c_v*, a parameter which is used for determining the deformation rate as described in 6.4.4 may be determined. In col 3 of Pre-shear Data Sheet No. 1 of Appendix B, fill in square root of *t*, the elapsed time, and in col 5 fill in ΔV , the change in sample volume, being the difference between burette reading at each time and the initial burette reading. Plot ΔV *versus* square root of time as shown in Fig. 3 and determine t_{100} . *c_v* can then be determined from the formula:

$$c_v = \frac{\pi D^2}{100 t_{100}}$$

where *D* is the diameter of the sample in cm.

This formula is valid only for a sample whose length is twice its diameter and which has a coarse porous stone on its two ends and is enveloped with filter paper strips.

6.4 Pre-shear Operations — Before proceeding to shear the soil sample, a number of operations should be completed and a few decisions taken as described in 6.4.1 to 6.4.4.

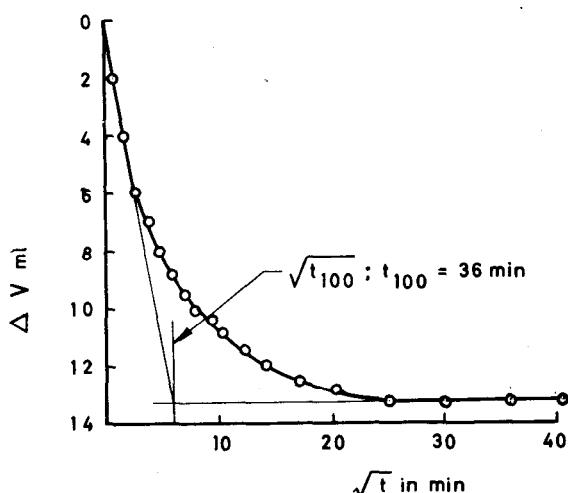


FIG. 3 PLOT OF ΔV *versus* \sqrt{t}

6.4.1 Application of Back Pressure — During the consolidation process described in 6.3, the pore water allowed to drain into the burette until equilibrium was achieved. This implies that the pore water pressure at the end of consolidation became zero, that is, atmospheric pressure. The total stress on the sample is equal to the cell pressure and since pore water pressure is zero, the effective stress is also equal to the cell pressure. The sample can be sheared under undrained conditions with this same effective stress and sample volume but by using elevated cell and pore water pressure. This is achieved by merely increasing both the cell pressure and the pore water pressure by equal amounts. The

difference between the two elevated pressures thus equals the initial cell pressure. Testing under an artificially elevated cell pressure and pore water pressure is referred to as testing under a back pressure. The back pressure equals the elevated pore water pressure. This has two advantages:

- During shear, negative pore water pressure is induced in some soils. If pre-shear pore water pressure is zero, development of negative pore water pressure implies below atmospheric pore water pressure which is difficult and sometimes impossible to measure on account of the consequent cavitation in the water in the pore water pressure measuring system. Development of negative pore water pressure during shear, when sample has a back pressure, results merely in lowering the positive value of pore water pressure and if back pressure selected is higher than the maximum negative pore water pressure induced, the magnitude of pore water pressure remains above atmospheric and is readily measurable.
- Even in supposedly saturated soil samples, the pore space sometimes contains some air which, on application of total stress to the sample, compresses and causes volume change in the sample as well as causes effective stress to increase even under undrained conditions. By application of back pressure, the air gets compressed and dissolved in pore water, and one can ensure that the soil is fully saturated. This can be tested by measuring the B-factor of the soil as described in 6.4.2. Back pressure may be continued to be increased until B-factor becomes unity thus assuring that soil is 100 percent saturated.

6.4.1.1 To apply back pressure, cell pressure and pore water pressure should be increased simultaneously by the same amount. This is achieved as follows (see Fig. 1):

Close valves B_2 , B_1 and C_2 (valves C_1 and A_1 are already closed). By operating valves C_3 , G_2 , G_1 , M_1 , M_2 , M_3 and associated mercury pots as described in 3.4.3, increase cell pressure to be applied by an amount equal to the back pressure to be applied (Back pressure should be applied in small steps of about 0.5 kgf/cm^2 so as to avoid creating stress concentration in soil sample). Close valve G_2 . Operate valves G_1 , G_3 , B_3 , M'_1 , M'_2 and M'_3 and the associated mercury pots as described in 3.4.5, and set the system to apply the desired amount of back pressure. Simultaneously open valves B_1 and C_2 and let the sample come to equilibrium by allowing the new stresses to act on it for say 2 to 4 hours. Repeat the above process in steps until enough back pressure has been applied to achieve the two advantages described in (a) and (b) of 6.3.1.

6.4.2 Testing for B-Factor — As noted in 6.4.1 (b), the sample is saturated when it exhibits a B-factor of preferably 1.0 but not less than 0.9. The sample can be tested for B-factor at any stage during the process of back pressure application. The procedure is as given in 6.4.2.1 (see Fig. 1).

NOTE — In certain soils such as residual clays and very stiff soils, B-factor may be less than one at saturation.

6.4.2.1 Open valves A_2 and A_3 and bring pressure in the pore pressure measuring system to a value approximately equal to the pressure than existing in the pore water of the sample by operating screw control cylinder (29). Open valve A_1 and let the pressure in the pore pressure measuring system equalize with the existing pore water pressure. Tilt the null indicator (27) and set the mercury in the left limb of the U-tube as described in 3.4.8. Close valve B_1 . Increase cell pressure through valve C_2 by known amount and measure the increase in pore water pressure as described in 3.4.8. The ratio of increase in pore water pressure to the increase in cell pressure is the B-factor which should be recorded at the bottom of Pre-shear Data Sheet No. 1 of Appendix B. If B-factor is less than 1.0, greater back pressure needs to be applied. To bring the system back to the set up used for applying back pressure, set the back pressure to be applied using valves M'_1 , M'_2 , M'_3 , etc, and use screw control cylinder (29) to increase the pore water pressure to the desired level of back pressure, then open valve B_1 . Use screw control cylinder (29) to withdraw mercury from the left limb of the U-tube to the bottom part of the U-tube and then close valve A_1 . Let the sample equilibrate under the new cell and back pressure.

6.4.3 Setting Proving Ring and Dial Gauge

6.4.3.1 Loading frames subject the soil to axial deformation. The load required to cause deformation is usually measured by a proving ring placed between the yoke of the loading frame and the loading ram of the triaxial cell (see Fig. 4). An appropriate proving ring should be chosen for each test. The proving ring should be selected so that its capacity is greater than the load required to fail the sample but not so great that precision in measuring the load is lost. An estimate of the load required to fail the sample may be made by assuming reasonable values for the angle of shearing resistance in terms of effective stress, ϕ' and the A-factor at failure, A_f for the soil and using the equation below:

$$\text{Load to fail} = P_f = \sigma_c A_r + 2A \times \frac{(\sigma_c - \mu_B) \sin \phi'}{1 - (1 - 2A_f) \sin \phi'}$$

where

σ_c = cell pressure,

A_r = the area of the loading ram,

A = the area of the sample, and

μ_B = the back pressure.

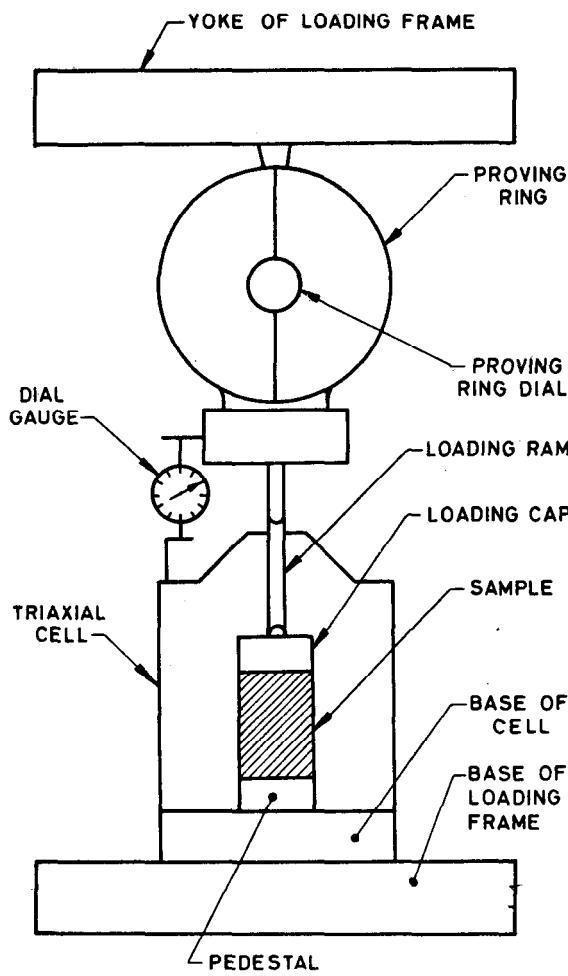


FIG. 4 SCHEMATIC SKETCH SHOWING PROVING RING DIAL AND DIAL GAUGE

Proving ring to be used should have a capacity about 1.5 to 2.0 times the load required to cause failure as computed above.

6.4.3.2 A dial gauge is usually used to observe axial deformation of the soil sample. It should have a least count of at least 0.02 mm and should be mounted on the proving ring as shown in Fig. 4. As the loading frame operates, it reduces the space between the yoke of the frame and the base of the cell. This reduction in space is shared by compression of the proving ring and compression of the soil sample. By mounting the dial gauge on the proving ring only, the axial deformation of the sample is measured. The proving ring dial measures the compression of the proving ring which is related to the load on the proving ring by the calibration curve of the proving ring.

6.4.4 Setting Deformation Rate — The rate of deformation, at which the loading frame should be set, should be selected for each soil. Since pore

water pressure is being measured only at the base of the sample and the failure zone is away from the base, it is imperative to shear slowly so that the pore water has an opportunity to equalize and the measured value equals the value in the shear zone. For 95 percent equalization, the time to failure, t_f^* may be computed from:

$$t_f = \frac{0.071 L^2}{4c_v}$$

where

L = post-consolidation length of sample; and
 c_v = as given in 6.3.3 and filter paper strips, discs and porous stones are used as described in 6.2.

and by estimating axial strain necessary to produce failure ϵ_f , rate of deformation may be calculated as:

$$\text{Deformation rate} = \frac{\epsilon_f L + \frac{P_f}{K}}{t_f}$$

where

P_f = load to fail, and
 K = a linear estimate of the proving ring calibration characteristics.

6.5 Shearing of Sample — When the sample is ready to be sheared, the pore water pressure measuring equipment should be again brought into the circuit as described in initial part of 6.4.2.1 and valve $B1$ closed. The reading in gauge (30) should be recorded in first row of col 2 of Shear Data Sheet No. 2 of Appendix B and is taken to be equivalent to a pore pressure in the soil sample equal to the back pressure. The proving ring should be suspended from the yoke and in the suspended position the proving ring dial should be set to zero and the zero reading recorded in first row of col 5 of Shear Data Sheet No. 2 of Appendix B. Using manual control of loading frame, the loading ram should be then pushed into the cell but not allowed to touch the loading cap. The loading frame should be run at the selected deformation rate. During this operation, the proving ring records the force arising from the cell pressure acting upon the area of the loading ram, $\sigma_c A_r$, and the friction mobilized between the ram and bush; this should be recorded in second row in col 5 of Shear Data Sheet No. 2 of Appendix B. Electrical operation of the loading frame should then be stopped. With manual controls, the loading ram should be pushed further into the cell gently bringing it in contact with the loading cap. The dial gauge for measuring axial deformation of the sample should now be aligned and set to zero (see Fig. 4). The sample is now ready to be subjected

*This is valid if only the condition of failure is of interest; if, however, the complete stress path is required, this time should equal the time to the first significant value to be plotted.

to additional axial stresses, that is, it is ready to be sheared. During the process of shearing, by a constant gradual adjustment of the screw control cylinder (29), the level of mercury in the left hand limb of the U-tube of the null indicator shall be maintained at its initially set location.

6.5.1 Recording Data — During shear the three observations listed below should be recorded at regular intervals of axial deformation as read on the dial gauge and noted in col 3 of Shear Data Sheet No. 2 of Appendix B corresponding to axial strain values of about 0.33 percent, 0.67 percent, 1 percent, 2 percent, 3 percent, 4 percent, etc, until failure or until 20 percent of axial strain. Observations may also be made at other suitable values of axial strain:

- The reading on the proving ring dial in col 5 of Shear Data Sheet No. 2 of Appendix B,
- The reading on the pressure gauge (30) of pore water pressure in col 2 of Shear Data Sheet No. 2 of Appendix B, and
- Elapsed time in col 1 of Shear Data Sheet No. 2 of Appendix B.

6.5.2 Dismantling (see Fig. 1) — Upon completion of the test, first close valve *A1*, thereby isolating the pore water pressure measuring system and thus eliminating any hazard of altering the water content of the sample during dismantling. Then shut off the loading frame and using the manual control on the loading frame, remove all additional axial stress from the sample. Next shut off valve *M1/M2* and *M3* and open valve *W1* to let the cell pressure reduce to about zero. Open temporarily air and oil vents and let oil spill over the top of the triaxial cell which can be wiped clean by a dust free rag. Close valve *G1* to isolate gauge and apply vacuum to (I); then open air vent and water will be forced up into water reservoir (7). Close valve *C2* when there is just a little water left in the cell and shut off vacuum at (I). Remove top of triaxial cell. Wipe rubber membrane. Slip off rubber 'O' rings (17) and membrane (16), and remove loading cap (15) and top coarse porous stone (18) and recover sample. Peel off filter paper strips and discs, and weigh the soil sample making sure that no part of the sample is lost. The post-shear weight of the sample, and the post-shear length and shape should be recorded in the Shear Data Sheet No. 2 of Appendix B. Water content data readings should be recorded in Shear Data Sheet No. 2 of Appendix B.

The triaxial cell should be cleaned with grit-free soap and water, the loading ram oiled, and the rubber membrane washed, dried and sprinkled with french chalk powder for storage until required for the next test.

6.5.3 Computation of Results — The entire computations for each triaxial test may be done on Shear Data Sheet No. 2 of Appendix B (*see also*

Note). At the end of the test, col 1 is filled with readings of elapsed time, col 2 with gauge readings of pore water pressure, col 3 with values of axial deformation in terms of dial gauge readings, and col 5 with readings of proving ring dial. Calculations should prove as follows:

- By dividing axial deformation (col 3) by post-consolidation length, fill up col 4 for percentage axial strain.
- Using calibration curve for the proving ring used, fill up col 6 for load on proving ring.
- By subtracting each reading of pore water pressure (col 2) from the initial reading of pore water pressure (col 2, row 1), obtain change in pore water pressure and note it in col 7.
- By subtracting the value of load on proving ring when the loading frame was operated without the loading ram touching the sample (col 6, row 2) from each value of load on proving ring (col 6), obtain respective values of axial load for col 8.
- By dividing post-consolidation area A_1 by $(1 - \epsilon)$ where ϵ is the axial strain, obtain for each ϵ the value of the area of the sample A_1 at that strain.
- By dividing each value of axial load (col 8) by corresponding value of area of the sample A_1 (col 9), obtain values of deviator stress $(\sigma_1 - \sigma_3)$ in col 10.
- By subtracting from the value of initial effective cell pressure, that is, cell pressure minus back pressure, each value of change in pore water pressure (col 7), obtain values of minor principal effective stress σ_3 for col 11.
- By adding values of deviator stress (col 10) and minor principal effective stress (col 11) for each row in turn obtain values of major principal effective stress σ_1 , for col 12.
- By adding value of minor principal effective (col 11) and major principal effective stress (col 12) for each row in turn obtain values of sum of principal stresses $\bar{\sigma}_1 + \bar{\sigma}_3$, for col 13.
- By dividing each value of major principal effective stress (col 12) by corresponding value of minor principal effective stress (col 11) obtain values of principal effective stress ratio $\bar{\sigma}_1/\bar{\sigma}_3$ for col 14.
- By dividing each value of change in pore water pressure (col 7) by corresponding value of deviator stress (col 10), obtain values of A-factor for col 15.

NOTE — For soils of low shear strength, suitable corrections may be applied for the effects of membrane, filter strip and loading ram friction. These corrections may not be necessary for routine testing.

7. DETERMINATION OF STRENGTH PARAMETERS

7.1 For determining strength parameters, it is necessary to test at least three samples of the soil under investigation at three different effective cell pressures in the stress range of interest. The three soil samples should initially be as identical to each other as possible.

7.2 Strength Parameters in Terms of Effective Stress — From respective Shear Data Sheets of Appendix B or from respective stress-strain curves (see Fig. 5), identify the condition of failure (see Note 1 under 7.2.1) of each of the three samples. Plot a Mohr circle for the state of stress at failure in terms of effective stresses for each of the three samples (see Fig. 6). Draw the best common tangent to the three circles. The angle the tangent makes with the horizontal is the angle of shearing resistance in terms of effective stresses, ϕ' and the intercept the tangent makes on the y -axis is the cohesion intercept in terms of effective stresses, c' (see Fig. 6).

7.2.1 The strength parameters mathematically describe the best tangent, that is, the failure envelope as follows:

$$\tau_{tf} = c' + \bar{\sigma}_{tf} \tan \phi'$$

where

τ_{tf} = the shear stress at failure on the plane of tangency (see Note 2), and

$\bar{\sigma}_{tf}$ = the normal effective stress on the plane of tangency.

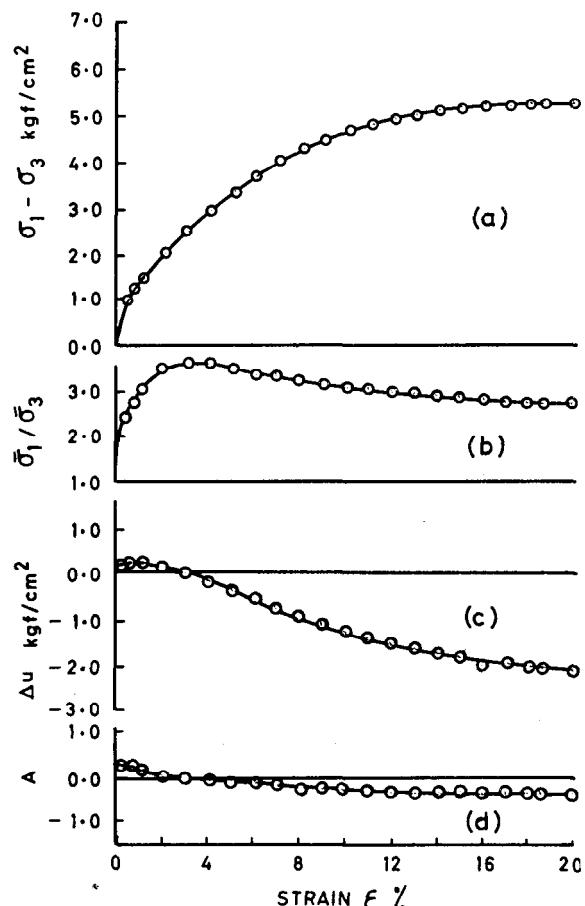


FIG. 5 STRESS-STRAIN CURVES

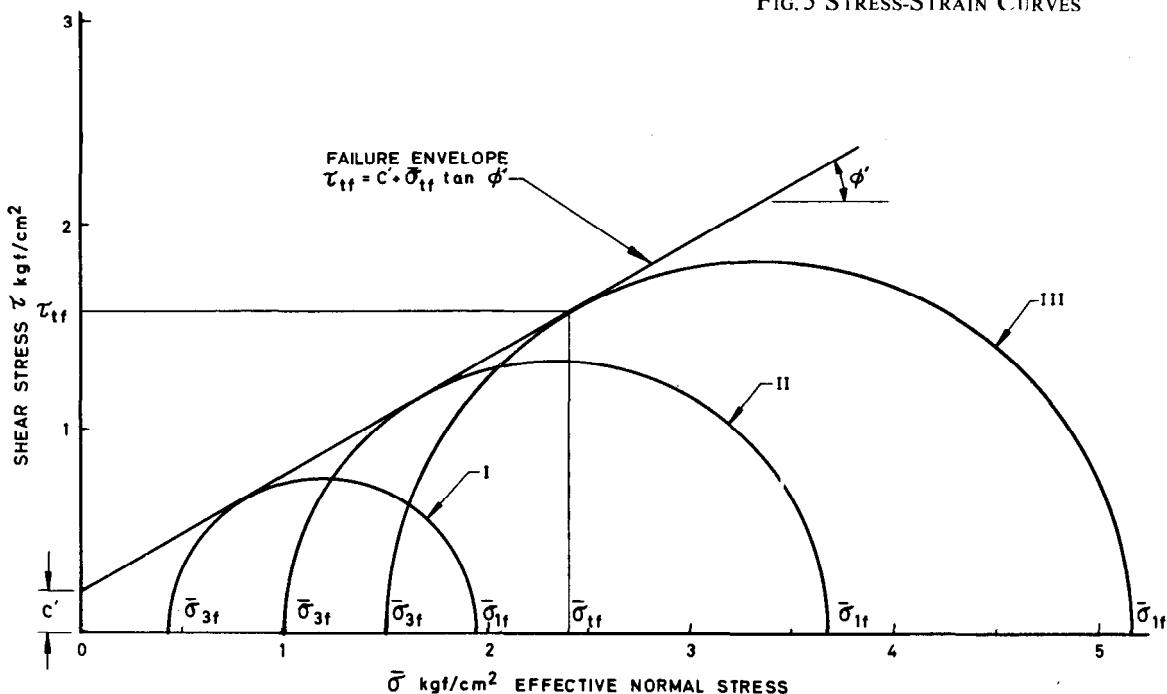


FIG. 6 STRESS CONDITIONS AT FAILURE IN TERMS OF EFFECTIVE STRESSES

NOTE 1 — What constitutes failure, depends on the context in which results are to be used. Often used criteria are: (a) at peak deviator stress, (b) at peak principal effective stress ratio, (c) at 5 percent axial strain, and (d) at 20 percent axial strain.

NOTE 2 — For engineering purposes, the plane of tangency may be considered identical to the failure plane and c' and ϕ' may be considered as follows:

$$\tau_{tf} = c' + \bar{\sigma}_f \tan \phi'$$

where

τ_{tf} = shear stress at failure on the failure plane, and

$\bar{\sigma}_f$ = effective normal stress at failure on the failure plane.

7.3 Strength Parameters in Terms of Total Stresses

Follow the procedure as described in 7.2 with the difference that the Mohr circles are to be plotted in terms of total stresses. The major/minor principal total stress at failure is equal to the major/minor principal effective stress at failure plus the pore water pressure at failure. The pore water pressure at failure is equal to the back pressure plus the change in pore water pressure until failure (from col 7 Appendix B Data Sheet No. 2). The angle the tangent makes with the horizontal is angle of shearing resistance in terms of total stresses as obtained from a CU test, ϕ_{CU} , and the intercept the tangent makes on the y-axis is the cohesion intercept in terms of total stresses as obtained from a CU test, c_{CU} (see Fig. 7).

7.3.1 ϕ_{CU} and c_{CU} are parameters that mathematically describe the failure envelope in terms of total stresses as follows:

$$\tau_{tf} = c_{CU} + \sigma_{tf} \tan \phi_{CU}$$

where

τ_{tf} = shear stress at failure on the plane of tangency, and

σ_{tf} = the total normal stress at failure on the plane of tangency (see Note).

NOTE — Plane of tangency obtained from failure envelope in terms of total stress is different from the plane obtained in terms of effective stresses; only the latter may be considered as being identical to the failure plane in the soil sample.

7.4 Undrained Strength Over Effective Confining Stress Ratio

This ratio can be obtained by obtaining for each sample the ratio of half the deviator stress at failure to the initial effective cell pressure. For normally consolidated soil, this ratio is usually a constant.

7.5 c' and ϕ' may also be obtained by plotting

$$\frac{\sigma_1 - \sigma_3}{2} \text{ at failure versus } \frac{1 + \bar{\sigma}_3}{2} \text{ at failure}$$

for the samples tested, as shown in Fig. 8.

8. PRESENTATION OF RESULTS

8.1 Stress-Strain Results — The results of the test on each sample may be presented in the form of stress-strain curves as follows:

Fig. 5(a) shows deviator stress *versus* strain.

Fig. 5(b) shows principal effective stress ratio *versus* strain.

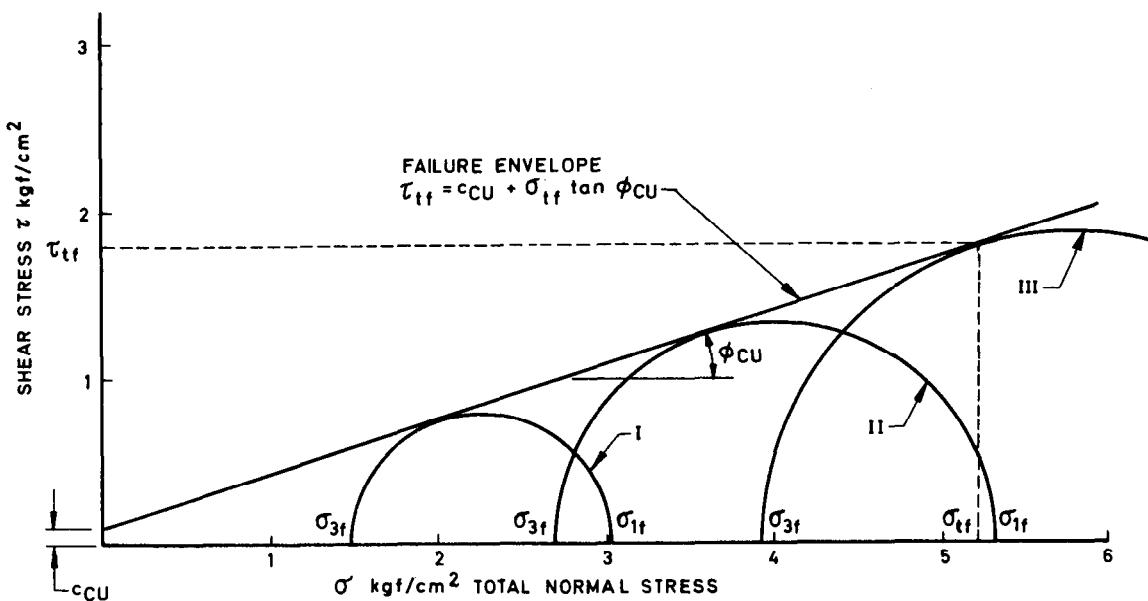


FIG. 7 STRESS CONDITION AT FAILURE IN TERMS OF TOTAL STRESS

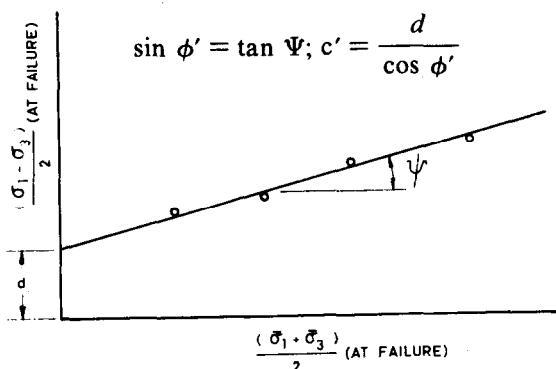


FIG. 8 DETERMINING c' AND ϕ' USING $\frac{\sigma_1 - \sigma_3}{2}$ (AT FAILURE) versus $\frac{\sigma_1 + \sigma_3}{2}$ (AT FAILURE) PLOT

Fig. 5(c) shows change in pore water pressure *versus* strain

Fig. 5(d) shows A-factor *versus* strain.

8.2 Failure Stress Results — The failure condition of all the three samples may be shown in terms of Mohr circles at failure, both in terms of effective stress, Fig. 6 and in terms of total stresses, Fig. 7.

A P P E N D I X A (Clause 5.2)

SETTING UP SAMPLES OF COHESIONLESS SOIL

A-1. PROCEDURE

A-1.1 In order to make samples of cohesionless soil for use in a triaxial test, it is necessary to use a former which will maintain the required specimen shape until effective stress of sufficient magnitude to make the sample self-supporting can be applied. The former (*see* Fig. 9) is a split mould of 38.3 mm internal diameter which encloses the rubber membrane and is clamped to the base of the cell. The lower 'O' rings are accommodated in a groove in the former.

A-1.2 After the equipment has been commissioned as described in 5.3, the sample can be set up as given in A-1.2.1 to A-1.2.3. (All valves in Fig. 1 are assumed to be closed).

A-1.2.1 Coarse porous stone should be placed on the pedestal. The rubber membrane should be sealed to the pedestal by two 'O' rings and the split former clamped into position. The upper ring (1) in Fig. 9 should be placed inside the top of the membrane and held with the clamp (2) in Fig. 9 before placing the funnel and rubber bung in position. The membrane and funnel should be then filled with de-aired water; the pressure due to the head of water holds the rubber membrane against the inside of the former. Sufficient sand to fill the former should be weighed out and saturated by mixing in a beaker with enough water just to cover the sand. The mixture should be boiled to remove trapped air and then placed with a spoon in the funnel, the stopper (3) being in position.

A-1.2.2 The sample should be built up by allowing a continuous rapid flow into the former. To increase density of sample, the former may be subjected to vibration. The funnel and stopper should then be removed. The 'O' rings should be slipped off the metal ring and the membrane folded over on to the sides of the former. After the surface of the sample has been levelled, a coarse porous stone should be placed on it and the loading cap should be lowered into position. Rubber 'O' rings should be used to seal the membrane to the cap.

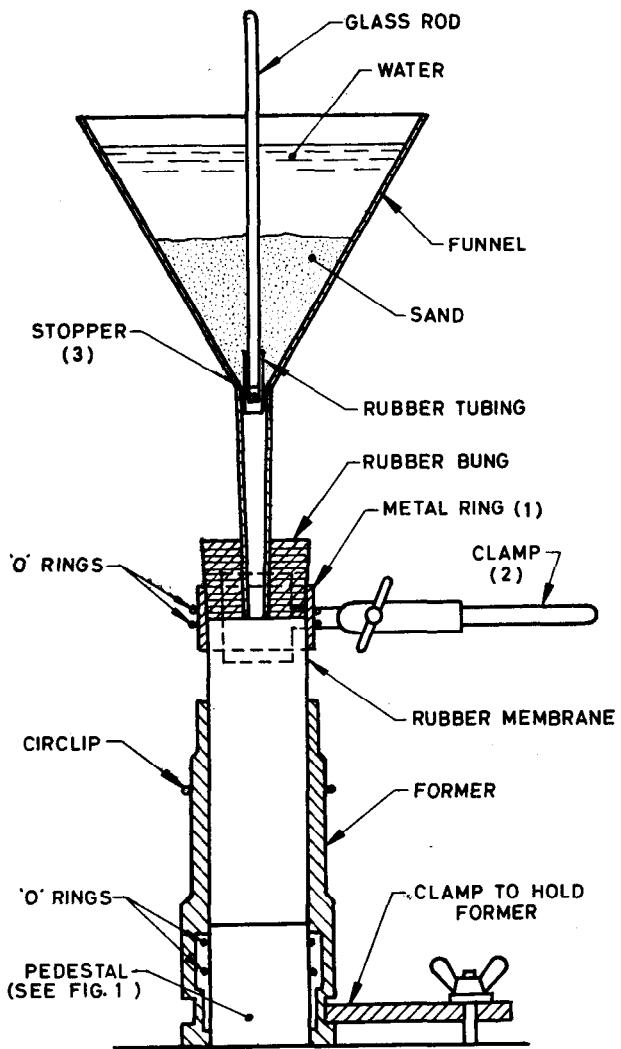


FIG. 9 SET UP FOR PREPARING SAMPLES OF COHESIONLESS SOIL

A-1.2.3 A small negative pore water pressure should be applied to the sample to give it rigidity, by opening valves B_1 and B_2 (see Fig. 1) and lowering the burette (10) (see Fig. 1) to the floor. Consolidation under this effective stress occurs almost at once, and is indicated by the change in the water level in the burette. The split mould should then be removed and the height and diameter of the sample measured, the thickness of the membrane being deducted to obtain actual sample dimensions. The rest of the test proceeds as described in 6.2 to 6.4 except that in the dismantling process, the sample again loses its shape; the entire sample is used to determine the dry weight of the soil used.

A P P E N D I X B
(Clause 5.4)

PROFORMA FOR RECORD OF OBSERVATION OF CU TRIAXIAL SHEAR TEST

Pre-shear Data Sheet No. 1

Project	Test No.
Sample No.	Date
Soil Identification	Tested by
Sample Measurements:	
Initial dia, D_o	Initial Water Content
Initial length, L_o	Can No.
Initial area, A_o	Weight of can + Wet soil
Initial volume, V_o	Weight of can + Dry soil
Initial weight	Weight of water
	Weight of can
	Weight of dry soil
	Water content
Specific Gravity	Void Ratio
Effective Confining Pressure	

Time	Elapsed Time, t	\sqrt{t}	Burette Reading	ΔV				

Post-Consolidation Water Content,
 Post-Consolidation Void Ratio c_v

Back Pressure						
B-factor						

Remarks:

CU Triaxial Shear Test — Shear Data Sheet No. 2

Project..... Loading Frame No. Cell No. Test No.
 Sample No. Proving Ring No. Date.....
 Soil Identification..... Deformation Rate..... Tested by.....
 Post-consolidation Length, L Confining Pressure, σ_c
 Post-consolidation Dia, D
 Post-consolidation Area, A Back Pressure..... Post-Shear Weight.....

ELAPSED TIME (1)	GAUGE u (2)	DIAL GAUGE (3)	STRAIN % (4)	PROVING RING DIAL (5)	LOAD ON PROVING RING (6)	Δu (7)	AXIAL LOAD (8)	AREA OF SAMPLE A_1 (9)	$\sigma_1 - \sigma_3$ (10)	$\bar{\sigma}_3$ (11)	$\bar{\sigma}_1$ (12)	$\bar{\sigma}_1 + \bar{\sigma}_3$ (13)	$\bar{\sigma}_1/\bar{\sigma}_3$ (14)	A FACTOR (15)	(16)	(17)	Post-Shear Water Content
0		Proving Ring Suspended															Specimen Location
0		Proving Ring acted up by $\sigma_c A_r$															Can No.
0		000	0					*									Weight of Can + Wet Soil
																	Weight of Can + Dry Soil
																	Weight of Water
																	Weight of Can
																	Weight of Dry Soil
																	Water Content

Post-Shear Length.....

Post-Shear Sample Shape.....

Indian Standard

METHODS OF TEST FOR SOILS

PART 35 MEASUREMENT OF NEGATIVE PORE WATER PRESSURE

0. FOREWORD

0.1 This part 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.

1. SCOPE

1.1 This standard (Part 35) 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 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 redundant. 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).

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 at 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/cm^2 .

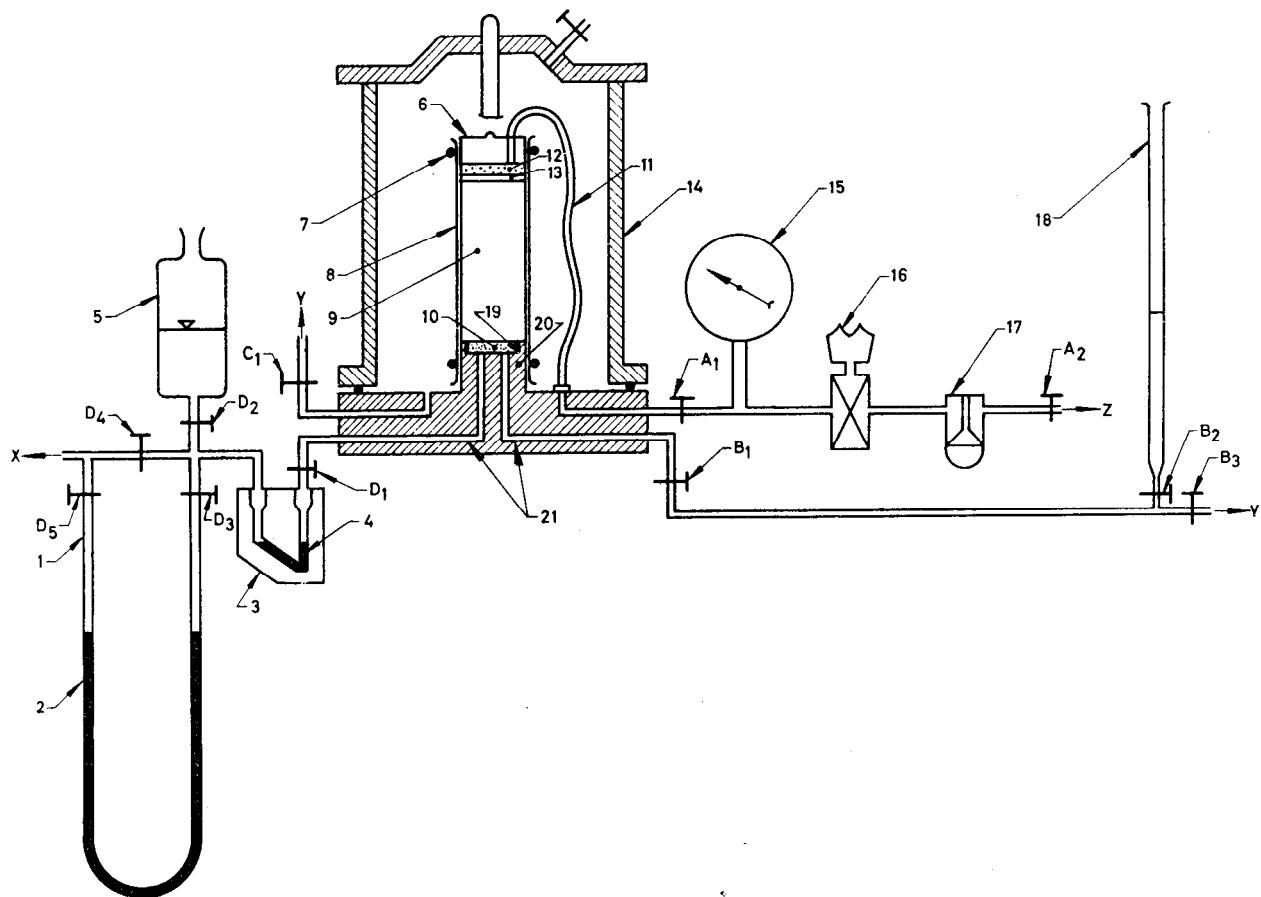
4.2.3 Open valves B_1 and B_2 and let the water flow through the ceramic stone, the pore water line into the burette. Flush water equivalent to about half the volume of the cell, then close valves B_1 and B_2 .

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



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

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

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 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/cm^2 reducing the increment to 0.1 kg/cm^2 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 prefected 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 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 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/cm^2 . 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 top 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 equilibrium 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 equilibrium pressure in kg/cm^2 .

6.10 The absolute value of the negative pore water pressure in the soil samples is $(1.0 - \text{equilibrium pressure}) \text{ kg/cm}^2$.

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 'O' 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/cm^2 . 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 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.

Indian Standard
METHODS OF TEST FOR SOILS
PART 30 LABORATORY VANE SHEAR TEST
(First Revision)
(Incorporating Amendment No. 1)

0. FOREWORD

0.1 The laboratory vane shear test for the measurement of shear strength of cohesive soils is useful for soils of low shear strength of less than about 0.5 kgf/cm^2 . This test gives the undrained strength of the soil, and the undisturbed and remoulded strengths obtained are used for evaluating the sensitivity of the soil. This standard was first published in 1968. This revision has been prepared to incorporate revised shape of vane found useful for this test.

1. SCOPE

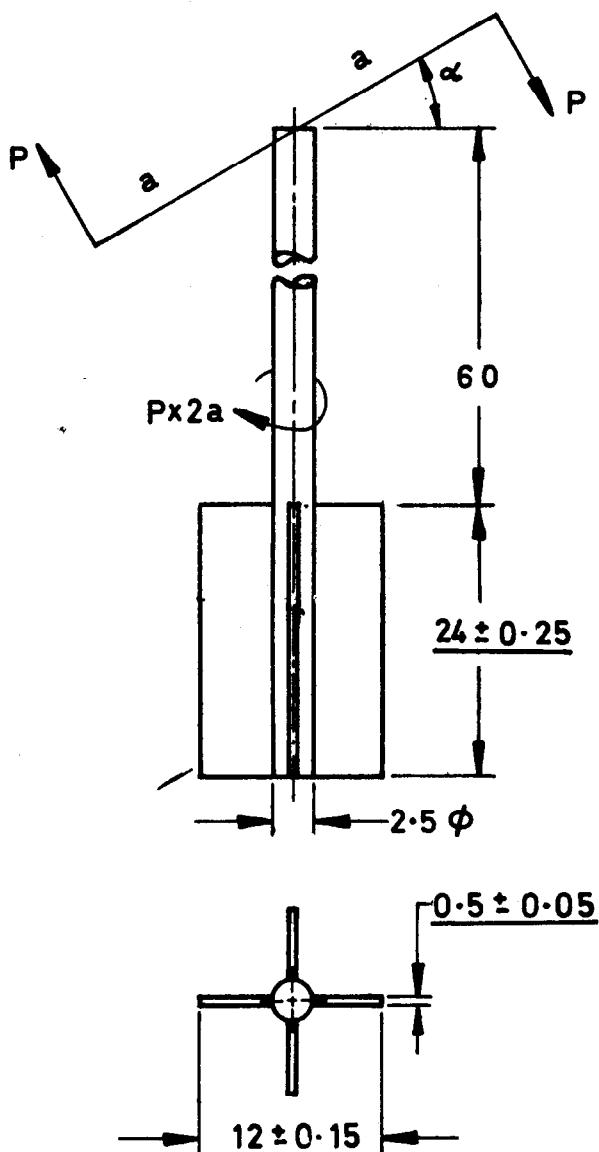
1.1 This standard (Part 30) covers the procedure of conducting laboratory vane shear test on cohesive soils of low shear strength for determining their undrained shear strength.

2. APPARATUS

2.1 Vane — The vane shall consist of four blades each fixed at 90° to the adjacent blades as illustrated in Fig. 1. The vane should not deform under the maximum torque for which it is designed. The penetrating edge of the vane blades shall be sharpened having an included angle of 90° . The vane blades shall be welded together suitably to a central rod, the maximum diameter of which should preferably not exceed 2.5 mm in the portion of the rod which goes into the specimen during the test. The vane should be properly treated to prevent rusting and corrosion.

2.2 The apparatus may be either of the hand-operated type or motorized. Provisions should be made in the apparatus for the following:

- Fixing of vane and shaft to the apparatus in such a way that the vane can be lowered gradually and vertically into the soil specimen.
- Fixing the tube containing the soil specimen to the base of the equipment for which it should have suitable hole.
- Arrangement for lowering the vane into the soil specimen (contained in the tube fixed to



All dimensions in millimetres.
 Essential dimensions underlined.

FIG. 1 PRINCIPLE OF VANE SHEAR TEST

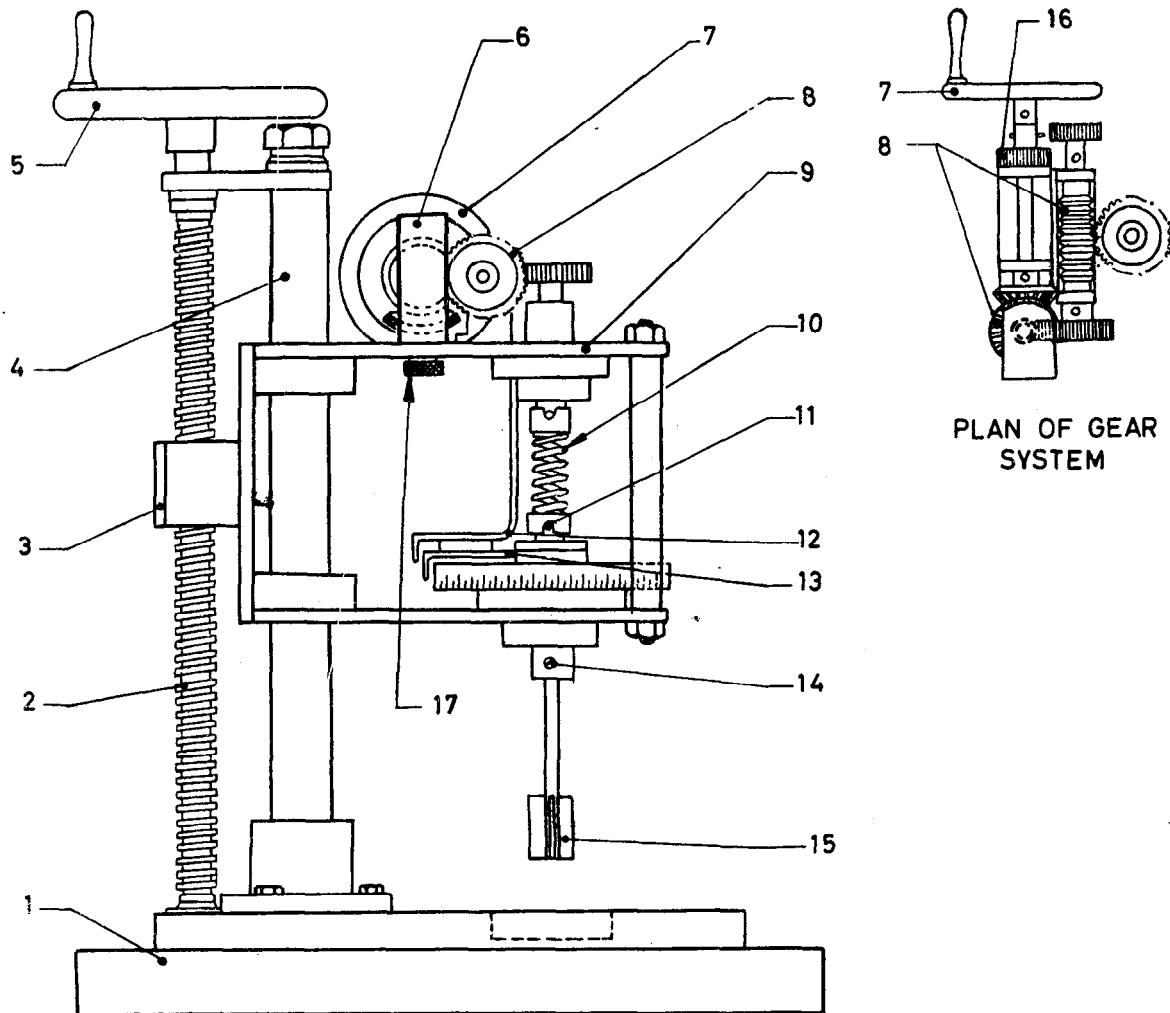
the base) gradually and vertically, and for holding the vane properly and securely in the lowered position.

- d) Arrangement for rotating the vane steadily at a rate of approximately 1/60 rev/min ($0.1^\circ/\text{s}$) and for measuring the rotation of the vane.
- e) A torque applicator to rotate the vane in the

soil and a device for measuring the torque applied to an accuracy of 0.05 cm.kgf.

- f) A set of springs capable of measuring shear strength of 0.5 kgf/cm².

2.2.1 A typical form of the hand operated apparatus is shown in Fig. 2.



This is only a typical example, and any design of apparatus satisfying the requirements specified in 2 may be used.

1. Base	10. Torque spring
2. Lead screw	11. Locating pins
3. Nut	12. Strain indicating pointer
4. Support pillar	13. Maximum pointer
5. Lead screw handle	14. Vane fixing screw
6. Gear bracket	15. Shear vanes
7. Torque applicator handle	16. Normal speed gear
8. Slow motion bevel & work gears	17. Gear bracket clamp screws
9. Bracket	

FIG. 2 LABORATORY VANE SHEAR APPARATUS

3. PROCEDURE

3.1 The specimen in the tube should be at least 30 mm in diameter and 75 mm long. Mount the specimen container with specimen on the base of the vane shear apparatus and fix it securely to the base. If the specimen container is closed at one end, it should be provided at the bottom with a hole of about 1 mm diameter. Lower the shear vanes into the specimen to their full length gradually with minimum disturbance of the soil specimen so that the top of the vane is at least 10 mm below the top of the specimen. Note the readings of the strain and torque indicators. Rotate the vane at a uniform rate approximately $0.1^\circ/\text{s}$ by suitably operating the torque applicator handle until the specimen fails. Note the final reading of the torque indicator. Torque readings and the corresponding strain readings may also be noted at desired intervals of time as the test proceeds.

3.2 Just after the determination of the maximum torque, rotate the vane rapidly through a minimum of ten revolutions. The remoulded strength should then be determined within 1 minute after completion of the revolution.

4. COMPUTATIONS

4.1 For vane testing instruments that do not read the torque directly, a calibration curve to convert the readings to cm. kgf of torque shall be provided. These calibration curves shall be checked periodically.

4.2 Calculate the shear strength of the soil using the following formula:

$$S = \frac{3}{19}T$$

where

S = shear strength in kgf/cm^2 , and

T = torque in $\text{cm}.\text{kgf}$.

NOTE 1 — This formula is based on the following assumptions:

- a) Shearing strengths in the horizontal and vertical directions are the same;
- b) At the peak value, shear strength is equally mobilized at the end surface as well as at the centre; and
- c) The shear surface is cylindrical and has a diameter equal to the diameter of the vane.

NOTE 2 — It is important that the dimensions of the vane are checked periodically to ensure that the vane is not distorted or worn.

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SECTION 11

Determination of Chemical Properties of Soil

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Indian Standard
METHOD OF TEST FOR SOILS
PART 26 DETERMINATION OF pH VALUE
(Second Revision)

0. FOREWORD

0.1 The acidic or alkaline characteristics of a soil sample can be quantitatively expressed by hydrogen ion-activity commonly designated as *pH*, which is conveniently expressed by the following:

$$pH = -\log_{10} (H^+) = \log_{10} \frac{1}{H^+}$$

wherein H^+ is the hydrogen ion-concentration in moles/litre.

In pure water, at $25^\circ C$, $H^+ = 1.00 \times 10^{-7}$ and thus $pH = 7.00$. This value corresponds to exact neutrality. At this temperature, acidic solutions have *pH* values less than 7 ($H^+ > 10^{-7}$) and alkaline solutions have *pH* values greater than 7 ($H^+ < 10^{-7}$).

0.2 Two methods, namely, electrometric method (standard method) and colorimetric method are commonly used to determine *pH* values of soilwater solutions. The *pH* is measured electrometrically by means of an electrode assembly consisting of one glass electrode and one calomel reference electrode with a saturated potassium chloride solution. Potassium chloride is used for salt bridge because of the fact that the transference of the K^+ and Cl^- ions takes place at the rate in true solution. The *pH* determination by this method is based on the assumption that the potential recorded is totally due to the potential difference across the glass membrane brought about by the difference in H^+ ion activity between solutions inside and outside the glass electrode. The outside solution is hydrochloric acid.

0.3 The colorimetric method can be considered as approximate but rapid. A colorimetric *pH* indicator is an organic dye, the colour of which is controlled by hydrogen ion activity in solution. This method is useful for determination of soil *pH*, both in the laboratory as well as in the field.

0.4 Several factors are known to affect the *pH* value of a particular soil sample. Prominent amongst these are soil-water ratio, soluble salts concentration, carbon dioxide pressure, exchangeable cations and temperature. With the dilution of soil suspension, its *pH* increases. Increase in salt concentration, in general, decreases the *pH*. A defi-

nite relationship exists between carbon dioxide pressure of soil air and *pH*, for example, the *pH* of calcareous soils is reduced in proportion to the logarithm of carbon dioxide pressure of soil air. In alkaline soils, the *pH* is principally influenced by exchangeable cations. With increase in temperature, *pH* decreases. The evaluation factors associated with soil *pH* shall thus be based on the full consideration of the soil constituents and not on *pH* value alone.

0.5 The hydrogen-ion concentration of soil water solution is of interest in problems involving grouting in weak rocks, soil stabilisation processes using lime and resinous materials, corrosion of metals in contact with soils and reclamation of marine soils. The *pH* value also helps in interpreting some of the soil chemical tests.

0.6 This standard was first published in 1967 and revised in 1973. In this revision, procedures have been elaborated and proforma for presentation of result have been added. The references in respect of equipments have been updated.

1. SCOPE

1.1 This standard (Part 26) lays down the procedure for the determination of *pH* value of soil suspension.

2. ELECTROMETRIC METHOD (STANDARD METHOD)

2.1 Apparatus

2.1.1 *pH Meter* — Direct reading type conforming to IS : 2711-1979 'Specification for direct reading *pH* meters (third revision)' with glass electrode and a calomel reference electrode or any other suitable electrode.

2.1.2 *Balance (Analytical)* — sensitive to 0.001 g.

2.1.3 *Three 100-ml Glass Beakers* — with covering glasses and stirring rods.

2.1.4 *Two 500-ml Volumetric Flasks*

2.1.5 *Wash Bottle* — containing distilled water.

2.1.6 *Mortar with Rubber Covered Pestle*

NOTE — The glass apparatus used should be such that it is not affected by alkali.

2.2 Buffer Solutions — The buffer solutions given in 2.2.1 and 2.2.2 shall be used for the test. Unless specified otherwise, pure chemicals (see Note) shall be used in tests.

NOTE — 'Pure chemicals' shall mean chemicals that do not contain impurities which affect the result of analysis.

2.2.1 Buffer Solutions pH 4.0 (at 25°C) — Dissolve 5.106 g of potassium hydrogen phthalate in distilled water and dilute to 500 ml with distilled water.

2.2.2 Buffer Solution pH 9.2 (at 25°C) — Dissolve 9.54 g of sodium tetraborate (borax) in distilled water and dilute to 500 ml.

NOTE 1 — Special care should be taken for preparation of buffer, particularly for alkaline buffer, when the distilled water used should be free from carbon dioxide.

NOTE 2 — The date of preparation of the buffer solutions should be indicated on the bottles. The buffer solutions shall be stored in well stoppered bottles. These solutions are susceptible to mould growth and hence may deteriorate in storage. Hence it is advisable either to use freshly prepared solution or to add toluene or a crystal or thymol to the solution prior to storing.

2.3 Soil Specimen — The soil sample received from the field shall be prepared in accordance with IS : 2720 (Part 1)-1983. All aggregations of particles shall be broken down so that, if the samples were sieved on a 425-micron IS Sieve, discrete particles would be retained. The sample, after having been broken up, shall be thoroughly mixed and then subdivided either by quartering or by riffling until a representative sub-sample is obtained.

2.4 Procedure — 30 g of the soil from the sample, prepared as in 2.3, shall be taken in a 100-ml beaker. 75 ml of distilled water (see Note) shall be added to it. The suspension shall be stirred for a few seconds. The beaker shall then be covered with a glass cover and allowed to stand for one hour with occasional stirring. It shall be again stirred well immediately before testing.

NOTE — The distilled water used should be aerated by bubbling air through it for some time.

2.4.1 The pH meter shall be calibrated by means of standard buffer solutions following the procedure recommended by the manufacturer. The electrodes shall be washed with distilled water dried with the help of an ordinary filter paper and then immersed in the soil suspension. Two or three readings of the pH of the soil suspension shall be made with brief stirring in between each reading. The reading should agree within ± 0.05 pH units (the pH readings of the soil suspension should reach a constant value in about one minute. No readings should be taken until the pH meter has reached equilibrium). The electrodes shall be removed from the suspension immediately and washed with distilled water. The calibration of the pH meter shall be again checked with one of the standard buffer solutions. If the instrument is out of adjustment by more

than 0.05 pH units, it shall be set to the correct adjustment till consistent readings are obtained (when not in use, the electrodes shall be left standing in a beaker of distilled water).

2.5 Record of Observations

2.5.1 The data sheet to record the observations of electrometric method is given in Appendix A.

2.6 Calculations

2.6.1 No calculations are needed as the pH meter directly provides pH values.

2.7 Presentation of Results

2.7.1 The pH value of the soil suspension shall be reported to the nearest 0.1 pH units as indicated on data sheet. It should be mentioned that the above test was carried out by the electrometric method.

3. COLORIMETRIC METHODS (SUBSIDIARY METHODS)

3.1 Universal Indicator Method

3.1.0 This method gives a rough idea (to an accuracy of about 0.5) about the pH value of the soil and should be used where exact pH is not required.

3.1.1 Preparation of Universal Indicator — Dissolve in 100 ml of alcohol the following (in given order):

- a) 0.06 g of methyl yellow,
- b) 0.04 g of methyl red,
- c) 0.08 g of bromothymol blue,
- d) 0.10 g of thymol blue, and
- e) 0.02 g of phenolphthalein.

Titrate the solution to yellow colour with 0.1 N sodium hydroxide solution. The indicator gives the colour value as given below:

pH 1 Cherry red	pH 6 Yellow
pH 2 Rose	pH 7 Yellow green
pH 3 Red orange	pH 8 Green
pH 4 Orange red	pH 9 Blue green
pH 5 Orange	pH 10 Blue

3.1.2 Procedure — 20 g of soil from the representative soil sample should be taken in a 100-ml beaker. To it 50 ml of distilled water (see Note under 2.4) should be added, stirred for 10 min continuously and allowed to stand for an hour (see Note), 20 ml of the clear solution should be then pipetted out and to it 2 or 3 drops of universal indicator should be added into a clean test tube solution gently shaken. The colour of the solution should then be compared with standard charts from which pH should be directly read. While comparing the colour of the solution with that of the chart, care should be taken to avoid the effect of reflection and shadow.

NOTE — In order to accelerate the settlement of soil particles so that a clear solution is obtained for the pH test, barium sulphate

should be added. The ratio of weight of barium sulphate and soil should be 1/3, 1 and 3 for sand, silt and clay respectively.

3.2 Indicator Paper Method

3.2.1 Indicator Papers—Supplied in booklets or as rolled tape carrying the colour chart and of range as follows:

Bromocresol green	: Phenolphthalein
Bromothymol blue	: Thymol blue
Chlorophenol red	: Thymolphthalein
Methyl orange	: Titan yellow
Methyl red	: (Clayton yellow)

3.2.2 Procedure—20 g of soil from the representative soil sample should be taken in a 100-ml beaker. To it 50 ml of distilled water (see Note under 2.4) should be added, stirred for 10 min continuously and allowed to stand for an hour (see Note under 3.1.2). 20 ml of the clear solution should be then pipetted out into a clean test tube. The leaf of the indicator paper or a strip should be dipped into

this solution. The colour of the moistened indicator paper should be compared with those provided with the indicator paper. The pH of the solution should be designated as the number written on a particular colour shade with which the colour of the moistened indicator paper matches closely.

3.3 Record of Observations

3.3.1 The data sheet to record the observations of colorimetric methods is given in Appendices B and C.

3.4 Calculations—Interpretations.

3.4.1 The comparison of the colour of the solution prepared with the standard chart provides the pH value.

3.5 Presentation of Results

3.5.1 The results of pH shall be reported in terms of number as indicated in Appendices B and C.

A P P E N D I X A (Clause 2.5.1)

DETERMINATION OF pH

Electrometric Method (Standard Method)

Project _____

Test No. _____

Sample No. _____

Date _____

Soil Identification _____

Tested by _____

Temperature _____

Sample Passing _____

Sieve No. _____

pH meter reading, pH scale

Remark:

A P P E N D I X B (Clause 3.3.1)

SOIL MECHANICS LABORATORY

DETERMINATION OF pH

Colorimetric Method (Universal Indicator)

Project _____

Test No. _____

Sample No. _____

Date _____

Soil Identification _____

Tested by _____

Temperature _____

Sample Passing _____

Sieve No. _____

Colour value	_____
pH	_____

Remark:

A P P E N D I X C

(Clause 3.3.1)

SOIL MECHANICS LABORATORY

DETERMINATION OF pH

Colorimetric Method (Indicator Paper)

Project _____

Test No. _____

Sample No. _____

Date _____

Soil Identification _____

Tested by _____

Temperature _____

Sample Passing
Sieve No. _____

Matching range, pH	
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Remark:

Indian Standard

METHODS OF TEST FOR SOILS

PART 24 DETERMINATION OF CATION EXCHANGE CAPACITY

(First Revision)

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 This part, which was originally published in 1967, covers the method for the determination of cation exchange capacity of soil. Cation exchange capacity gives an indication of the affinity of soil for water and its capacity for swelling.

0.2 In this revision, a method to determine the exchangeable metallic cations and a method to determine the exchangeable hydrogen ions separately have been given. The sum of the exchangeable ions determined by these methods gives the total exchangeable ions in the soil; however, because of fixation of potassium and ammonium by illite and vermiculite type of minerals, the cation exchange capacity values as determined by these ions, are generally lower than the true values. A single method which determines the cation exchange capacity (metallic and hydrogen ions together) has also been included. In keeping with the latest trend, the term 'base exchange capacity' has been replaced by the term 'cation exchange capacity'.

1. SCOPE

1.1 This standard (Part 24) lays down the methods for the determination of exchangeable metallic cation and exchangeable hydrogen ion, sum of which will be the cation exchange capacity of soils.

1.1.1 It also lays down a single method which determines the cation exchange capacity (metallic and hydrogen ions together).

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definition shall apply.

2.1 Cation Exchange Capacity — Cation exchange is the physio-chemical process whereby one type of ions (cation) adsorbed on soil particles is replaced by another type. The cation exchange capacity signifies the capacity of soil to retain cations up to its highest limit; or it can also be defined as the power of the soil to combine with cation in such a manner

that they cannot be easily removed by leaching with water, but can be exchanged by an equivalent amount of other cations.

3. DETERMINATION OF EXCHANGEABLE METALLIC CATIONS

3.1 Standard Method

3.1.1 Reagents

3.1.1.1 Ammonium acetate solution — 1 N. Prepared by adding 576 ml of glacial acetic acid (relative density 1.052) diluted to 5 litre, to 540 ml (of relative density 0.88) or 750 ml (of relative density 0.91) of ammonium hydroxide solution diluted to 5 litres.

The above two solutions should be mixed in equal volumes. The pH of the mixed solution should be determined in a comparator using bromothymol blue as indicator. If pH is close to 7.0, a little more of acetic acid solution or ammonium hydroxide solution should be added to have the pH exactly 7.0.

3.1.1.2 Hydrochloric acid — 0.05 N. Dilute 50 ml of N hydrochloric acid solution to one litre in a volumetric flask.

3.1.1.3 Sodium hydroxide — 0.05 N.

NOTE — The solution should be standardized afresh while using.

3.1.1.4 Methyl red indicator

3.1.2 Apparatus

3.1.2.1 Buchner funnel — Designation 110 (see IS : 5009-1968 'Specification for Buchner funnels').

3.1.2.2 Pipettes — 25 and 50 ml [see IS: 4162-1967 'Specification for graduated pipettes', and IS : 1117-1975 'Specification for one-mark pipettes (first revision)'].

3.1.2.3 Cylinders graduated — 100 and 250 ml capacity (see IS : 878-1975).

3.1.2.4 Filter paper — Whatman No. 44 or equivalent, 15 or 18.5 cm diameter.

3.1.2.5 Silica basins — 500 and 100 ml capacity.

3.1.2.6 Water-bath

3.1.2.7 Hot-plate — See IS : 365-1983 'Specification for electric hot plates (second revision)'.

3.1.2.8 Muffle furnace

3.1.2.9 Burette — 50 ml with stand see IS : 1997-1989 'Specification for burettes (second revision)'.

3.1.2.10 Chemical balance — of 0.1 or 0.2 mg sensitivity.

3.1.2.11 Beaker — 400 ml capacity [see IS : 2619-1971 'Specification for glass beakers (first revision)'].

3.1.2.12 Flask — 1 litre capacity.

3.1.3 Procedure

3.1.3.1 Transfer 50 to 100 g (see Note 1) of soil to 400-ml beaker, add 250 ml of 1 N ammonium acetate solution, stir well and allow to stand overnight at room temperature. Then decant through a 15- or 18.5-cm filter paper and leach with further portions of the ammonium acetate solution in small quantities, allowing the filter to drain completely between each addition, in a 1-litre flask. Continue leaching until one litre of the filtrate has been collected (see Note 2).

NOTE 1 — Take 50 g of soil when more than 20 to 25 milli-equivalent percent of exchangeable cation are present and 100 g when less than 10 milli-equivalent percent are present, as determined by the rapid method with 0.05 N hydrochloric acid.

NOTE 2 — Where possible the extraction may be done by centrifuge.

3.1.3.2 Transfer a suitable aliquot of the leachate corresponding to 10 g of soil, to 500-ml silica basin and evaporate to small volume on the water-bath. Transfer the solution at this stage to a 100-ml silica basin and continue the evaporation to dryness, finishing the operation over a hot-plate. Ignite in a muffle furnace, gently at first and then for 20 minutes at a medium to full red heat, so converting the acetates of the exchangeable metal ions to carbonates or oxides. Support the silica basin on a triangle to prevent the bottom being overheated.

3.1.3.3 When cold, add 20 to 50 ml of 0.05 N hydrochloric acid, or sufficient quantity to ensure an excess of acid at this stage; warm gently and leave to stand until solution of the alkalis is complete. Then titrate the excess of acid with 0.05 N sodium hydroxide using methyl red as indicator. If the methyl red is absorbed as the titration proceeds, add further a drop or two just before the end-point.

3.1.4 Calculations — Calculate the amount of total exchangeable metallic ions originally present in the soil, in milli-equivalents percent from the following expression:

$$meq = (V_a - V_b) \times N \times \frac{1000}{V_e} \times \frac{100}{W}$$

where

meq = total exchangeable metallic ions, in milli-equivalents percent;

V_a = volume of standard hydrochloric acid taken;

V_b = volume of standard sodium hydroxide used in back titration;

N = normality factor;

V_e = volume of extract taken; and

W = weight of soil extracted.

3.2 Rapid Method — (See Note).

NOTE — The rapid method is not suitable for highly calcareous soils (calcium carbonate in excess of 15 percent).

3.2.1 Reagents

3.2.1.1 Hydrochloric acid solution — 0.05 N.

3.2.1.2 Lime water — freshly prepared and of known normality.

3.2.1.3 Bromothymol blue indicator

3.2.2 Apparatus

3.2.2.1 Pipettes — 100 and 25 ml (see IS : 1117-1975 and IS : 4162-1967).

3.2.2.2 Test tube — 175 × 32 mm with stopper (see IS : 2618-1963 'Specification for test-tubes').

3.2.2.3 Filter paper — Whatman No. 30 or equivalent.

3.2.2.4 Erlenmeyer flask — 125 ml capacity.

3.2.2.5 Beaker — 250 ml capacity (see IS : 2619-1971).

3.2.2.6 Chemical balance

3.2.2.7 Burette — 100 ml with stand (see IS : 1997-1982).

3.2.2.8 Glass rod — (See IS : 7374-1974 'Specification for glass rods and tubing for laboratory glassware').

3.2.3 Procedure

3.2.3.1 Pipette 100 ml of 0.05 N hydrochloric acid into a test-tube (175 × 32 mm), add a weighed amount of soil (1 to 5 g), stopper, stir well and allow to stand overnight. The amount of soil taken should be sufficient to neutralize not more than about 20 percent of the standard acid. In general, the larger amount may be taken for sandy loams or soils slightly podolized. For heavy clays and base saturated soils, only 1 to 2 g should be used. The values obtained by this method are equilibrium values and therefore depend on the proportion of soil to acid.

3.2.3.2 Filter through a dry 11-cm Whatman No. 30 or equivalent filter paper, collecting the filtrate in a dry 125-ml Erlenmeyer flask, rejecting

the first portion. Titrate a 25-ml aliquot against standard lime water using bromothymol blue as indicator. As the end-point is approached, add 2 or 3 more drops of indicator to overcome absorption by any sesquioxide precipitate. Titrate a blank similarly.

3.2.4 Calculation

3.2.4.1 Then the approximate value for total exchangeable metallic ions in milli-equivalents percent is given by the expression:

$$meq = (B - T) \times N \times \frac{100}{25} \times \frac{100}{W}$$

where

meq = total exchangeable metallic ions,
B = blank titration in ml of lime water of known normality,
T = actual titration in ml of lime water of known normality,
N = normality of the lime water, and
W = mass of soil taken.

If any calcium carbonate is present (say up to 15 percent), express its amount in milligram equivalents percent, and deduct it from the value calculated for total exchangeable metallic ions.

4. DETERMINATION OF EXCHANGEABLE HYDROGEN IONS

4.1 Reagents

4.1.1 Barium Acetate Solution — 1 N of pH 8.1, adjust with barium hydroxide.

4.1.2 Phenolphthalein Indicator — 1 percent.

4.1.3 Sodium Hydroxide — 0.05 N.

4.2 Apparatus

4.2.1 Carbon Filter Funnel — See Note under 4.3.1.

4.2.2 Conical Flask — 500 ml capacity.

4.2.3 Beaker — 600 ml capacity (see IS : 2619-1971).

4.3 Procedure

4.3.1 Transfer 25 g of soil to the funnel with care to prevent soil from sticking to the sides of the carbon filter funnels (see Note). Level off the soil and place silica sand on the top to a depth of about 5 mm. Pour 350 ml of the barium acetate solution to the soil. Leaching rate from the funnel should not exceed 10 to 20 drops per minute.

When all the extraction solution is passed through, measure the volume in a graduated cylinder and transfer it to a 600-ml beaker. Add approximately 10 drops of 1 percent phenolphthalein solution and back titrate the extraction solution with 0.05 N sodium hydroxide solution to a faint

pink colour. Make a blank titration on 100 ml of barium acetate solution extracted through the carbon filter funnel but without the soil sample.

NOTE — It is a special type carbon funnel having arrangement for flow rate regulation by screw clamp, fine glass wool and acid washed silica sand (coarse). This funnel is wetted with a little of barium acetate solution and the glass wool compressed. A small quantity of pure silica is then spread over the glass wool.

4.4 Calculation — Express the results obtained in terms of *meq* of H⁺ per 100 g of soil :

meq exchangeable

$$H^+ \text{ per } 100 \text{ g soil} = (T - B) \times N \times \frac{100}{\text{mass of soil in g}}$$

where

T = volume of sodium hydroxide solution used in titration of soil extraction, ml;

B = volume of sodium hydroxide solution used for the blank titration, ml; and

N = normality of standard sodium hydroxide solution.

5. METHOD FOR DETERMINATION OF CATION EXCHANGE CAPACITY (METALLIC AND HYDROGEN IONS TOGETHER)

5.1 Reagents

5.1.1 Sodium Acetate Solution — 1 N. Adjusted to pH 5.0 containing 82 g of salt and about 28 ml of acetic acid per litre.

5.1.2 Sodium Acetate Solution — Neutral, 1 N. Containing 82 g of salt per litre, with pH adjusted to 7.0 with acetic acid to neutralize sodium hydroxide normally formed by hydrolysis of this salt.

5.1.3 Calcium Chloride — Neutral, 1 N. Containing approximately 109 g of calcium chloride, hexahydrate or 73 g of calcium chloride, per litre of carbon dioxide-free distilled water, with pH adjusted to 7.0 with calcium hydroxide.

5.1.4 Acetone — 80 percent.

5.1.5 Special Solutions — The following special solutions are required for calcium versene procedure.

5.1.5.1 Standard calcium solution — 0.500 5 g of pure dried calcium carbonate is dissolved in a minimum of 0.2 N hydrochloric acid. The solution is boiled to expel carbon dioxide and is then diluted to 1 litre. The solution is 0.010 0 N with respect to calcium.

5.1.5.2 Ammonium chloride-ammonium hydroxide buffer of pH 10 — This buffer is made up of 100 ml of 1 N ammonium chloride and 500 ml of 1 N ammonium hydroxide.

5.1.5.3 Eriochrome black T indicator — This solution is prepared by dissolution of 0.5 g of the

indicator with 4.5 g of hydroxylamine hydrochloride in 100 ml of methanol.

5.1.5.4 Sodium cyanide solution — 2 percent.

5.1.5.5 Standard versene solution — A 2-g portion of disodium versenate (disodium dihydrogen ethylenediamine tetra acetic acid) is dissolved in 900 ml of water. Then approximately 50 mg of magnesium chloride crystals ($MgCl_2 \cdot 6H_2O$) are added to the solution. The normality of versene is then determined by titration of 25 ml portion of the standard calcium solution.

5.3 Apparatus

5.3.1 Centrifuge Tubes — 100 ml.

5.3.2 Centrifuge — See Note under 5.4.1.

5.3.3 Beaker — 250 ml (see IS : 2619-1971).

5.3.4 Conical Flask — 500 ml.

5.3.5 Pipette — 25 ml (see IS : 4162-1967).

5.3.6 Burette — with stand (see IS : 1997-1982).

5.4 Procedure

5.4.1 Take 5 g of soil in a 100-ml centrifuge tube and stir in 50 ml of 1 N sodium acetate of pH 5.0 with a policeman-tipped rod. Digest the soil suspension in a near boiling water-bath for 30 minutes with intermittent stirring. Remove the salts by centrifugation of the suspension and decantation of the clear supernatant liquid (see Note). Give two additional washings with 1 N sodium acetate of pH 5.0, the 30 minutes boiling waterbath treatment being repeated if the sample is known to be calcareous. If still the presence of salts is doubted, give two more

washings with 1 N sodium acetate of pH 5.0. Then give the sample 5 washings with 1 N calcium chloride solution. Remove the excess salts by washings (usually 5) with 80 percent acetone, until excess calcium chloride is removed as indicated by a negative $AgNO_3$ test for chloride in the last of the washings. Finally replace calcium by means of 5 washings with a neutral 1 N sodium acetate solution. Place in a 500-ml conical flask, the calcium solution (about 250 ml) resulting from displacement in the determination of cation-exchange capacity. Then, add 10 ml of the ammonium chloride-ammonium hydroxide buffer solution to bring the solution to pH 10; and then add 10 drops of erichrome black T indicator solution and 1 ml of 2 percent sodium cyanide solution. Similarly prepare a blank of sodium acetate and titrate it to a bright blue end-point with standardized (about 0.01 N) versene solution. Titrate the test sample to the same colour.

NOTE — In lieu of centrifuge washing, the sample may be washed in an ordinary funnel with filter paper.

5.5 Calculation

5.5.1 Calculate the milli-equivalent cation exchange capacity per 100 g of soil as follows:

meq exchange capacity

$$\text{per 100 g} = \frac{\text{ml of versene solution} \times N \times 100}{\text{mass of soil in g}}$$

where *N* is the normality of the versene solution.

SECTION 12

Determination of Organic and Inorganic Contents of Soil

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Indian Standard

METHODS OF TEST FOR SOILS

PART 21 DETERMINATION OF TOTAL SOLUBLE SOLIDS

(First Revision)

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 This part deals with the method of test for the determination of total soluble solids in soils. The presence of soluble solids in a soil is one of the important aspects requiring examination since these water soluble solids greatly influence the engineering properties of the soil. Two methods for the determination of soluble solids are given. The first method, the gravimetric method (designated as the standard method), gives the percentage of soluble solids accurately in absolute terms. The second method, the conductimetric method (designated as the subsidiary method), may be used for rapid assessment.

0.2 This standard was first published in 1965. In this revision, the conductimetric method has been simplified by specifying the use of a conductivity meter or bridge.

1. SCOPE

1.1 This standard (Part 21) lays down the determination of total soluble solids content in soil both by gravimetric method which has been specified as the standard method and conductimetric method which has been specified as a subsidiary method.

2. GRAVIMETRIC METHOD (STANDARD METHOD)

2.1 Apparatus

2.1.1 *Bottle Shaker*

2.1.2 *Oven* — Thermostatically controlled oven to maintain the temperature between 105 and 110°C, with interior of non-corroding material.

2.1.3 *Chemical Balance* — sensitive to 0.001 g.

2.1.4 *Buchner or Glass Funnel* — about 10 cm diameter.

2.1.5 *Glazed Porcelain Dish or Glass Dish*

2.1.6 *Filtering Flask* — capacity 500 ml.

2.1.7 *Glass Bottle* — capacity 250 ml, with rubber bung.

2.1.8 *Measuring Cylinder* — capacity 100 ml.

2.1.9 *Pipette* — 50 ml and 100 ml.

2.1.10 *Vacuum Pump*

2.1.11 *Desiccator* — with any desiccating agent other than sulphuric acid.

2.1.12 *Thermometer*

2.1.13 *Water Bath*

2.1.14 *Filter Candle*

2.1.15 *Filter Paper* — Whatman No. 42 or its equivalent.

2.2 Procedure

2.2.1 A representative sample passing a 2-mm IS Sieve from the air dried sample prepared in accordance with IS:2720 (Part 1)-1983 shall be dried to constant weight in an oven at a temperature of 105 to 110°C. Out of this, about 10 g of soil shall be accurately weighed and transferred to a 250-ml glass bottle. 100-ml of distilled water shall be added to it; the bottle shall then be stoppered and fitted in the shaker and shaken overnight (at least 15 h). The soil shall then be allowed to settle and the clear portion decanted off and filtered through Whatman No. 42 filter paper or equivalent. If by simple filtration the filtrate is not clear, the operation shall be repeated employing a filter candle with a vacuum pump.

2.2.2 Take 50-ml of the clear filtrate in pre-weighed porcelain dish, or glass dish and concentrate by evaporating in the water bath before finally drying in the oven at 110°C. The dish shall then be cooled to room temperature in a desiccator and weighed to get the weight of the residue. The percentage of total soluble solids in the soil shall then be calculated on the basis of the soil taken for analysis.

NOTE — In case the value of the solubility is more than 2 percent, the test be repeated with some distilled water.

2.3 Report

2.3.1 The results shall be reported to the nearest 0.01 percent as a percentage by weight of oven-dry soil.

2.3.2 The observations of the test shall be suitably recorded. A recommended proforma for the record is as given in Appendix A.

3. CONDUCTIMETRIC METHOD (SUBSIDIARY METHOD)

3.1 Apparatus

3.1.1 Conductivity Meter/Bridge with Known Cell Constant (Unbreakable) — The instrument is designed to carry out the measurement of specific conductance and specific resistance of various electrolytes and also measurement of ohmic resistance with measuring accuracy of ± 3 percent in 7 or 8 ranges varying from at least 1 mhos to 10 mhos.

3.1.2 Physical Balance — sensitivity 0.01 g.

3.1.3 Measuring Cylinder — capacity 50-ml.

3.1.4 Beaker — 150-ml.

3.1.5 Glass Rod or Stirrer

3.2 Procedure — Take 10 g of oven-dry soil sample as mentioned in 2.2. Distilled water shall be added to it and stirred intermittently with a glass rod or by

any stirring machine. The soil suspension thus prepared shall be allowed to settle in the beaker for about 30 minutes. The supernatant liquid shall be transferred into another beaker and specific conductivity determined using the conductivity meter/bridge.

NOTE — The equipment, before using, shall be checked with a saturated calcium sulphate solution which shall give specific conductivity of 2.2 mhos/cm at 25°C. If not, the conductivity cell is to be cleaned.

3.3 Report

3.3.1 The results shall be reported in millimhos/cm.

3.3.2 The results obtained by conductivity meter/bridge may be interpreted as indicated below:

<i>Conductivity meter/ bridge readings</i>	<i>Total soluble solid content</i>
Below 1 millimho/cm	Normal
1 to 2 millimhos/cm	Fairly good
2 to 3 millimhos/cm	High
Above 3 millimhos	Very high

A P P E N D I X A

(Clause 2.3.2)

PROFORMA FOR RECORDING

Project	Details of Sample		
1. Sample number			
2. Mass of oven-dry soil taken (w), in g			
3. Volume of clear filtrate taken, in ml	50	50	50
4. Porcelain dish or glass dish number, in g			
5. Mass of dish with residue after oven drying, in g			
6. Mass of dish, in g			
7. Mass of residue (w_1), in g			
8. Percentage of soluble solids $\frac{2 w_1}{w} \times 100$			

Indian Standard
METHODS OF TEST FOR SOILS
PART 23 DETERMINATION OF CALCIUM CARBONATE

(First Revision)

0. FOREWORD

0.1 This part 23 deals with the method of test for determination of calcium carbonate content in soils for civil engineering purposes. The calcium carbonate content of soil affects the engineering properties of the soils and is of interest to the engineer.

0.2 This standard (Part 23) was first published in 1966. In the present revision, acetic acid has been replaced by hydrochloric acid which is comparatively less costly. The factor 0.074 used for the calculation in the original method has been omitted as its effect on the ultimate result is insignificant. Blank titration has also been omitted to save time. It is considered that the accuracy given by this method is sufficient for interpretation of engineering properties of soils.

1. SCOPE

1.1 This standard (Part 23) lays down the method for rapid determination of the calcium carbonate content in soil.

2. APPARATUS

2.1 Burette — 50 ml, conforming to IS: 1997-1982.

2.2 Conical Flask — 500 ml capacity.

2.3 Glass Funnel — 75 mm diameter

2.4 Filter Paper — Whatman No. 40 or equivalent, of 12.5 cm diameter.

3. REAGENTS AND INDICATOR

3.1 Sodium Hydroxide Solution — 1 N. Dissolve slightly more than 40 g sodium hydroxide in 1 litre of distilled water and standardize against N hydrazine sulphate to get exact strength, using methyl red as indicator.

3.2 Hydrochloric Acid — 1 N. Dilute 175 ml of concentrated hydrochloric acid to 2 litres and standardize it against sodium hydroxide solution prepared as in 3.1 and determine the exact factor (strength) if the solution is not exactly 1 N.

3.3 Bromothymol Blue Indicator

4. PROCEDURE

4.1 Weigh 5 g (see Note 1) of soil accurately and transfer to a 150-ml beaker and add 100 ml of hydrochloric acid solution prepared as in 3.2 (see Notes 2 and 3). Cover with a watch-glass and stir vigorously several times for 1 hour. After settling, pipette off 20 ml of the supernatant liquid and take into a conical flask; add 6 to 8 drops of bromothymol blue indicator and titrate with sodium hydroxide solution (see Notes 2 and 3) prepared as in 3.1. With some soils, the colour of the indicator may fade as the end-point is approached. In such cases, add more indicator and complete the titration:

NOTE 1 — First take about 1 g of soil a test tube and pour a few drops of concentrated hydrochloric acid. Note the intensity of reaction:

- For vigorous reaction, take only 2.5 g of soil and multiply the result by 2.
- In case of moderate reaction, follow the above procedure.
- If there is feeble reaction, take 10 g of soil and divide the result by 2.

NOTE 2 — Accurate weighing and standardization of hydrochloric acid and sodium hydroxide are important for correct results.

NOTE 3 — Intermittent checking of the strength of stock solution is necessary.

5. CALCULATION

5.1 One millilitre of 1N hydrochloric acid is equivalent to 0.05 g of calcium carbonate present in the soil sample.

$$\begin{aligned} \text{Carbonate present in} &= \left[\frac{\text{Volume of 1N hydro-}}{\text{soil, percent by mass}} \right] \\ &\quad \times \frac{\text{chloric acid used for}}{5 \text{ g of soil}} \\ &= \frac{100}{5} \\ &= \text{Volume of hydrochloric acid consumed for } 5 \text{ g of soil.} \end{aligned}$$

Details are shown in the example given below:

Example :

1 ml of N hydrochloric = 0.05 g of calcium carbonate

Strength of NaOH	= 0.93 N
Strength of HCl	= 1.023 N
Quantity of NaOH used in titration	= 19.0 ml
Therefore, quantity of 1N HCl added in 5 g of soil	= 100×1.023 ml = 102.3 ml
Therefore, quantity of 1N NaOH required for titration of 20 ml of the extractant	= 19.0×0.93 = 17.67

$$\begin{aligned}
 &\text{Therefore, for 100 ml extractant} \\
 &\quad = 17.67 \times 5 \\
 &\quad = 88.35 \\
 &\text{Therefore, 1N HCl consumed by 5 g of soil} \\
 &\quad = (102.30 - 88.35) \\
 &\quad = 13.95 \\
 &\text{Therefore, percentage of } \text{CaCO}_3 \\
 &\quad = \frac{13.95 \times 0.05 \times 100}{5} \\
 &\quad = 13.95 \\
 &\text{Thus, percentage of } 1\text{N HCl consumed by } \text{CaCO}_3 \\
 &\quad = 13.95
 \end{aligned}$$

Indian Standard

METHODS OF TEST FOR SOILS

PART 27 DETERMINATION OF TOTAL SOLUBLE SULPHATES

(First Revision)

0. FOREWORD

0.1 This Part 27 deals with the method for the determination of total soluble sulphates in soils. Sodium sulphate is present in some Indian soils. The salt is easily hydrated and dehydrated under the influence of climatic changes. There are enormous volume changes during this process of hydration and dehydration, which influence the engineering properties of soils. Both soluble sulphate content and moisture content of soil are subject to seasonal fluctuations and are mutually interdependent.

0.2 This standard was first published in 1968. In this revision, a colorimetric or turbidimetric method, which is a rapid method, has been added.

1. SCOPE

1.1 This standard (Part 27) lays down the procedure for determining the total soluble sulphate content of soils by: (a) precipitation method, (b) volumetric method, and (c) colorimetric or turbidimetric method.

2. PRECIPITATION METHOD (STANDARD METHOD)

2.1 Apparatus

- 2.1.1** Analytical Balance — sensitive to 0.001 g.
- 2.1.2** Glass Beaker — of 250 ml capacity.
- 2.1.3** Glass Funnel — 50 mm diameter.
- 2.1.4** Glass Bottle — of 250 ml capacity with a rubber cork.
- 2.1.5** Crucible — of 50 ml capacity.
- 2.1.6** Heating Equipment
- 2.1.7** Pipette — 25 ml.
- 2.1.8** Burette — 50 ml with 0.1 ml graduation.
- 2.1.9** A Mortar with Rubber Covered Pestle
- 2.1.10** Filter Paper — Whatman No. 42 or equivalent.
- 2.1.11** Muffle Furnace
- 2.1.12** Mechanical Shaker
- 2.1.13** Drying Oven

2.2 Reagents

2.2.1 Phenolphthalein Indicator Solution — Dissolve 0.1 g of phenolphthalein in 60 ml of rectified spirit and dilute with distilled water to 100 ml.

2.2.2 Concentrated Hydrochloric Acid — specific gravity 1.18 [conforming to IS : 265-1976 'Specification for hydrochloric acid (second revision)'].

2.2.3 Barium Chloride Solution — 5 percent. Dissolve 5 g of barium chloride in 100 ml of distilled water.

2.2.4 Silver Nitrate Indicator Solution — 0.5 percent. Dissolve 500 mg of silver nitrate in 100 ml of distilled water.

NOTE — Unless specified otherwise, pure chemicals and distilled water [see IS : 1070-1977 'Specification for water for general laboratory use (second revision)'] shall be used in tests. 'Pure chemicals' shall mean chemicals that do not contain impurities which affect the results of analysis.

2.3 Soil Sample — The soil sample shall be brought to a state in which it may be crumbled, if necessary, by drying it in an oven maintained at 105 to 110°C. The aggregations of particles shall be broken up in mortar with rubber covered pestle or the mechanical device. The sample shall be thoroughly mixed and then sub-divided by quartering.

2.4 Principle of the Method — The method depends upon preparing an aqueous extract of the soil and determining the sulphate content of this extract or an aliquot portion of it by the precipitation of sulphate as barium sulphate, filtering off the precipitate and weighing it.

2.5 Procedure — Take 10 g of soil from the sample prepared as given in 2.3, in a 250-ml bottle with 100 ml of distilled water. Give occasional shaking for 2 h by means of the mechanical shaker. Allow the soil suspension to stand overnight (in case the soil is in a dispersed condition, add 0.5 to 1.0 g of pure potassium nitrate to flocculate the particles). Filter and take 25 ml of filtrate in a beaker and add concentrated hydrochloric acid to just neutralize the solution if it is found alkaline to phenolphthalein indicator. Add further 4 ml concentrated hydrochloric acid to make the solution acidic. Boil

the solution. Remove the solution from the source of heat and add hot barium chloride solution in a fine stream with constant stirring till there is no precipitation with further addition. Place the beaker on a steam-bath for a minimum period of 4 h and allow the precipitate to settle. Filter the precipitate through ashless filter paper, wash free from chloride ions (see Note), dry and ignite. The filtration may also be done through a preweighed sintered glass crucible or a Gooch crucible. In the case of filter paper, after drying, ashing shall be done on a low flame and the precipitate then ignited over a burner or in a muffle furnace at 600 to 700°C for half an hour. Cool in a desiccator, weigh and note the weight of the residue. This is the weight of barium sulphate. A corresponding weight of sodium sulphate should be calculated and thus its percentage determined (see 2.6).

Note — To check whether the residue is free of chloride ions, collect the washings in a separate test-tube at different time intervals and add a drop of 0.5 percent silver nitrate solution to it. The formation of white cloudy precipitate shows the presence of chloride ions in the precipitate. Continue washing until the white precipitate is not formed in the washings by the addition of silver nitrate solution. Hot water may be used for washing.

2.6 Calculations

2.6.1 Calculate as follows:

$$\text{a) Sulphates (as } \text{SO}_4\text{), by mass} = 41.15 \frac{W_1}{W_2}$$

b) Sulphates (as Na_2SO_4),

$$\text{percent by mass} = 60.85 \frac{W_1}{W_2}$$

where

W_1 = mass in g of the precipitate, and

W_2 = mass in g of the soil contained in the solution taken for precipitation.

3. VOLUMETRIC METHOD (SUBSIDIARY METHOD)

3.1 Principle — The volumetric method depends upon insoluble barium sulphate forming and settling rapidly when barium chloride solution is added to the sulphate solution. The barium chloride reagent is added in excess and the excess is determined by the standard solution of barium chromate. With the formation of potassium chromate, the slight excess of chromate reagent becomes evident from the resultant yellow colour of the supernatant solution. The end point can be further tested (confirmed) by silver nitrate solution used as an external indicator. A brick red colouration is obtained when a drop of silver nitrate is added to a drop of the chromate solution.

3.2 Apparatus

3.2.1 *Analytical Balance* — sensitive to 0.001 g.

3.2.2 *Glass Beakers* — two, of 150 ml capacity.

3.2.3 *Glass Funnel* — 6 cm diameter.

3.2.4 *Measuring Flasks* — one of 100 ml and two of 500 ml capacity.

3.2.5 *Burette* — two, of 25 ml, 1/20 ml graduation.

3.2.6 *Conical Flasks* — six, of 150 ml capacity.

3.2.7 *Pipette* — 10 ml.

3.2.8 *Filter Papers*

3.2.9 *Heating Equipment*

3.2.10 *Drying Oven*

3.3 Reagents

3.3.1 *Barium Chloride Solution* — N/4. Dissolve 30.54 g of barium chloride in one litre of distilled water.

3.3.2 *Potassium Chromate Solution* — N/4. Dissolve 24.275 g of potassium chromate in a small amount of distilled water. Add a few drops of silver nitrate solution to it to remove any chloride, filter and dilute to 250 ml.

3.3.3 *Silver Nitrate Indicator Solution* — 0.5 percent. Dissolve 500 mg of silver nitrate in 100 of distilled water.

3.3.4 *Dilute Solution of Ammonium Hydroxide* — (sp gr 0.888). Mix ammonium hydroxide and distilled water in the ratio of 1:2 (one part of ammonia and two parts of distilled water).

3.3.5 *Concentrated Hydrochloric Acid* — sp gr 1.11 (conforming to IS : 265-1976).

NOTE — Unless specified otherwise, pure chemicals and distilled water (see IS : 1070-1977) shall be used in tests. 'Pure chemicals' shall mean chemicals that do not contain impurities which affect the results of analysis.

3.4 Procedure — Weigh 10 g of the soil specimen obtained by the method specified in 2.3, in a beaker and add about 50 ml water. Stir well, allow to decant, filter, wash the soil on filter paper with a small quantity of water and make the filtrate to 100 ml. Pipette out 10 ml of the water extract in a conical flask, make it slightly acidic by adding concentrated hydrochloric acid and heat to boiling. While boiling, add barium chloride solution (N/4) from the burette till the precipitation is complete and barium chloride solution is in slight excess.

3.4.1 Neutralize the solution with ammonium hydroxide and titrate the excess of barium chloride against potassium chromate solution (N/4). The end point may be confirmed, if considered necessary, by using silver nitrate solution as an external indicator (see 3.1).

3.5 Calculation — Calculate as follows:

Sulphates as sodium sulphate in soil,
percent by mass = $0.0177 \times 100 (x-y)$

where

- x = volume of N/4 barium chloride added, ml;
- y = volume of N/4 potassium chromate solution used in back titration; and
- $x-y$ = N/4 barium chloride actually used for precipitating sulphate.

4. COLORIMETRIC OR TURBIDIMETRIC METHOD (SUBSIDIARY METHOD)

4.1 Apparatus

- 4.1.1 *Conical Flask* — 250 ml.
- 4.1.2 *Volumetric Flask* — 25 ml.
- 4.1.3 *Analytical Balance* — sensitivity 0.001 g.
- 4.1.4 *Photoelectric Colorimeter or Turbidimeter*
- 4.1.5 *Filter Paper* — Whatman No. 42 or equivalent.

4.2 Reagents

- 4.2.1 *Morgan's Extraction Solution* — 100 g of sodium acetate and 30 ml of 99.5 percent acetic acid dissolved and mixed in 500 ml of water and the volume made to 1 litre.

4.2.2 *Barium Chloride Crystals*

4.2.3 *25 Percent Gum Acatia*

- 4.3 **Procedure** — Weigh 20 g air-dry soil specimen in a 250-ml conical flask. Add 100 ml of Morgan's extraction solution. Shake the suspension for

one-half hour and filter through Whatman's No. 42 filter paper or equivalent. Take 10 or 20 ml aliquot and transfer to a 25-ml volumetric flask. Add 1 g of barium chloride crystals (ground to pass 500-micron IS sieve and to be retained on 250-micron IS sieve) to the aliquot in the flask and shake for 1 minute. Add 1 or 2 ml of 25 percent gum acatia. Pour distilled water up to the mark of volumetric flask and shake for a minute. Precipitate the suspension and take the reading between 5 to 30 minutes after precipitation either by photoelectric colorimeter using blue filter or by turbidimeter. Sulphate is then determined by the standard sulphate curve.

4.4 Preparation of Standard Sulphate Curve

- 4.4.1 *Stock Solution* — Dissolve 0.888 g anhydrous sodium sulphate Na_2SO_4 /1 alcoholic (N) ammonium chloride (NH_4Cl). This gives a concentration of 0.60 mg of SO_4 /ml.

NOTE — Absolute alcohol should be used for the preparation of the solution

- 4.4.2 *Working Standard Solution* — Dilute 0.60 mg SO_4 /ml stock solution with alcoholic (N) ammonium chloride to give 0.06 mg SO_4 /ml. Take 2, 4, 6, 8, 10 ml of this to give range of 0.12-0.60 mg of SO_4 .

- 4.4.3 The standard curve should be prepared by taking readings with photoelectric colorimeter using blue filter or by turbidimeter using the working standard solution.

Indian Standard

METHODS OF TEST FOR SOILS

PART 25 DETERMINATION OF SILICA SESQUIOXIDE RATIO

(First Revision)

0. FOREWORD

0.1 This part covers method for determination of silica sesquioxide ratio. The silica sesquioxide ratio of clay is one of the fundamental properties of the soil. This is used as a guide in the mineralogical classification of soil. Usually clay minerals of high exchange capacity have also high silica sesquioxide ratio values while those of low exchange capacity have a low ratio. The ratio is determined on the clay fraction (particle size less than 0.002 mm) of the soil. This standard was first published in 1967. This revision covers improved method of initial treatment of the soil specimen for conducting this test.

1. SCOPE

1.1 This standard (Part 25) lays down the method for determining the silica sesquioxide ratio of soils.

2. APPARATUS

2.1 Glass Bottles — of 300, 500 and 1 000 ml capacity.

2.2 Cylinder — tall, wide mounted, 1 200 ml capacity.

2.3 Dishes, Porcelain

2.4 Buchner Funnel

2.5 Vacuum Trolley

2.6 Aspirator

2.7 Flask — measuring 100 and 250 ml.

2.8 Crucible with Lid

2.9 Tongs

2.10 Platinum Dish

2.11 Beaker — 400 and 800 ml capacity.

2.12 Muffle Furnace

2.13 Filter Paper — Whatman No. 42 and 50 or equivalent.

2.14 Reagents — The following reagents shall be used for the test. Unless specified otherwise, pure chemicals (see Note) shall be used in tests.

NOTE — 'Pure chemicals' shall mean chemicals that do not contain impurities which affect the results of analysis.

2.14.1 Hydrochloric Acid

2.14.2 Sodium Hydroxide

2.14.3 Ammonium Chloride

2.14.4 Ammonia

2.14.5 Rosolic Acid

2.14.6 Fusion Mixture

3. PROCEDURE

3.1 Initial Treatment of Soil Specimen — Ten grams of the dried clay substance be separated by centrifuging — 2 micron fraction. It should then be freed of exchangeable cations by dialysis or with an exchange resin. Colloidal impurities and organic impurities be then oxidized with hydrogen peroxide. Later iron oxide be dissolved away with oxalic acid and clay fraction washed free of oxalate ions and dried. It should then be used for estimation of silica, aluminium oxide and iron oxide.

3.2 Estimation of Silica — About one gram of the dried clay accurately weighed shall be taken in a platinum dish and mixed with fusion mixture 5 to 6 times the weight of the clay. It shall then be ignited in the muffle furnace or any suitable arrangement (at about 900°C) and cooled. The dish shall then be placed in the 800-ml beaker filled with distilled water. A few millilitres of concentrated hydrochloric acid shall be added and the beaker covered with watch glass. After sometime when the effervescence stops, platinum dish shall be washed with distilled water into the beaker containing the dish with the ignited mass. The whole mass shall be evaporated to dryness on a sand bath till whole of the hydrochloric acid disappears. If necessary, the process may be repeated to ensure complete baking or dehydration of silica. The evaporation shall be continued for another hour to remove the last traces of hydrochloric acid. Two hundred millilitres of distilled water shall be added and heated for at least another 10 minutes, filtered through Whatman filter paper No. 42 or equivalent and washed free from acid. The whole of silica along with filter paper shall be placed in a preweighed crucible. The crucible shall be placed in the muffle furnace for

sometime till the weight of crucible with its contents becomes constant, then cooled and weighed. The weight of silica shall be calculated by subtracting the empty weight of the crucible.

3.3 Estimation of Aluminium Oxide and Iron Oxide

3.3.1 The sesquioxide ($\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$) in the crucible shall be fused with fusion mixture and then dissolved in hydrochloric acid. It shall be added to the filtrate obtained in 3.2. About 5 ml of bromine water shall be added and the contents shall be made to 250 ml. Half of it shall be taken for estimation of aluminium oxide and iron oxide. The other half shall be taken for the estimation of iron oxide only.

3.3.2 To the first half, about four grams of ammonium chloride (NH_4Cl) and a few drops of rosolic acid solution shall be added and heated to boiling. A little paper pulp shall then be added and the solution made very slightly ammoniacal with dilute ammonia as shown by a faint pink colour of rosolic acid and finally filtered through Whatman filter paper No. 42 or equivalent. The precipitates along with filter paper shall be placed in a weighed crucible which shall then be ignited in the muffle furnace or any other suitable arrangement. The final weight shall be noted. The total weight of aluminium oxide plus iron oxide shall be obtained by subtracting from the final weight, the weight of the empty crucible.

3.3.3 To the second half of the filtrate obtained in 3.3.1, an excess of concentrated sodium hydroxide shall be added and boiled. The precipitate of iron hydroxide so formed shall be filtered. The aluminium hydroxide dissolves in sodium hydroxide. The precipitates shall be washed free from alkali by hot distilled water and dissolved in the minimum quantity of hydrochloric acid. Ammonium chloride (solid) shall be added and the solu-

tion heated and again allowed to cool. Excess of ammonium hydroxide solution shall then be added and precipitates so formed filtered, dried along with the filter paper and transferred to the pre-weighed crucible. The crucible shall be ignited in the muffle furnace or any other suitable arrangement, cooled, reweighed and the weight of iron oxide calculated. The difference between the weights of aluminium oxide plus iron oxide ($\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) and iron oxide gives the weight of aluminium oxide.

4. CALCULATIONS

4.1 The values of silica, iron and alumina shall be expressed as percentage of clay. Each value shall be divided by its molecular weight to obtain the gram molecular percentage as given below:

Gram molecular percentage of silica (SiO_2),

$$a = \frac{\text{Weight of } \text{SiO}_2}{\text{Weight of clay}} \times \frac{100}{60}$$

Gram molecular percentage of aluminium oxide (Al_2O_3),

$$b = \frac{\text{Weight of } \text{Al}_2\text{O}_3}{\text{Weight of clay}} \times \frac{100}{102}$$

Gram molecular percentage of iron oxide (Fe_2O_3),

$$c = \frac{\text{Weight of } \text{Fe}_2\text{O}_3}{\text{Weight of clay}} \times \frac{100}{159.7}$$

The silica sesquioxide ratio is given by the following equation:

$$\frac{a}{b+c}$$

4.2 The average of three determinations shall be taken as the silica sesquioxide ratio of the soil sample.

Indian Standard
METHODS OF TEST FOR SOILS
PART 22 DETERMINATION OF ORGANIC MATTER
(First Revision)
(Incorporating Amendment No. 1)

0. FOREWORD

0.1 This part deals with the method of test for the determination of organic matter content in the soil. Organic matter is an undesirable constituent of the soil from the engineering point of view since it causes swelling or shrinkage of the soil when the moisture content or the applied load changes. The estimation of organic matter, therefore, forms an important part of soil examination.

0.2 A wide variety of both dry and wet combustion methods are in use for the determination of the organic matter of soils. Two methods, which are widely in use, are given in this revision of the standard. These methods give reproducible results and the results are sufficiently accurate for common engineering purposes. The first method is given as the standard method and the other as an alternative method.

SECTION 1 METHOD BASED ON ORGANIC CARBON CONTENT OF SOIL

1. SCOPE

1.1 Section 1 of this standard (Part 22) lays down the method for determining the percentage by weight of the organic matter present in soils based on the determination of the organic carbon content of the soil.

2. APPARATUS

2.1 **Oven** — thermostatically controlled to maintain the temperature between 105 and 110°C with interior of non-corroding material.

2.2 **Chemical Balance** — sensitive to 0.001 g.

2.3 **Volumetric Flask** — two, of one-litre capacity.

2.4 **Burettes** — two, of 25 ml, graduated in 0.1 ml.

2.5 **Pipettes** — 10-ml pipette and 1-ml pipette fitted with a rubber teat.

2.6 **Conical Flasks** — two, of 500-ml capacity.

2.7 **Graduated Measuring Cylinders** — 200-ml and 25-ml.

2.8 **Desiccator** — with any desiccating agent other than sulphuric acid.

2.9 **Glass Weighing Bottle** — approximately 25 mm in diameter and of 50 mm height fitted with a ground glass stopper.

2.10 **Sieves** — 10-mm IS Sieve and 425-micron IS Sieve and receivers.

2.11 Wash Bottle

3. REAGENTS

3.1 The reagents used shall be of analytical quality.

3.1.1 **Potassium Dichromate Normal Solution** — Dissolve 49.035 g of potassium dichromate in distilled water to make one litre of solution.

3.1.2 **Ferrous Sulphate, Approximately 0.5 N Solution** — Dissolve approximately 140 g of ferrous sulphate in 0.5 N sulphuric acid to make one litre of solution (add 14 ml of concentrated sulphuric acid to distilled water to make one litre of solution for 0.5 N sulphuric acid).

NOTE — This solution is unstable in air and should be kept tightly stoppered. It should be standardized against the potassium dichromate solution at least once in a week.

3.1.3 **Sulphuric Acid, Concentrated** — of specific gravity 1.830 [see IS : 266-1977 'Specification for sulphuric acid (first revision)'].

3.1.4 **Orthophosphoric Acid, 85 percent** — of specific gravity 1.70 to 1.75.

3.1.5 **Indicator Solution** — 0.25 g of sodium diphenylamine-sulphonate dissolved in 100 ml of distilled water.

4. STANDARDIZATION OF FERROUS SULPHATE SOLUTION

4.1 Ten millilitres of the normal potassium dichromate solution will be run from a burette into a 500-ml conical flask. Twenty millilitres concentrated sulphuric acid shall then be added carefully and the mixture swirled and allowed to cool for some minutes. Two hundred millilitres of distilled water shall then be added to the mixture followed

by 10 ml of phosphoric acid and 1 ml of the indicator, and the mixture shall be shaken thoroughly. Ferrous sulphate solution shall then be added from the second burette in 0.5 ml increments, the contents of the flask being swirled until the colour of the solution changes from blue to green. A further 0.5 ml of potassium dichromate shall then be added changing the colour back to blue. Ferrous sulphate solution shall then be added drop by drop with continued swirling until the colour of the solution changes from blue to green after the addition of a single drop. The total volume of ferrous sulphate solution used (X) shall be noted to the nearest 0.05 ml (1 ml ferrous sulphate solution is equivalent to $10.5/X$ ml potassium dichromate).

5. SOIL SAMPLE FOR TEST

5.1 The soil sample as received from the field shall be prepared in accordance with IS : 2720 (Part 1)-1983. The portion of the air-dried sample selected for the purpose of this test shall be weighed, its moisture content determined using separate sample for the purpose and the equivalent oven-dried weight (W_1) recorded. It shall then be sieved on a 10-mm IS Sieve and all particles other than stones crushed to pass through the sieve. The equivalent weight on oven-dry basis of the material passing 10-mm IS Sieve (W_2) shall be calculated and recorded to the nearest 0.1 percent of its total weight. A sample weighing approximately 100 g shall be obtained from the material passing 10-mm IS Sieve by quartering (see Notes 1 and 2). This sample shall then be pulverized so that it passes the 425-micron IS Sieve.

NOTE 1 — The method gives high results of organic content in soils containing sulphides. The sulphides can be destroyed at this stage by the addition of dilute (2 N) sulphuric acid. Acid shall be added until no further evolution of hydrogen sulphide occurs.

NOTE 2 — The method gives high results of organic content in soils containing chlorides. The chlorides may be removed at this stage by washing the soil with distilled water until no turbidity is obtained when a drop of the washing water is tested with silver nitrate solution. Alternatively, the effect of chlorides on the determination can be partly eliminated by using concentrated sulphuric acid in which silver sulphate has been dissolved in place of concentrated sulphuric acid specified in 3.1.3. If the ratio of carbon to chloride does not exceed unity, 25 g of silver sulphate per litre of sulphuric acid will be sufficient to precipitate the chloride.

5.1.1 A 5-gram soil sample shall be taken from the thoroughly mixed portion of the material passing the 425-micron IS Sieve and used for the test.

6. PROCEDURE

6.1 The sample shall be placed in a glass weighing bottle and weighed to 0.001 g. A small quantity, from 5 g to 0.2 g depending on the organic content (see Note) shall be transferred to a dry 500-ml conical flask, the weighing bottle reweighed and the

equivalent weight on oven-dry basis of soil specimen removed (W_3) calculated by difference and allowing for the moisture content of the soil.

NOTE — The size of the specimen for chemical analysis will vary with the amount of organic matter present in the soil. As much as 5 g may be required for soil low in organic matter and as little as 0.2 g with a very peaty soil. After a number of determinations have been made, experience will indicate the most suitable size of specimen to be taken. In unfamiliar types of soil, it is suggested that a series of specimens of varying sizes should be weighed out and tested. The determination giving a total of 5 to 8 ml dichromate solution reduced should be taken as the correct result.

6.2 Ten millilitres of N potassium dichromate solution shall be run into the conical flask from a burette, and add 20 ml of concentrated sulphuric acid very carefully from a measuring cylinder. The mixture shall be thoroughly swirled for about one minute and allowed to stand on a heat insulating surface, such as asbestos or wood for 30 min to allow oxidation of the organic matter to proceed. During this period, the flask shall be protected from draughts. Distilled water, 200 ml, shall then be added along with 10 ml of orthophosphoric acid and one ml of the indicator (see Note). The mixture shall be shaken vigorously. If the indicator is absorbed by the soil, a further 1 ml of the solution shall be added. Ferrous sulphate solution shall then be added from the second burette in 0.5 ml increments, the contents of the flask being swirled, until the colour of the solution changes from blue to green. A further 0.5 ml of potassium dichromate shall then be added, changing the colour of the solution back to blue. Ferrous sulphate solution shall then be added drop by drop with continued swirling until the colour of the solution changes from blue to green after the addition of a single drop. The total volume of the ferrous sulphate solution used (Y) shall be noted to the nearest 0.05 ml.

NOTE — If complex ferric ions which interfere with the end point are present in the soil, after the addition of 10 ml of orthophosphoric acid, 0.2 g of sodium fluoride may be added before the addition of the indicator.

7. CALCULATIONS

7.1 The volume (V ml) of potassium dichromate used to oxidize the organic matter in the soil is given by the following formula:

$$V = 10.5 (1 - Y/X)$$

where

Y = total volume of ferrous sulphate used in this test, and

X = total volume of ferrous sulphate used in the standardization test (see 4.1).

7.2 The percentage of organic matter (OM) present in the oven-dried sample shall be calculated from the following formula:

$$\text{OM, percent by weight} = \frac{0.67 W_2 V}{W_1 W_3} \text{ (see Note)}$$

where

W_2 = weight on oven-dry basis of the soil sample passing 10-mm IS Sieve,

V = total volume of postassium dichromate used to oxidize the organic matter (as in 7.1),

W_1 = weight on oven-dry basis of the total soil sample taken for the test before sieving, and

W_3 = weight on oven-dry basis of the soil specimen used in the test.

NOTE — The method is based on the determination of the organic carbon content of the soil and it assumes that soil organic matter contains an average of 50 percent of carbon by weight. With the technique employed, approximately 77 percent of the carbon in the organic material is oxidized. These factors are included in the formula given in 7.2.

8. REPORT

8.1 The test results should be recorded suitably. A recommended *proforma* for recording the results is given in Appendix A.

8.2 The organic matter content present shall be reported to the nearest 0.1 percent of the original oven-dry soil.

SECTION 2 DETERMINATION OF ORGANIC MATTER (ALTERNATIVE METHOD BY THE CHROMIC OXIDATION EQUIVALENT OF SOIL ORGANIC MATTER)

9. SCOPE

9.1 Section 2 of this standard (Part 22) lays down the method for determining the percentage by weight of the organic matter present in soils, by the chromic oxidation equivalent of soil organic matter.

9.2 Determination of organic matter of soil by chromic acid method is the most rapid and popular type of analysis and has the advantage of moderately satisfactory discrimination of humus from highly condensed forms including graphite and charcoal.

10 APPARATUS

10.1 Electric Hot Plate — with adjustable temperature.

10.2 Beakers — 250-ml and 400-ml.

10.3 Heat Resistant Glass Test Tubes — 30 × 200 mm.

10.4 Heat Resistant Glass Beaker (Bath) — of 2-litre capacity.

10.5 Thermometer — one, 0 to 250°C range.

10.6 A One-Litre Shallow Heat Resistant Glass Tray (Bath)

10.7 Torsion Balance — sensitive to 0.05 g.

10.8 Capillary Tube, Stirrer and Compressed Air Supply

10.9 Stirring Rod — With ends flattened.

10.10 Volumetric Pipettes

10.11 Burette — 50-ml.

11. REAGENTS

11.1 Orthophosphoric Acid, 85 Percent — of specific gravity 1.70 to 1.75.

11.2 Chromic Acid, 0.4 N Solution — Exactly 19.61 g of potassium dichromate (oven-dry) is dissolved in about 50 ml of water and then the solution is diluted to one litre with concentrated sulphuric acid.

11.3 Ferrous Ammonium Sulphate 0.2 N Solution — Exactly 78.44 g of ferrous ammonium sulphate is dissolved in 300 ml of water containing 20 ml of concentrated sulphuric acid, and the solution is diluted to 1 litre with water. This solution is made fresh, or titrated against the standard chromic acid each day.

11.4 Orthophenonanthroline Indicator 0.025 M Solution

12. SOIL SAMPLE FOR TEST

12.1 The soil sample shall be ground to pass a 212-micron IS Sieve and 0.25 g of soil (0.05 g if peat, 1.00 g if soil has less than one percent organic matter) shall be taken in a 250-ml beaker or 30 × 200 mm test tube (see also 5.1).

13. PROCEDURE

13.1 Oxidation of Organic Matter — From a pipette, 20 ml of 0.4 N chromic acid solution shall be added to the soil sample in the 250-ml beaker or test tube, and similar quantity shall be taken for the standardization blank. The vessel with mixture shall be placed in the orthophosphoric acid bath and heated on the electric hot plate at such a rate that a temperature of 155°C is reached in 20 to 25 min. The contents of tube or beaker shall be mixed every 5 min during the heating period. The temperature is held at 155 to 160°C for an additional 5 min. The thermometer shall be kept in the blank, which is simultaneously heated, to follow the solution temperature.

13.2 The vessels with samples and blank shall be then removed from the bath, allowed to drain in the

air for 30 s, and then placed in a water bath at room temperature for 2 min. The thermometer shall be removed with care not to break it by thermal shock.

13.3 Back Titration — The chromic acid solution, now cooled to room temperature, shall be diluted with water to 75 to 200 ml, either in the tube or 250-ml beaker. Then 5 ml of 85 percent orthophosphoric acid and 4 drops of orthophenonothroline indicator shall be added. The solution shall be back titrated with the 0.2 N ferrous ammonium sulphate until solution colour turns from green to red at the end point. An air jet stirrer should be used with the tube. The colour at start is dark brownish, and then shifts sharply from blue to red at the end point. The blank shall be similarly titrated. More chromic acid shall be added to fresh samples if the amount added proves to be inadequate; not over one-half of the chromic acid should be consumed by oxidation of organic matter.

14. CALCULATION OF RESULTS

14.1 The percentage of organic matter in a soil shall be estimated as follows:

Organic matter,

$$\text{percent (in soil)} = 20 \left(1 - \frac{T}{S} \right) \times \frac{0.23}{x} \text{ (see Note)}$$

where

T = sample titration, ml of approximately 0.2 N ferrous solution;

S = standardization blank titration, ml of approximately 0.2 N ferrous solution; and

x = weight of soil sample taken, in g.

NOTE 1 — In deriving the constant 0.23, it is assumed a 4 valance change of carbon occurs, 58 percent carbon occurs in soil organic matter, only carbon is oxidized, and only 90 percent of total soil organic matter is oxidized.

14.2 The organic matter content present shall be reported to the nearest 0.1 percent of the original oven-dry soil.

A P P E N D I X A

(Clause 8.1)

PROFORMA FOR RECORDING TEST RESULTS**Determination of Organic Matter Content of Soil**

Project Details of soil samples

Sample number				
Total weight of original sample (W_1), in g				
Weight of soil passing 10-mm IS Sieve (W_2), in g				
Weighing bottle number				
Weight of weighing bottle and dry soil before taking specimen for test, in g				
Weight of weighing bottle and dry soil after taken specimen for test, in g				
Weight of dry soil specimen used (W_3), in g				
Volume of ferrous sulphate solution added to standardize potassium dichromate solution (X), in ml				
Volume of ferrous sulphate solution used to oxidize excess potassium dichromate solution (Y), in ml				
Volume of potassium dichromate solution used to oxidize organic matter in soil $V = 10.5$ ($1 - Y/X$), ml				
Percentage of organic matter in soil = $\frac{0.6 W_2 V}{W_1 W_3}$				
Remarks				

SECTION 13

Determination of Consolidation Properties

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Indian Standard
METHODS OF TEST FOR SOILS
PART 15 DETERMINATION OF CONSOLIDATION PROPERTIES
(First Revision)

0. FOREWORD

0.1 This 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 are used in predicting the rate and the amount of settlement of structure. The two most important soil properties furnished by a consolidation test are the coefficient of compressibility (a_s), 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 tersaghi theory of consolidation is used for extrapolating laboratory consolidation test results in order to predict the settlements of structures in the filed.

0.2 This standard was first published in 1965. This 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.

1. SCOPE

1.1 This standard (Part 15) covers the method for conducting one dimensional consolidation test using either fixed or the floating ring for determining the consolidation characteristic 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 material which is non-corrosive. 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 silicone 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 case, diameter may be 50 mm.

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

3.2 Porous Stones

3.2.1 These stones shall be placed at the top and 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 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 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 'Specification for plunger type dial gauges (*first revision*)'].

3.5 Loading Device

3.5.1 A device which enables vertical force to be applied axially in suitable increments, to the test specimen, through a suitable loading yoke. The device 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.

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 and Drying Air-oven Maintained at $110 + 5^\circ\text{C}$, Desiccator

3.11 Balance Sensitive to 0.01 g — For weighing the specimen and 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 (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 overconsolidated 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/cm² shall be applied to the specimen.

4.2.4 The consolidation cell 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 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 kgf/cm², etc, 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, min, etc, up to 24 h or 0, 1/4, 1/2, 1, 2, 4, 8, 15, 30, and 60 min, and 2, 4, 8 and 24 h. These time sequences facilitate plotting of thickness or change of thickness of specimen against square root of time or against log 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 24 h are 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 1/4 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 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 be carefully 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.

6. CALCULATIONS

6.1 Determination of Coefficient of Consolidation (c_v) — Plot dial gauge 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.

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_o is found by extrapolating the straight line portion of the curve, that is, CD back to $t = 0$.

6.1.1.2 A straight line is then drawn from d_o 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:

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

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_o , 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 $\frac{1}{4}$ but less than $\frac{1}{2}$ 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:

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

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 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 specimen, w_s , the volume of soil solids, V_s , shall be obtained as:

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

where G_s is specific gravity of the solid particles and V_w unit of water.

6.2.1.3 The equivalent height of soil solids can be determined as:

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

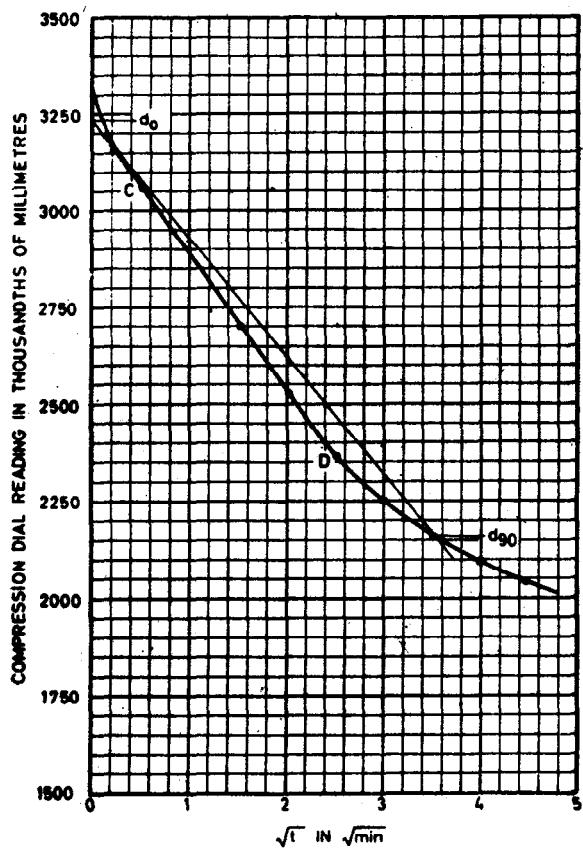
6.2.1.4 From col 2 of Appendix A, determine ΔH for each pressure increment, record it in col 3.

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 the H of the specimen prior to application of that increment. This is to be recorded in col 4 of Appendix A.

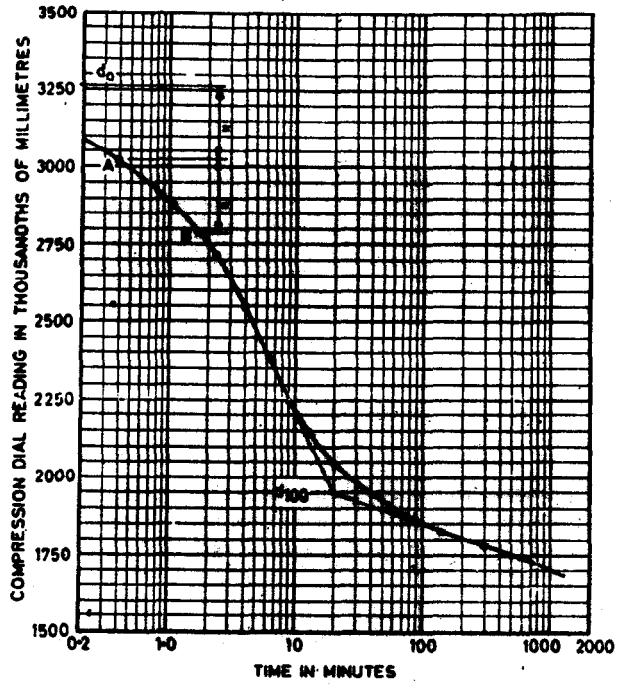
6.2.1.6 Void ratio, e , is obtained as:

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

and recorded in col 5 of Appendix A.



1A THE SQUARE ROOT OF TIME FITTING METHOD



1B THE LOGARITHM OF TIME FITTING METHOD

FIG. 1 FITTING METHODS

6.2.1.7 Values of d_e and $d\sigma$ obtained from col 5 of Appendix A respectively are recorded in col 6 and 7 of Appendix A.

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

$$a_v = \frac{d_e}{d\sigma}$$

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 $\log \sigma$. 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:

$$C_c = \frac{d_e}{\log \left(\frac{\sigma_f}{\sigma_c} \right)}$$

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 $\log \sigma$, of a_v versus $\log \sigma$ and of C_c versus $\log \sigma$. The value of C_c is also reported separately.

A P P E N D I X A
SOIL MECHANICS LABORATORY
CONSOLIDATION TEST : PRESSURE-VOID RATIO DATA

Project	Specimen measurements	Water content
Sample No.	Diameter Dcm	Can No. =g
Soil identification	Area, $A = \pi D^2/4 =$cm ²	Wt. of can + wet soil =g
Specific gravity	Thickness $H_o =$cm	Wt. of can + dry soil =g
Specimen preparation	Wt. of ring (W_1) =g	Wt. of can =g
Procedure	Wt. of specimen + ring (W_2) =g	Wt. of water =g
Type of water used	Final wt. of specimen (W_3) =g	Wt. of dry soil =g
	Dry wt. of specimen + ring (W_4)g	Water content, percent =
	Dry wt. of specimen (W_5) = $W_4 - W_1$g	
	Equivalent height of solids =cc	

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

Test No. Tested by
 Date

Applied Pressure (kgf/cm ²) σ	Final Dial Read- ing	Com- pression ΔH (mm)	Specimen height (cm)	$e = \frac{H}{H_s} - 1$	d_e	$d\sigma$	$a_v = \frac{d_e}{d\sigma}$ (cm ² /kg)	t_{50} or t_{90} (min)	H_{av} (cm)	c_v cm ² /min	Remarks
1	2	3	4	5	6	7	8	9	10	11	12

A P P E N D I X B
CONSOLIDATION TEST : PRESSURE INCREMENT DATA

Project	Loading frame No.	Test No.
Sample	L.C. of dial gauge	Date
Soil identification		Page No.

Pressure Increment			Pressure Increment			Pressure Increment			Pressure Increment		
From to kgf/cm ²			From to kgf/cm ²			From to kgf/cm ²			From to kgf/cm ²		
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

SECTION 14
Determination of CBR

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Indian Standard

SPECIFICATION FOR CBR MOULDS AND ITS ACCESSORIES

(incorporating Amendments No. 1 and 2)

0. FOREWORD

0.1 The equipment covered in this standard is used for determination of CBR value covered in IS: 2720 (Part 16)-1979.

1. SCOPE

1.1 This standard covers the details of mould, cutting collar, base plate, spacer disc, weights, penetration plunger and other accessories used for the determination of CBR value.

2. DIMENSIONS

2.1 Dimensions with tolerance of different equipment shall be as detailed in Fig. 1 to 9. Except where tolerances are specifically mentioned against the dimensions, all dimensions shall be taken as nominal dimensions and tolerances as given in IS: 2102 (Part 1)-1980.

3. MATERIALS

3.1 The materials construction of the various equipment shall be as given in Table 1.

4. CONSTRUCTION

4.1 Mould — The mould shall be smooth from inside and shall have two ears either cast integral with the body or welded. It shall have suitable seatings at the ends for positioning the collar and the base plate (*see* Fig. 1).

4.2 Collar — The collar be made from same material as that of mould. Two similar ears as in the case of the mould shall be cast integral with the body or welded. It shall have suitable seatings at the lower end for sitting flush with the mould (*see* Fig. 2).

4.3 Base Plate — A suitable seating about 2 mm deep shall be provided on the top face for proper

TABLE I MATERIALS FOR CONSTRUCTION OF DIFFERENT EQUIPMENTS
(*Clause 3.1*)

Sl. No.	EQUIPMENT	MATERIAL	SPECIAL REQUIREMENTS, IF ANY	RELEVANT INDIAN STANDARD
(1)	(2)	(3)	(4)	(5)
1. a) Mould (<i>see</i> Fig. 1)	a) Copper alloy or Brass	—	—	IS : 318-1981*
b) Cutting collar (<i>see</i> Fig. 2)	b) Brass or	—	—	IS : 292-1983†
c) Base plate (<i>see</i> Fig. 3)	c) Phosphor bronze or	—	—	IS : 28-1975‡
	d) Mild steel	Chrome-plated	—	IS : 513-1973§
2. Spacer disc and handle (<i>see</i> Fig. 4)	Mild steel	—	—	IS : 513-1973§
3. Weights (<i>see</i> Fig. 5)	Cast iron	—	—	IS : 210-1978
4. Adjustable stem with perforated plate (<i>see</i> Fig. 6)	Brass	—	—	IS : 410-1977
5. Penetration plunger (<i>see</i> Fig. 7)	Mild steel	Plated	—	IS : 513-1973§
6. Stay rod (<i>see</i> Fig. 8)	Mild steel	—	—	IS : 513-1973§
7. Wing nut and washer (<i>see</i> Fig. 9)	Forged steel or Cast steel	Cadmium/ chrome-plated	—	—
8. Tripod (<i>see</i> Fig. 4.4)	Copper alloy	—	—	IS : 318-1981*

*Specification for leaded tin bronze ingots and castings (*second revision*).

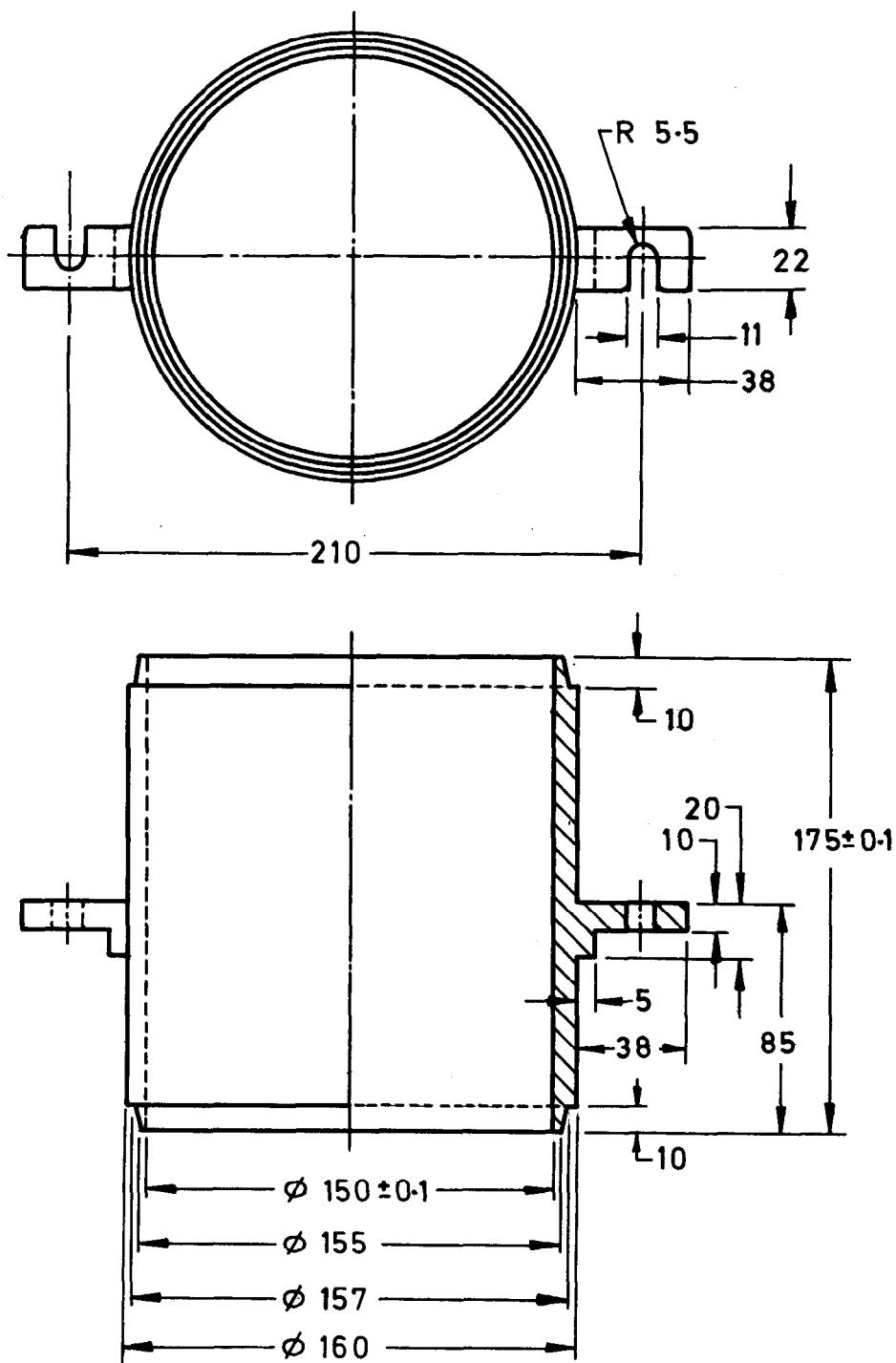
† Specification for leaded brass ingots castings (*second revision*).

‡ Specification for phosphor bronze ingots and castings (*third revision*).

§ Specification for cold rolled carbon steel sheets (*second revision*).

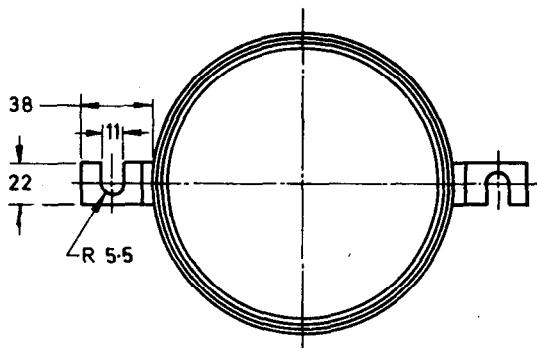
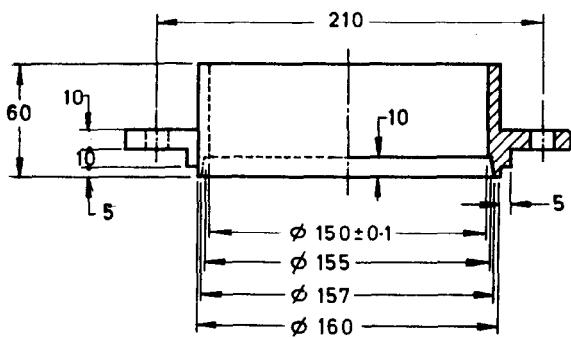
|| Specification for grey iron castings (*third revision*).

¶ Specification for cold rolled brass sheet, strip and foil (*third revision*).



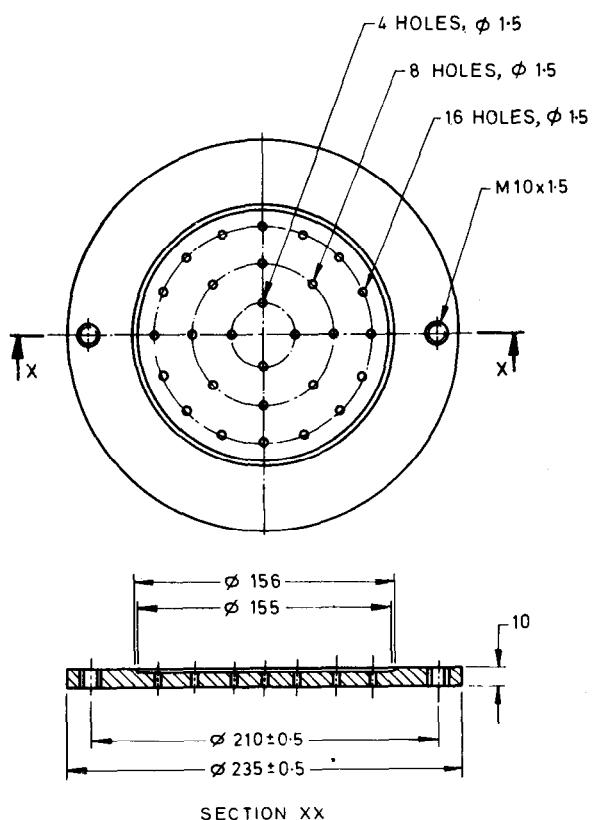
All dimensions in millimetres.

FIG. 1 MOULD



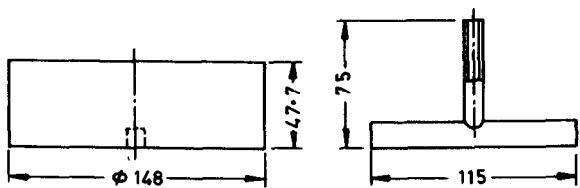
All dimensions in millimetres.

FIG. 2 CUTTING COLLAR



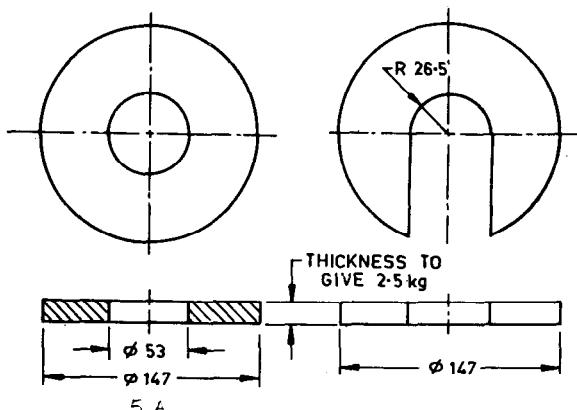
All dimensions in millimetres.

FIG. 3 BASE PLATE



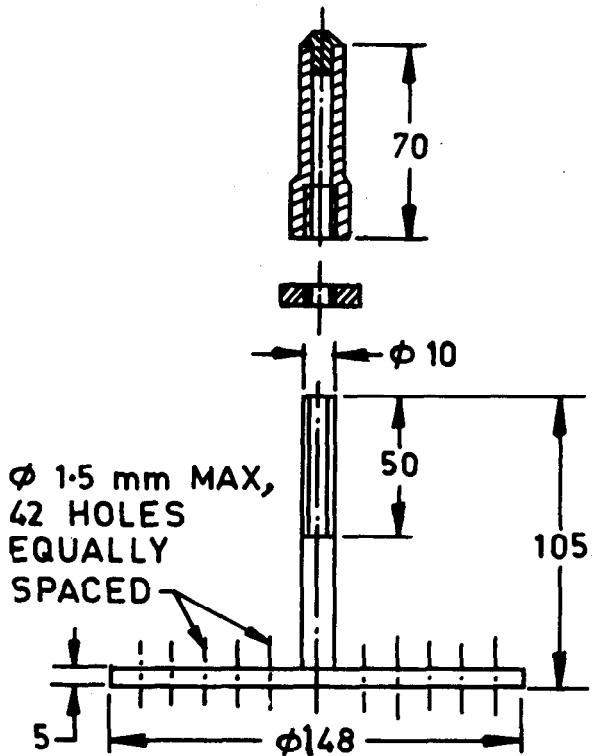
All dimensions in millimetres.

FIG. 4 SPACER DISC AND HANDLE



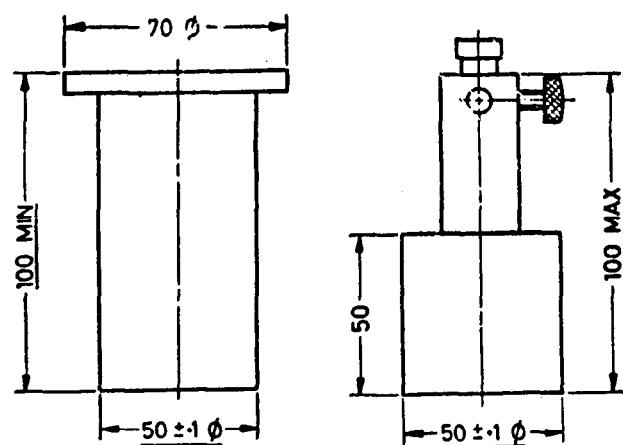
All dimensions in millimetres.

FIG. 5 METAL WEIGHTS



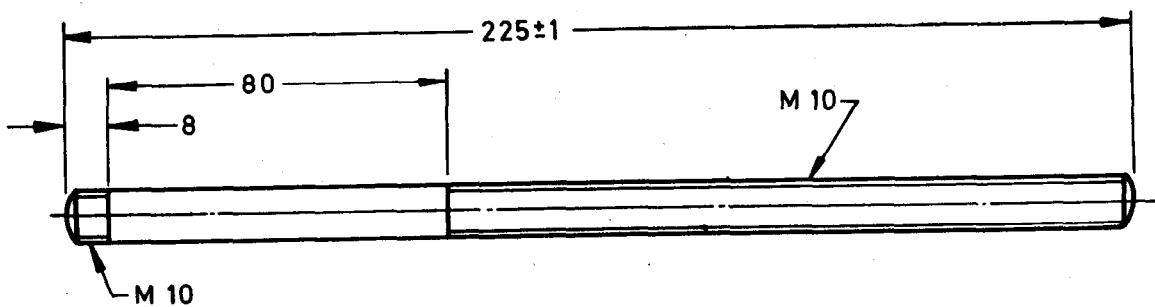
All dimensions in millimetres.

FIG. 6 ADJUSTABLE STEM AND PERFORATED PLATES



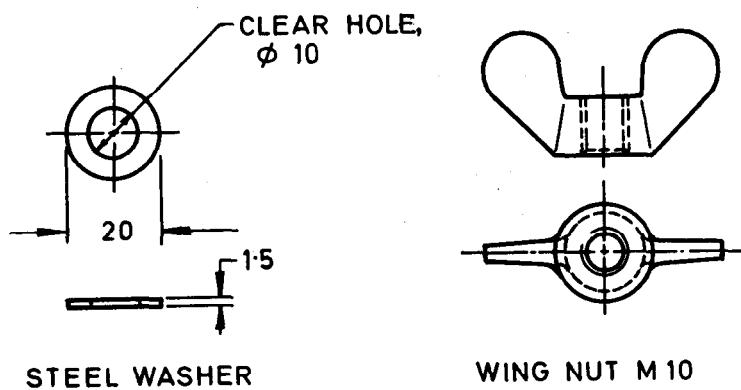
All dimensions in millimetres.

FIG. 7 PENETRATION PLUNGER



All dimensions in millimetres.

FIG. 8 STAY ROD



All dimensions in millimetres.
FIG. 9 WING NUT AND WASHER

seating of the mould (see Fig. 3), and shall be of same material as mould.

4.4 The details of other accessories, namely, spacer disc, weights, adjustable stem perforated plates, penetration plunger, stay rod and wing nut, are given from Fig. 4 to 9. The details of tripod are given in Fig. 10.

5. MARKING

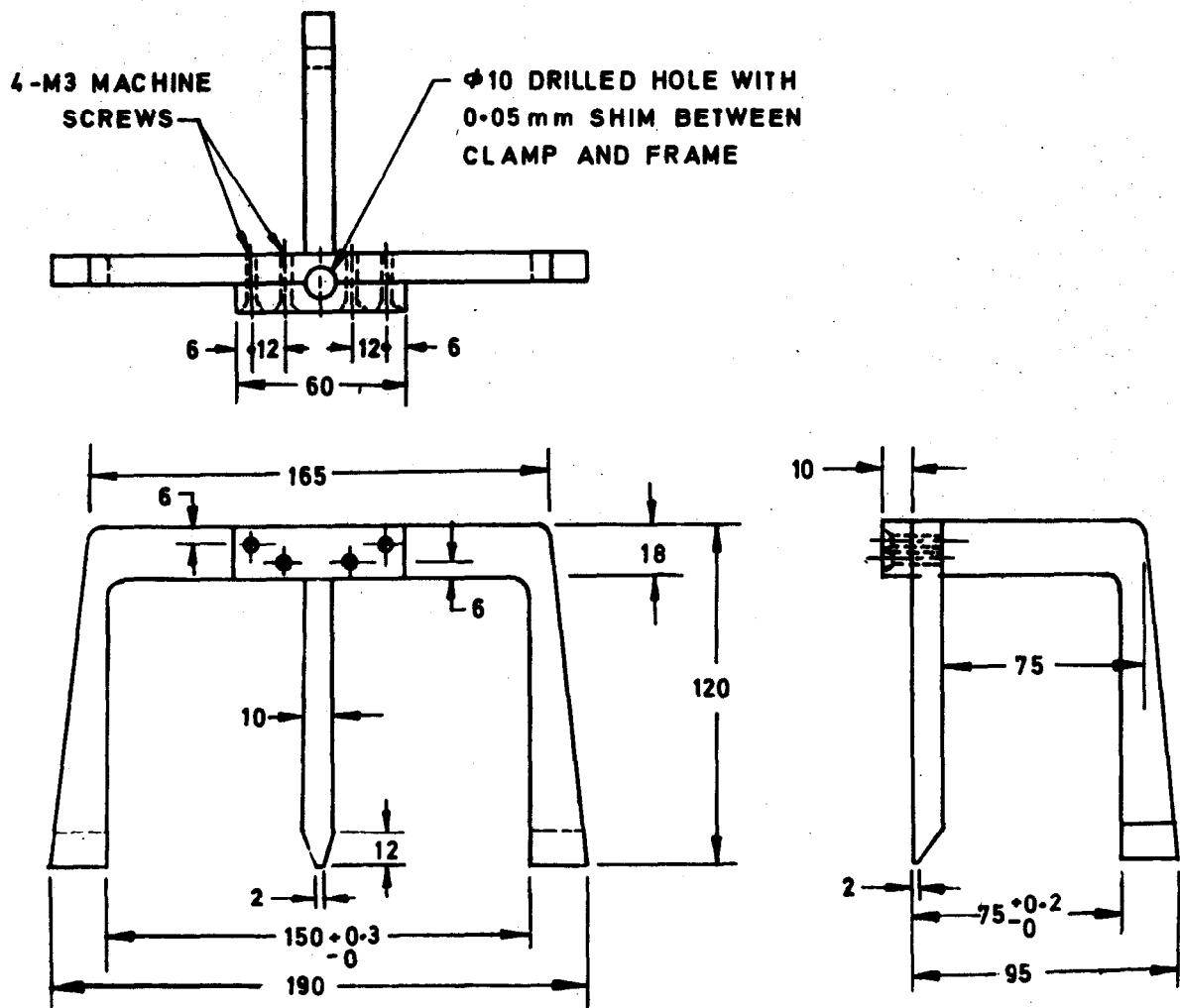
5.1 The following information shall be clearly and indelibly marked on each equipment:

- Name of the manufacturer or his registered trade-mark or both,
- Type of material used, and

c) Date of manufacture.

5.1.1 The equipment may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.



All dimensions in millimetres.
FIG. 10 METAL TRIPOD

Indian Standard

METHODS OF TEST FOR SOILS

PART 16 LABORATORY DETERMINATION OF CBR

(First Revision)

(Incorporating Amendments No. 1 and 2)

0. FOREWORD

0.1 This standard (Part 16) which deals with the laboratory determination of California bearing ratio was originally published in 1965. This revision brings in line with other international standards specially in regard to the procedure of testing. The California bearing ratio test (usually abbreviated as CBR test) is an *ad hoc* penetration test developed by the California State Highway Department of USA for the evaluation of subgrade strengths for roads and pavements. The results obtained by these tests are used in conjunction with empirical curves based on experience for the design of flexible pavements.

0.2 The test is arbitrary and the results give an empirical strength number which may not be directly related to fundamental properties governing the strength of soils, such as cohesion, angle of internal friction, etc. However, it should be noted that attempts have been made of late to correlate CBR values to certain properties of soil, such as the bearing capacity and the plasticity index.

0.3 Since the test is an *ad hoc* test, the procedure should be strictly adhered to if results are to be comparable with those previously obtained and correlated. The results have a direct application to the method of design for which the test has been devised.

1. SCOPE

1.1 This standard (Part 16) covers the laboratory method for the determination of California bearing ratio (CBR) of undisturbed soil specimens obtained from the field and also remoulded specimens of the soil compacted in the laboratory both by the static and dynamic method, and in the soaked and unsoaked state.

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS: 2809-1972 and the following shall apply.

2.1 Standard Load — Load which has been obtained from the test on crushed stone which was

defined as having a California bearing ratio of 100 percent (*see also 6.3*).

2.2 California Bearing Ratio (CBR) — The ratio of the force per unit area required to penetrate a soil mass with a circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration of a standard material. The ratio is usually determined for penetrations of 2.5 and 5 mm. Where the ratio at 5 mm is consistently higher than that at 2.5 mm, the ratio at 5 mm is used.

3. APPARATUS

3.1 Moulds with Base Plate, Stay Rod and Wing Nut — These shall conform to 4.1, 4.3 and 4.4 of IS: 9669-1980.

3.2 Collar — It shall conform to 4.2 of IS: 9669-1980.

3.3 Spacer Disc — It shall conform to 4.4 of IS: 9669-1980.

3.4 Metal Rammer — As specified in IS: 9198-1979.

3.5 Expansion Measuring Apparatus — The adjustable stem with perforated plates and tripod shall conform to 4.4 of IS: 9669-1980.

3.6 Weights — This shall conform to 4.4 of IS: 9669-1989.

3.7 Loading Machine — With a capacity of at least 5 000 kg and equipped with a movable head or base that travels at a uniform rate of 1.25 mm/min for use in forcing the penetration plunger into the specimen. The machine shall be equipped with a load indicating device that can read to an accuracy of one-half percent of loads.

3.8 Penetration Plunger — This shall conform to 4.4 of IS: 9669-1980. To use a plunger of greater length, a suitable extension rod may be used.

3.9 Dial Gauges — Two dial gauges reading to 0.01 mm.

3.10 Sieves — 47.5-mm IS Sieve and 19-mm IS Sieve [*see IS: 460 (Part 1)-1978*].

3.11 Miscellaneous Apparatus — Other general apparatus, such as a mixing bowl, straightedge,

scales, soaking tank of pan, drying oven, filter paper, dishes and calibrated measuring jar.

4. PREPARATION OF TEST SPECIMEN

4.1 The test may be performed:

- a) on undisturbed specimens, and
- b) on remoulded specimens which may be compacted either statically or dynamically.

NOTE — The static method of compaction gives the required density but requires considerable pressure and there is a possibility of the actual density varying with the depth though the mean density may be the one desired.

4.2 Undisturbed Specimens — Undisturbed specimens shall be obtained by fitting to the mould, the steel cutting edge of 150 mm internal diameter and pushing the mould as gently as possible into the ground. This process may be facilitated by digging away the soil from the outside as the mould is pushed in. When the mould is sufficiently full of soil, it shall be removed by underdigging, the top and bottom surfaces are then trimmed flat so as to give the required length of specimen ready for testing. If the mould cannot be pressed in, the sample may be collected by digging at a circumference greater than that of the mould and thus bringing out a whole undisturbed lump of soil. The required size of the sample to fit into the test mould shall then be carefully trimmed from this lump.

If the specimen is loose in the mould, the annular cavity shall be filled with paraffin wax thus ensuring that the soil receives proper support from the sides of the mould during the penetration test. The density of the soil shall be determined either by weighing the soil with mould when the mould is full with the soil, or by measuring the dimensions of the soil sample accurately and weighing or by measuring the density in the field in the vicinity of the spot at which the sample is collected in accordance with the method specified in IS: 2720 (Part 28)-1973 or IS: 2720 (Part 29)-1975. In all cases, the water content shall be determined in accordance with IS: 2720 (Part 2)-1973

4.3 Remoulded Specimens — The dry density for a remoulding shall be either the field density or the value of the maximum dry density estimated by the compaction tests [see IS: 2720 (Part 7)-1980 and IS: 2720 (Part 8)-1983] or any other density at which the bearing ratio is desired. The water content used for compaction should be the optimum water content or the field moisture as the case may be.

4.3.1 Soil Sample — The material used in the remoulded specimen shall pass a 19-mm IS Sieve. Allowance for larger material shall be made by replacing it by an equal amount of material which passes a 19-mm IS Sieve but is retained on 4.75-mm IS Sieve.

4.3.2 Statically Compacted Specimens — The mass of the wet soil at the required moisture content to give the desired density when occupying the standard specimen volume in the mould shall be calculated. A batch of soil shall be thoroughly mixed with water to give the required water content. The correct mass of the moist soils shall be placed in the mould and compaction obtained by pressing in the displacer disc, a filter paper being placed between the disc and the soil.

NOTE — When the top of the displacer disc is flush with the rim of mould, the required volume of specimen is obtained although with some soil types it may be necessary to continue loading until the displacer disc is just below the rim in order to allow for the elastic recovery of the soil when the load is removed.

4.3.3 Dynamically Compacted Specimen — For dynamic compaction, a representative sample of the soil weighing approximately 4.5 kg or more for fine-grained soils and 5.5 kg or more for granular soils shall be taken and mixed thoroughly with water. If the soil is to be compacted to the maximum dry density at the optimum water content determined in accordance with IS: 2720 (Part 7)-1980 or IS: 2720 (Part 8)-1983, the exact mass of soil required shall be taken and the necessary quantity of water added so that the water content of the soil sample is equal to the determined optimum water content.

4.3.3.1 The mould with the extension collar attached shall be clamped to the base plate. The spacer disc shall be inserted over the base plate and a disc of coarse filter paper placed on the top of the spacer disc. The soil-water mixture shall be compacted into the mould in accordance with the methods applicable to the 150 mm diameter mould specified in IS: 2720 (Part 7)-1983 or IS: 2720 (Part 8)-1983. If other densities and water contents are desired, they may be used and indicated in the report.

4.3.3.2 The extension collar shall then be removed and the compacted soil carefully trimmed even with the top of the mould by means of a straightedge. Any hole that may then develop on the surface of the compacted soil by the removal of coarse material, shall be patched with smaller size material; the perforated base plate and spacer disc shall be removed, and the mass of the mould and the compacted soil specimen recorded. A disc of coarse filter paper shall be placed on the perforated base plate, the mould and the compacted soil shall be inverted and the perforated base plate clamped to the mould with the compacted soil in contact with the filter paper.

4.3.4 In both cases of compaction, if the sample is to be soaked, representative samples of the material at the beginning of compaction and another sample of the remaining material after compaction shall be taken for the determination of water con-

tent. Each water content sample shall weigh not less than 100 g for fine-grained soils and not less than 500 g for granular soils.

If the sample is not to be soaked, a representative sample of material from one of the cut-pieces of the material after penetration shall be taken to determine the water content. In all cases, the water content shall be determined in accordance with IS: 2720 (Part 2)-1973.

5. PROCEDURE

5.1 Test for Swelling

NOTE — The swelling test may be omitted if it is unnecessary and the penetration test specified in 5.2 may be carried out directly.

5.1.1 A filter paper shall be placed over the specimen and the adjustable stem and perforated plate shall be placed on the compacted soil specimen in the mould. Weights to produce a surcharge equal to the weight of base material and pavement to the nearest 2.5 kg shall be placed on the compact soil specimen. The whole mould and weights shall be immersed in a tank of water allowing free access of water to the top and bottom of the specimen. The tripod for the expansion measuring device shall be mounted on the edge of the mould and the initial dial gauge reading recorded. This set-up shall be kept as such undisturbed for 96 hours (see Note) noting down the readings every day against the time of reading. A constant water level shall be maintained in the tank throughout the period.

At the end of the soaking period, the final reading of the dial gauge shall be noted, the tripod removed and the mould taken out of the water tank.

The free water collected in the mould shall be removed and the specimen allowed to drain downward for 15 minutes. Care shall be taken not to disturb the surface of the specimen during the removal of the water. The weights, the perforated plate and the top filter paper shall be removed and the mould with the soaked soil sample shall be weighed and the mass recorded.

NOTE — Soaking for 96 hours is the standard procedure. However, certain types of soils may require more or less period of soaking. The designer may therefore decide on the period of soaking depending upon soil and environmental conditions.

5.2 Penetration Test (see Fig. 1) — The mould, containing the specimen, with the base plate in position, but the top face exposed, shall be placed on the lower plate of the testing machine. Surcharge weights, sufficient to produce an intensity of loading equal to the weight of the base material and pavement shall be placed on the specimen. If the specimen has been soaked previously, the surcharge shall be equal to that used during the soaking period. To prevent upheaval of soil into the hole of the surcharge weights, 2.5 kg annular weight shall

be placed on the soil surface prior to seating the penetration plunger after which the remainder of the surcharge weights shall be placed. The plunger shall be seated under a load of 4 kg so that full contact is established between the surface of the specimen and the plunger. The stress and strain gauges shall then be set to zero. The initial load applied to the plunger shall be considered as the zero load when determining the load penetration relation. Load shall be applied to the penetration plunger so that the penetration is approximately 1.25 mm per minute. Reading of the load shall be taken at penetrations of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0 and 12.5 mm.

The maximum load and penetration shall be recorded if occurs for a penetration of less than 12.5 mm. The plunger shall be raised and the mould detached from the loading equipment. About 20 to 50 g of soil shall be collected from the top 30 mm layer of the specimen and the water content determined according to IS: 2720 (Part 2)-1973. If the average water content of the whole specimen is desired, water content sample shall be taken from the entire depth of the specimen. The undisturbed specimen for the test should be carefully examined after the test is completed for the presence of any oversize soil particles which are likely to affect the results if they happen to be located directly below the penetration plunger.

NOTE — Theoretically the CBR should increase with the increase in surcharge and confining pressures. However, in partly cohesionless soils, the CBR increases with the surcharge weight only up to a particular point beyond which the CBR almost remains constant. Hence the CBR should not be considered meaningful for application to purely cohesionless soils such as sands.

5.2.1 The penetration test may be repeated as a check test for the reserve end of the sample.

6. CALCULATION

6.1 Expansion Ratio — The expansion ratio based on tests conducted as specified in 5.1 shall be calculated as follows:

$$\text{Expansion ratio} = \frac{d_f - d_s}{h} \times 100$$

where

d_f = final dial gauge reading in mm,

d_s = initial dial gauge reading in mm, and

h = initial height of the specimen in mm.

6.2 Load Penetration Curve — The load penetration curve shall be plotted (see Fig. 2) This curve will be mainly convex upwards although the initial portion of the curve may be concave upwards due to surface irregularities. A correction shall then be applied by drawing a tangent to the upper curve at the point of contraflexure. The corrected curve shall be taken to be this tangent plus the convex portion

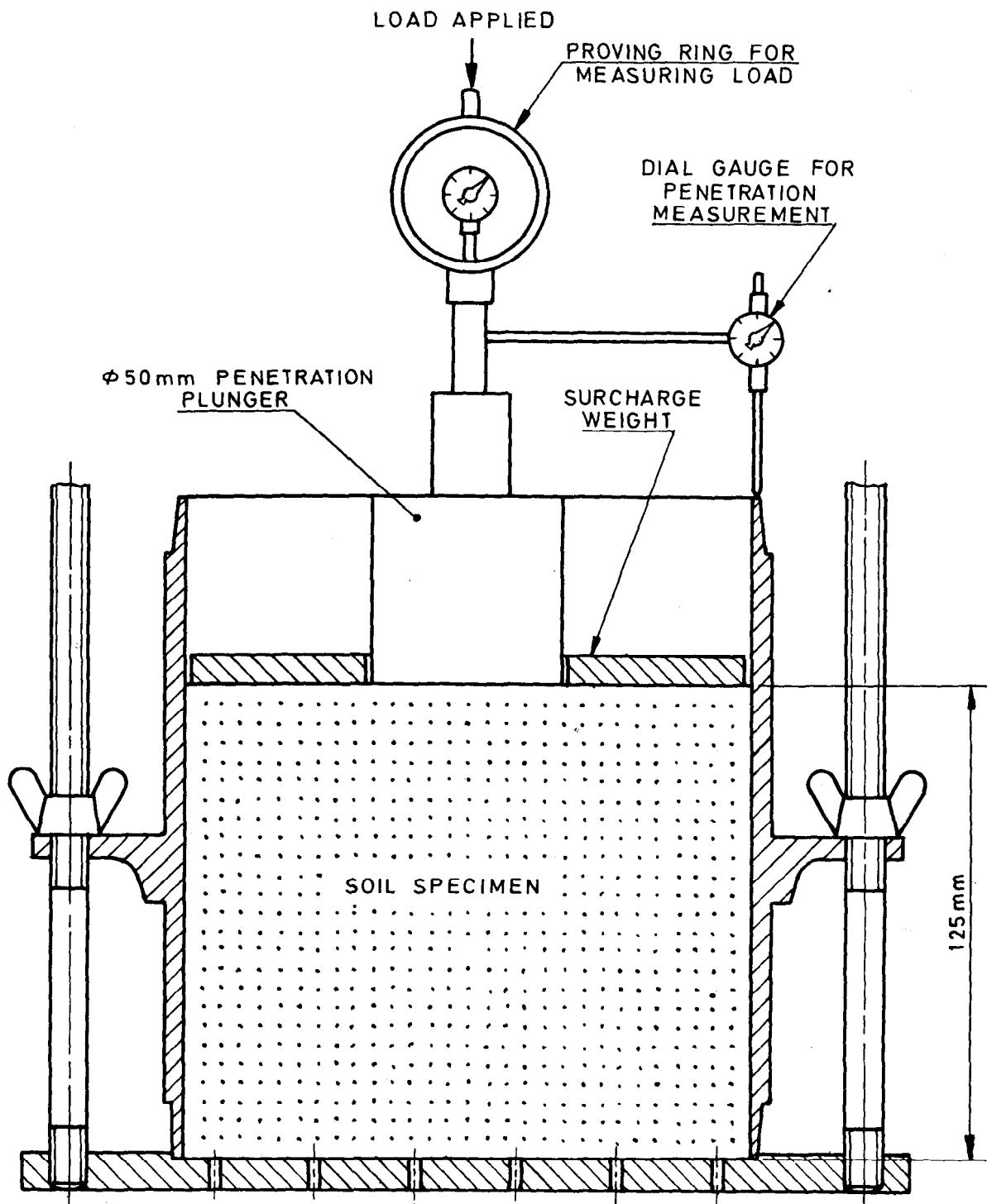


FIG. 1 SETUP FOR CBR TEST

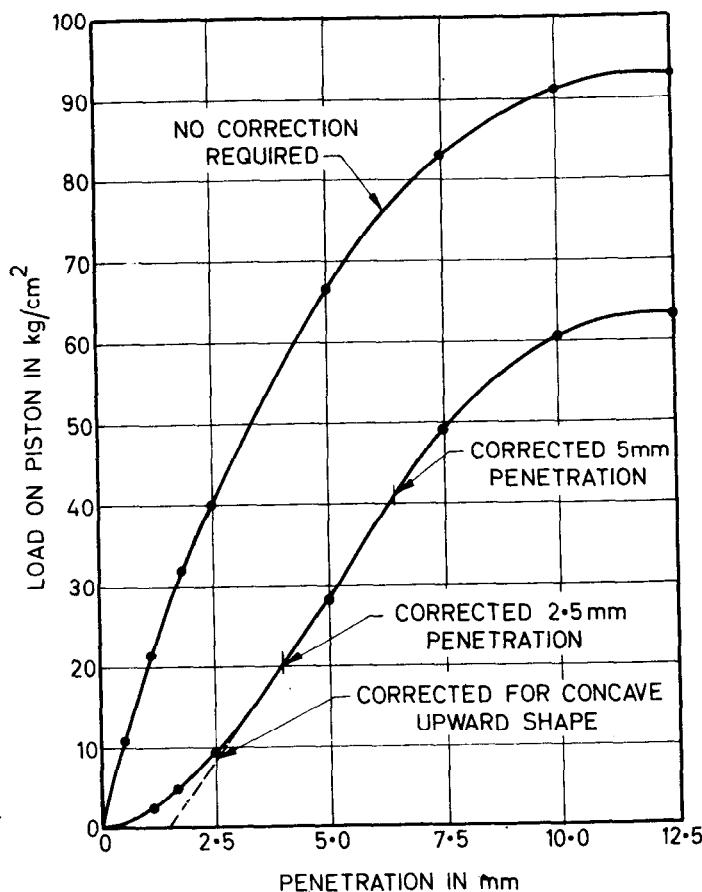


FIG. 2 CORRECTION LOAD PENETRATION CURVES

of the original curve with the origin of strains shifted to the point where the tangent cuts the horizontal strain axis as illustrated in Fig. 2.

6.3 Bearing Ratio — Corresponding to the penetration value at which the California bearing ratio is desired, corrected load value shall be taken from the load penetration curve and the California bearing ratio calculated as follows:

$$\text{California bearing ratio} = \frac{P_T}{P_s} \times 100$$

where

P_T = corrected unit (or total) test load corresponding to the chosen penetration from the load penetration curve, and

P_s = unit (or total) standard load for the same depth of penetration as for P_T taken from Table 1.

The CBR values are usually calculated for penetration of 2.5 mm and 5 mm. Generally, the CBR value at 2.5 mm penetration will be greater than that at 5 mm penetration and in such a case the former shall be taken as the CBR value for design purposes.

If the CBR value corresponding to a penetration of 5 mm exceeds that for 2.5 mm, the test shall be repeated. If identical results follow, the bearing ratio corresponding to 5 mm penetration shall be taken for design.

TABLE 1 STANDARD LOAD

PENETRATION DEPTH (1) mm	UNIT STANDARD LOAD (2) kgf/cm ²	TOTAL STANDARD LOAD (3) kgf
2.5	70	1 370
5.0	105	2 055
7.5	134	2 630
10.0	162	3 180
12.5	183	3 600

7. REPORT

7.1 The CBR value shall be reported correct to the first decimal place. The details in the recommended proforma given in Appendix A shall be reported.

A P P E N D I X A

(Clause 7.1)

PROFORMA FOR CALIFORNIA BEARING RATIO TEST

Project Tested by

Location Date

Details of soil sample obtained from site

Method used for preparation of specimen

Type of compaction used

Condition of specimen at test: Soaked
Unsoaked

Surcharge weight used

Period of soaking

Percentage of soil fraction above 19 mm replaced

Density of Specimen

- a) Dry density before soaking
- b) Bulk density before soaking
- c) Bulk density after soaking

Water Content

- a) Field equilibrium water content for undisturbed specimens
- b) Before compaction
- c) After compaction in the mould
- d) Top 3-cm layer after soaking
- e) Average after soaking

Observations and Calculations

a) Swelling test:

- Surcharge weight used
- Period of soaking
- Expansion ratio

b) Penetration test:

- Surcharge weight used
- c) Observations regarding the maximum particle size in the undisturbed specimen, if any

<i>Penetration, mm</i>	<i>Load, kgf</i>	<i>Corrected Load, kgf (see 5.2)</i>
CBR of specimen at 2.5 mm penetration		
CBR of specimen at 5 mm penetration		
CBR of specimen at Penetration*		
Results of repeat test, if conducted		

*Specify the penetration value.

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SECTION 15

Determination of Properties of Stabilized Soil Mixtures

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Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 1 METHOD OF SAMPLING AND PREPARATION OF STABILIZED SOILS FOR TESTING

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization, in the broadest sense, is the alteration of any inherent property of a soil to improve its engineering performance. The classification of the methods of stabilization is based on the treatment given to the soil (for example, dewatering, compaction, etc), process involved (for example, thermal, electrical, etc) and on additives employed (for example, asphalt, cement, etc). The choice of a particular method depends on the characteristics of the problem on hand. For studying the effectiveness of a stabilization technique under investigation, certain standard methods of test are required and these are being published in parts. This part [IS : 4332 (Part 1)-1967] lays down the method of sampling and preparation of stabilized soils for testing.

1. SCOPE

1.1 This standard (Part 1) lays down the general principles of sampling for obtaining disturbed samples and the method for preparation of stabilized soils for testing.

2. SAMPLING

2.1 The purpose for which a sample is required may be considered either as being to represent as large a body of material as possible in order to study its average properties, or as being one of a series representing a relatively small body of material in order to study the variability of its properties. The former samples will be referred to as 'representative' and typical of these are those samples taken in advance of construction to assess the suitability of a given source of soil. The latter samples will be referred to as 'selected' and typical are those samples taken for control tests carried out during construction where the samples represent only a small proportion of the whole work.

2.2 Representative samples should be obtained by taking a number of sub-samples from delimited areas from which material is being sampled, and these sub-samples should be thoroughly mixed. The number of sub-samples should be a minimum of

five or more depending on the area. The quantity of the resulting sample shall be reduced to that required for tests. If the quantity of the test sample is one-eighth or more of the total sample, it shall be obtained by riffling or quartering. If the quantity of the test sample is less than one-eighth of the total sample, it shall be obtained by mixing six small samples of appropriate quantity taken from the total sample.

2.3 Where several sub-samples are taken, they should normally each be taken so as to eliminate as far as possible any segregation that occurred in the placing of the material being sampled. For example, the coarse material of a stock-pile or lorry load will normally be concentrated at the base and edges and apex will be deficient in it. Care should also be taken that the size of the sampling tool is not so small that the coarser material rolls off.

2.4 In some instances, the whole of a selected sample may be taken from one place without sub-sampling. For sampling a representative sample from a quantity of material of about 4 m^3 in size, about 10 sub-samples may be required. It is convenient of the size if the sub-sample can be chosen such that no reduction in the size of this mixed sample is required. Selected samples will often be taken from soil mixed with a stabilizer, and in many such instances speed of treatment will be of greater importance than thoroughness of mixing of the sub-samples. The changes in uniformity brought about by mixing may be undesirable, because the selected sample may become better mixed than the material from which it was taken.

2.5 The size of sample required will depend on the particle size distribution and the purpose to which it is to be put.

NOTE — The sample taken should be sufficient to provide the weights of prepared soil specified for each test in the respective standards.

2.6 Where samples are being taken for the determination of moisture content or for testing without change of moisture content, the use of shallow trays for storing or carrying should be avoided as these

expose the sample unnecessarily to evaporation or rainfall. The sample should be taken in air-tight containers. Likewise, particularly at a site laboratory where much of the work may be carried out in the open, such samples should be kept covered over, if not sealed up, except when material is actually being abstracted.

3. PREPARATION OF SAMPLES FOR TESTING

3.1 Apparatus

3.1.1 Containers or Bags — Containers with air-tight lids or bags capable of being sealed, suitable for samples of various size up to 50 kg in weight.

3.1.2 Non-corrodible Metal Trays — Trays of sizes ranging from 450 cm² to 8 400 cm².

3.1.3 Pulverizing Apparatus — Either mortar and rubber covered pestle or a mechanical device consisting of a mortar and a power driven rubber covered pestle suitable for breaking up the aggregation of soil particles without reducing the size of individual grains.

3.1.4 Balances — capable of weighing up to 10 kg and 25 kg readable and accurate to 1 g and 5 g respectively.

3.1.5 Oven — thermostatically controlled capable of maintaining a temperature of 25 to 50°C and 105 to 110°C.

3.1.6 Mechanical Mixers — Mixers (preferably electrically operated) of suitable capacities or suitable tools for hand mixing, for example, a spatula, a trowel and a shovel.

3.1.7 Graduated Glass or Polythene Cylinders — of 100 ml and 1 000 ml capacity.

3.1.8 Sieves — of sizes 40 mm, 20 mm, 10 mm, 4.75 mm and 2 mm IS Sieves.

3.1.9 Sampler — a suitable riffle sampler or sample splitter for quartering the samples (*see IS: 1607-1960 'Methods for dry sieving'*).

3.2 Quantity of sample for determination of moisture content.

3.2.1 If the moisture content of the natural soil is required, the soil sample shall be obtained and tested in accordance with IS: 2720 (Part 2)-1973.

3.2.2 If the moisture content of stabilized soil mixtures as received is required, a representative or selected portion of the material of the following minimum weights shall be obtained [*see also IS: 4332 (Part 2)-1967*].

<i>Grading of Soils</i>	<i>Minimum Quantity of Sample of Stabilized Soil Mixtures: Weight in g</i>	
	<i>Soil with non-volatile stabilizer</i>	<i>Soil with volatile stabilizer</i>
(1)	(2)	(3)
For stabilized soil mixture 90 percent of which passes a 2-mm IS Sieve	30	200
For stabilized soil mixture 90 percent of which passes a 20-mm IS Sieve	300	500
For stabilized soil mixture 90 percent of which passes a 40-mm IS Sieve	3 000	3 000

3.2.2.1 Where one-eighth or more of the total sample is being used for the moisture content determination, the sample shall be obtained, if practicable by riffling or quartering but otherwise by combining not less than four sub-samples taken from the main sample. Where a greater reduction in size is required, it shall be obtained by combining ten sub-samples taken from the main sample, as repeated riffling or quartering would, in many cases, reduce the moisture content of the sample. The main sample shall be mixed before such sub-samples are taken, care being taken that the moisture content is not appreciably reduced during this process.

3.3 Samples of Natural Soil for Other Tests — If tests are to be conducted on natural soil for purposes of comparison, the sample shall be prepared as specified in IS: 2720 (Part 1)-1983.

3.4 Mixing of Natural Soils with Water and Stabilizing Agents

3.4.1 Blending Different Soils — If it is desired to blend two or more soils, appropriate weights of the different soils to be blended, with due allowance for moisture content, shall be thoroughly mixed to a uniform condition in the mechanical mixer, or by hand using a spatula or trowel. An appropriate quantity of the dried material shall be mixed with water and stabilizer in the manner indicated in 3.4.2 to 3.4.5.

3.4.2 Mechanical Stabilization — The required amount of water shall be incorporated with the soil by mixing thoroughly to a uniform condition in a mechanical mixer or by hand, taking care to minimize loss of moisture. The moist soil shall then be allowed to stand for 24 hours in an air-tight container. This procedure applies either to soil which is inherently mechanically stable or to soils which are blended to achieve this result.

3.4.3 Stabilization with Powders

3.4.3.1 An amount of water as much close to the required moisture content as possible shall be incorporated with the soil by mixing thoroughly to a uniform condition in a mechanical mixer or by hand, taking care to minimize loss of moisture. In the case of heavy clays, the moist soil shall be allowed to stand overnight in an air-tight container.

3.4.3.2 The required quantity of stabilizer shall then be added to the soil and mixed to a uniform condition either by mixing in a mechanical mixer for about one to two minutes or by hand using a spatula, trowel or other suitable tool. The remainder of the water shall then be added, and mixing continued for a further period of about eight minutes.

3.4.3.3 When cement stabilized soil is being mixed for compaction tests or for the making of cylinder or cube specimens, no more soil then can be used within 30 minutes of adding the cement to the soil shall be mixed. If any stabilized soil remains at the end of this period, it shall be discarded.

3.4.4 Emulsified Oil or Emulsified Asphaltic Bitumen Stabilization

3.4.4.1 Sufficient water shall be incorporated with the soil to bring the soil mortar approximately to the plastic limit. The material shall be mixed, either in a mechanical mixer or by hand using a spatula or other suitable tool, for 10 minutes or until it is judged by visual inspection that adequate dispersion of the water has been obtained, taking care to minimize loss of moisture in mixing. The moist soil shall be allowed to stand for 24 hours in an air-tight container.

3.4.4.2 The required quantity of emulsion diluted, if considered necessary, with distilled water, shall then be added to the soil and mixing started. Additional water shall be added, if necessary during the mixing, to ensure a uniform distribution of the emulsified stabilizer. Any other additive shall be incorporated in a manner appropriate to the process of stabilization under consideration (see Note).

NOTE — The time of mixing cannot be specified in advance, guidance may be obtained from the suppliers of the stabilizer or by means of preliminary trials. It should be noted that excessive mixing may be deleterious in certain cases.

3.4.4.3 The mixer shall then be allowed to dry uniformly in air until it has the moisture content required for the subsequent test.

3.4.5 Oil Asphaltic Bitumen and Other Stabilizers — The required amount of water shall be incorporated with the soil by mixing thoroughly to a uniform condition in a mechanical mixer, or by hand using a spatula or other suitable tool, taking care to minimize loss of moisture. The moist soil shall be allowed to stand for 24 hours in an air-tight container. The required quantity of stabilizer and any other additive shall be incorporated in the soil in a manner appropriate to the process under consideration (see Note under 3.4.4.2).

3.5 Initial Preparation of Previously Mixed Stabilized Soil Mixture for Strength Test

3.5.1 For fine-grained cohesive soils, the sample as received may have compacted aggregations that have been produced as a result of mixing. For mixes prepared in a laboratory mixer, it is recommended that all the material shall be passed through a 20-mm IS Sieve by working material greater than 10 mm through the mesh. The material shall then be thoroughly re-mixed by hand before preparing the test specimens. This procedure will result in a more uniformly compacted specimen. For mixes taken from construction site work, the specimens shall be made from all the mixed material and the size of the specimen used shall be determined by the size of the aggregations of stabilized soil produced by the mixing plant.

3.5.2 For materials that are stabilized with cement, it is essential that all operations including compaction are completed within about 30 minutes, after the mixing is completed, to avoid considerable loss in strength which may occur as a result of the hydration of the cement.

Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 2 DETERMINATION OF MOISTURE CONTENT OF STABILIZED SOIL MIXTURES

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization is the alteration of any property of a soil to improve its engineering performance. There are several methods of stabilization and these may be broadly on the basis of treatment given to the soil (for example, dewatering and compaction), process involved (for example, thermal and electrical) and on additives employed (for example, asphalt and cement). The choice of a particular method depends on the characteristics of the problem on hand. For studying in the laboratory, the methods and effects of stabilization, certain standard methods of test for the evaluation of properties of stabilized soils and their analysis are required. This standard on methods of test for stabilized soils is being published in parts and this part lays down the methods for the determination of moisture content of stabilized soil mixtures.

1. SCOPE

1.1 This standard (Part 2) lays down the method for the determination of moisture content of stabilized soil mixtures with non-volatile stabilizers (Section 1) and with volatile stabilizers (Section 2).

SECTION 1 STABILIZED SOIL MIXTURES WITH NON-VOLATILE STABILIZERS (OVEN DRYING METHOD)

2. APPARATUS

2.1 *Drying Oven* — thermostatically controlled and capable of maintaining a temperature of 105 to 110°C.

2.2 For stabilized soil mixtures 90 percent of which pass a 2-mm IS Sieve, the following apparatus are required.

2.2.1 *Glass Weighing Bottle* — fitted with a ground glass stopper or cap, or a suitable air-tight non-corrodible metal container (a convenient size is 5 cm diameter and 2.5 cm high).

2.2.2 *Balance* — readable and accurate to 0.01 g.

2.2.3 *Desiccator* — with any desiccating agent other than sulphuric acid.

2.3 For stabilized soil mixtures 90 percent of which pass a 20-mm IS Sieve, the following apparatus are required.

2.3.1 *Container* — air-tight non-corrodible of about 500 g capacity.

2.3.2 *Balance* — readable and accurate to 0.1 g.

2.3.3 *Scoop* — A convenient size is one about 20 cm long and 10 cm wide.

2.4 For stabilized soil mixtures 90 percent of which pass a 40-mm IS Sieve, the following apparatus are required.

2.4.1 *Container* — air-tight non-corrodible of about 3 kg capacity.

2.4.2 *Balance* — readable and accurate to 1 g.

2.4.3 *Scoop* — A convenient size is one about 20 cm long and 10 cm wide.

3. SOIL SAMPLE

3.1 For determination of the moisture content of a stabilized soil mixture, the size of the sample taken shall be such that it is representative of the mass. This is influenced by the gradation and the maximum size of the particles, and on the accuracy of weighing. The following quantities are recommended for general laboratory use:

<i>Grading of Soil</i>	<i>Minimum Quantity of Sample, Weight in g</i>
For stabilized soil mixture 90 percent which passes a 2-mm IS Sieve	30
For stabilized soil mixture 90 percent of which passes a 20-mm IS Sieve	300
For stabilized soil mixture 90 percent of which passes a 40-mm IS Sieve	3 000

NOTE 1 — For sizes of sieves, see IS: 460 (Part 1)-1978.

NOTE 2 — Drier the soil, higher shall be weight of the soil taken.

4. PROCEDURE

4.1 The container with the lid shall be cleaned, dried and weighed (W_1). The sample of stabilized soil mixture, of which the moisture content is required, shall be crumbled and placed loosely in the container and the container with its lid shall then be kept in the oven, the temperature of which is maintained between 105 and 110°C. The sample shall be dried in the oven to constant weight. The lid shall not be replaced while the sample is in the oven. After drying the container, the contents shall be removed from the oven, the lid replaced and the whole allowed to cool. For stabilized soil mixtures of the type indicated in 2.2, the oven-dried sample shall be cooled in the desiccator. The final constant weight (W_3) of the container with the lid and the oven-dried sample shall be determined. All the weights in this test shall be determined to an accuracy of 0.04 percent of the weight of the sample taken for the test.

NOTE 1 — For complete drying, stabilized soil mixtures of sandy soils take about four hours and those of clays take about 14 to 16 hours. The drying time will also depend on the amount of material in the oven.

NOTE 2 — Certain soils contain gypsum which, on heating, loses its water of crystallization. In such cases, the moisture content determined by this method may not be the moisture content desired. If it is suspected that gypsum is present in the soil used, the sample used for moisture content determination shall be dried at not more than 80°C and possibly for a longer time.

NOTE 3—Soils Stabilized With Cement or Lime — The measured moisture contents of cement or lime stabilized soil samples are low because the water of hydration of the cement or of the lime-clay reaction cannot be removed by normal drying processes. The error in the result depends on a number of factors, the chief of which are the age of the sample and the rate at which water is removed once the sample is placed in the oven. It may be as high as 20 percent of the stabilizer content for samples that are older than 28 days or in cases where because of the large size of sample taken or to overloading of the oven, drying is very slow.

5. CALCULATIONS

5.1 In the case of soil stabilized with a solid stabilizer, the moisture content (w) shall be calculated as a percentage of the dry soil plus stabilizer weight from the formula:

$$w = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \text{ percent}$$

where

W_2 = weight of container with lid with wet soil,
 W_3 = weight of container with lid with dry soil,
and
 W_1 = weight of empty container with lid.

5.2 In the case of soil stabilized with a fluid stabilizer, the moisture content (w) shall be calculated as a percentage of the dry soil weight, from the

formula:

$$w = \frac{W_2 - W_3}{W_3 - W_1} (100 + s) \text{ percent}$$

where

s = the non-aqueous fluid stabilizer content of the stabilized soil, expressed as a percentage by weight of dry soil.

6. REPORTING OF RESULTS

6.1 The results of the test shall be tabulated suitably. A recommended proforma is given in Appendix A.

6.2 To moisture content w or W shall be reported to two significant figures.

SECTION 2 STABILIZED SOIL MIXTURES WITH VOLATILE STABILIZERS (DISTILLATION METHOD)

7. SCOPE

7.1 The method covers the determination of the moisture content of stabilized soil as a percentage of the weight of the dry soil or weight of dry soil plus stabilizer. It is necessary to use this method when the stabilizer contains significant proportion of volatile matter, for example, in the case of certain bituminous materials. The method may also be used with other stabilizing agents.

8. APPARATUS

8.1 For stabilized soil mixtures 90 percent of which passes a 2-mm IS Sieve, the following apparatus and a carrier liquid (8.1.4) are required.

8.1.1 Distillation Apparatus — A distillation apparatus as shown in Fig. 1 comprising:

- a) a round bottom flask of 500-ml capacity, the top of which shall be ground to form a suitable socket;
- b) a water cooled glass condenser with shape and dimensions shown in Fig. 1; and
- c) a 25-ml glass receiver with ground glass joints of the shape, dimensions and tolerances given in Fig. 1 and below:

Volume equivalent to smallest 0.2 ml sub-division

Tolerance on capacity 0.1 ml

The graduated portion of the receiver shall be cylindrical throughout its length. The graduation marks shall be fine, cleanly etched permanent lines of uniform thickness, lying in planes at right angles to the axis of the tube. They shall be confined to the cylindrical portion of the tube and there shall be no evident irregularity in their spacing. The graduation marks of every millilitre shall be carried completely round the tube and other marks of every millilitre shall be carried completely round the tube and other

marks shall be carried approximately two-thirds of the way round the tube. The graduations shall be numbered from bottom to top.

8.1.2 Balance — readable and accurate to 0.1 g.

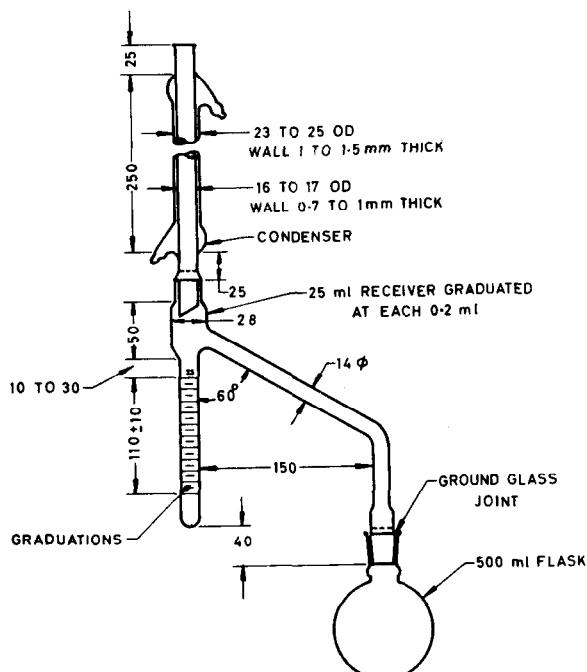
8.1.3 Wire — a length of 0.71 mm metal wire approximately 60 cm long.

8.1.4 Carrier Liquid — either toluole (nitration grade) or petroleum spirit.

8.2 For stabilized soil mixtures 90 percent of which passes 20-mm IS Sieve, the following apparatus and carrier liquid (8.2.5) are required.

8.2.1 Distillation Apparatus — A distillation apparatus as shown in Fig. 2 to 4 comprising:

- a) a metal still approximately 90 mm internal diameter and 150 mm long, having a flange at the top, to which the head can be tightly attached by means of a clamp. The head is also of metal and a graphited asbestos gasket moistened with the water extraction spirit is provided for insertion between the flange and the head (see Fig. 3). The still head shall be joined



NOTE — The design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

FIG. 1 APPARATUS FOR THE DETERMINATION OF MOISTURE CONTENT BY DISTILLATION (FOR STABILIZED SOIL MIXTURE 90 PERCENT OF WHICH PASSES A 2-mm IS SIEVE)

by means of a flanged joint or, alternatively, by means of a cork fitting into an outlet tube of about 2.5 cm diameter (see Fig. 2 and 4);

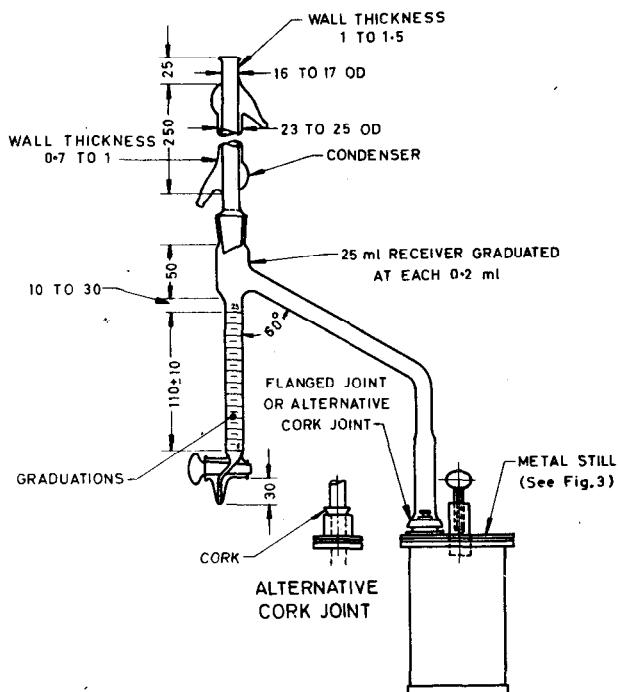
- b) a water cooled glass condenser with shape and dimensions shown in Fig. 2; and
- c) a 25-ml glass receiver with ground glass joints with a stop cock and of the shape, dimensions and tolerances given in Fig. 2. The other requirements given in 8.1.1(c) shall also be satisfied.

8.2.2 Measuring Cylinder — of 100 ml capacity conforming to IS : 878-1975.

8.2.3 Balance — readable and accurate to 1 g.

8.2.4 Wire — a length of 0.71 mm metal wire approximately 60 cm long.

8.2.5 Carrier Liquid — either toluole (nitration grade) or petroleum spirit.



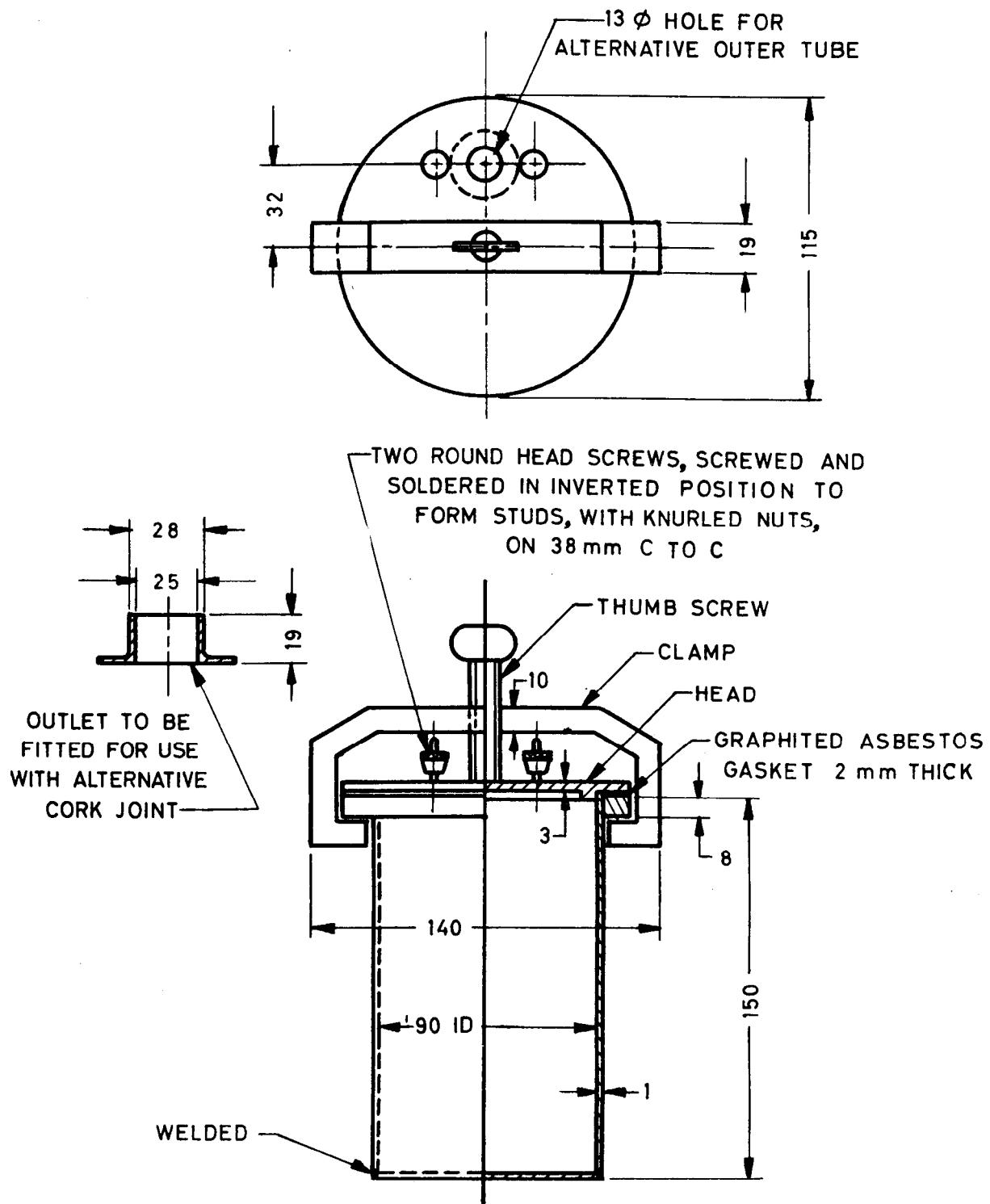
NOTE — This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

All dimensions in millimetres.

FIG. 2 APPARATUS FOR THE DETERMINATION OF MOISTURE CONTENT BY DISTILLATION (FOR STABILIZED SOIL MIXTURE 90 PERCENT OF WHICH PASSES A 20-mm IS SIEVE)

8.3 For stabilized soil mixtures 90 percent of which passes a 40-mm IS Sieve, the following apparatus and a carrier liquid (8.3.5) are required.

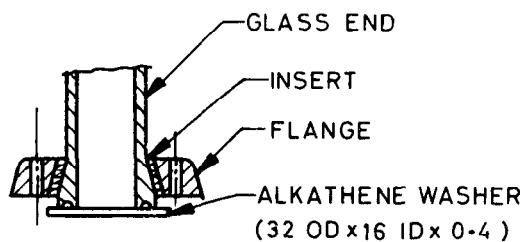
8.3.1 Distillation Apparatus — A distillation apparatus as shown in Fig. 5 and 6



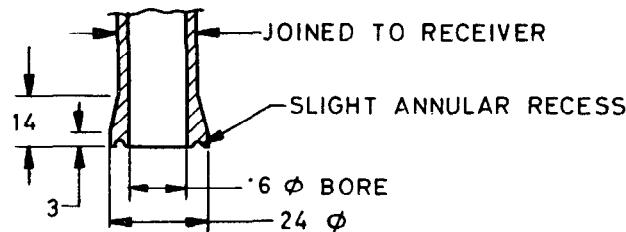
NOTE I — This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

All dimensions in millimetres.

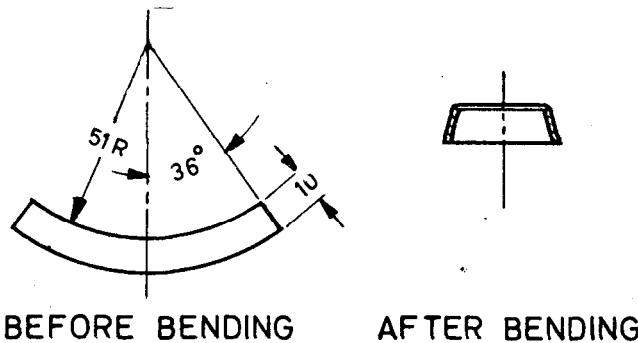
FIG. 3 METAL STILL FOR THE DETERMINATION OF MOISTURE CONTENT BY DISTILLATION (FOR STABILIZED SOIL MIXTURE 90 PERCENT OF WHICH PASSES A 20-mm IS SIEVE)



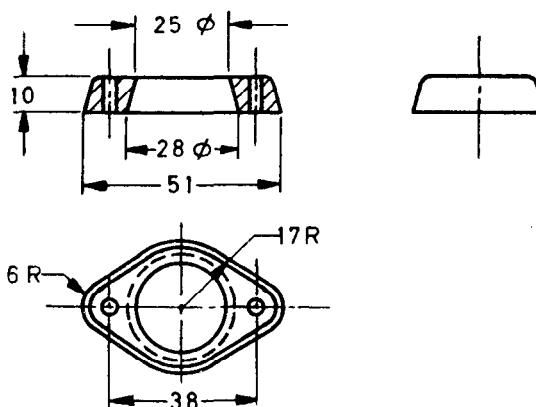
FLANGED JOINT ASSEMBLY



TAPERED GLASS RECEIVER



2 mm GRAPHITED ASBESTOS INSERT

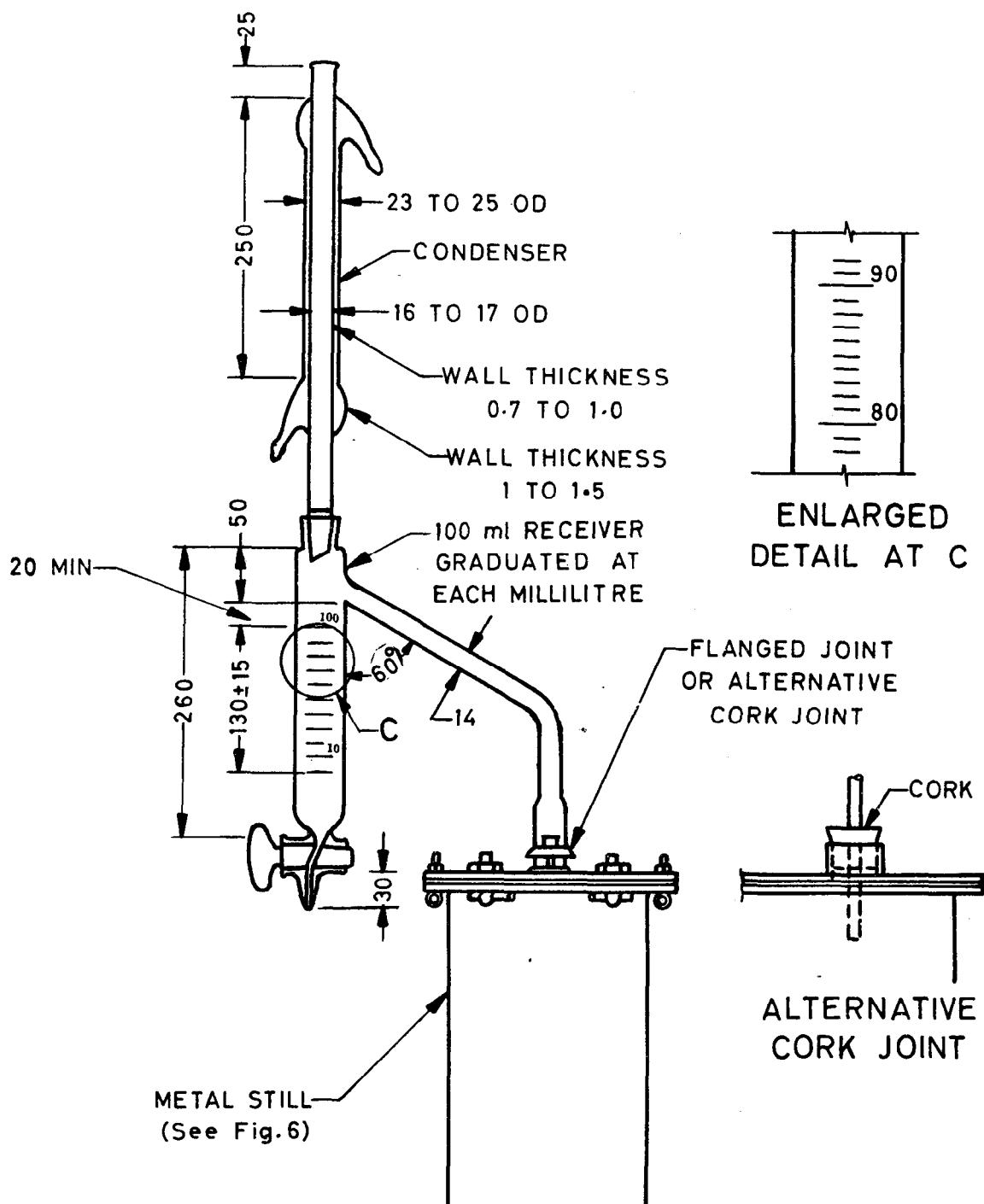


PLASTIC OR METAL FLANGE

NOTE — This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

All dimensions in millimetres.

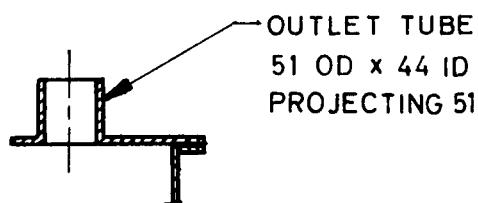
FIG. 4 ASSEMBLY AND DETAILS OF FLANGED JOINT BETWEEN RECEIVER AND METAL STILL



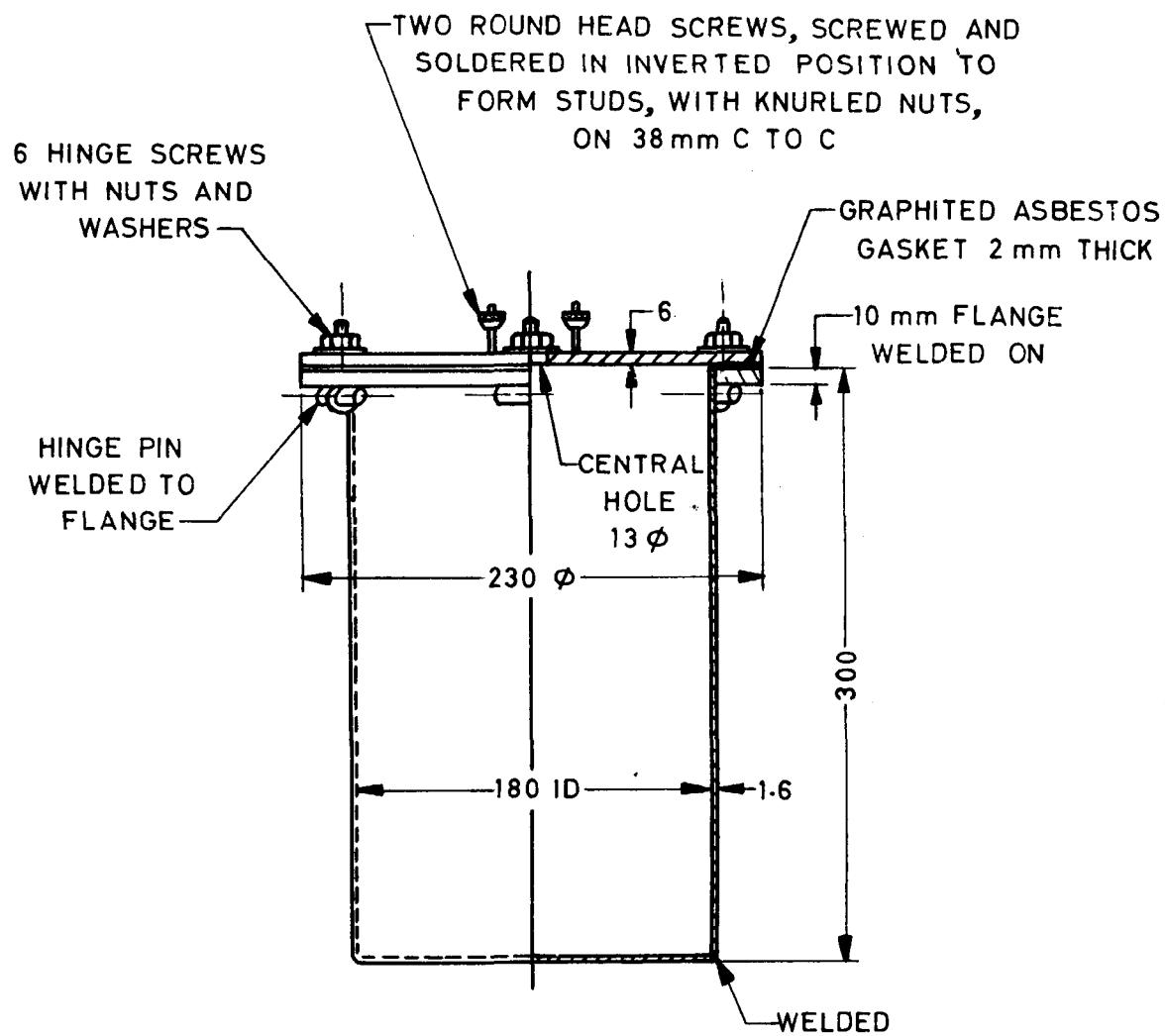
NOTE — This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

All dimensions in millimetres.

FIG. 5 APPARATUS FOR THE DETERMINATION OF MOISTURE CONTENT BY DISTILLATION (FOR STABILIZED SOIL MIXTURE 90 PERCENT OF WHICH PASSES A 40-mm IS SIEVE)



OUTLET TUBE TO BE FITTED FOR
USE WITH ALTERNATIVE CORK JOINT



NOTE -- This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled.

All dimensions in millimetres.

FIG. 6 METAL STILL FOR THE DETERMINATION OF MOISTURE CONTENT BY DISTILLATION (FOR STABILIZED SOIL MIXTURE 90 PERCENT OF WHICH PASSES A 40-mm IS SIEVE)

comprising:

- a) a metal still approximately 18 cm internal diameter and 30 cm long, having a flanged face at the top to which the head can be tightly attached by means of nuts. The head is also of metal and graphited asbestos gasket moistened with the water extraction spirit is provided for insertion between the flange and the head (see Fig. 6). The still head and receiver shall be joined by means of a flanged joint or, alternatively, by means of a cork fitting into an outlet tube of about 4.5 cm diameter (see Fig. 4 and 5);
- b) a water cooled glass condenser with shape and dimensions shown in Fig. 5; and
- c) a 100-ml glass receiver with ground glass joints of the shape, dimensions and tolerances given in Fig. 5 and below:

Volume equivalent to smallest sub-division	1 ml
Tolerance on capacity	1.0 ml

The graduation marks shall be confined to the front of the tube and shall be varied in length as shown in Fig. 5

8.3.2 Measuring Cylinder — of 500-ml capacity conforming to IS: 878-1975.

8.3.3 Balance — readable and accurate to 5 g.

8.3.4 Wire — a length of 0.71 mm metal wire approximately 60 cm long.

8.3.5 Carrier Liquid — either toluole (nitration grade) or petroleum spirit.

9. SOIL SAMPLE

9.1 For determination of the moisture content of a stabilized soil mixture, the size of the sample taken shall be such that it is representative of the mass. This is influenced by the gradation and the maximum size of the particles, on the accuracy of weighing and upon their moisture content. The following quantities are recommended for general use:

<i>Grading of Soil</i>	<i>Minimum Quantity of Sample, Weight in g</i>
For stabilized soil mixture 90 percent of which passes a 2-mm IS Sieve	200
For stabilized soil mixture 90 percent of which passes a 20-mm IS Sieve	500
For stabilized soil mixture 90 percent of which passes a 40-mm IS Sieve	3 000

9.2 The quantity of stabilized soil mixture should preferably be such that it yields approximately 15 ml of water in the case of the first two grades of stabilized soil mixture and approximately 60 ml in the case of the third grade (see 9.1).

10. PROCEDURE

10.1 The sample of stabilized soil obtained in 9 shall be weighed (weight W_1) to the balance accuracies specified for each grading of stabilized soil mixture (see 8.1.2, 8.2.3 and 8.3.3). With soils stabilized with a fluid stabilizer, unless the fluid stabilizer contents is known, it shall be determined by a suitable method.

10.2 Carrier liquid shall be placed in the flask or still with the sample, in the proportion of 1 ml liquid to 1 g of the sample. The apparatus shall then be assembled by connecting the flask or still and the condenser to the receiver, care being taken that the lower end of the condenser is remote from the delivery tube of the receiver.

10.2.1 If there is any reason to suppose that the sample will yield less than 5 ml of water after distillation, 5 ml of distilled water shall be measured out with a pipette into the graduated receiver before the commencement of the test.

10.3 Cold water shall be circulated through the water jacket of the condenser, and heat shall be applied to flask or still and adjusted so as to avoid any intense local heating, while providing a steady reflux action so that the condensate falls from the end of the condenser at a rate of two to five drops per second. If more than 25 ml or 100 ml collects in the receivers as shown in Fig. 2 and 5 respectively, it shall be drained off into the measuring cylinder, leaving about 2 ml and 10 ml respectively in the receiver on each occasion.

10.4 Distillation shall be maintained until no condensed water accumulates in any part of the apparatus except at the bottom of the receiver. Any ring of condensed water at the top of the receiver shall be removed by agitation with the fine wire. When the volume of water in the receiver is constant, the source of heat shall be removed, and the receiver and contents allowed to cool to room temperature. Any droplets of water adhering to the sides of the receiver shall be dislodged by means of the fine wire.

10.5 The volume of condensed water, in millilitres, measured in the graduated receiver, and in any measuring cylinder used, at room temperature after subtracting the volume of water, if any, placed in the receiver before distillation was commenced, shall be noted (V).

11. CALCULATIONS

11.1 In the case of soil stabilized with a solid stabilizer, the moisture content w shall be calculated as a percentage of the dry soil plus stabilizer weight from the formula:

$$w = \frac{100 V}{W_1 - V}$$

where

V = volume of condensed water in ml, and
 W_1 = original weight of sample in g.

11.2 In the case of soil stabilized with a fluid stabilizer, the moisture content w shall be calculated as a percentage of the dry soil weight from the formula:

$$w = \frac{(100 + s)V}{W_1 - V}$$

where

s = the non-aqueous fluid stabilizer content of the stabilized soil expressed as a percentage of the dry soil weight.

12. REPORTING OF RESULTS

12.1 The results of the test shall be tabulated suitably. A recommended proforma is given in Appendix B.

12.2 The moisture content of the stabilized soil shall be reported to the nearest whole number.

A P P E N D I X A

(Clause 6.1)

DETERMINATION OF MOISTURE CONTENT OF STABILIZED SOIL (OVEN-DRYING METHOD)

Operator Job

Date Stabilizer

- | | |
|---|--|
| 1. Determination No. | |
| 2. Container No. | |
| 3. Weight of container with lid with wet stabilized soil (W_2), g | |
| 4. Weight of container with lid with dry stabilized soil (W_3), g | |
| 5. Weight of container (W_1), g | |
| 6. Weight of moisture ($W_2 - W_3$), g | |
| 7. Weight of dry stabilized soil ($W_3 - W_1$), g | |
| 8. Moisture content, w percent | |
| 9. Fluid stabilizer content, if any | |
| 10. Moisture content, w percent | |
| 11. Remarks | |

A P P E N D I X B
(Clause 12.1)

**DETERMINATION OF MOISTURE CONTENT OF STABILIZED SOIL
(DISTILLATION METHOD)**

1. Determination No.
2. Still No.
3. Weight of wet stabilized soil, W_1 g
4. Volume of water added to the receiver, if any, ml
5. Volume of water distilled, V ml
6. Moisture content, w percent
7. Fluid stabilizer content, if any
8. Moisture content, w percent
9. Remarks

Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 3 TEST FOR DETERMINATION OF MOISTURE CONTENT-DRY DENSITY RELATION FOR STABILIZED SOIL MIXTURES

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization, in the broadest sense, is the alteration of any inherent property of a soil to improve its engineering performance. The classification of the methods of stabilization is based on the treatment given to the soil (for example, dewatering, compaction, etc) process involved (for example, thermal, electrical, etc), and on additives employed (for examples, asphalt, cement, etc). The choice of a particular method depends on the characteristics of the problems on hand. For studying the effectiveness of a stabilization technique under investigation, certain standard methods of test are required and these are being published in parts. This part [IS: 4332 (Part 3)] lays down the method of test for determination of moisture content-dry density relation for stabilized soil mixtures.

1. SCOPE

1.1 This standard (Part 3) lays down the method for the determination of the relation between the moisture content and the dry density of a stabilized soil mixture. In this test, a 2.6 kg rammer falling through a height of 310 mm (light compaction) or a 4.89 rammer falling through a height of 450 mm (heavy compaction) is used.

2. TERMINOLOGY

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

3. APPARATUS

3.1 Cylindrical Metal Mould — shall conform to IS : 10074-1982.

3.2 Metal Rammer — shall conform to IS : 9198-1979.

3.3 Balance — one of capacity 10 kg, sensitive to 1 g and another of capacity 200 g, sensitive to 0.01 g.

3.4 Palette Knife — A convenient size is one having a blade approximately 10 cm long and 2 cm wide.

3.5 Steel Straight Edge — about 30 cm in length and having one bevelled edge.

3.6 Sieves — 50-mm, 20-mm and 4.75-mm IS Sieves conforming to the requirements of IS:460 (Part 1)-1978

3.7 Large Metal Tray — A convenient size is one about 60 cm × 45 cm and with sides 7 cm deep.

3.8 Mixing Tools — Miscellaneous tools, such as mixing pan, spoon trowel, spatula, etc, or a suitable mechanical device.

3.9 Apparatus for the determination of moisture content shall be in accordance with IS : 4332 (Part 2)-1967.

3.10 Sample Extruder (Optional) — It consists of a jack, lever frame or other device adopted for the purpose of extruding compacted specimens from the mould.

4. MARKING

4.1 The cylindrical metal moulds and the metal rammers shall have firmly attached to them a marking plate bearing the following information:

- Manufacturer's name or trade-mark,
- Year of manufacture, and
- Essential dimensions.

4.1.1 The cylindrical metal moulds and the metal rammers may also be marked with the ISI Certification Mark.

NOTE 1 — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act, and the Rules and Regulations made thereunder. Presence of this mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard, under a well-defined system of inspection, testing and quality control during production. This system, which is devised and supervised by ISI and operated by the producer, has the further safeguard that the products as actually marketed are continuously checked by ISI for conformity to the standard. Details of conditions, under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standard Institution.

5. PREPARATION OF SOIL SAMPLE

5.1 Preparation of Sample Passing 20-mm IS Sieve — A representative sample weighing about 20 kg or more of the thoroughly mixed material obtained in accordance with IS : 4332 (Part 1)-1967.

5.1.1 The soil sample shall be made to pass through 20-mm and 4.75-mm IS Sieves, separating the fractions retained and passing these sieves. Care shall be exercised so as not to break the aggregates while pulverising. The percentage of each fraction shall be determined. The fraction retained on 20-mm IS Sieve shall not be used in the test. The percentage of soil coarser than 4.75-mm IS Sieve and the percentage of soil coarser than 20-mm IS Sieve shall be determined.

5.1.2 The ratio of fraction passing 20-mm IS Sieve and retained on 4.75-mm IS Sieve to the soil passing 4.75-mm IS Sieve shall be determined. The material retained on and passing 4.75-mm IS Sieve shall be mixed thoroughly in the determined proportion to obtain about 16 kg of soil sample.

NOTE — In case of material passing 20-mm IS Sieve and retained on 4.75-mm IS Sieve is more than 20 percent, the ratio of such material to the material passing 4.75-mm IS Sieve shall be maintained for each determination in a test. If the coarse material retained on 4.75-mm IS Sieve is less than 20 percent, the sample may be used as such.

5.2 Preparation of Sample Passing 4.75-mm IS Sieve — A representative sample weighing approximately 16 kg of the thoroughly mixed material obtained in accordance with IS: 4332 (Part 1)-1967, shall be taken.

5.3 Mixing of Water and Stabilizer — Out of the soil sample obtained as described in 5.1 and 5.2, eight 2-kg samples of stabilized soil shall be prepared in the manner described in IS: 4332 Part 1)-1967.

6. PROCEDURE

6.1 The empty mould shall be cleaned, dried, greased lightly on the inside, if necessary, and weighed to the nearest one gram. The mould with the collar shall be fitted on to the base plate and placed on a solid base.

6.2 Water shall be mixed with each of the samples (one sample for each moisture content) obtained as described in 5 before compaction so as to give moisture content as follows:

- Sandy and Gravelly Soils* — 7 percent and above in steps of about 1½ percent.
- Clayey Soils* — 10 percent and above in steps of about 3 percent.

6.3 Each of the samples of stabilized soil-water mixture shall be compacted in the desired mould with the desired compactive efforts using the appropriate rammer as follows:

Type of Compaction	Size of Mould	Number of Layers	Number of Blows per Layer
Light	1 000 ml	3	25
	2 250 ml	3	56
Heavy	1 000 ml	5	25
	2 250 ml	5	56

6.3.1 The compaction on each sample shall be completed within 20 minutes of completion of mixing. The blows shall be uniformly distributed over the surface of each layer. Care shall be taken to keep the sleeve free from the stabilized soil mixture to ensure a free fall of the rammer and any lump of soil sticking to the rammer at any stage shall be removed. Each layer of the compacted stabilized soil mixture shall be scored with a spatula before putting the stabilized soil mixture for the succeeding layer. The amount of the stabilized soil mixture used shall be just sufficient to fill the mould leaving about 5 mm to struck off (see Note) when the collar is removed. The collar shall then be removed and the compacted stabilized soil mixture shall be carefully levelled off to the top of the mould by means of the straight edge. The mould with the compacted stabilized soil mixture shall then be weighed to the nearest one gram.

NOTE — It is necessary to control the total volume of stabilized soil mixture compacted, since it has been found that if the amount of soil struck off, after removing the extension, is too great, the test results will be inaccurate.

6.4 The compacted specimen shall be ejected out of the mould, cut in the middle and a representative soil specimen shall be taken in an air-tight container from the cut surface. The moisture content of this representative specimen shall be determined in accordance with IS: 4332 (Part 2)-1967.

7. CALCULATION

7.1 Soils Stabilized with a Solid Stabilizer

7.1.1 Wet Density — The wet density of the compacted stabilized soil mixture shall be calculated as follows:

$$\gamma_m = \frac{W - W_m}{1000} \text{ g/cm}^3$$

where

γ_m = wet density of compacted stabilized soil in g/cm^3 ,

W = weight of mould with moist compacted stabilized soil in g, and

W_m = weight of empty mould in g.

7.1.2 Dry Density — Dry density of the compacted stabilized soil mixture shall be calculated as follows:

$$\gamma'_d = \frac{m}{\left(1 + \frac{w'}{100}\right)} \text{ g/cm}^3$$

where

γ'_d = dry density of compacted stabilized soil in g/cm^3 ,

γ_m = wet density of compacted stabilized soil in g/cm^3 , and

w' = moisture content of the soil plus solid stabilizer (percent).

7.1.3 Air Voids Lines — For determining the air voids lines, the following formula may be used:

$$\gamma'_d = \frac{\gamma_w \left(1 - \frac{V_a}{100}\right)}{\frac{1}{G} + \frac{w'}{100}}$$

where

γ'_d = dry density of soil plus solid stabilizer in g/cm³;
 γ_w = density of water in g/cm³ (= 1 g/cm³);
 V_a = volume of air voids in the compacted stabilized soil mixture expressed as a percentage of the total volume of mixture;
 w' = moisture content of the soil plus solid stabilizer, percent; and
 G = combined specific gravity of the soil plus stabilizer (see 7.1.3.1).

7.1.3.1 The combined specific gravity of the soil plus stabilizer (G) may be calculated from the following formula:

$$G = \frac{1 + \frac{x}{100}}{\frac{1}{G_s} + \frac{x}{100 G_c}}$$

where

x = stabilizer content, expressed as a percentage of the weight of dry soil;
 G_s = specific gravity of the soil particles, determined in accordance with the method given in IS: 2720 (Part 3/Sec 2)-1980; and
 G_c = specific gravity of the solid stabilizer.

7.2 Soil Stabilized with a Fluid Stabilizer

7.2.1 Wet Density — The wet density of the compacted stabilized soil mixture shall be calculated as in 7.1.1.

7.2.2 Dry Density — The dry density of the compacted stabilized soil mixture shall be calculated as follows:

$$\gamma_d = \frac{\gamma_m}{1 + \left(\frac{w+s}{100}\right)}$$

where

γ_d = dry density of compacted stabilized soil in g/cm³,
 γ_m = wet density of compacted stabilized soil in g/cm³,
 w = moisture content of the soil (percent), and
 s = the non-aqueous fluid stabilizer content of the soil (percent).

7.2.3 Air Voids Line — For determining the air voids lines, the following formula may be used:

$$\gamma_d = \frac{\gamma_w \left(1 - \frac{V_a}{100}\right)}{\frac{1}{G_s} + \frac{w+s}{100}}$$

where

γ_d = dry density of soil in g/cm³,
 γ_w = density of water in g/cm³ (= 1 g/cm³),
 V_a = volume of air voids in the compacted stabilized soil mixture expressed as a percentage of the total volume of the mixture,
 w = moisture content of the soil (percent),
 s = the non-aqueous fluid stabilizer content of the soil (percent), and
 G_s = specific gravity of the soil particles, determined in accordance with IS : 2720 (Part 3/Sec 2)-1980.

8. REPORT

8.1 Record of Results — The test results shall be recorded suitably. A recommended proforma for recording the results is given in Appendix A.

8.2 Moisture (Dry Density Curve) — The dry densities of the compacted soil stabilizer mixture obtained in a series of determinations shall be plotted against the corresponding moisture contents. A smooth curve shall be drawn through the resulting points. The dry density corresponding to the maximum point of the curve and the corresponding moisture content shall also be reported.

8.3 The following shall also be reported:

- The amount of soil retained on the 20-mm IS Sieve, passing the 20-mm IS Sieve and passing 4.75-mm IS Sieve;
- The method of obtaining the results, namely, light compaction or heavy compaction; and
- The amount and type of stabilizer used.

A P P E N D I X A
(Clause 8.1)
COMPACTION TEST DATA SHEET

Name of the project	Location
Sample reference	Height of fall of the rammer
Type of Test: Light/ Heavy compaction	
Volume of the mould	
Weight of the rammer	
Percentage of material	<div style="display: flex; align-items: center;"> { <ul style="list-style-type: none"> a) Retained on 20-mm IS Sieve b) Passing 20-mm IS Sieve c) Passing 4.75-mm IS Sieve </div>
Ratio of (b) to (c)	
Stabilizer used	
Quantity of stabilizer used	
Specific gravity of the soil	
Specific gravity of the stabilizer	
Remarks :	

Determination No.	1	2	3	4	5	6	7
Weight of mould + compacted soil-stabilizer mixture in g							
Weight of mould in g							
Weight of compacted soil-stabilizer mixture in g							
Wet density in g/cm ³							
Average moisture content, percent							
Fluid stabilizer content, percent							
Dry density in g/cm ³							

Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 4 WETTING AND DRYING, AND FREEZING AND THAWING TESTS FOR COMPACTED SOIL-CEMENT MIXTURES

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization is the permanent alteration of any property of the soil to improve its engineering performance. One of the methods of stabilization is to add cement to soil and then compact the mixture at the required moisture content. For evaluating the improvement obtained by stabilization standard methods of tests are required and these are being published in parts. This part [IS: 4332 (Part 4)] lays down the method for determining the effect of wetting and drying, and freezing and thawing on compacted specimens of cement stabilized soil.

SECTION I WETTING AND DRYING TEST

1. SCOPE

1.1 Section 1 of this standard (Part 4) covers the procedure for determining the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by repeated wetting and drying of hardened soil-cement specimens.

2. APPARATUS

2.1 Cylindrical Metal Mould — shall conform to IS: 10074-1982

2.2 Metal Rammer — shall conform to IS: 9198-1979.

2.3 Sample Extruder — a jack, lever frame or other device adopted for the purpose of extruding compacted specimens from the mould.

2.4 Balances — one of capacity 10 kg, sensitive to 1 g, and another of capacity 1 kg, sensitive to 0.1 g.

2.5 Oven — thermostatically controlled with interior of non-corroding material to maintain temperature between 105 and 110°C.

2.6 Container — any suitable non-corrodible airtight container to determine the moisture content.

2.7 Moist Chamber — a moist chamber of suitable covered container capable of maintaining a temperature of 25 to 30°C and relative humidity of 100 percent for 7-day storage of compacted specimens.

2.8 Water-Bath — a suitable tank for submerging compacted specimens in water at room temperature of 25 to 30°C.

2.9 Wire-Scratch Brush — made of 50 × 1.6 mm flat 0.45 mm thick wire bristles assembled in 50 groups of 10 bristles each and mounted to form 5 longitudinal rows and 10 transverse rows of bristles on a 190 × 65 mm hardwood block.

2.10 Steel Straightedge — about 30 cm in length and having one bevelled edge.

2.11 Sieves — 20-mm and 4.75-mm IS Sieves conforming to the requirements of IS : 460 (Part 1)-1978.

2.12 Mixing Tools — Miscellaneous tools, such as mixing pan and trowel or a suitable mechanical device for thoroughly mixing the soil with cement and water (for mechanical device, see IS: 1727-1967).

2.13 Scarifier — a suitable tool to remove the smooth compaction plane at the top of the first and second layers of the specimen.

2.14 Measuring Device — suitable for accurately measuring the heights and diameters of test specimens to the nearest 0.2 mm.

2.15 Graduated Glass Cylinder — of 250-ml capacity for measuring water.

3. PREPARATION OF SOIL SAMPLE AND SPECIMENS FOR TEST

3.1 Preparation of Material for Moulding Specimens

3.1.1 The soil sample shall be prepared in accordance with the procedure described in 5.1 and 5.2 of IS: 4332 (Part 3)-1967.

3.1.2 A sufficient quantity of the soil sample prepared in accordance with 3.1.1 should be selected to provide four (see Note) compacted specimens and required moisture samples.

NOTE — Usually two specimens (identified as No. 3 and 4) are required for routine testing. The other specimens (identified as No. 1 and 2) are made for research work and for testing unusual soils.

3.1.3 The soil, potable water and required amount of cement conforming to IS 269-1976 'Specification for ordinary and low heat portland cement (*third revision*)' or IS: 455-1976 'Specification for portland slag cement (*third revision*)' shall be mixed as specified in IS: 4332 (Part 1)-1967. The mixture should be broken up without reducing the natural size of individual particles.

3.2 Preparation of Specimens

3.2.1 The specimens shall be formed by immediately compacting the soil-cement mixture in the mould (with the collar attached) and later trimming the specimens in accordance with IS: 4332 (Part 3)-1967. In addition, the tops of the first and second layers shall be scarified to remove smooth compaction planes before placing and compacting the succeeding layers. This scarification shall form grooves at right angles to each other approximately 3 mm in width and 3 mm in depth and approximately 6 mm apart.

3.2.2 During compaction, a representative sample of the soil-cement mixture weighing not less than 100 g shall be taken from the batch and its moisture content determined in accordance with IS: 4332 (Part 2)-1967.

3.2.3 The compacted specimen shall be weighed with the mould. The specimens shall then be removed from the mould. The oven-dry density in g/cm^3 shall be calculated. The specimens shall be identified suitably as No. 1 and 2. These specimens may be used to obtain data on moisture and volume changes during the test.

3.2.4 Two more specimens shall be similarly formed, and their moisture content and dry density determined. These specimens shall be identified as No. 3 and 4 and used to obtain data on soil-cement losses during the test.

3.2.5 The average diameter and height of specimens No. 1 and 2 shall be measured and their volume shall be determined.

3.2.6 All the four specimens shall be placed on suitable carriers in the moist chamber and protected from free water for a period of seven days.

3.2.7 Specimens No. 1 and 2 should be weighed and measured at the end of the seven-day period to provide data for calculating their moisture content and volume (*see Note*).

NOTE — It is important that all height and diameter measurements be accurate to within 0.2 mm and be taken at the same points on the specimen at all times.

4. PROCEDURE FOR THE WETTING AND DRYING TEST

4.1 At the end of the storage in the moist room, the specimens shall be submerged in potable water at room temperature for a period of 5 h and removed.

Specimens No. 1 and 2 shall be weighed and their dimensions measured.

4.2 All four specimens shall then be placed in an oven at 70°C for 42 h and removed. Specimens No. 1 and 2 shall be weighed and their dimensions measured again.

4.3 Specimens No. 3 and 4 shall be given two firm strokes on all areas with the wire-scratch brush. The brush shall be held with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required to cover all areas of the specimen. These strokes shall be applied to full height and width of the specimen with a firm stroke corresponding to approximately 1.4 kgf. For measurement of pressure (*see Note*), 18 to 20 vertical brush strokes may be required to cover the sides of the specimen twice and four strokes may be required at each end.

NOTE — A specimen should be clamped in a vertical position on the edge of a platform scale. Vertical brushing strokes should be applied to the specimen and the force necessary to register approximately 1.4 kg noted.

4.4 The procedures described in **4.1** to **4.3** constitute one cycle (48 h) of wetting and drying. The specimens shall again be submerged in water and the procedure continued for 12 cycles.

NOTE — Weight determinations of specimens No. 3 and 4 before and after brushing may be made at the end of each cycle when conducting research and making special investigations.

4.5 Testing of No. 1 and 2 specimens may be discontinued prior to 12 cycles, should the measurements become inaccurate due to soil-cement loss of the specimen.

NOTE — If it is not possible to run the cycles continuously because of Sundays, holidays or for any other reason, the specimens should be held in the oven during the layover period, if possible.

4.6 After 12 cycles of test, the specimens shall be dried to constant weight at 110°C and weighed to determine the oven-dry weight of the specimens.

4.7 The data collected will permit calculations of volume and moisture changes of specimens No. 1 and 2 and the soil-cement losses of specimens No. 3 and 4 after the prescribed 12 cycles of test.

5. CALCULATIONS

5.1 The volume and moisture changes and the soil-cement losses of the specimens should be calculated as in **5.1.1** and **5.1.4**.

5.1.1 For specimens No. 1 and 2, the difference between the volumes of specimens at the time of moulding and subsequent volumes as a percentage of the original volume should be calculated.

5.1.2 The moisture content of specimens No. 1 and 2 at the time of moulding and subsequent

moisture contents should be calculated as a percentage of the original oven-dry weight of the specimen.

5.1.3 The oven-dry weight of specimens No. 3 and 4 as obtained in **4.6** shall be corrected for water that has reacted with the cement and soil during the test and is retained in the specimen at 110°C, as follows:

$$\text{Corrected oven-dry weight} = \frac{W_d}{(w + 100)} \times 100$$

where

W_d = oven-dry weight after drying at 110°C, and
 w = percentage of water retained in specimen.

The percentage of water retained in the specimens No. 3 and 4 after drying at 110°C for use in the above formula may be assumed to be equal to the average percentage of water retained in specimens No. 1 and 2.

5.1.4 The soil-cement loss of specimens No. 3 and 4 shall be calculated as a percentage of the original oven-dry weight of the specimen as follows:

$$\text{Soil cement loss, percent} = \frac{A}{B} \times 100$$

where

A = original calculated oven-dry weight minus final corrected oven-dry weight, and
 B = original calculated oven-dry weight.

6. REPORT

6.1 The report should include the following:

- The designed optimum moisture and maximum density of the moulded specimens.
- The moisture content and density obtained in moulded specimens (see Note).

NOTE -- Good laboratory practice permits the following tolerances between design values and those obtained in the moulded specimen:

Moisture content	± 1 percentage point
Density	± 0.05 g/cm ³

- The designed cement content, in percent, of the moulded specimens.
- The cement content, in percent, obtained in moulded specimens.
- The maximum volume change, in percent, and maximum moisture content during test of specimens No. 1 and 2.
- The soil-cement loss, in percent, of specimens No. 3 and 4.

SECTION 2 FREEZING AND THAWING TEST

7. SCOPE

7.1 Section 2 of this standard (Part 4) covers the procedure for determining the soil-cement losses,

moisture changes and volume changes (swell and shrinkage) produced by repeated freezing and thawing of hardened soil-cement specimens.

8. APPARATUS

8.1 The apparatus required is the same as described in **2** except the water-bath described in **2.8**. In addition, the equipment described in **8.2** and **8.3** are also required.

8.3 Freezing Cabinet — capable of maintaining temperature of — 23°C or lower.

8.3 Absorptive Pads — 5 mm thick felt pads, blotters or similar absorptive material for placing between specimens and specimen carriers.

9. PREPARATION OF SOIL SAMPLE AND SPECIMENS FOR TEST

9.1 The soil sample and specimens shall be prepared in accordance with the procedure laid down in **3**.

10. PROCEDURE FOR THE FREEZING AND THAWING TEST

10.1 At the end of the storage in the moist room, water saturated felts about 5 mm thick, blotters or similar absorptive material shall be placed between the specimens and the carriers. The assembly shall be placed in a freezing cabinet having a constant temperature not warmer than — 23°C for 24 h and removed. The No. 1 and 2 specimens shall be weighed and measured.

10.2 The assembly should be placed in the moist chamber or suitably covered container having a temperature of 25 to 30°C and a relative humidity of 100 percent for 23 h and removed. Free potable water shall be made available to the absorbent pads under the specimens to permit the specimens to absorb water capillary action during the thawing period. The No. 1 and 2 specimens shall be measured and weighed.

10.3 Specimens No. 3 and 4 shall be given two firm strokes on all areas with the wire-scratch brush. The brush shall be held with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required to cover all areas of the specimen. The strokes shall be applied to the full height and width of the specimen with a firm stroke corresponding to approximately 1.4 kgf (see Note under **4.3**). Eighteen to twenty vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end.

10.4 After being brushed, the specimens shall be turned over end for end before they are placed on the water saturated pads.

10.5 The procedures described in **10.1** to **10.4** constitute one cycle (48 h) of freezing and thawing. The specimens shall be placed in the freezing cabinet and the procedure continued for 12 cycle.

NOTE — Weight determinations of specimens No. 3 and 4 before and after brushing are usually made at the end of each cycle when conducting research and making special investigations. Some specimens made of silty and clayey soils tend to scale on sides and ends particularly after about the sixth cycle of test. This scale shall be removed with a sharp pointed instrument since the regular brushing may not be effective.

10.6 The No. 1 and 2 specimens may be discontinued prior to 12 cycles, should the measurements become inaccurate due to soil-cement loss of the specimen.

10.7 After 12 cycles of test, the specimens shall be

dried to constant weight at 110°C and weighed to determine the oven-dry weight of the specimens.

10.8 The data collected will permit calculations of volume and moisture changes of specimens No. 1 and 2 and the soil-cement losses of specimens No. 3 and 4 after the prescribed 12 cycles of test.

11. CALCULATIONS

11.1 The volume and moisture changes and the soil-cement losses of the specimens should be calculated as given in **5**.

12. REPORT

12.1 The report should include the details given in **6**.

Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 5 DETERMINATION OF UNCONFINED COMPRESSIVE STRENGTH OF STABILIZED SOILS

0. FOREWORD

0.1 Soil stabilization is the alteration of any property of a soil to improve its engineering performance. There are several methods of stabilization and these may be broadly on the basis of treatment given to the soil (for example, dewatering and compaction), process involved (for example, thermal and electrical) and on additives employed (for example, asphalt and cement). The choice of a particular method depends on the characteristics of the problem on hand. For studying in the laboratory, the methods and effects of stabilization, certain standard methods of test for the evaluation of properties of stabilized soils and their analysis are required. The required standards on methods of test for stabilized soils are being published in parts. This part (Part 5) lays down the method for the determination of unconfined compressive strength stabilized soil.

SECTION A TEST FOR FINE AND MEDIUM GRAINED STABILIZED SOIL

1. SCOPE

1.1 This standard (Part 5) covers the determination of the unconfined compressive strength of stabilized soil specimens made with fine and medium grained soils. It covers the preparation and testing of cylindrical specimens prepared to a pre-determined dry density or with a constant compactive effort. The method in which the specimens are prepared to a constant dry density is preferred and should be used whenever possible.

2. GROUPING OF SOIL

2.1 For the purpose of this standard, soils shall be grouped as follows:

- a) *Fine-Grained Soils* — Not less than about 90 percent of the soil passing a 2.36-mm IS Sieve.
- b) *Medium-Grained Soils* — Not less than about 90 percent of the soil passing a 20-mm IS Sieve.
- c) *Coarse-Grained Soils* — Not less than about 90 percent of the soil passing a 40-mm IS Sieve.

3. APPARATUS

3.1 For specimens compacted to a pre-determined dry density.

3.1.1 *4.75-mm and 20-mm IS Test Sieves* — For fine and medium-grained soils respectively.

3.1.2 *Balance* — readable and accurate to 1 g.

3.1.3 *Tapered Moulds* — each having two steel plugs of dimensions shown in Fig. 1 and 3 for the preparation of specimens of the following dimensions (see Note 1):

a) For fine-grained soils 100 mm high \times 50 mm mean diameter (see Fig. 1).

b) For medium-grained soils 200 mm high \times 100 mm mean diameter (see Fig. 3).

3.1.4 Ejecting plungers and displacing collars for use with the above moulds of dimensions shown in Fig. 2 and 4.

3.1.5 *Compression Testing Machine of the Lever, Self-Indicating or Proving Ring Type* — Capable of exerting a load up to 5 tonnes for fine-grained soil specimens and 50 tonnes for medium-grained soil specimens, and of providing a uniform rate of deformation in the test specimen of approximately 1.25 mm/min.

In addition to the equipment specified in 3.1.5, use may be made of a jack and frame or other mechanical device to force the plugs into the mould and so avoid the use of a compression testing machine for this purpose.

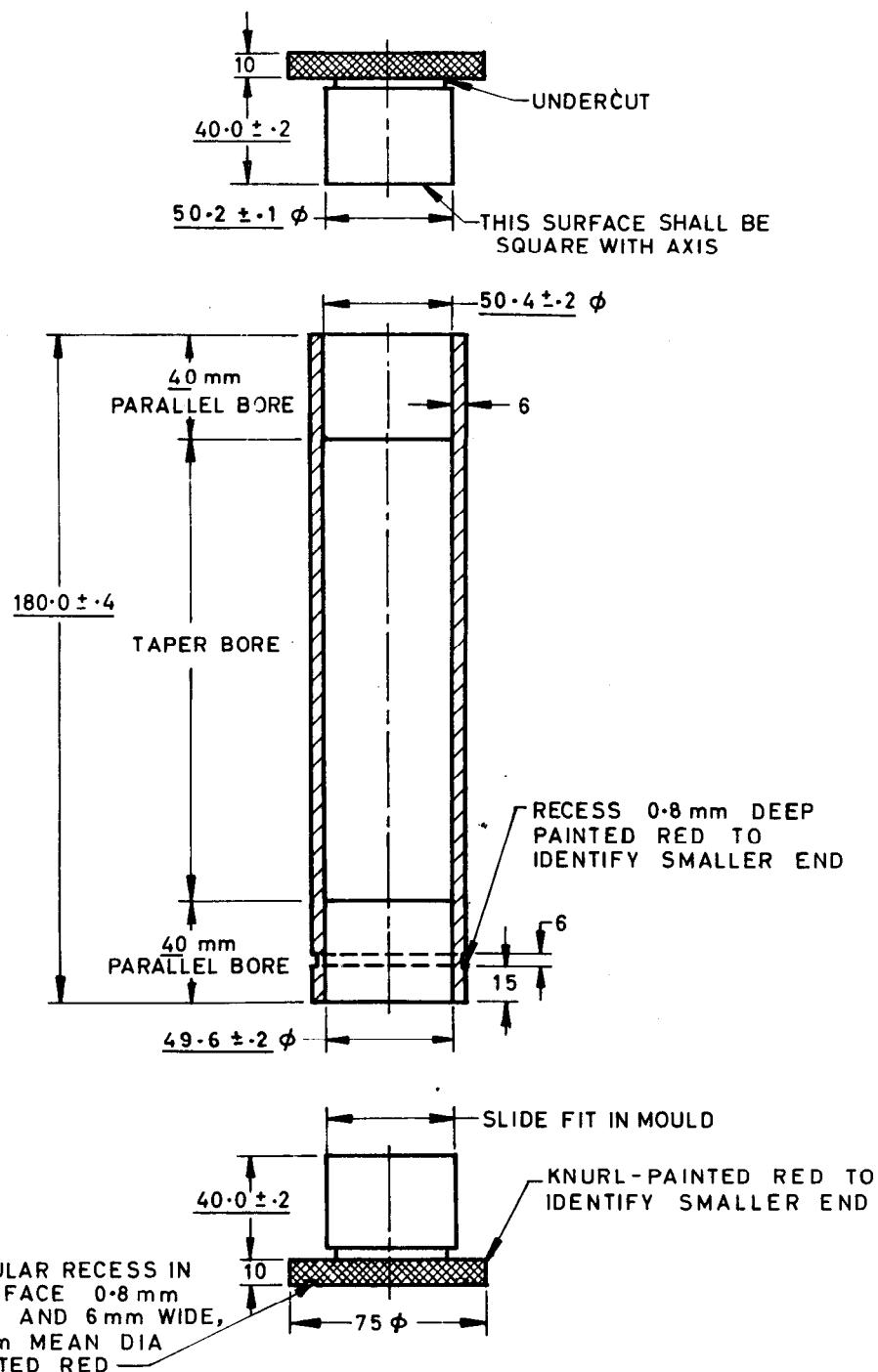
3.1.6 *Steel Tamping Rod* — 6 to 12 mm diameter and of suitable length.

3.1.7 *Device* — for moisture content determination in accordance with IS: 4332 (Part 2)-1967.

3.1.8 *Hide or Copper-Faced Hammer* — a suitable weight being 2 kg.

3.1.9 *Metal Funnel or Scoop* — to fit the neck of the moulds.

3.1.10 *Calipers* — readable and accurate to 0.25 mm with an opening not less than 100 mm or 200 mm when testing fine or medium-grained soils respectively.

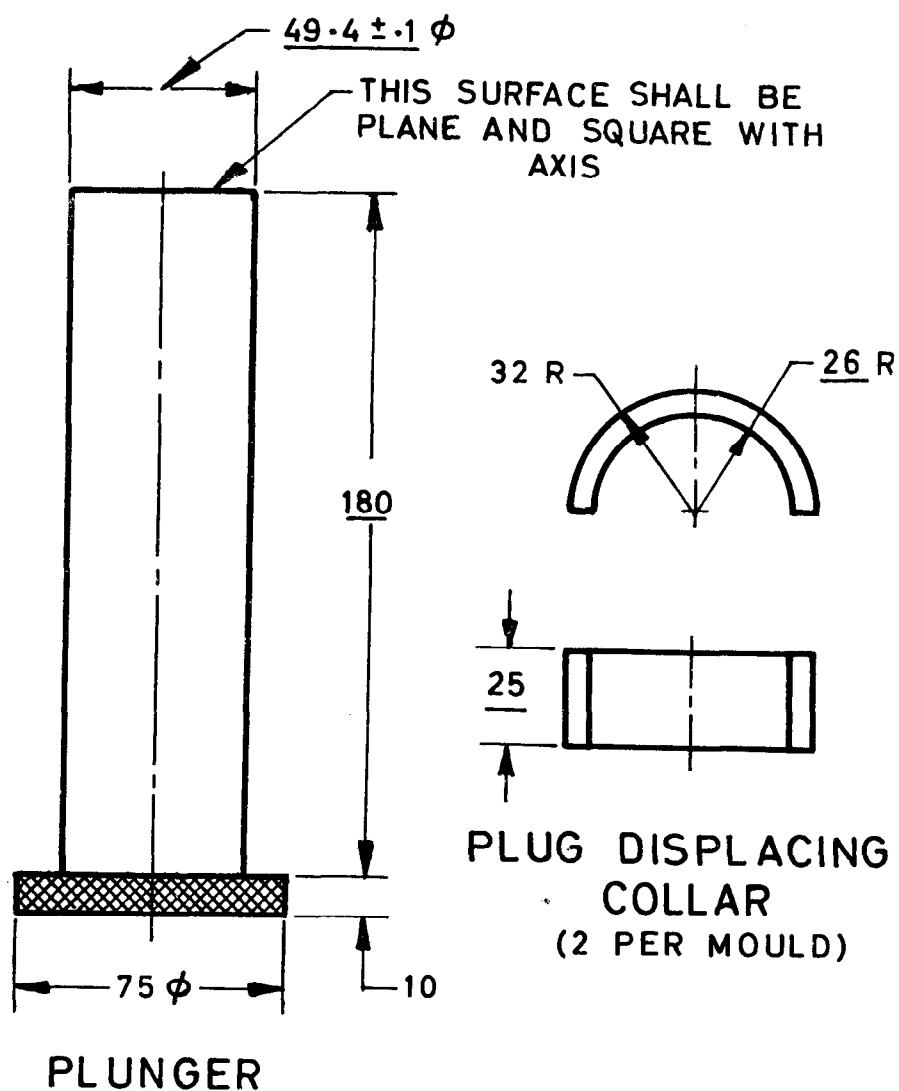


NOTE 1 — All surfaces should be smooth and free from cool marks.
 NOTE 2 — *Material* — mild steel.

This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled. Essential dimensions are underlined.

All dimensions in millimetres.

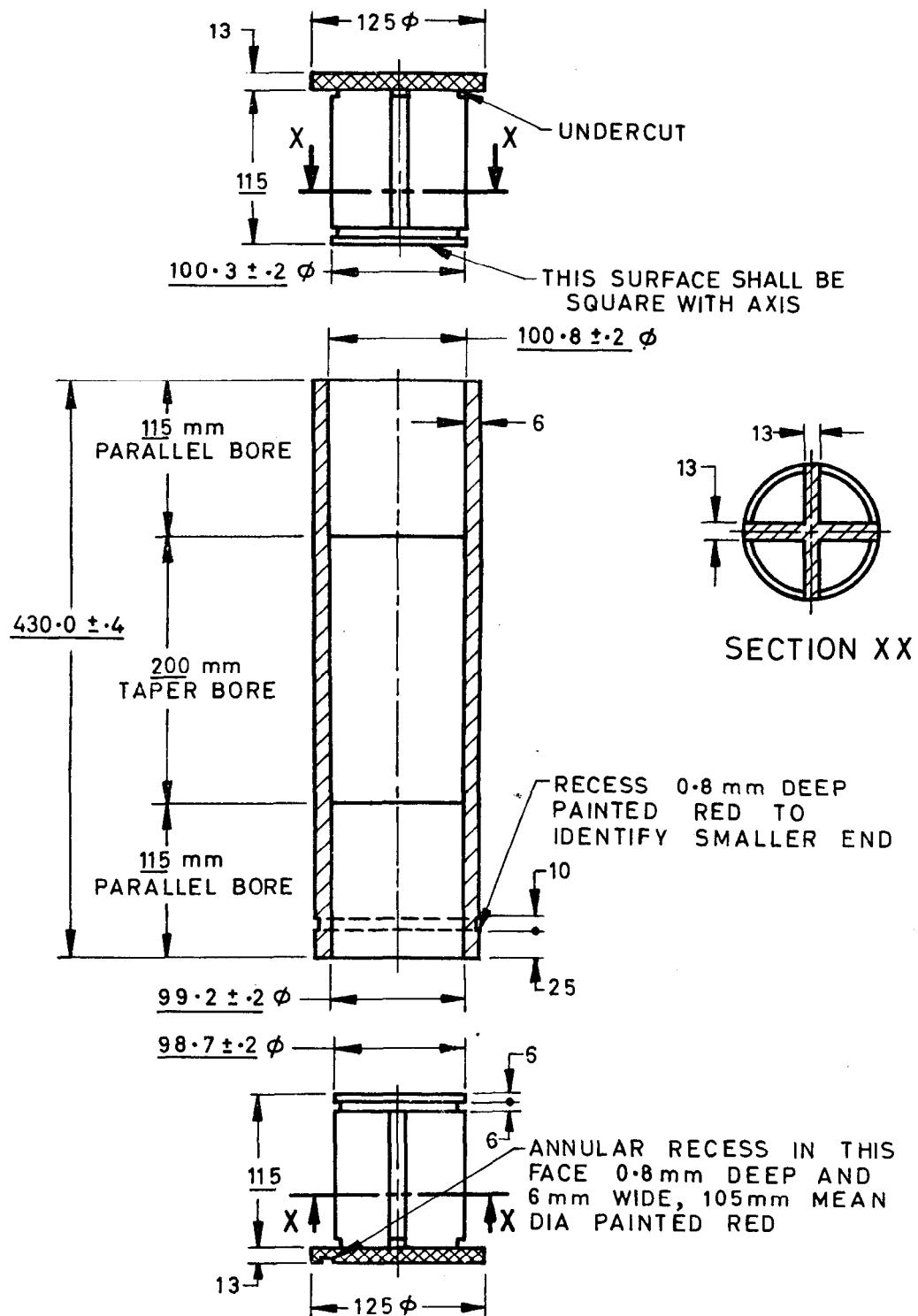
FIG. 1 TAPERED CYLINDRICAL MOULD WITH PLUGS FOR PREPARATION OF SPECIMENS FOR THE UNCONFINED COMPRESSIVE STRENGTH TEST (FINE-GRAINED STABILIZED SOIL)



This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled. Essential dimensions are underlined.

All dimensions in millimetres.

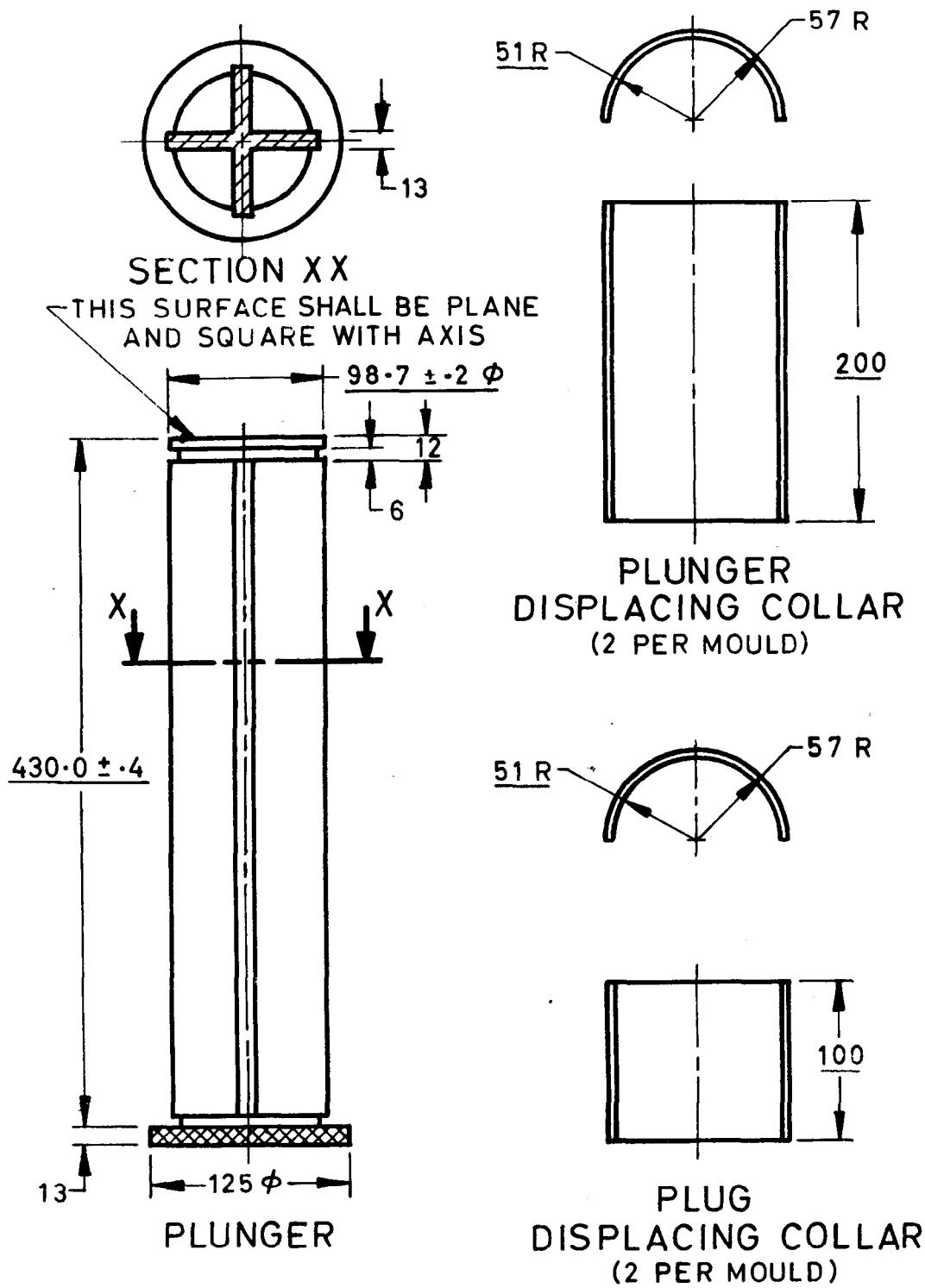
FIG. 2 PLUNGER AND DISPLACING COLLAR FOR USE WITH TAPERED CYLINDRICAL MOULD SHOWN IN FIG. 1



This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled. Essential dimensions are underlined.

All dimensions in millimetres.

FIG. 3 TAPERED CYLINDRICAL MOULD WITH PLUGS FOR PREPARATION OF SPECIMEN FOR THE UNCONFINED COMPRESSIVE STRENGTH TEST (MEDIUM-GRAINED STABILIZED SOIL)



This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled. Essential dimensions are underlined.

All dimensions in millimetres.

FIG. 4 PLUNGER AND DISPLACING COLLAR FOR USE WITH TAPERED CYLINDRICAL MOULD SHOWN IN FIG. 3

3.2 For specimens compacted to a constant compactive effort, additional apparatus given in 3.2.1 to 3.2.3 is required.

3.2.1 Metal Rammer — 50 mm diameter having a weight of 2.6 kg and a controlled drop of 310 mm.

3.2.2 Palette Knife — a convenient size is one having a blade 200 mm long and 30 mm wide.

3.2.3 Straight Edge — for example, a steel strip 300 mm long, 25 mm wide and 3 mm thick, with one bevelled edge.

4. MATERIAL

4.1 Paraffin wax or other suitable wax for coating the test specimen to maintain it at its specified moisture content.

5. PREPARATION OF SPECIMEN

5.1 For specimens compacted to a pre-determined dry density.

5.1.1 Compaction Using Compression Device — Using only material passing the 4.75-mm IS test sieve for fine-grained soils, and only material passing the 20-mm IS test sieve for medium-grained soils, the stabilized soil shall be prepared as described in IS : 4332 (Part 1)-1967.

The weight of the stabilized soil (W_1) required for moulding into a specimen of the required dry density shall be calculated in accordance with the mould used. In the case of soils stabilized with a solid stabilizer, for example, cement, this weight shall be calculated from the formulae:

For fine-grained soils (100 × 50 mm moulds):

$$W_1 = \left(V_f + \frac{V_f m}{100} \right) \gamma_d g = (196 + 1.96m) \gamma_d g$$

For medium-grained soils (200 mm × 100 mm moulds):

$$W_1 \left(V_m + \frac{V_m m}{100} \right) \gamma_d g = (1570 + 15.7m) \gamma_d g$$

where

V_f = Volume of mould for fine-grained soils in cm^3 ,

m = the moisture content of the soils plus stabilizer in percent,

γ_d = density of dry soil plus stabilizer in g/cm^3 , and

V_m = volume of mould for medium-grained soils in cm^3 .

The appropriate weight of material shall be placed in the mould into which, using a displacing collar, the lower plug has been inserted to a distance of 15 mm. During filling, the stabilized soil shall be tamped gently and uniformly so that the upper plug can be inserted at a distance of 15 mm. The upper

plug should be inserted and the mould assembly placed in the compression device or testing machine. After removal of the displacing collars, pressure shall be applied to the plugs until the flanges are in contact with the barrel of the mould. After the pressure has been maintained for about $\frac{1}{2}$ minute, the load shall be released and the mould removed from the press. The plugs shall then be removed from the mould. The plunger shall then be inserted into the end of the mould having the smaller diameter and the specimen released from the taper by gentle hammering or pressure. The specimen shall then be removed from the mould and weighed to the nearest 1 g (W_2) (see Note 2).

5.1.2 Compaction Using Hammer — The procedure shall be as in 5.1.1 except that the specimen shall be compacted by driving home the end plugs, with a hide or copper-faced hammer.

5.2 For Specimens Compacted with Constant Compactive Effort — Using only material passing the 4.75-mm IS test sieve for fine-grained soils, and only material passing the 20-mm IS test sieve for medium-grained soils, the stabilized soil shall be prepared as described in IS : 4332 (Part 1)-1967

5.2.1 For Fine-Grained Soils — The appropriate plug shall be inserted into the bottom of the mould (that is, the larger diameter uppermost) and a quantity of the material sufficient to give a specimen length of 100-115 mm after compaction (that is, about 450 g) shall be added to the mould, being tamped uniformly and gently with the tamping rod during the operation.

The other plug shall be inserted into the mould, and the soil shall be compacted by 15 blows of the rammer dropped from a height of 310 mm into the plug (this plug should not have been driven fully home at this stage; if it has, then there is insufficient material in the mould). The mould containing the specimen shall then be inverted and the uppermost plug replaced by the plunger. The soil shall then be further compacted by 15 blows from the rammer applied to the plunger.

The compacted specimen shall be rejected for subsequent testing if its length exceeds 115 mm.

The plunger shall then be inserted into the end of the mould having the smaller diameter and the specimen released from the taper by gentle hammering or pressure. The specimen shall then be removed from the mould and weighed to the nearest 1 g (W_2) (see Note 2).

5.2.2 For Medium-Grained Soils — The appropriate plug shall be inserted into the bottom of the mould (that is, the larger diameter uppermost) and a quantity of material sufficient to give a specimen of 200-215 mm after compaction (that is, about 3.5 kg) shall be compacted into the mould in six equal

layers, each layer being given 25 blows of the rammer dropped from a height of 310 mm above the stabilized soil. The blows shall be uniformly distributed over the surface of each layer, which shall be scarified with the palette knife before the next layer is added. The compacted specimen shall be rejected for subsequent testing if its length exceeds 215 mm.

The plunger shall then be inserted into the end of the mould having the smaller diameter and the specimen released from the taper by gently hammering or pressure. Any length in excess of 200 mm shall be extruded beyond the mould. This length is gauged by placing the 200 mm long displacing collars on the plunger. The face of the specimen shall be carefully levelled off to the end of the mould using the straight edge, and any irregularities shall be filled with fine material from the same sample. The specimen shall then be removed from the mould and weighed to the nearest 1 g (W_2) (see Note 2).

6. CURING

6.1 The specimen shall be completely coated with paraffin wax or other suitable wax or otherwise suitably protected by methods such as wrapping in polythene to maintain it at its specified moisture content (see Note 3), care being taken not to leave holes in the wax film and to complete the coating as quickly as possible to prevent the absorption of wax, and it shall then be weighed to the nearest 1 g (W_3). It shall subsequently be stored for period (see Note 4), the length of which will depend on the process and type of stabilizer employed, under conditions in which it is protected from mechanical damage and kept at a temperature of $27 \pm 2^\circ\text{C}$ (see Note 5).

After the curing period and before testing, the specimen shall again be weighed to the nearest 1 g (W_4). Any 100 mm high \times 50 mm diameter specimen which has lost more than 2 g in weight and any 200 mm high \times 100 mm diameter specimen which has lost more than 5 g in weight during the curing period shall be discarded.

7. TEST PROCEDURE

7.1 After weighing, the wax shall be removed from the end of the specimen and, if desired, from the sides, care being taken to avoid damaging the soil surface.

7.2 The length of the specimen (L) shall be measured to the nearest 0.25 mm by means of the calipers, and recorded.

7.2.1 The specimen shall then be placed centrally on the lower platen of the compression testing machine and the load shall be applied to the ends of the specimen. The load shall be applied so that the

rate of deformation is uniform, approximately 1.25 mm/min. The maximum load exerted by the machine during the test shall be recorded P kg.

7.3 The moisture content shall be determined in accordance with IS : 4332 (Part 2)-1967 on a representative sample of fragments taken from the interior of the specimen, and recorded.

8. CALCULATIONS

8.1 The unconfined compressive strength (p) of the specimen shall be calculated from the formulae:

a) For fine-grained soils

$$p = P/A_f = P/1963 \text{ MN/m}^2$$

b) For medium-grained soils

$$p = P/A_m = P/7854 \text{ MN/m}^2$$

where

P = maximum recorded load, N (see 7.2.1);

A_f = cross-sectional area of specimen for fine-grained soil (mm^2); and

A_m = cross-sectional area of specimen for medium-grained soils (mm^2).

8.2 In the case of soils stabilized with solid stabilizer, the weight of the dry solids/ cm^3 [dry soil plus stabilizer density (γ_d)] in the specimen shall be calculated from the formulae:

a) For fine-grained soils

$$\gamma_d = \frac{100 W_2}{A_f L (100 + m)} = \frac{100 W_2}{19.63 L (100 + m)} \text{ g/cm}^3$$

b) For medium-grained soils

$$\gamma_d = \frac{100 W_2}{A_m L (100 + m)} = \frac{100 W_2}{78.54 L (100 + m)} \text{ g/cm}^3$$

where

W_2 = weight of specimen before coating with wax in g;

A_f = cross-sectional area of specimen for fine-grained soil (cm^2);

A_m = cross-sectional area of specimen for medium-grained soils (cm^2);

L = length of specimen (cm); and

m = moisture content of the soil plus stabilizer after curing, in percent.

9. REPORTING OF RESULTS

9.1 The unconfined compressive strength of the specimen shall be reported as follows:

a) Values of compressive strength up to MN/m^2 (20 kg/cm^2) report to the nearest 0.05 MN/m^2 (0.5 kg/cm^2).

b) Values of compressive strength above 2 MN/m^2 (20 kg/cm^2), report to the nearest 0.1 MN/m^2 (1 kg/cm^2).

9.2 The report shall include relevant details of the size and shape of the specimen and the composition

of the stabilized soil mixture, the dry soil or dry soil plus stabilizer density, the moisture content as determined in 7.3, the methods of compaction and curing, and the curing period and temperature.

NOTE 1 — The standard has been written on the basis of internally-tapered moulds being used. Although these have the advantage that they are very convenient in use, split moulds with parallel bores may also be employed. The moulds should be lightly coated with suitable oil before use.

NOTE 2 — *Removal of specimen from mould* — When dealing with cohesive mixture of stabilized soil, it is possible to remove the specimen from the mould immediately after preparation. However, with non-cohesive soils mixed with stabilizers capable of developing cohesion, it may be advantageous to allow the specimen to remain in the mould for some time, for example, 24 hours.

NOTE 3 — Coating with wax has been specified as this has been found to be the best method of maintaining the moisture content of the specimen at a constant value of and is very simple to carry out. To simplify its removal from the specimen, the wax should be used as cool as possible.

NOTE 4 — *Period of storage* — With many stabilizing agents, the strength of the stabilized soil increases with storage. In such cases, tests should be made on specimens that have been stored for various periods to determine whether or not the strength is increasing satisfactorily. With cement-stabilized specimens, suitable periods of storage are 3, 7, 14 and 28 days.

In certain circumstances, however, it will be convenient to obtain a simple assessment of the quality of the stabilized mixture as rapidly as possible. In such cases, tests should be made on specimens that have been stored for a single fixed period, the time chosen depending on the process of stabilization under consideration. With cement stabilized specimens, this period should normally be seven days.

NOTE 5 — The tolerance on the curing temperature of $\pm 2^{\circ}\text{C}$ is essential for all laboratory work and for preliminary testing to ascertain the cement content required. For site conditions, where strength tests are being made only for quality control purposes, however, the tolerance may be relaxed to $\pm 5^{\circ}\text{C}$. If this is done, the maximum and minimum curing temperature should be ascertained and reported with the results.

SECTION B TEST FOR MEDIUM AND COARSE GRAINED STABILIZED SOIL

10. SCOPE

10.1 This method covers the determination of the unconfined compressive strength of stabilized soil specimens made with medium and coarse-grained soils. It covers the preparation and testing of cubical specimens prepared to a pre-determined dry density, with a constant compactive effort or by compaction to refusal. The method, in which the specimens are prepared to a pre-determined dry density, is preferred and should be used whenever possible.

11. GROUPING OF SOIL

11.1 For the purpose of this standard, soils shall be grouped as follows:

a) *Fine-grained soils* — Not less than about 90 percent of the soil passing a 2.36-mm IS Sieve.

- b) *Medium-grained soils* — Not less than about 90 percent of the soil passing a 20-mm IS Sieve.
- c) *Coarse-grained soils* — Not less than about 90 percent of the soil passing a 40-mm IS Sieve.

12. APPARATUS

12.1 For all methods of compaction.

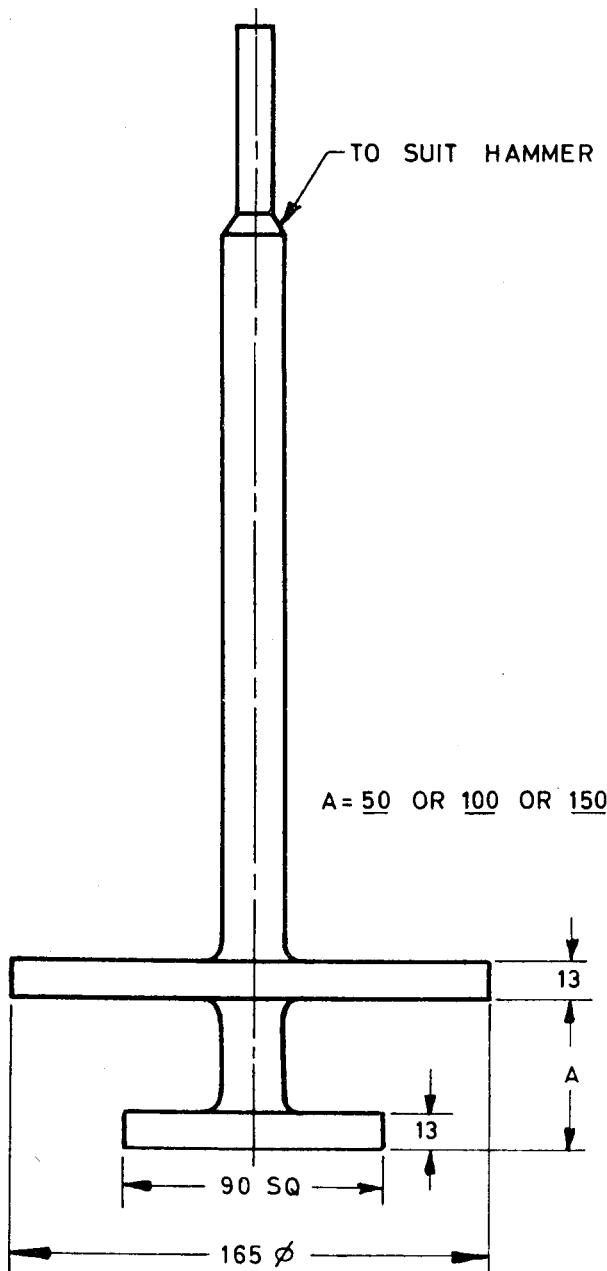
- a) 20-mm and 40-mm IS test sieve for medium and coarse-grained soils respectively.
- b) *Balance* — readable and accurate to 1 g.
- c) *Steel or Cast Iron Moulds* — suitable for casting 150 mm cubes.

The mould shall be strong enough to prevent distortion and constructed in such a manner as to facilitate removal of the specimen without damage. The mould shall be so machined that when it is assembled ready for use the dimensions and internal surfaces are accurate within the following limits:

The height of the mould and the distance between the opposite faces shall be 150 ± 0.2 mm. The angle between adjacent interior faces, and between interior faces and top and bottom planes of the mould shall be $90 \pm 0.5^{\circ}$. The interior faces of the mould shall be plane surfaces with a permissible variation of 0.03 mm. Each mould shall be provided with a baseplate having a plane surface. The baseplate shall be attached to the mould with robust clamps.

The parts of the mould shall be lightly oiled before assembly, and when assembled shall be positively and rigidly held together during filling and subsequent handling of the filled mould.

- d) *Plasterer's Steel Trowel*
- e) *Curing Tins* — $160 \times 160 \times 155$ mm deep with well-fitting lids, and suitable sealing tape.
- f) *Compression Testing Machine of the Lever, Self-Indicating or Proving Ring Type* — capable of exerting sufficient load for the tests and of providing a uniform rate of increase of stress in the test specimen of approximately $35 \text{ kgf/cm}^2/\text{min}$.
- g) *Palette Knife* — a convenient size is one having a blade 200 mm long and 30 mm wide.
- h) *Flat Metal Plates* — measuring approximately $200 \text{ mm} \times 200 \text{ mm} \times 3 \text{ mm}$ for preventing loss of moisture from top of cube mould.
- j) *Apparatus* — for moisture content determination in accordance with IS : 4332 (Part 2)-1967.



This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled. Essential dimensions are underlined.

All dimensions in millimetres.

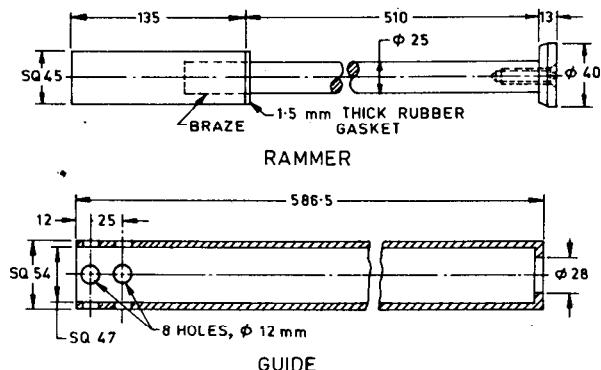
FIG 5 TAMPER WITH SPACING COLLAR, FOR USE WITH A VIBRATING HAMMER, FOR PREPARATION OF SPECIMENS MADE UP TO A PRE-DETERMINED DRY DENSITY FOR THE UNCONFINED COMPRESSIVE STRENGTH TEST (MEDIUM AND COARSE-GRAINED STABILIZED SOILS)

12.2 For Specimens Compacted to a Pre-determined Dry Density — The following additional apparatus is required:

- Suitable Electric or Pneumatic Vibrating Hammer*
- Square or Rectangular Tamper* — preferably square, of approximately 8 000 mm² area for use with the vibrating hammer having a collar rigidly and accurately attached to its shank so that the tamper foot is prevented from entering the mould further than 50 mm (see Fig. 5).
- As in (b) but with entry into the mould limited to 100 mm.
- As in (b) but with entry into the mould limited to 150 mm.

12.3 For Specimens Compacted to a Constant Compactive Effort — The following additional apparatus is required:

- Metal Rammer* — having a 45 mm × 45 mm square faces, a weight of 4.89 kg and a controlled drop of 450 mm (see Fig. 6).
- Straightedge* — for example, a steel strip 300 mm long, 25 mm wide and 3 mm thick with one bevelled edge.



This design has been found satisfactory, but alternative designs may be employed, provided that the essential requirements are fulfilled. Essential dimensions are underlined.

NOTE — Rammer — Adjust to make total weight 4.89 kg. Guide length of travel of rammer 450 mm.

All dimensions in millimetres.

FIG. 6 RAMMER FOR PREPARATION OF SPECIMENS COMPACTED TO A CONSTANT COMPACTIVE EFFORT FOR THE UNCONFINED COMPRESSIVE STRENGTH TEST (MEDIUM AND COARSE-GRAINED STABILIZED SOIL)

12.4 For Specimens Compacted to Refusal — The following additional apparatus is required:

- Electric Pneumatic Vibrating Hammer*
- Square or Rectangular Tamper* — preferably square, of approximately 8 000 mm² area for use with the vibrating hammer.
- Straightedge* — for example, a steel strip 300 mm long, 25 mm wide and 3 mm thick with one bevelled edge.

13. PREPARATION OF SPECIMEN

13.1 For Specimens Compacted to a Pre-determined Dry-Density — Using only material passing the 20-mm IS testing sieve for medium-grained soils, and only material passing the 40-mm IS Test Sieve for coarse-grained soils, the stabilized soil shall be prepared as described in IS : 4332 (Part 2)-1967.

The weight of stabilized soil (W_1) required for moulding into a specimen of the required dry density shall be calculated from the formula:

For soils stabilized with a solid stabilizer:

$$W_1 = \left(V + \frac{V}{100} m \right) \gamma_d g = (3375 + 33.75 m) \gamma_d g$$

where

V = volume of the mould in cm^3 ,

m = moisture content of the soil plus stabilizer in percent, and

γ_d = density of dry soil plus stabilizer in g/cm^3

The material (W_1) shall be divided into three equal parts by weight. One of the parts shall be placed in an assembled mould and the surface levelled off. Using a tamper fitted with a collar at the 10 cm mark and a vibrating hammer, the material shall be compacted uniformly until the collar comes into contact with the upper surface of the mould. The surface of the layer shall be scarified with the palette knife before adding the next layer, which shall be compacted in similar manner to the first layer, but using a tamper fitted with a collar at the 5 cm position. A 150 mm cube mould less baseplate shall then be placed squarely on top of the mould, the compacted surface scarified with the palette knife, and the final layer added using the tamper with the collar at the 150 mm position. The upper mould shall then be removed and the surface of the specimen carefully levelled off to the end of the mould using the trowel and vibrating tamper, care being taken not to spill any loose material during this final operation. The mould containing the specimen shall then be covered with a metal plate and stored at a temperature of $27 \pm 2^\circ\text{C}$ (see Note 1) until the following day when the specimen shall be removed from the mould for further curing. The specimen shall then be weighed to the nearest 1 g (W_2).

13.2 For Specimen Compacted to a Constant Compactive Effort — Using only material passing the 20-mm IS Test Sieve for medium-grained soils, and only material passing the 40-mm IS Test Sieve for coarse-grained soils, the stabilized soil shall be prepared as described in IS : 4332 (Part 1)-1967.

13.2.1 The mould shall be assembled on its baseplate and another mould, less baseplate, placed squarely on top. A quantity of stabilized soil suffi-

cient to give a specimen of 150 to 165 mm depth after compaction (that is, about 8 kg) shall be compacted into the mould in three equal layers, each layer being given 35 blows of the rammer dropped from a height of 450 mm above the stabilized soil. The blows shall be uniformly distributed over the surface of each layer, which shall be scarified with the palette knife before the next layer is added. The compacted specimen shall be rejected for subsequent testing if its height exceeds 165 mm.

13.2.2 After removing the upper mould, excess material shall be struck off level with the top of the lower mould by means of a straightedge, and any irregularities shall be filled with fine material from the same sample. The mould containing the specimen shall then be covered with a metal plate and stored at a temperature of $27 \pm 2^\circ\text{C}$ (see Note 1) until the following day when the specimen shall be removed from the mould for further curing. The specimen shall then be weighed to the nearest 1 g (W_2).

13.3 For Specimen Compacted to Refusal — Using only material passing the 20-mm IS Test Sieve for medium-grained soils and only material passing the 40-mm IS Test Sieve for coarse-grained soils, the stabilized soil shall be prepared as described in IS : 4332 (Part 1)-1967.

13.3.1 The mould shall be assembled on its baseplate and another mould, less baseplate, placed squarely on top. A quantity of stabilized soil sufficient to give a specimen of 150 to 165 mm depth after compaction (that is, about 8 kg) shall be compacted into the mould in three equal layers, each layer being compacted with a tamper fitted to a vibrating hammer until it is judged that no further compaction is possible. Each layer shall be scarified with the palette knife before the next layer is added. The compacted specimen shall be rejected for subsequent testing if its height exceeds 165 mm.

13.3.2 After removing the upper mould, excess material shall be struck off, level with the top of the lower mould by means of a straight edge, and any irregularities in the surface shall be filled with material from the same sample. The mould containing the specimen shall then be covered with a metal plate and stored at a temperature of $27 \pm 2^\circ\text{C}$ (see Note 1) until the following day when the specimen shall be removed from the mould for further curing. The specimen shall then be weighed to the nearest 1 g (W_2).

14. CURING

14.1 The curing tin shall be placed over the specimen, and the tin and specimen then inverted. The lid shall then be placed in position and sealed with suitable tape (see Note 2). The tin containing the specimen shall then be weighed to the nearest 1 g

(W_2). It shall subsequently be stored for period (see Note 3), the length of which will depend on the process and type of stabilizer employed, at a temperature of $27 \pm 2^\circ\text{C}$ (see Note 1).

14.2 After the curing period and before testing, the tin containing the specimen shall again be weighed to the nearest 1 g (W_4). Any specimen that has lost more than 10 g in weight during the storage period shall be discarded.

15. TEST PROCEDURE

- a) After weighing, the specimen shall be removed from the tin.
- b) The specimen shall then be placed centrally on the lower platen of the compression testing machine in such a manner that the load shall be applied to opposite sides of the cube as cast, that is, not to the top and bottom. The load shall be applied without shock and increased continuously at a rate of approximately $35 \text{ kgf/cm}^2/\text{min}$ until the resistance of the cube to the increasing load breaks down and no greater load can be sustained. The maximum load exerted by the machine can be recorded ($P \text{ kg}$).
- c) The moisture content shall be determined in accordance with IS : 4332 (Part 2)-1967 on a representative sample of fragments taken from the interior of the specimen and recorded.

16. CALCULATIONS

- a) The unconfined compressive strength (p) of the specimen shall be calculated from the formula:

$$p = P/A \text{ MN/m}^2 = P/22500 \text{ MN/m}^2$$

where

P = maximum recorded load, N; and
 A = area of cross-section of specimen in mm^2 .

- b) In the case of soils stabilized with a solid stabilizer, the weight of dry solids per cubic foot (dry soil plus stabilizer density, γ_d) in the specimen shall be calculated from the formula:

$$\begin{aligned}\gamma_d &= \frac{100 W_2}{V(100 + m_1)} \text{ g/cm}^3 \\ &= \frac{100 W_2}{3375(100 + m_1)} \text{ g/cm}^3\end{aligned}$$

where

W_2 = weight of specimen after removal from the mould in g,

V = Volume of mould in cm^3 , and

m_1 = moisture content of soil plus stabilizer after curing in percent.

17. REPORTING OF RESULTS

17.1 The unconfined compressive strength of the specimen shall be reported as follows:

- a) Values of compressive strength up to 3.5 MN/m^2 (35 kg/cm^2), report to the nearest 0.1 MN/m^2 (1 kg/m^2).
- b) Values of compressive strength above 3.5 MN/m^2 (35 kg/cm^2), report to the nearest 0.15 MN/m^2 (1.5 kg/m^2).

17.2 The report shall include relevant details of the size and shape of the specimen and the composition of the stabilized soil mixture, the dry soil or dry soil plus stabilizer density, the moisture content as determined in 15 (c), the methods of compaction and curing, and the curing period and temperature.

NOTE 1 — The tolerance on the curing temperature of $\pm 2^\circ\text{C}$ is essential for all laboratory work and in preliminary testing to ascertain the cement content required. For site conditions where strength tests are being made only for quality control purposes, however, the tolerance may be relaxed to $\pm 5^\circ\text{C}$. If this is done, the maximum and minimum temperatures shall be ascertained and reported with the results.

NOTE 2 — Storage in a sealed tin has been specified in the case of cubes as this has been to be the best method of maintaining the moisture content at a constant value and is very simple to carry out.

This method of curing, at constant moisture content, has been found to be suitable for stabilization with cement or lime but with other stabilizers, guidance on a suitable method of curing should be sought from the manufacturers of the stabilizers.

NOTE 3 — *Period of storage* — With many stabilizing agents, the strength of the stabilized soil increases with storage. In such cases, tests should be made on specimens that have been stored for various periods, to determine whether or not the strength is increasing satisfactorily. With cement-stabilized specimens, suitable periods of storage are 3, 7, 14 and 28 days.

In certain circumstances, however, it will be convenient to obtain a simple assessment of the quality of the stabilized mixture as rapidly as possible. In such cases, tests should be made on specimens that have been stored for a single fixed period, the time chosen depending on the process of stabilization under consideration. With cement-stabilized specimens, this period should normally be seven days.

With other stabilizers, guidance on a suitable period of storage should be sought from the manufacturers of the stabilizers.

Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 6 FLEXURAL STRENGTH OF SOIL-CEMENT USING SIMPLE BEAM WITH THIRD-POINT LOADING

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization is the alteration of any property of a soil to improve its engineering performance. There are several methods of stabilization and these may be broadly classified on the basis of treatment given to the soil (for example, dewatering and compaction), process involved (for example, thermal and electrical) and on additives employed (for example, asphalt and cement). The choice of a particular method depends on the characteristics of the problem on hand. For studying in the laboratory, the methods and effects of stabilization, certain standard methods of test for the evaluation of properties of stabilized soils and their analysis are required. The required standards on methods of test for stabilized soils are to be published in parts and this part [IS: 4332 (Part 6)-1972] lays down the procedure for determining the flexural strength of soil-cement by the use of a simple beam with third-point loading.

1. SCOPE

1.1 This standard covers the procedure for determining the flexural strength of soil-cement by the use of a simple beam with third-point loading.

2. APPARATUS

2.1 For the Preparation of Test Specimen

2.1.1 *Moulds* — having inside dimensions of $75 \times 75 \times 300$ mm (Fig. 1). The moulds shall be so designed that the specimen may be moulded with its longitudinal axis in a horizontal position. The parts of the moulds shall be tight-fitting and positively held together. The sides of the moulds shall be sufficiently rigid to prevent spreading or warping. The interior faces of the moulds shall be plane surfaces with a permissible variation, in any 75 mm line on a surface, of 0.05 mm for new moulds and 0.075 mm for mould in use. The distance between opposite sides shall be 75 ± 0.25 mm for new moulds and 75 ± 0.4 for moulds in use. The height of the moulds shall be $75 + 0.25$ m — 0.15 mm for both new moulds and moulds in use. Four 10-mm

spacer bars and top and bottom machined steel plates shall be provided. The plates shall fit the mould with a clearance of 0.15 mm on all sides. The moulds shall be made of metal having a Rockwell hardness between B80 and B85.

2.1.2 *Sieves* — 50-mm, 20-mm, 4.75-mm, 1.18-mm conforming to the requirements of IS:460 (Part 1)-1978.

2.1.3 *Balances* — A balance or scale of capacity 10 kg, sensitive to 5 g (Class C beam scale of IS : 1433-1965) and a balance of 1 kg, sensitive to 100 mg (Class B beam scale of IS : 1433-1965).

2.1.4 *Drying Oven* — thermostatically controlled, capable of maintaining a temperature of $110 \pm 5^\circ\text{C}$ for drying moisture samples.

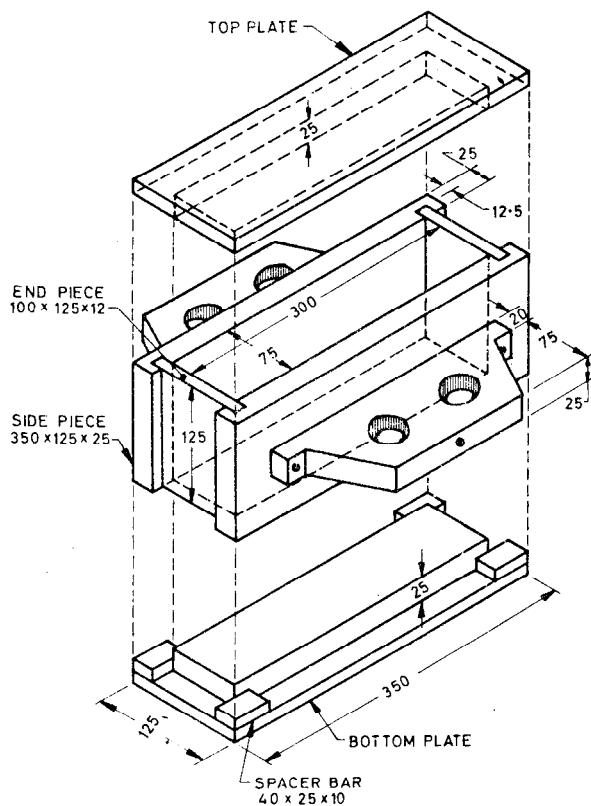
2.1.5 *Tamping Rod* — A square-end cut 12 mm diameter smooth steel rod 500 mm in length.

2.1.6 *Moist Room or Cabinet* — capable of maintaining a temperature of $27 \pm 2^\circ\text{C}$ and relative humidity of not less than 96 percent for moist curing specimens.

2.2 For Testing Flexural Strength

2.2.1 *Testing Machine* — The testing machine may be of any type having sufficient capacity (at least 500 kg) and control to provide the rate of loading prescribed in 5.2. The testing machine shall be equipped with a spherically seated head block having a bearing surface of 100 percent of the width of the beam but not greatly in excess of the width of the beam. The movable portion of this block shall be held closely in the spherical seat, but the design shall be such that the bearing face may be rotated freely and tilted through small angles in any direction.

2.2.2 The third-point loading methods used in making flexure tests of soil-cement shall employ bearing blocks that will ensure that forces applied to the beam will be vertical only and applied without eccentricity. A diagrammatic drawing of an apparatus which satisfies this condition is shown in Fig. 2. The apparatus shall be designed to incorporate the principles given in 2.2.2.1 to 2.2.2.4.



All dimensions in millimetres.

FIG. 1 MOULD FOR SOIL-CEMENT BEAM FOR FLEXURE TEST

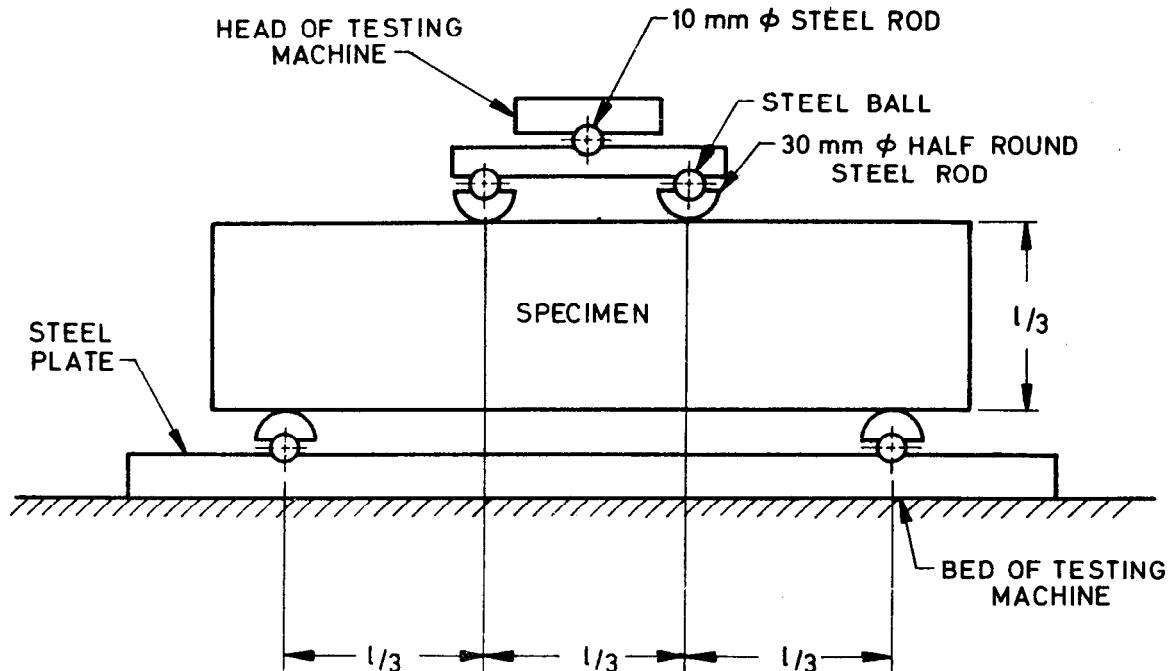


FIG. 2 DIAGRAMMATIC VIEW OF APPARATUS FOR FLEXURE TEST OF SOIL-CEMENT BY THIRD POINT LOADING METHOD

2.2.2.1 The distance between supports and points of load application shall remain constant for a given apparatus.

2.2.2.2 The direction of the reactions shall be parallel to the direction of the applied load at all times during the test.

2.2.2.3 The load should be applied at a uniform rate and in such a manner as to avoid shock.

2.2.2.4 The directions of loads and reactions may be maintained parallel by use of linkages, rocker bearings and flexure plates. Eccentricity of loading can be avoided by use of spherical bearings.

3. PREPARATION OF MATERIALS

3.1 Materials shall be brought to room temperature.

3.2 Cement — Cement shall be stored in a dry place, in moisture-proof containers, preferably made of metal. The cement shall be thoroughly mixed in order that the sample may be uniform throughout the tests. It shall be passed through a 1.8-mm IS Sieve and all lumps rejected.

3.3 Water — The mixing water shall be free of acids, alkalies and oils, and in general suitable for drinking.

3.4 Soil

3.4.1 The soil sample, if damp when received from the field, shall be dried until it becomes friable

under a trowel. Drying may be in air or by use of drying apparatus such that the temperature of the sample does not exceed 60°C. The aggregations shall be thoroughly broken up in such a manner as to avoid reducing the natural size of individual particles.

3.4.2 An adequate quantity of representative pulverized soil shall be sieved on the 50-mm, 20-mm and 4.75-mm sieves. Any fraction retained on the 50-mm sieve shall be discarded. Fraction passing the 50-mm sieve and retained on the 20-mm sieve shall be removed, and replaced with an equal weight of fraction passing the 20-mm sieve and retained on the 4.75-mm sieve. Soil for replacement shall be obtained from the original sample.

NOTE — It is intended that the methods for making soil-cement specimens for the flexure test be used primarily with soil materials having not more than 35 percent soil retained on the 4.75-mm sieve not more than 85 percent retained on the 425-micron sieve.

3.4.3 The fraction passing the 20-mm sieve and retained in the 4.75-mm sieve shall be soaked in water for 24 hours, removed and surface dried. The absorption properties of this fraction shall be determined in accordance with IS: 2386 (Part 3)-1963.

3.4.4 A 100-g sample of the soil passing the 4.75-mm sieve shall be taken and dried in the drying oven to constant weight, and the moisture content of the sample determined to permit calculation of the quantity of water that shall be added to the soil-cement mixture to bring it to the proper moisture content for moulding specimens.

3.4.5 A representative sample of sufficient quantity to make three flexure test specimens shall be taken of the soil passing the 4.75-mm sieve and also of the fraction passing the 20-mm sieve and retained on the 4.75-mm sieve prepared as described in **3.4.1**, **3.4.2** and **3.4.3**.

3.5 Weighing Materials — The designed quantities of soil passing the 4.75-mm sieve and of aggregate passing the 20-mm sieve and retained on the 4.75-mm sieve shall be weighed to the nearest 5 g. The designed quantity of cement shall be weighed to the nearest gram and the designed quantity of water shall be measured to the nearest millilitre.

4. PREPARATION OF TEST SPECIMEN

4.1 Mixing Materials

4.1.1 General — Soil-cement shall be mixed either by hand or in a suitable laboratory mixer in batches of such size as to leave ten percent excess after moulding test specimens. This material shall be protected against loss of moisture, and a representative part of it shall be weighed and dried in the drying oven to constant weight to determine the actual moisture content of the soil-cement mixture. When the soil-cement mixture contains aggregate

retained on the 4.75-mm sieve, the sample for moisture determination shall weigh at least 500 g and shall be weighed to the nearest gram. If the mixture does not contain aggregate retained on the 4.75-mm sieve, the sample shall weigh at least 100 g and shall be weighed to the nearest 0.1 g.

4.1.2 Hand Mixing — The batch shall be mixed in a clean, damp, metal pan or on top of a steel table, with a blunt brick-layer's trowel, using the following procedures:

- Calculated amount of water to give moisture content 2 percent less than the required final moisture content should be added to the soil passing 4.75-mm IS Sieve, thoroughly mixed and kept in a sealed container to avoid moisture loss overnight for uniform distribution of moisture.
- The additional water required for bringing the moisture to the required level should be calculated. The calculated weight of the moist soil and cement required for making the specimens should be mixed thoroughly. The remaining quantity of water to make up to the required moisture content of the soil-cement mixture should be added and thoroughly mixed.
- The saturated surface-dry coarse fraction of the soil shall be added and the entire batch mixed until the coarse fraction is uniformly distributed throughout the batch.

4.1.3 Machine Mixing — The sequence specified for hand mixing shall be followed. To eliminate segregation, machine-mixed soil-cement shall be deposited in a clean, damp-metal pan and remixed by trowel.

NOTE — The operation of mixing and compacting test specimens shall be continuous and the elapsed time between the addition of water and final compaction shall not exceed 30 minutes.

4.2 Size of Specimens — Flexure test specimens shall be rectangular beams with a length as tested at least 50 mm greater than three times the depth. The procedure provides for beams 75 × 75 × 300 mm, but the same procedure may be used for moulding smaller or larger specimens.

4.3 Moulding Specimens

4.3.1 The test specimens shall be formed with the longitudinal axis horizontal. The mould parts shall be lightly oiled and assembled with sides and ends separated from the base plate by the 10-mm spacer bars, one placed at each corner of the mould.

4.3.2 Divide into three equal batches a predetermined weight of uniformly mixed soil-cement to make a beam of the designed density. Place one batch of the material in the mould and level by hand. When the soil-cement contains aggregate

retained on the 4.75-mm sieve, carefully spade the mix around the sides of the mould with a thin spatula. Compact the soil-cement initially from the bottom up by steadily and firmly forcing (with little impact) a square-end cut 12 mm diameter smooth steel rod repeatedly through the mixture from the top down to the point of refusal. Approximately 90 roddings distributed uniformly over the cross-section of the mould are required; that care so as not to leave holes in clayey soil-cement mixtures. Level this layer of compacted soil-cement by hand and place and compact layers two and three in an identical manner. The specimen at this time shall be approximately 95 mm high.

4.3.3 Place the top plate of the mould in position and remove the spacer bars. Obtain final compaction with a static load applied by the compression machine or compression frame until the height of 75 mm is reached.

4.3.4 Immediately after compaction, carefully dismantle the mould and remove the specimen onto a smooth, rigid wood or sheet metal pallet.

NOTE — A suggested method for removing the specimen from the mould is to remove first the top and then the sides and end plates of the mould. The specimen is then resting on the bottom plate of the mould. The flat face of a carrying pallet is then placed against one side of the specimen and then the bottom mould plate, the specimen, and the pallet are rotated 90° so that the specimen rests on its side on the pallet. The bottom mould plate is then carefully removed.

4.4 Curing the Specimens — Cure the specimens on pallets in the moist room and protect from free water for the specified moist curing period. Generally the specimen will be tested in the moist condition directly after removal from the moist room.

NOTE — Other conditioning procedures, such as soaking in water, air drying or oven drying, alternate wetting and drying, or alternate freezing and thawing, may be specified after an initial moist curing period. Curing and conditioning procedures shall be given in detail in the report.

4.4.1 Flexural test of moist cured specimens shall be made as soon as practicable after removing from the moist room, and during the period between removal from the moist room and testing, the specimens shall be kept moist by a wet burlap or blanket covering.

4.5 Report — The report on the preparation of specimens shall include the following:

- Gradation of soil as received and as used in making specimens,
- Specimen identification number,
- Designed moisture content,
- Designed oven-dry density,
- Designed cement content,
- Actual moisture content,
- Actual oven-dry density,
- Actual cement content, and

j) Details of curing and conditioning periods.

5. PROCEDURE FOR FLEXURAL TEST

5.1 Turn the specimen on its side with respect to its moulded position (with the original top and bottom surfaces as moulded perpendicular to the testing machine bed) and centre it on the lower half-round steel supports, which shall have been spaced apart a distance of three times the depth of the beam. Place the load applying block assembly in contact with the upper surface of the beam at the third point between the supports. Carefully align the centre of the beam with the centre of thrust of the spherically seated head block of the machine. As this block is brought to bear on the beam-loading assembly, rotate its movable portion gently by hand so that uniform seating is obtained.

5.2 Apply the load continuously and without shock. A screw power testing machine, with the moving head operating at approximately 1.2 mm/min, when the machine is running idle, may be used. With hydraulic machines, adjust the loading to such a constant rate that the extreme fibre stress is within the limits of $7 \pm 0.4 \text{ kg/cm}^2/\text{min}$. Record the total load at failure of the specimen to the nearest 5 kg.

6. MEASUREMENTS OF SPECIMENS AFTER TEST

6.1 Make measurements to the nearest 0.2 mm to determine the average width and depth of the specimens at the section of failure.

7. CALCULATIONS

7.1 If the fracture occurs within the middle third of the span length, calculate the modulus of rupture as follows:

$$R = \frac{Pl}{bd^2} \text{ (weight of beam neglected)}$$

$$R = \frac{l}{bd^2} \left(P + \frac{3}{4} W \right) \text{ (weight of beam taken into account)}$$

where

R = modulus of rupture in kg/cm^2 ,

P = maximum applied load in kg,

l = span length in cm,

b = average width of specimen in cm,

d = average depth of specimen in cm, and

W = weight of the specimen in kg.

7.2 If the fracture occurs outside the middle third of the span length by not more than 5 percent of the span length, calculate the modulus of rupture as follows:

$$R = \frac{3Pa}{bd^2}$$

where

a = distance between line of fracture and the nearest support measured along the centre line of the bottom surface of the beam (as tested).

8. REPORT

8.1 The report shall include the following:

- a) Specimen preparation details in accordance with 4.5;

- b) Specimen identification number;
- c) Average width and depth at section of failure to the nearest 0.2 mm;
- d) Maximum load, to the nearest 5 kg;
- e) Modulus of rupture calculated to the nearest 0.5 kg/cm²;
- f) Defects, if any, in specimen;
- g) Age of specimen; and
- h) Moisture content at time of test.

*Indian Standard***METHODS OF TEST FOR STABILIZED SOILS****PART 7 DETERMINATION OF CEMENT CONTENT OF CEMENT STABILIZED SOILS**

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization is the chemical or mechanical treatment designed to increase or maintain the stability of mass of soil or otherwise to improve its engineering properties. There are several methods of stabilization and these may be broadly classified on the basis of treatment given to the soil (for example, dewatering and compaction), process involved (for example; thermal and electrical) and additives employed (for example, asphalt and cement). The choice of a particular method depends on the characteristics of the problem on hand and on the nature of soil type encountered. For studying in the laboratory the methods and effects of stabilization, certain standard methods of test for the evaluation of properties of stabilized soils and their analysis are required. The required standards on methods of test for stabilized soils are being published in parts and this part lays down the method of test for determining cement content of cement stabilized soils.

1. SCOPE

1.1 This standard (Part 7) lays down the method of test for determining cement content of cement of stabilized soils.

2. APPARATUS

- 2.1 Analytical Balance** — sensitive to 0.001 g.
- 2.2 Glass Beakers** — three of 250-ml capacity and two of 600-ml capacity.
- 2.3 Glass Funnel** — 6 cm diameter.
- 2.4 Burette** — one, 50 ml.
- 2.5 Pipette** — 25 ml.
- 2.6 Conical Flasks** — two of 250-ml capacity.
- 2.7 Filter Papers** — Whatman No. 41 and 42 or equivalent.
- 2.8 Heating Equipment**
- 2.9 Drying Oven**
- 2.10 Sieves** — 40-mm, 20-mm, 4.75-mm and 425-micron IS Sieves conforming to the requirements of IS: 460 (Part 1)-1978.

3. REAGENTS

3.0 Quality of Reagents — Unless specified otherwise, pure chemicals and distilled water (*see* IS: 1070-1960) shall be used in tests.

NOTE — 'Pure chemicals' shall mean chemicals that do not contain impurities which affect the results of analysis.

3.1 Potassium Permanganate Solution — N/10; dissolve 3.2 to 3.25 g of potassium permanganate on a watch-glass and dissolve in one litre of distilled water. Heat the solution to boiling and allow the solution to cool to room temperature. Filter the solution through a funnel containing a plug of purified glass wool. The solution should be stored in a glass stoppered bottle and kept in dark and its exact normality ascertained with standard oxalic acid solution.

3.2 Oxalic Acid — N/10; weigh 1.575 g of $\text{H}_2\text{C}_2\text{O}_4\text{H}_2\text{O}$ and make up to 250 ml in a volumetric flask.

3.3 Sulphuric Acid — 2 N; add 12.5 ml of pure sulphuric acid to 240 ml of water.

3.4 Ammonium Nitrate — Dissolve 20 g of ammonium nitrate in one litre of water.

3.5 Hydrochloric Acid — 2 N; sp gr 1.19 mixed with equal volume of distilled water.

3.6 Ammonium Oxalate — saturated solution.

3.7 Ammonium Hydroxide — sp gr 0.89. Mix ammonium hydroxide and distilled water in the ratio of 1:2 (one part of ammonia and two parts of distilled water).

3.8 Calcium Chloride Solution — Dissolve one part by weight of salt in 100 parts by weight of distilled water.

4. SAMPLES

4.0 Samples given in **4.1** to **4.3** shall be selected for the test as given in IS: 4332 (Part 1)-1967.

4.1 Raw Soil — representative of the soil phase of the soil-cement mixture.

NOTE — The results of this test are very sensitive to the variation of calcium content in soil. Hence, due attention should be paid to sampling to obtain representative samples and the number of samples to be tested.

4.2 Cement — representative of the cement phase of the soil-cement mixture.

4.3 Soil-Cement — representative sample of the mixture to be analyzed.

5. PROCEDURE

5.1 Dry 25 g of each sample in the drying oven at $110 \pm 5^\circ\text{C}$ to a constant weight. Pulverize the samples to pass through a 425-micron IS Sieve.

5.2 Weight out separately on analytical balance raw soil, 5 g; and cement, 1 g. Transfer each of the weighed samples to separate 250-ml beakers. Add 50 ml of hydrochloric acid (2N) to each sample. Cover it and boil gently on a hot-plate for 5 min.

5.3 To each of the beakers add 25 ml of hot distilled water and filter the contents through Whatman No. 42 filter paper and receive each filtrate in a 250-ml volumetric flask separately. The material on the filter should be washed with small amounts of hot water repeatedly till free from chloride ions (about 4 times) (check with silver nitrate solution).

5.3.1 Take a small quantity of filtrate (say 1 cc) obtained from the soil-cement mixture treated by hydrochloric acid and add 3 cc of ammonium molybdate reagent and a few drops of concentrated nitric acid and warm to 40°C . A yellow precipitate indicates the presence of phosphate ions.

5.4 After completion of washing, discard the filter paper and dilute the filtrate in the volumetric flask to 250 ml with cold water. Shake the contents well and remove a 50-ml aliquot and transfer to the original 250-ml beaker (see 5.2) using 25-ml pipette. Dilute to 100 ml. Add a few millilitres of bromine water or a few drops of concentrated nitric acid. Boil, cool and make the solution slightly ammoniacal with ammonium hydroxide. Boil for two minutes and allow the hydroxide to settle.

5.4.1 In case of soil-cement mixture containing phosphate, dissolve the precipitates of hydroxides in the minimum quantity of dilute hydrochloric acid. To the main solution, add dilute ammonia solution drop by drop with stirring, until either a faint permanent precipitate is just obtained or the solution is just alkaline. Then add 2 to 3 ml of dilute acetic acid (1:1) and 10 ml of 3N ammonium acetate solution. Discard any precipitate which may form at this stage. If the solution is red, sufficient ferric ion is present in the solution combined with all the phosphate ions. If the solution is not red in colour, add neutral ferric chloride (FeCl_3) solution, drop by drop and with stirring until the solution acquires a deep brownish red colour. Dilute the solution to 150 ml with hot water, boil gently, filter hot and

wash the residue with a little boiling water. The residue will contain the phosphates of Fe, Al and Cr and may be discarded. Boil down the filter to 20 to 25 cc and proceed as given in 5.6.

5.5 Filter hydroxides except soil-cement mixture containing phosphates for which the process of separation has been given in 5.4.1 through Whatman No. 41 filter paper, receiving filtrate in a 600-ml beaker. Wash the original 250-ml beaker into the filter once with a stream of ammonium nitrate and then with hot ammonium nitrate twice. Set aside the filtrate and place original beaker under funnel. Perforate the paper with a rod and wash the hydroxides into the original beaker with hot ammonium nitrate to remove most of the precipitate from the filter paper. Treat the paper with 2 ml of hot hydrochloric acid (1:3). Wash the paper several times with hot water and then discard the paper. Dilute the solution to 75 ml.

5.6 Make the solution slightly ammoniacal with constant stirring and boil for 1 to 2 minutes. Allow the precipitate to settle and filter through Whatman No. 41 filter paper. Receive the filtrate in 600-ml beaker (see 5.5). Wash the precipitate with ammonium nitrate three to four times. Discard the hydroxide precipitate. Add 2 to 3 drops of methyl red indicator and ammonium hydroxide (sp gr 0.89) to the filtrate till the colour changes from faint pink to yellow ($\text{pH} = 5$, optimum for calcium oxalate precipitation). Heat the solution to boiling and add 10 ml of hot saturated ammonium oxalate solution. Keep the mixture near boiling until the precipitate becomes 'granular', then set aside on a warm hot-plate for 30 min or more. Check the completeness of precipitation. Filter off calcium oxalate precipitate through Whatman No. 42. Clean the beaker with rubber policeman and transfer the contents to the filter with a stream of hot water. Wash the filter 8 to 10 times with hot water or preferably four times each with ammonium hydroxide (2:98) to make sure that soluble oxalates are completely removed. This can be checked with calcium chloride solution.

NOTE — Calcium content in the soil-cement mixture may also be determined by rapid method given below:

Filter the acid solution (see 5.4), wash and make up to 100 ml of which 50 ml are just neutralized with liquid ammonia. Dissolve the precipitates of aluminium oxide and ferric oxide thus formed by just the quantity of glacial acetic acid required for dissolving the precipitates. Then add in excess saturated solution of ammonium oxalate to the solution to form a copious precipitate of calcium oxalate. Filter off calcium oxalate precipitate, wash with hot water till free from oxalates. Dissolve the oxalates in (1:4) sulphuric acid and titrate with standard potassium permanganate solution to determine the percentage of calcium.

5.7 Open the filter paper carefully and wash the precipitate into the beaker in which the precipitation was affected. Dilute to 200 ml and add 10 ml of sulphuric acid (1:1).

5.8 Heat the aliquot portion (5.7) to 65°C on a water-bath maintained at 60 to 65°C and titrate it with standard potassium permanganate solution to a persistent pink colour for 10 seconds. Take two more readings. Five times the average value is the reading P as in 6.1.

5.9 Blank — Make a blank determination, following the same procedure using same amount of reagents.

6. CALCULATIONS

6.0 Cement Content of the Soil — Cement mixture should be calculated as given in 6.1 and 6.2.

6.1 Calculate the percentages of calcium oxide in the soil, the cement and the soil-cement mixture as follows:

Percentage of calcium oxide =

$$\frac{(P-Q) R \times 0.028}{S} \times 100$$

where

P = ml of potassium permanganate solution required for titration of the sample;

Q = ml of potassium permanganate solution required for titration of the blank;

R = normality of the potassium permanganate solution = 0.1;

S = weight of sample represented by the aliquot titrated, in g; and

0.028 = calcium oxide equivalent of 1 ml of 1N potassium permanganate.

6.2 Calculate the percentage by weight of cement in the soil-cement mixture as follows:

$$\text{Percentage cement} = \frac{(X - Y)}{Z} \times 100$$

where

X = percentage of calcium oxide in soil-cement mixture,

Y = percentage of calcium oxide in raw soil, and

Z = percentage of calcium oxide in cement.

NOTE — When hydrated soil-cement mixtures (that is, mixtures prepared and laid sometime earlier) are analyzed, the value of percentage by weight of cement obtained is in terms of hydrated cement. Such values need to be converted to an approximate equivalent of dry cement, through a factor which is of the order of 1.04.

Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 8 DETERMINATION OF LIME CONTENT OF LIME STABILIZED SOILS

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization, in the broadest sense, is the alteration of any inherent property of a soil to improve engineering performance. The classification of the methods of stabilization is based on the treatment given to the soil (for example, dewatering, compaction, etc), process involved (for example, thermal, electrical, etc) and on additives employed (for example, asphalt, cement, lime, etc). The choice of a particular method depends on the characteristics of the problem on hand. For studying the effectiveness of a stabilization technique under investigation, both in the laboratory and the field, certain standard methods of test are required and these are being published in parts. This part [IS: 4332 (Part 8)-1969] lays down the method for the determination of lime content of lime stabilized soils.

1. SCOPE

1.1 This standard (Part 8) covers the determination of the proportion by weight of the lime present in a lime stabilized soil. It is done by comparing the combined calcium and magnesium contents of the stabilized soil with those of the natural soil and lime, and it is essential that samples of these should all be available. The method is not applicable to soils containing a large or variable amount of calcium or magnesium salts or to soils which also contain cement, and in such cases it may not be possible to determine the lime content by chemical means.

2. DEFINITIONS

2.1 For the purposes of this standard, the following definitions shall apply:

<i>Grading</i>	<i>Definition</i>
Fine-grained soil or soil-lime mixture	90 percent of the soil or soil-lime mixture should pass a 2-mm IS Sieve
Medium-grained soil or soil-lime mixture	90 percent of the soil or soil-lime mixture should pass a 20-mm IS Sieve

Coarse-grained soil or soil-lime mixture 90 percent of the soil or soil-lime mixture should pass a 40-mm IS Sieve

3. APPARATUS

3.1 Thermostatically-Controlled Drying Oven — capable of maintaining a temperature of 105-110°C.

3.2 Balance — readable and accurate to 1 g.

3.3 Balance — readable and accurate to 0.001 g.

3.4 Desiccator — containing anhydrous silica gel.

3.5 Sieves — 40 mm, 20-mm, 12.5-mm, 6.3-mm, 2-mm IS Sieves and 425-micron IS Sieve conforming to the requirement of IS: 460 (Part 1)-1978.

3.6 Volumetric Flasks — four of 500 ml capacity.

3.7 Graduated Measuring Cylinders — one 10-ml, one 25-ml, one 100-ml and one 1 000-ml.

3.8 Sample Dividers — of the multiple slot type (riffle box) having the following widths of openings:

<i>Soil Type</i>	<i>Width of Opening</i>
For fine-grained soils	6 mm
For medium-grained soils	6 mm and 2.5 cm
For coarse-grained soils	6 mm and 5 cm

3.9 Pulverizer — preferably mechanical.

3.10 Glass Weighing Bottles — three, approximately 5 cm high and 2.5 cm in diameter, fitted with ground glass stoppers.

3.11 Plastics Wash Bottle — containing distilled water.

3.12 Glass Funnels — three, approximately 7.5 cm diameter.

3.13 Burettes — one, 50 ml; and two, 25 ml.

3.14 Pipettes — three, 25 ml; and two, 50 ml.

3.15 Conical Flasks — three of 250 ml capacity.

3.16 Volumetric Flasks — six of 250 ml capacity.

3.17 Electric Bench Lamp

3.18 Round or Flat-Bottomed Flasks — two, fitted with reflux condensers, as follows:

- a) For medium-grained soils 500 ml, capacity.
- b) For coarse-grained soils, 1 000 ml capacity.

3.19 Electric Hotplate or Bunsen Burner

4. REAGENTS

NOTE — The reagents shall be of analytical quality.

4.1 EDTA — Dissolve 4 g of disodium dihydrogen ethylenediamine tetra-acetate (also known as EDTA, versene, sequestric acid and complexone) in one litre of distilled water. The exact strength of this reagent need not be known since the calculations are on relative basis.

4.2 Buffer Solution — Dissolve 33.7 g of ammonium chloride in 285 ml of ammonia solution (sp gr 0.880) and dilute to 500 ml.

4.3 Dilute Ammonia Solution (1:4) — Dilute 100 ml of ammonia solution (sp gr 0.880) to 500 ml with distilled water.

4.4 Hydrochloric Acid, 50 Percent Solution — Add 250 ml of concentrated hydrochloric acid to 250 ml of distilled water. (Larger volumes will be required in the case of medium and coarse-grained soils and soil-lime samples.)

4.5 Indicator — Dissolve 0.1 g of metalphthalein (*o*-cresolphthalein dimethylimino diacetic acid), 0.005 g of methyl red and 0.05 g of naphthol green in a few drops of the ammonia solution and dilute to 100 ml with distilled water. This solution should be freshly prepared at least once a week (eriochrome blue black or eriochrome black T prepared by dissolving 0.5 g in 100 ml of methanol may also be used but the end-point is less distinct).

4.6 Ammonium Chloride, 20 Percent Solution — Dissolve 100 g of ammonium chloride in water and dilute to 500 ml (larger volumes will be required in the case of medium and coarse-grained soil and soil-lime samples).

4.7 Red Litmus Papers

5. PREPARATION OF SAMPLE OF THE SOIL-LIME MIXTURE AND NATURAL SOIL

5.1 The bulk sample may, if desired, be roughly broken up and, in order to facilitate further breaking, shall be dried either in air or in the oven at 105-110°C and cooled. It shall then be broken down by crushing or other similar means until the whole sample passes the appropriate sieve. The fine-grained materials shall pass a 2-mm IS Sieve, the medium-grained materials shall pass a 6.3-mm IS Sieve and the coarse-grained materials shall pass a 12.5-mm IS Sieve. Throughout these and all subsequent operations, it is essential that there is no loss of fines of any material.

5.2 The material treated as in 5.1 shall then be divided by successive riffling on the appropriate sample divider to produce a representative sample of the weight indicated below:

<i>Soil Type</i>	<i>Weight of Soil Sample to be Taken</i>
Fine-grained soils	250-300
Medium-grained soils	2 500-3 000
Coarse-grained soils	6 000-6 500

5.2.1 Throughout this and any subsequent operations, the material available for any division shall be thoroughly mixed and all precautions taken to avoid segregation during riffling.

5.3 The representative sample obtained as in 5.2 shall then be oven-dried at 105-110°C for not less than 16 hours and cooled, preferably in a desiccator. The oven-dried material shall be pulverized, using a mechanical pulverizer or any other suitable means so that the whole of the sample passes 425-micron IS Sieve. The oven-dried pulverized material shall then be sub-divided by riffling on a sample divider having a width of opening of 6 mm until a sample weighing approximately 5 g for fine-grained soils, 25 g for medium-grained soils and 50 g for coarse-grained soils is obtained (in the case of the medium- and coarse-grained soil samples, riffling may more conveniently be done on the larger sample dividers but when the size of sample has been reduced to 250 g, the sample divider having a width of opening of 6 mm shall be used). This sample shall be placed in the glass weighing bottle and dried at 105-110°C. The period required for drying may vary with the type of soil and size of sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample at intervals of 4 hours do not exceed 0.1 percent of the original weight of the sample. For practical purposes, 16-24 hours is usually sufficient.

6. ANALYTICAL PROCEDURE

6.1 Analysis of the Prepared Soil and Soil-lime Samples

6.1.1 For soils of low sesquioxide content, where effects of co-precipitation of calcium can be ignored (see Note), the procedure given in 6.1.1(a) to (d) shall be followed.

NOTE — Two procedures are given for extracting the lime from the stabilized soil. Hydrochloric acid is the more effective extractant but with soils of high sesquioxide content it also removes the sesquioxides which may cause interference with the determination of the calcium. Ammonium chloride solution extracts the lime but does not remove the sesquioxide and is, therefore, to be preferred with soils of high sesquioxide content, even though it may take 15 minutes or longer to extract the lime from the sample compared with the 2-3 minutes that hydrochloric acid takes. In general, ammonium chloride should be used in cases where a soil containing no calcium and a high proportion of iron or aluminium has been stabilized with a low proportion of lime

6.1.1.1 Preparation of the acid extracts

- a) *For fine-grained soils and soil-lime mixtures* — The weighing bottle containing 5 g sample of dried soil or soil-lime shall be removed from the oven, cooled in the desiccator and weighed to the nearest 0.001 g. The sample shall then be transferred to a 250-ml conical beaker, the weighing bottle re-weighed and the weight of the soil or soil-lime sample (W) calculated by difference. Fifty millilitres of 50 percent hydrochloric acid shall then be added and the beaker covered with a cover glass and the contents brought to boil. After boiling for one minute, the beaker shall be removed and allowed to cool. The contents of the beaker shall then be quantitatively transferred through a glass funnel to a 250-ml volumetric flask, care being taken that no solid material remains in the beaker, and the volume adjusted to 250 ml with distilled water. The flask shall be shaken and the suspension shall then be allowed to settle for a few minutes. A 50-ml aliquot shall be removed with a pipette and transferred to another 250-ml volumetric flask.
- b) *For medium-grained soils and soil-lime mixtures* — The weighing bottle containing the 25 g sample of dried soil or soil-lime shall be removed from the oven, cooled in the desiccator and weighed to the nearest 0.001 g. The sample shall then be transferred to a dry, 500-ml, round-bottomed or flat-bottomed flask, the weighing bottle re-weighed and the weight of soil or soil-lime (W) calculated by difference. Exactly 250 ml of 50 percent hydrochloric acid shall be added from a volumetric flask to the flask which shall be fitted with a tight-fitting reflux condenser, and the solution boiled for about five minutes. After the contents of the flask have ceased to boil, exactly 250 ml of distilled water shall be added and the contents of the flask mixed by shaking. 25 ml of this solution after cooling shall be removed with a pipette and transferred to a 250-ml volumetric flask.
- c) *For coarse-grained soils and soil-lime mixtures* — The procedure given in (b) shall be followed except that a 1 000-ml flask containing 500 ml of 50 percent hydrochloric acid shall be used and this solution after cooling shall be removed with a pipette and transferred to a 250-ml volumetric flask.
- d) *For the lime* — About 1 g of lime shall be placed in a weighing bottle and dried at 105–110°C. The sample shall be deemed to be dry when the differences in successive weighings

of the cooled sample at intervals of 4 hours do not exceed 0.1 percent of the original weight of the sample. The procedure given in 6.1.1.1(a) shall be followed, except that 10 ml of 50 percent hydrochloric acid and 25 ml of distilled water shall be used for the digestion and a 25 ml aliquot portion of the 250 ml solution retained for analysis.

- 6.1.2 For soils of high sesquioxide content where co-precipitation of calcium occurs, the procedure given in 6.1.1.1(a) to (d) shall be followed except that a 20 percent solution of ammonium chloride shall be used in the place of 50 percent hydrochloric acid as the extractant. The soil-lime mixtures, the soils and the lime samples shall be boiled with the appropriate quantity of ammonium chloride solution until no further evolution of ammonia occurs. This may be checked by holding a moistened red litmus paper over the mouth of the beaker; the paper will turn blue if ammonia is still being evolved. Care shall be taken during boiling to ensure that the solution is not boiled dry, and if necessary additional water shall be added to prevent this occurring.**

- 6.2 Analysis of the Acid or Ammonium Chloride Extracts** — A small piece of red litmus paper shall be dropped into each volumetric flask and dilute ammonia solution shall be added (preferably from a burette) until the litmus changes from red to blue (this may not be necessary if ammonium chloride was used as the extractant). After the addition of the ammonia solution, the volume of the suspension shall be adjusted to exactly 250 ml with distilled water and the contents of the flask thoroughly mixed by shaking. The flask shall then be set aside until the precipitate has settled to the bottom. When the precipitate has settled, 50 ml of the clear supernatant liquid shall be removed by means of a pipette, and placed in a 250-ml conical flask or beaker. Add 2 ml of the buffer solution and 3 or 4 drops of the indicator. The EDTA solution shall then be added from the 50 ml burette until the colour changes from pale purple to colourless and then to pale green (metalphthalein indicator) or from pink to blue (eriochrome indicator) (see Note). The volume of EDTA required shall be noted to the nearest 0.05 ml (V).

NOTE — The colour change of the metalphthalein indicator is from purple to grey or colourless and then to green. The end point is best observed in artificial light. It is advisable to carry out practice titrations in order to obtain experience of the colour change at the end-point. If eriochrome is used, the colour change is from pink to blue; the actual end-point occurs when all traces of pink colour have disappeared when the solution is viewed in artificial light.

7. CALCULATIONS

- 7.1** The lime content shall be calculated as given in 7.1.1.

7.1.1 The volume of EDTA solution which would be required to neutralize the calcium and magnesium in 1 g of soil (X ml), 1 g of the uncarbonated soil-lime (Y ml) and 1 g of lime (Z ml) shall be calculated from the following formula:

- a) For fine-grained soil or soil-lime samples,

$$X \text{ or } Y = \frac{25V}{W} \text{ ml}$$

where

V = volume of EDTA solution required in titration (ml), and

W = weight of prepared oven-dry soil or soil-lime sample (g).

- b) For medium or coarse-grained soil or soil-lime samples,

$$X \text{ or } Y = \frac{100V}{W} \text{ ml}$$

- c) For lime samples,

$$Z = \frac{50V}{W} \text{ ml}$$

where

W = weight of prepared oven-dry lime sample (g).

- d) The lime content of an uncarbonated soil-lime sample (C_1) (see Note), expressed as a per-

tage of the weight of soil-lime, shall be calculated from the formula:

$$C_1 = \frac{100(Y - X)}{Z - X} \text{ percent}$$

- e) The lime content of the uncarbonated soil-lime sample (C_2) (see Note), expressed as a percentage of the dry soil weight, shall be calculated from the formula:

$$C_2 = \frac{100C_1}{100 - C_1} \text{ percent}$$

NOTE — A soil-lime mixture may, on exposure to air, increase in weight due to the carbonation of the lime present. To allow for this weight increase in calculating the lime content of a mixture which has carbonated, it is necessary to know the calcium and carbonate contents of the natural soil, the soil-lime mixture and the lime. In addition, if appreciable amounts of magnesium are present in either the soil or the lime, it is also necessary to know the magnesium contents of the natural soil, the soil-lime mixture and the lime. Since, however, the error involved in ignoring the weight increase due to the carbonation is in most cases quite small, the lime content for carbonated soil-lime mixtures is usually calculated in the manner described in 7.1 for uncarbonated samples.

7.2 Reporting of Results — The results (C_1 or C_2) shall be reported to the nearest 0.2 percent.

7.2.1 The observations and results of the analysis shall be recorded suitably. A recommended proforma for such a record is given in Appendix A.

A P P E N D I X A
(Clause 7.2.1)

DETERMINATION OF THE LIME CONTENT OF LIME STABILIZED SOIL

Name of job	Operator		
Sample reference	Date		
Location			
Sample No.			
Description of sample			
Weighing bottle number			
Weight of weighing bottle + oven-dry sample in g			
Weight of weighing bottle in g			
Weight of oven-dry sample (W) in g			
Initial burette reading in ml			
Final burette reading in ml			
Volume of EDTA solution titrated (V) in ml			
Soil Sample $\left(X = \frac{25V}{W} \right) \text{ or } \left(X = \frac{100V}{W} \right) \text{ ml}$ (fine-grained soils) (medium- and coarse- grained soils)			
Soil-lime sample $\left(Y = \frac{25V}{W} \right) \text{ or } \left(Y = \frac{100V}{W} \right) \text{ ml}$ (fine-grained soils) (medium- and coarse- grained soils)			
Lime sample $Z = \frac{50V}{W} \text{ ml}$			
Lime content (percentage of the weight of soil-lime) $\left[C_1 = \frac{100(Y - X)}{Z - X} \right] \text{ percentage}$			
Lime content (percentage of the weight of dry soil) $\left[C_2 = \frac{100C_1}{100 - C_1} \right] \text{ percentage}$			

Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 9 DETERMINATION OF THE BITUMINOUS STABILIZER CONTENT OF BITUMEN AND TAR STABILIZED SOILS

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization is the alteration of any property of a soil to improve its engineering performance. There are several methods of stabilization and these may be broadly on the basis of treatment given to the soil (for example, dewatering and compaction), process involved (for example, thermal and electrical) and on additives employed (for example, asphalt and cement). The choice of a particular method depends on the characteristics of the problem on hand. For studying in the laboratory the methods and effects of stabilization, certain standard methods of test for the evaluation of properties of stabilized soils and their analysis are required. The required standards on methods of test for stabilized soils are being published in parts. This part (Part 9) lays down the method for the determination of the bituminous stabilizer content of bitumen and tar stabilized soils.

SECTION A TEST WHERE AMBIENT TEMPERATURE DOES NOT EXCEED 30°C

1. SCOPE

1.1 This Section of the standard (Part 9) covers the determination of the proportion by weight of bituminous stabilizer present in a stabilized soil mixture. It is not suitable for use in climatic conditions where the ambient temperature exceeds 30°C because of the high rate of evaporation of the solvent used in the test.

2. GROUPING OF SOIL

2.1 For the purpose of this standard, soils shall be grouped as given below:

Fine-Grained Soils — Soils containing particles over about 90 percent of which pass a 2.36-mm IS Sieve [see IS: 460 (Part 1)-1978].

Medium-Grained Soils — Soils containing particles over about 90 percent of which pass a 20-mm IS Sieve [see IS: 460 (Part 1)-1978].

Coarse-Grained Soils — Soils containing particles over about 90 percent of which pass a 40-mm IS Sieve [see IS: (Part 1)-1978].

3. APPARATUS

3.1 Balance — readable and accurate to 0.001 g.

3.2 Balance — capable of weighing to 250 g, 5 kg and 10 kg, readable accurate to 0.01 g, 0.5 g and 1 g respectively.

3.3 Wide-Mouthed Metal Bottle — of approximately 600 ml, 2500 ml or 7000 ml capacity (as appropriate) with a tight fitting rubber stopper.

3.4 Steel Balls — three of 20 to 25 mm diameter.

3.5 Mechanical Bottle Shaker — preferably giving an end-over-end shaking action at 60 rev/min.

3.6 A 200-ml Carbon Dioxide Flask

3.7 Graduated Measuring Cylinders — 1000 ml, 500 ml and 250 ml.

3.8 Porous Alumina or Porous Porcelain or Sintered Ware Filter Candle — approximately 80 mm long × 30 mm diameter having a pore size 2-4 μ (see Fig. 1).

3.8.1 The filters are converted into enclosed filters by sealing in, to within 12 mm of the bottom end, a length of metal or glass tubing through a cork or metal ring placed in the open top end to act as a support. The tube is sealed in with a cementing paste composed of copper oxide powder (prepared by direct oxidation of copper wire) passing the 425-micron IS sieve and retained on 300-micron IS sieve [see IS: 460 (Part 1)-1978] mixed with phosphoric acid, applied immediately and left for a few hours to dry in air. Other sealing compound, such as plaster of paris mixed with asbestos fibre may be used. Alternatively, the filtration assembly may be replaced with a centrifuge capable of speed up to at least 4000 rev/min when carrying two or more buckets fitted with centrifuge tubes of 50 ml capacity and having a diameter not less than 28 cm from tip of the rotating tubes. The tubes shall be closed with caps.

3.9 Burette — of 50 ml with a two-way tap, connected to the filtering assembly in the manner shown in Fig. 2.

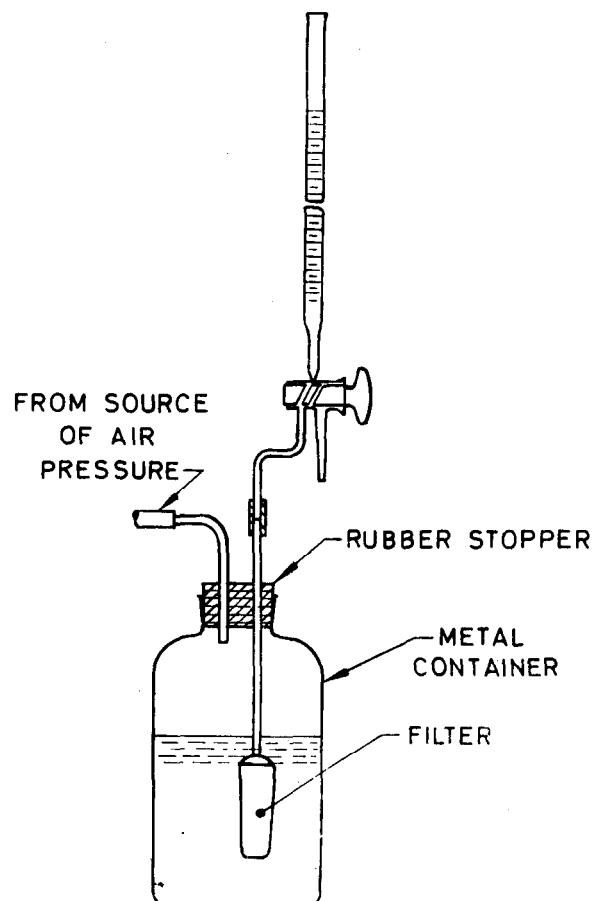
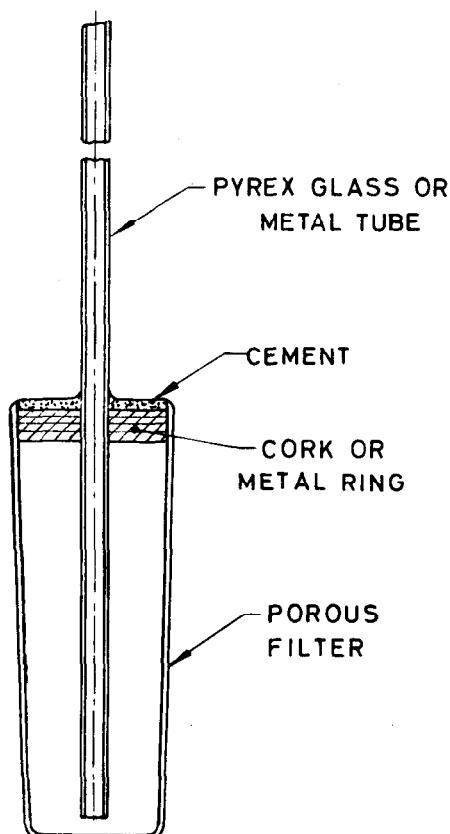


FIG. 1 ASSEMBLY OF FILTER FOR THE DETERMINATION OF THE BITUMINOUS STABILIZER CONTENT OF STABILIZED SOILS

FIG. 2 FILTERING ASSEMBLY FOR THE DETERMINATION OF THE BITUMINOUS STABILIZER CONTENT OF STABILIZED SOILS

3.10 Recovery Apparatus — consisting of a water bath approximately 15 cm diameter, a manometer, a vacuum reservoir and a source of vacuum (see Fig. 3).

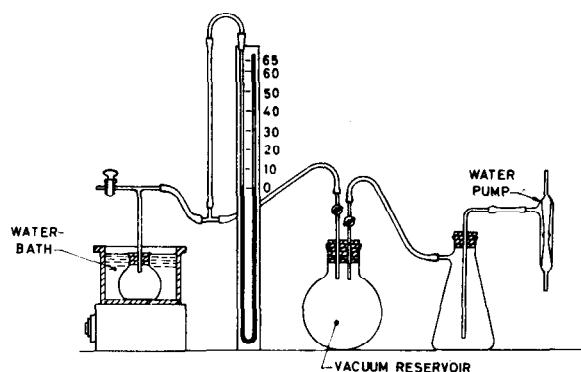


FIG. 3 APPARATUS FOR THE DETERMINATION OF BITUMINOUS STABILIZER CONTENT

3.11 Desiccator — containing anhydrous silica gel.

4. REAGENTS

4.1 The reagents shall be of recognized analytical reagent quality.

- Dichloromethane (methylene chloride)* — 95 percent collected between 39 and 40.5°C.
- Silica gel* — powdered, to pass a 75-micron IS Sieve.

5. PREPARATION OF SAMPLE

5.1 The bulk sample shall be reduced by hand into small pieces, and this may be facilitated if necessary by slight warming. The sample shall then be quartered successively until representative samples of the following weights are obtained:

Fine-grained soils	150-200 g
Medium-grained soils	1 000-1 500 g
Coarse-grained soils	5 000-6 000 g

6. PROCEDURE

6.1 The representative samples of the soil-bituminous stabilizer mixture, obtained as in 5 containing a known weight of water (a g) [which shall be determined in accordance with IS: 4332 (Part 2)-1967] shall be weighed to the nearest 0.01 percent of the weight taken (W) and introduced into a wide-mouthed metal bottle of appropriate capacity. Powdered silica gel shall be added to absorb water, the quantity being equal to half the weight of water present. In the case of fine-grained soils, three steel balls shall then be placed in the bottle to assist in breaking down the mix. A volume of dichloromethane measured to the nearest 0.5 percent of the volume taken (V ml) shall be added to the soil in sufficient quantity to obtain a solution containing 2 to 3 percent of stabilizer. After insertion of the rubber stopper, the bottle shall be shaken for 30 minutes on the mechanical shaker in the case of fine-grained soils and for 60 minutes in the case of medium- and coarse-grained soils.

6.2 A portion of the soil stabilizer solution so obtained shall be filtered through the alumina or porous filter into the burette by the arrangement shown in Fig. 2, or shall be centrifuged. If the solution is to be centrifuged, the centrifuge tubes shall be tightly stoppered to avoid losses due to evaporation. Sufficient quantity of the solution (v ml) shall then be transferred by means of a burette into 200 ml carbon dioxide flask, the weight of which shall be known to the nearest 0.001 g, to give an estimated weight of approximately 0.75-1.25 g of recovered stabilizer. If the first amount obtained lies outside these limits, another suitably adjusted portion of the solution shall be taken. The flask shall then be connected to the vacuum line, the manometer and the reservoir, and placed in a water-bath maintained at 100°C (see Fig. 3). The bulk of the solvent shall be evaporated with the pressure reduced to 500 ± 50 mm Hg, the flask being shaken with a rotary motion during the course of the evaporation. For complete removal of solvent, one of the following procedures shall be adopted.

- a) *For Bitumen Emulsions, Tar Emulsions, or Tars Above 42°C Equiviscous Temperature* — In the last stages of evaporation, when frothing occurs, pressure shall be reduced to 150 mm Hg in $1\frac{1}{2}$ minutes and maintained at this value for a further $3\frac{1}{2}$ minutes.
- b) *For Petroleum Oils, Cut-Back Bitumens or Tars of 42°C Equiviscous Temperature or Below* — In the last stages of evaporation, when frothing occurs, the pressure in the apparatus shall be increased to approximately atmospheric and subsequently lowered to 450 mm Hg in $1\frac{1}{2}$ minutes. This pressure shall be maintained for a further $3\frac{1}{2}$ minutes. The

reduced pressure may conveniently be obtained by a water filter-pump; if this is not available, a suitable mechanical vacuum pump may be used, in which case the following procedures shall be adopted:

The bulk the methylene chloride shall be distilled off before connecting the flask to the vacuum line. To ensure that solvent vapour does not reach the pump, the flask shall be connected to the pump through a reservoir consisting of a flask containing lubricating oil of medium viscosity, followed by a tower containing activated carbon (1.4 mm to 780 microns). The procedure subsequently followed shall be as given in 6.2(a) and (b).

6.3 The flask shall be removed from the water bath and air admitted gently to the apparatus. After wiping the flask, the last trace of dichloromethane shall be removed by means of a gentle air current. The flask shall then be cooled for 5 minutes in a desiccator and weighed to the nearest 0.001 g and the weight of recovered stabilizer (W_1) determined by difference.

6.4 Soluble Portion of Untreated Soil — A test shall be carried out under the same conditions on the untreated soil to determine the quantity (W_2) which may be soluble in dichloromethane, and this shall be deducted from the total soluble content of the stabilized soil. Unless the soil has been previously stabilized with bitumen, however, the soluble portion is usually negligible and may be ignored.

6.5 Insoluble Portion of Stabilizer — Bitumens are generally completely soluble in dichloromethane, but some petroleum stabilizing oils may contain wax which is insoluble; similarly, certain naturally occurring bitumens may contain insoluble mineral matter. Refined tars also contain a proportion of material insoluble in dichloromethane.

In such cases, allowance shall be made for the insoluble portion in the calculation of the total stabilizer content. The insoluble matter shall be determined by dissolving a representative portion of the stabilizer in dichloromethane and filtering through a Gooch or sintered silica crucible or a filter paper. The percentage of soluble stabilizer (P) shall then be calculated.

NOTE — For general principles of determination of insoluble matter, see IS : 1215-1978 'Specification for determination of matter insoluble in toluene (first revision).'

7. CALCULATIONS

7.1 The stabilizer content (S_1) of the mixture shall be calculated from the formula:

$$S_1 = \frac{100 (W_1 - W_2)V}{Wv} \times$$

$$\left[1 + \frac{W_1 - W_2}{\rho v} \right] \frac{100}{P} \text{ percent}$$

where

W_1 = weight of soluble material recovered from aliquot in g;

W_2 = weight of soil soluble in dichloromethane in g;

V = total volume of dichloromethane in ml;

W = weight of sample taken in g;

v = volume of aliquot of dichloromethane digest in ml;

ρ = density of recovered stabilizer (g/cm^3) (when a sample of original stabilizer is not available, an average value of 1.00 for bitumen and 1.175 for tars may be assumed); and

P = percentage of stabilizer soluble in dichloromethane.

7.2 The stabilizer content (S_2), expressed as a percentage of the weight of dry soil, shall be estimated from the formula:

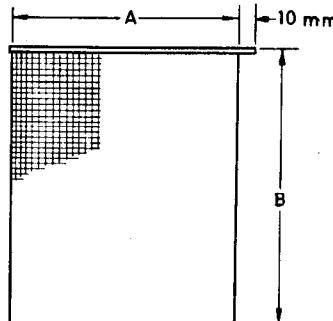
$$S_2 = \frac{100 WS_1}{100 (W-a)-WS_1} \text{ percent}$$

where

a = weight of water present in W g of sample determined as in IS: 4332 (Part 2)-1967.

8. REPORTING OF RESULTS

8.1 The results of the test should be suitably recorded.



A—From 125 mm to 200 mm ϕ as appropriate
B—From 125 mm to 250 mm ϕ

FIG. 4 CYLINDRICAL CONTAINER

8.2 The results shall be expressed as the proportion of stabilizer present to the nearest 0.1 percent.

SECTION B TEST WHERE AMBIENT TEMPERATURE EXCEEDS 30°C

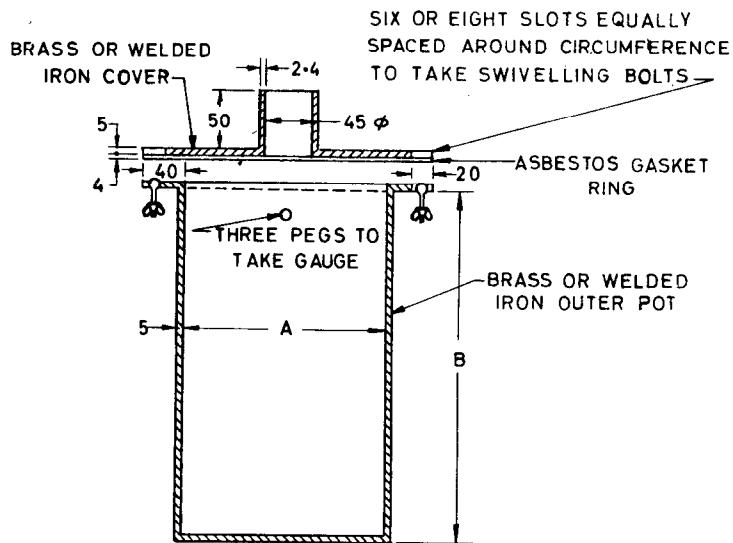
9. SCOPE

9.1 The Section of the standard (Part 9) covers the determination of the proportion by weight of bituminous stabilizer present in a stabilized soil mixture and is suitable for climatic conditions where temperature exceeds 30°C.

10. APPARATUS

10.1 The apparatus shall consist of a hot extractor as shown in Fig. 6 consisting of components as given below:

- a) A cylindrical container (Fig. 4) made from brass gauze of about 3 mm which is rested on or suspended from three pegs inside a brass or welded iron pot (Fig. 5). Alternatively, the brass gauze container may rest on a suitable 'stool' standing in the bottom of the pot. The pot is flanged and fitted with a cover and suitable jointing gasket. The cover is held in position by swivelling bolts fitted with wing nuts. The essential features of construction are indicated in Fig. 4, 5 and 6. It is advantageous to have containers and pots of more than one size, the size employed being appropriate to the quantity of material taken for analysis.



A—From 125 mm to 225 mm ϕ as appropriate
B—From 200 mm to 375 mm ϕ as appropriate

All dimensions in millimetres.

FIG. 5 BRASS OR WELDED IRON POT

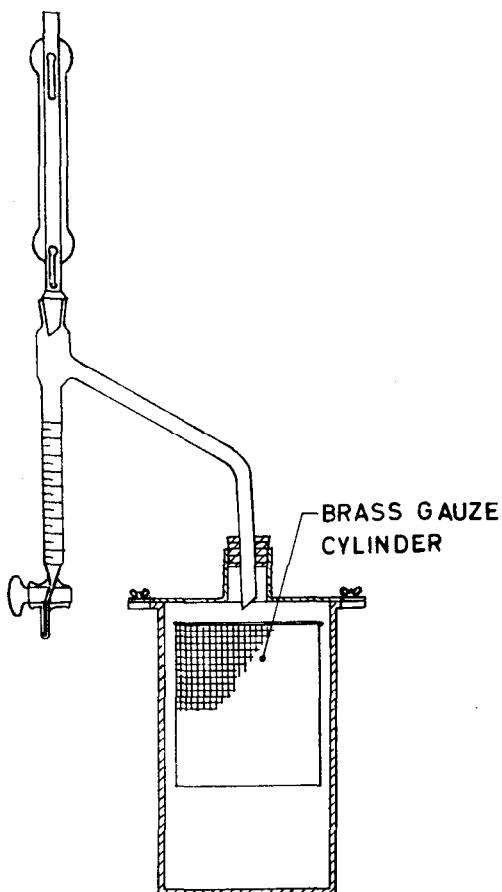
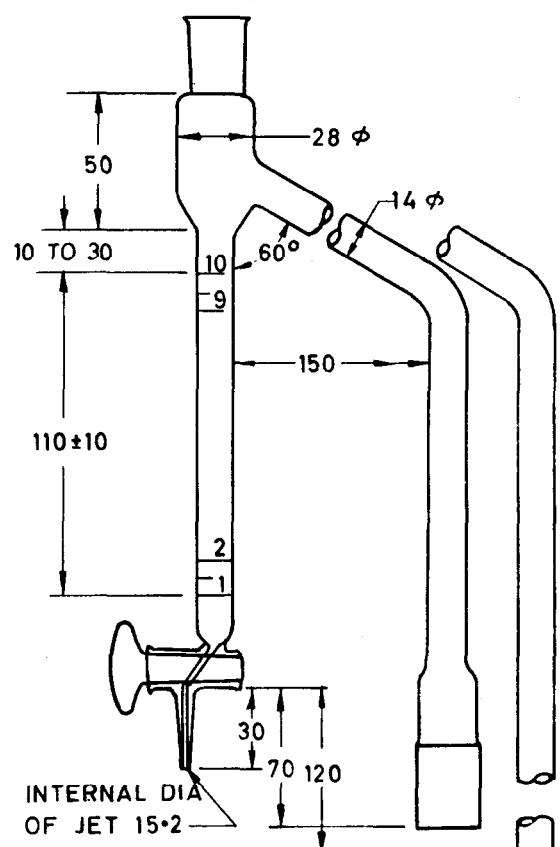


FIG. 6 ASSEMBLED APPARATUS



All dimensions in millimetres.

FIG. 7 10 ml RECEIVER SHOWING ALTERNATIVE CONNECTIONS TO DISTILLATION VESSEL

- b) A graduated receiver conforming to Fig. 7 and an adequate reflux container. There should be a sufficient flow of cold water to condense the solvent.
- c) A suitable heater, such as an electric plate or a gas ring.
- d) Suitable filter paper.

11. SOLVENT

11.1 The solvent shall be pure toluole in accordance with IS: 536-1968.

12. SIZE OF SAMPLE

12.1 The quantities of material taken shall be in accordance with Table 1.

13. PROCEDURE

13.1 The filter paper shall be dried at 100-120°C, placed in a large weighing bottle or jar, cooled in a desiccator and weighed. The filter paper shall then

be fitted into gauze cylinder to form a complete lining. The sample shall be warmed just sufficiently to facilitate breaking up, and a representative portion (see Note) obtained if possible by quartering, and having the weight as indicated in Table 1, shall be weighed to the nearest 0.05 percent of the weight taken and transferred without loss to the filter paper and placed inside the gauze cylinder. Alternatively, the cylinder and its lining may be placed on the balance and the material weighed into it. The gauze cylinder shall then be placed inside the pot and 800-1 500 ml of the solvent, according to the size of the extractor, shall be poured over the sample. The cover shall be bolted on with the dried gasket in position. Water shall be added to the receiver up to or a little beyond the lowest graduation and this quantity subsequently deducted from the total volume of water collected. After fixing the reflux condenser, heat shall be applied to the pot and so adjusted as to avoid intense local heating, but at the same time to ensure a steady reflex action of 2 to 5 drops per second falling from the end of the condenser.

TABLE 1 SIZE OF SAMPLE

(Clause 12.1)

SL. No.	GRADING OF SOIL	MINIMUM WEIGHT FOR EACH DETERMINATION
(1)	(2)	(3)
i)	More than 25 percent retained on a 40-mm IS Sieve	5 000
ii)	Largely retained on 20-mm but not more than 25 percent retained on a 40-mm IS sieve	3 000
iii)	Largely retained on 12-mm but not more than 25 percent retained on a 25-mm IS sieve	2 000
iv)	Largely retained on 6.3-mm but not more than 25 percent retained on a 20-mm IS sieve	1 000
v)	Largely retained on 3.35-mm but not more than 25 percent retained on a 6.3-mm IS sieve	500
vi)	Not more 25 percent retained on a 2.36-mm IS Sieve and not more than 20 percent passing a 75-micron IS sieve	200

NOTE — When quantity for the test exceeds the capacity of the apparatus, the extraction should be carried out in two operations.

13.2 Any water present in the sample will collect in the receiving tube, while the solvent will fill the tube, flow back over the sample and drain through the filter paper to the bottom of the pot.

13.3 If water is removed from the receiver during the extraction, in order to obviate fire risk, the gas flame should be extinguished before doing this.

13.3.1 Heating shall be continued until extraction is complete and water ceases to collect in the receiver.

13.4 The washed mineral aggregate, with its container, shall then be removed and dried to constant weight (see Note) at a temperature of 100-120°C. The cylinder and contents shall be cooled in a desiccator before weighing. In order to correct for any fine material present in the solution at the end of the test, the solvent shall be evaporated off, the residue weighed, and a representative portion of it (between 2 g and 3 g) treated with the solvent and filtered through a sintered silica or glass filtering crucible or filter paper as in the determination of insoluble matter (see IS: 1215-1978). In the case of materials containing natural asphalt or high filler content, the whole of the solution at the end of the test should be filtered or centrifuged.

NOTE — Material shall be deemed to be at constant weight when the difference between successive weighings at half-hourly intervals does not exceed 0.05 percent.

14. CALCULATIONS

14.1 The soluble binder content S shall be calcu-

lated on the dry sample by means of the following formula:

$$S = 100 \frac{W_1 - (W_2 + M + k W_3 / 100)}{W_1 - M} \text{ percent by weight}$$

where

W_1 = weight of undried sample in g,
 W_2 = weight of recovered aggregate in gauze cylinder in g.

M = weight of water collected in test in g,
 k = percent by weight of insoluble matter in residue obtained on evaporating the solvent, and

W_3 = weight in g of residue obtained on evaporating the solvent.

14.2 The total binder content B shall be calculated on the dry sample by means of the following formula:

$$B = \frac{100 S}{T} \text{ percent by weight}$$

where

S = soluble binder content as in **14.1**, and
 T = percent by weight of binder soluble in the solvent employed.

14.3 Reporting of Results — If the difference between the results obtained by the duplicate determination exceeds 0.4, they shall be discarded and the test repeated. If the difference does not exceed 0.4, the individual values and the mean value shall be reported.

Indian Standard

METHODS OF TEST FOR STABILIZED SOILS

PART 10 TEST FOR SOIL-BITUMINOUS MIXTURES

(Incorporating Amendment No. 1)

0. FOREWORD

0.1 Soil stabilization is the alteration of any property of a soil to improve its engineering performance. There are several methods of stabilization and these may be broadly on the basis of treatment given to the soil (for example, dewatering and compaction), process involved (for example, thermal and electrical) and on additives employed (for example, asphalt and cement). The choice of a particular method depends on the characteristics of the problem on hand. For studying in the laboratory the methods and effects of stabilization, certain standard methods of test for the evaluation of properties of stabilized soils and their analysis are required. The required standards on methods of test for stabilized soils are to be published in parts and this part [IS: 4332 (Part 10)-1969] lays down the method for the determination of water absorption, expansion, and extrusion characteristics of compacted soil or soil aggregate moistures containing liquid bituminous material.

1. SCOPE

1.1 This standard (Part 10) covers the determination of water absorption, expansion, and extrusion characteristics of compacted soil or soil-aggregate mixtures containing liquid bituminous material. The method is intended for determining the effects of water on these mixtures. It may also be employed to determine the same characteristics for untreated soil or soil-aggregate mixtures. The results are not intended for use in formulae to determine pavement thickness, nor to predict relative field performance of different bituminous materials as stabilization admixtures.

2. APPARATUS

2.1 Mechanical Mixer — capable of producing intimate mixtures of soil, water and bituminous material.

2.2 Compaction Apparatus — as shown in Fig. 1 and 2 consisting of the parts given in 2.2.1 to 2.2.3 (see Note).

NOTE — The inside diameters of all compaction and extrusion test apparatus and the diameter of the testing end of the test plunger shall be checked periodically to assure adherence to the specified tolerances on dimensions.

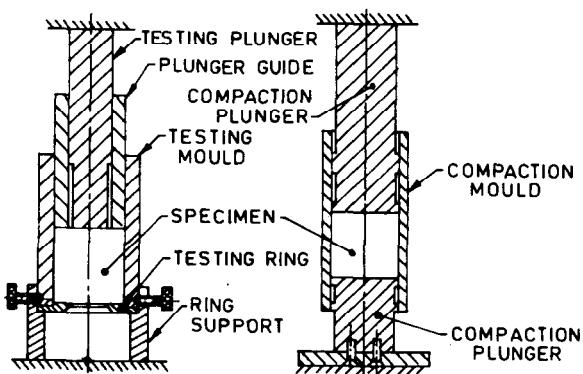
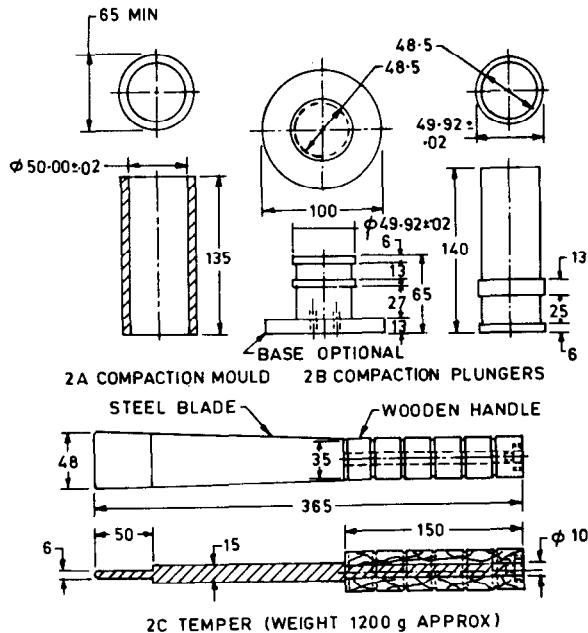


FIG. 1 TESTING ASSEMBLY AND MOULDING ASSEMBLY

2.2.1 Compaction Mould (Fig. 2A) — A cylindrical hardened steel mould having an inside diameter of 50.00 ± 0.02 mm, a length of 135 mm and an outside diameter of 65 mm or greater. The mould shall be equipped with a suitable device to control the specified drop and to protect the top of the mould during precompaction with the tamper (see Note under 2.2).

2.2.2 Compaction Plungers (Fig. 2B) — One hardened steel plunger having a circular face, 49.92 ± 0.02 mm in diameter and a length of 140 mm and one hardened steel plunger having a diameter of 49.92 ± 0.02 mm and a length of 65 mm (see Note under 2.2).

2.2.3 Tamper (Blade Type) (Fig. 2C) — The tamper shall be made of steel and shall have an overall length of 365 mm. For the upper 150 mm, it shall be turned to a steel shank 10 mm in diameter. The flat blade shall be 215 mm in length and shall be 35 mm in width next to the handle and 48 mm in width at the tamping end. The thickness of the flat blade shall be 15 mm at the handle and for a distance of 165 mm below the handle (see Note under 2.2)



All dimensions in millimetres.

FIG. 2 COMPACTION APPARATUS

2.2.3.1 The lower 50 mm of the blade shall be 6 mm in thickness and the tamping edge shall be finished to a rounded edge. The total weight of the tamper shall be approximately 1200 g.

2.3 Water Absorption Apparatus — A corrosion-resistant flat bottom pan approximately 5 cm in depth and a cabinet or moist-room maintained at a temperature between 18 and 27°C, and relative humidity of at least 90 percent.

2.4 Extrusion Test Assembly — The extrusion test assembly shall be as shown in Fig. 3 and shall consist of the parts given in 2.4.1 to 2.4.5 (see Note under 2.2).

2.4.1 Testing Mould (Fig. 3A) — A cylindrical hardened steel mould having an inside diameter of 51.8 ± 0.2 mm at the large end, tapered to an inside diameter of 50.50 ± 0.02 mm at a point 57.5 mm from the bottom continuing at a diameter of 50.50 ± 0.02 mm to the bottom for a total length of 115 mm and having an outside diameter of 75 mm (see Note under 2.2).

2.4.2 Testing Plunger (Fig. 3B) — A cylindrical hardened steel plunger having a diameter of 28.60 ± 0.02 mm on the testing end for a distance of 50 mm and then a diameter of 32.0 ± 0.1 mm for a distance of 100 mm for an overall length of 150 mm (see Note under 2.2).

2.4.3 Plunger Guide (Fig. 3C) — A cylindrical steel guide or sleeve having an outside diameter of 50.2 ± 0.1 mm, and inside diameter of 32.4 ± 0.1 mm and a length of 100 mm (see Note under 2.2).

2.4.4 Testing Ring (Fig. 3D) — A hardened tool steel annular plate 6.5 mm in thickness having a circular opening with a diameter of 28.60 ± 0.02 mm. The cutting edges of the aperture shall be 1.6 mm in thickness and the aperture shall be tapered outward from the cutting edge at an angle of approximately 30 degrees with the vertical. It shall be fitted with a seat 50.45 ± 0.02 mm in diameter and 1.3 mm in height (see Note under 2.2).

2.4.5 Testing Ring Support (Fig. 3E) — A testing ring support of the type shown in Fig. 3E or equivalent, adequate to support other parts of the extrusion test assembly.

2.5 Testing Machine — A loading device of at least 4500 kg capacity, capable of applying load through a uniform motion of the testing head at a rate of 25 mm/min. It shall be fitted with a device for continuously measuring the applied load. It may be equipped with a maximum load indicator.

2.6 Drying Oven — capable of maintaining a temperature of $60 \pm 3^\circ\text{C}$.

2.7 Measuring Device — accurately calibrated and equipped to determine heights and diameters of test specimens to the nearest 0.2 mm.

2.8 Moisture Content Determination Apparatus — conforming to the requirements of IS : 4332 (Part 2)-1967.

2.9 Balances — Two, one having a capacity of 2000 g or more and sensitive to 0.5 g or less, the other having a capacity of 500 g or more and sensitive to 0.05 g or less.

2.10 Sieves — 4.75-mm IS Sieve and 2.00-mm IS Sieve as prescribed in IS: 460 (Part 1)-1978.

2.11 Containers — metal containers with tight-fitting lids for storing and 'aging' mixtures.

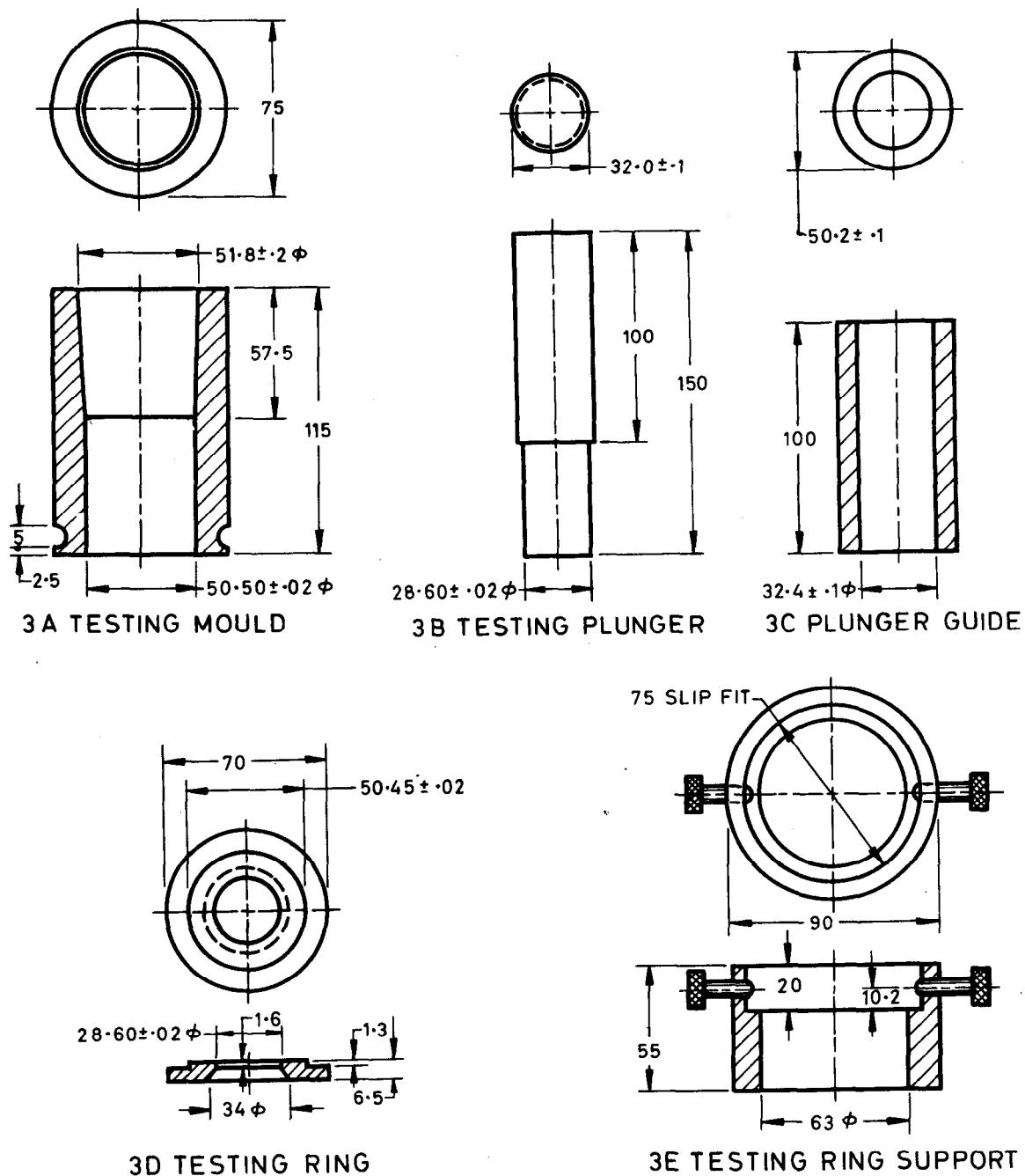
2.12 Miscellaneous Equipment — mixing pans, thermometers, etc.

3. MATERIALS

3.1 Bituminous Material — The bituminous material shall be emulsified asphalt, cut-back or other liquid asphalt or tar, the type and grade to be as specified in accordance with relevant Indian Standards.

4. PREPARATION OF SOIL

4.1 Pulverize the air-dry soil in such a manner as to separate the soil particles without reducing the particle size and screen through a 4.75-mm IS Sieve. Record the percentage retained on the 4.75-mm IS Sieve. Screen the soil passing the 4.75-mm IS Sieve through the 2.00-mm IS Sieve and if soil binder aggregations are retained on the 2.00-mm IS Sieve, further pulverize them to pass the 2.00-mm IS Sieve. Combine and intimately mix the material



All dimensions in millimetres.

FIG. 3 EXTRUSION TEST APPARATUS

passing the 4.75-mm IS Sieve and retained on the 2.00-mm IS Sieve with the material passing the 2.00-mm IS Sieve. Store the soil thus prepared in tightly closed containers. Conduct the water absorption, expansion and extrusion tests on the total material passing the 4.75-mm IS Sieve.

5. MOISTURE CONTENT AND DRY WEIGHT OF SOIL

5.1 Determine the moisture content w , of the air-dried soil by testing 100 g of the prepared soil in the moisture content determination apparatus in accordance with IS: 4332 (Part 2)-1967

5.2 Determine the calculated weight of dry soil in the air-dry soil to be used in the water-absorption, expansion and extrusion tests as follows:

$$W_d = \frac{100W}{100 + w}$$

where

W_d = calculated weight of dry soil in g,

W = weight of air-dry soil in g, and

w = determined moisture content in percent (see 5.1).

6. PREPARATION OF SOIL-STABILIZER MIXTURE

6.1 Tar and Liquid Asphalt

6.1.1 If the addition of water is required, weigh out the air-dried soil, prepared as prescribed in 4.1, in 1000 g portions (calculated on the dry soil basis) to provide sufficient mix material for the required number of test specimens. Place the weighed quantity of soil in the bowl of the mechanical mixer and add the specified amount of water, based upon the calculated dry weight of the soil and with due allowance for the determined moisture present, and roughly distribute it by cutting and stirring the mixture with a stiff knife. Start the mixer and continue mixing for a total mixing period of 5 min stopping when necessary to clean the sides of the mixing bowl and blade. Time spent in scraping the blade and sides of mixing bowl shall not be included in the mixing time. Place the soil-water mixture in a tightly closed metal container and allow to stand for a period of 16 to 24 hours.

6.1.2 Place the aged soil-water mixture or air-dried soil in 1000 g portions (calculated on the dry soil basis) in the bowl of the mechanical mixer. Add the specified amount of bituminous materials into a depression previously made in the prepared soil-water mixture and roughly stir into the mixture by means of a stiff knife. Attach the bowl containing the mixture to the mixer, start the mixer, and continue mixing for a total mixing period of 5 min, stopping when necessary to clean the sides of the mixing bowl and blade. Extra mixing may be performed by hand, if necessary, for an additional 5 min per period, using a rubber-tipped pestle. Place the soil-bituminous mixtures in a tightly closed container and allow to stand for a period of 4 hours. Form the mixture into specimens the same day the mix is prepared.

6.2 Emulsified Asphalt — Weigh out the air-dried soil prepared as described in 4.1 in 1000 g portions (calculated on the dry soil basis) to provide sufficient mix material for the required number of test specimens. Place the weighed quantity of soil in the bowl of the mechanical mixer, start the machine at slow speed and add the specified amount of water to the moving mass. Continue mixing for a total elapsed

period of 5 min, stopping when necessary to clean the sides of the mixing bowl and blade. Time spent in scraping the blade and sides of mixing bowl shall not be included in the mixing time. Add the specified amount of emulsified asphalt to the wetted soil and continue mixing for a minimum of 5 min or a maximum of 10 min so as to produce a mixture having a visual homogeneity. Place the completed mixture in the tared shallow pans and allow it to air-dry to the specified moisture content, with frequent stirring so as to prevent crusting (see Note).

NOTE — With certain soils that have a tendency toward formation of hard clods during drying, special precautions are at times necessary to improve the handling characteristics and uniformity of the mixture during compaction. In such cases, as soon as the consistency of the mixture will permit, it shall be cut with a spatula into dice-like sections having approximately 12 to 15 mm edges. These diced cubes shall be stirred occasionally during drying. When the cubes shall have dried to just below the plastic limit consistency of the soil, they shall be placed in the bowl of the mechanical mixer and mixed until a discrete, uniform, granular mass is obtained. This worked mass shall be placed in tared shallow pans and allowed to continue to air-dry while stirring with a spatula at intervals to the specified moisture content.

6.3 Moisture Content of Mixture — Determine the moisture content w of aged soil-bituminous mixture as a percentage of the dry soil weight in accordance with IS: 4332 (Part 2)-1967.

6.3.1 If the percentage of moisture does not vary from the specified moisture content by more than 0.15, form the soil-bituminous mixture into specimens as described in 7. If the moisture content does not fall within this allowable tolerance, discard the mixture and prepare a new mixture.

7. PREPARATION OF SPECIMENS

7.1 Three specimens shall be prepared for each test result desired, making each test result the average of three readings. Each of the three readings shall be recorded.

7.2 Portions of the soil-bituminous mixture, each sufficient to form specimen 50 mm diameter by 50 ± 1.2 mm in height shall be weighed and formed into specimens as described in 7.2.1 to 7.2.3.

7.2.1 Insert the short compaction plunger approximately 25 mm into the bottom of the compaction mould suitably supported to maintain its position during initial compaction. Place the weighed mixture in the compaction mould.

7.2.2 Obtain initial compaction by 25 blows with the tamper. Allow the tamper to fall freely from a height of 150 mm above the bottom of the specimen being formed and rotate it between application of the blows. Then insert the long compaction plunger into the top of the compaction mould, remove the support for the mould and place the entire assembly (see Fig. 1) in the testing machine.

7.2.3 Obtain final compaction by compressing the specimen at a constant rate of 25 mm/min until

a total load of about 2725 (± 25) kg is indicated. Maintain this load for 2 min. Remove the specimen from the mould, mark the top of the specimen as tamped and weigh, and measure the specimen for average height and diameter. The average height of the specimen shall be 50 ± 1.2 mm. Any specimens not conforming to the specified tolerance shall be discarded.

7.3 Calculate the density as follows, expressed on the basis of calculated weight of dry soil in the specimen, and assuming that no change has occurred in the composition of the mixture during compaction:

$$W_d = \frac{100 W_s}{100 + w + B} \text{ and } \gamma_d = \frac{W_d}{V}$$

where

W_d = calculated weight of dry soil in specimen in g,

W_s = weight of specimen in g,

w = percentage by weight of moisture in mixture moulded into specimens (6.3),

B = percentage by weight of bituminous material in mixture expressed as a percentage of dry soil weight,

γ_d = density of dry soil in g/cm^3 , and

V = volume of specimen in cm^3

8. CURING OF SPECIMENS

8.1 Unless otherwise specified, specimens containing emulsified asphalt shall be tested in the cured state. Prior to testing for moisture absorption, expansion and extrusion value, the specimen shall be cured as specified in 8.1.1 to 8.1.3.

8.1.1 Cure the soil-emulsified asphalt specimens in an oven maintained at $60 \pm 3^\circ\text{C}$ until 80 to 90 percent (unless otherwise specified) of the moisture at the time of moulding has been removed. This point shall be determined on a control specimen chosen from each group of three specimens. At the completion of the curing period, record the weight, average height and diameter of each specimen.

8.1.2 Place the control specimen, after removal from the curing oven in a desiccator for at least 30 min (to reach laboratory temperature) and then weigh. Remove all other specimens at the same time and place in a desiccator arrangement similar to that used for the control specimen, to ensure the same degree of drying.

8.1.3 The curing of specimens shall be conducted only during times when the laboratory is in operation. At times when control checks cannot be carried out, remove all specimens from the oven and place in a sealed container in order to retard further loss in weight.

8.2 Soil-asphalt and soil-tar specimens shall be tested in the uncured state, in the cured state or

both, as specified. If tests on cured specimens of soil-asphalt and soil-tar are required, prior to testing for moisture absorption, expansion and extrusion value, the specimens shall be cured as specified in 8.2.1 to 8.2.3.

8.2.1 Cure the specimens to constant weight in an oven maintained at $60 \pm 3^\circ\text{C}$. Constant weight of a specimen for this purpose shall be defined as that weight at which the loss in weight during a 6 h period in the oven is 0.3 g or less. From each set of three specimens, choose a control specimen for use in determining when constant weight has been obtained.

8.2.2 Place all specimens in an oven maintained at $60 \pm 3^\circ\text{C}$ for an initial curing period of 40 to 42 h after which remove all specimens from the oven, place in a desiccator for at least 30 min to reach laboratory room temperature, and weigh the control specimens. Again place all specimens in the oven and after an interval of 6 h remove, cool to room temperature in a desiccator and weigh the control specimens. Make further weight readings, after 6 h periods in the oven, until the control specimens have been dried to constant weight as defined in 8.2.1. After initial curing period when the last weight readings to be made on a given day have been made, remove all the specimens from the oven and place in a desiccator until the start to the next working day.

8.2.3 When a control specimen has been dried to constant weight, as defined in 8.2.1, remove all specimens represented by that control specimen from the desiccator and record the weight, average height and diameter of each specimen.

9. PROCEDURE FOR WATER ABSORPTION AND EXPANSION TESTS

9.1 The water absorption test shall be performed in an absorption cabinet or moist room maintained at a temperature between 18° and 27°C , and a relative humidity of at least 90 percent. Place the bottom of the specimen as tamped, downward in the water absorption test.

9.2 Place the specimens directly on the bottom of a flat-bottom pan, and adjust the height of distilled water in the pan and maintain at a height of 25 mm above the bottom of the specimens. After seven days, remove the specimens from the absorption cabinet or moist room and remove the free moisture from the surface by quick blotting. Record the weights and average diameters of the bottom of the specimens.

9.3 Calculation of Water Absorption — Calculate water absorption as follows:

$$\text{Water absorption, percent} = \frac{W_2 - W_1}{W_d} \times 100$$

where

W_2 = weight after absorption,

W_1 = weight before absorption, and

W_d = calculated weight of dry soil in specimen.

9.4 Calculation of Expansion — Calculate expansion during absorption as follows:

$$\text{Expansion percent} = \left(\frac{D_2^3}{D_1^3} - 1 \right) 100$$

where

D_2 = average diameter of bottom of specimen after absorption and

D_1 = diameter before absorption.

10. PROCEDURE FOR EXTRUSION TEST

10.1 The extrusion test shall be performed at room temperature on specimens that have been subjected to the water absorption test.

10.2 Assemble the testing cylinder, testing ring and ring support as shown in Fig. 1. After the specimen has been removed from the absorption cabinet, weighed and measured, place it in the testing mould with the face that was down during the absorption test downward. Insert the specimen into the large end of the testing cylinder until seated against the testing ring, gradually forcing it, if necessary, by use

of the compaction plunger. Insert the testing plunger and guide into the large end of the testing mould until resting on top of the test specimen.

10.3 Centre entire test assembly on the platform of the testing machine. Apply load to the test specimen through the testing plunger, which shall move at a constant rate of 25 mm/min. The extrusion value shall be taken as the maximum total load required to cause failure of the test specimen.

11. REPORT

11.1 The following data shall be reported:

- a) Details of soil sample;
- b) Stabilizer used;
- c) Quantity of stabilizer as a percentage of the dry soil weight;
- d) Water, if any, added to the soil as a percentage of the dry soil weight;
- e) Dimensions of each specimen before and after each test; and
- f) Density of the specimens.

11.2 The following data shall also be reported as the average of three determinations:

- a) Water absorption during the absorption test,
- b) Expansion during the absorption test,
- c) Extrusion value after the absorption test, and
- d) Additional data as may be specified.

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SECTION 16
Determination of Sand Equivalent Value of
Solids and Fine Aggregates

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Indian Standard

METHODS OF TEST FOR SOILS

PART 37 DETERMINATION OF SAND EQUIVALENT VALUE OF SOILS AND FINE AGGREGATES

0. FOREWORD

0.1 The term 'sand equivalent' expresses the concept that most granular soils and fine aggregates are mixtures of desirable coarse particles, sand and generally undesirable clay or plastic fines and dust. This test is not intended to replace the test covered by IS: 2720 (Part 4)-1975.

0.2 This test assigns an empirical value to the relative amount, fineness and character of claylike material present in the test specimen. A minimum sand equivalent value may be specified to limit the permissible quantity of claylike fines in an aggregate. This test provides a rapid field method for determining changes in the quality of aggregates during production or placement.

1. SCOPE

1.1 This standard (Part 37) covers the method for the determination of sand equivalent value of soils. This indicates, under standard conditions, the relative proportions of claylike or plastic fines, and dusts in granular soils and fine aggregates that pass 4.75-mm IS Sieve. This method is intended to serve as a rapid field-correlation test.

2. GENERAL PRECAUTIONS

2.1 Maintain the temperature of the working solution at $27 \pm 3^\circ\text{C}$ during the performance of this test.

2.1.1 If field conditions preclude the maintenance of the temperature range, frequent referee samples should be submitted to a laboratory where proper temperature control is possible. It is also possible to establish temperature correction curves for each material being tested where proper temperature control is not possible. However, no general correction curve should be utilized for several materials even within a narrow range of sand equivalent values. Samples that meet the minimum sand equivalent requirement at a working solution temperature below the recommended range need not be subjected to referee testing.

2.2 Perform the test at a location free from vibration. Excessive vibration may cause the suspended material to settle at a greater rate than normal.

2.3 Do not expose the plastic cylinders to direct sunlight any more than is necessary.

2.4 Occasionally it may be necessary to remove a fungus growth from the working calcium chloride solution container and from the inside of the flexible tubing and irrigator tube. This fungus can easily be seen as a slimy substance in the solution.

2.4.1 To remove this growth, prepare a cleaning solvent by diluting sodium hypochlorite solution (household chlorine bleach) with an equal quantity of water.

2.4.2 Fill the solution container with the prepared cleaning solvent, allow about 1 litre of the cleaning solvent to flow through the siphon assembly and irrigator tube, then place the pinch clamp on the end of the tubing to cut off the flow of solvent and to hold the solvent in the tube. Refill the container and allow to stand overnight.

2.4.3 After soaking, allow the cleaning solvent to flow out through the siphon assembly and irrigator tube.

2.4.4 Remove the siphon assembly from the solution container and rinse both with clear water. The irrigator tube and siphon assembly can be rinsed easily by attaching a hose between the tip of the irrigator tube and water faucet and backwashing fresh water through the tube.

2.5 Occasionally the holes in the tip of the irrigator tube may become clogged by a particle of sand. If the obstruction cannot be freed by any other method, use a pin or other sharp object to force it out using extreme care not to enlarge the size of the opening.

3. APPARATUS

3.1 Graduated Cylinder — of transparent acrylic plastic as shown in Fig. 1 having an inside diameter of 32 mm, a height of 430 mm, graduations up to 380 mm at 2 mm intervals, beginning at the bottom, and a rubber stopper to fit in the mouth of cylinder.

3.2 Irrigator Tube — as shown in Fig. 1, made of 6.4 mm outside diameter stainless steel tubing with one end closed to form a wedge-shaped point. Two holes of 1 mm diameter are drilled laterally through the flat side of the wedge near the point.

3.3 Siphon Assembly — as shown in Fig. 1, consisting of a 4-litre bottle, a 5-mm outside diameter copper bent tube 410 mm long, 1220 mm of 3-mm inside diameter rubber tubing (pure gum or equal) with pinch clamp, a blow tube consisting of 50 mm of 5-mm diameter copper tube and 50 mm of 3-mm inside diameter rubber tube (blow hose), and a 2-hole rubber stopper to fit the graduated cylinder specified in 3.1.

3.4 Weighted Foot Assembly — as shown in Fig. 1, consisting of a 6-mm diameter brass rod 445 mm long, threaded on both ends, a brass hexagonal foot of 17.5 mm side by 14 mm diameter, a cylindrical weight of 50 mm diameter and 53 mm height of cold-rolled steel and a nylon sand reading indicator of 28 mm diameter and 15 mm height. The weight is attached to the top end of the rod to give the assembly of the weight, rod and foot a total mass of 1000 ± 5 g. The foot is attached to the lower end of the rod.

3.5 Measuring Can — 90 ± 5 ml capacity.

3.6 Sieve — 4.75-mm IS Sieve, conforming to IS: 460-1962.

3.7 Funnel — wide mouth, for transferring soil into the cylinder.

3.8 4-Litre Bottles — two, to store stock solution and working solution.

3.9 Flat Pan — for mixing.

3.10 Timing Device — reading in minutes and seconds.

3.11 Sand Equivalent Shaker — mechanical or manually operated.

3.11.1 Mechanical — having a throw of 200 ± 1 mm and operating at 175 ± 2 cycles per minute.

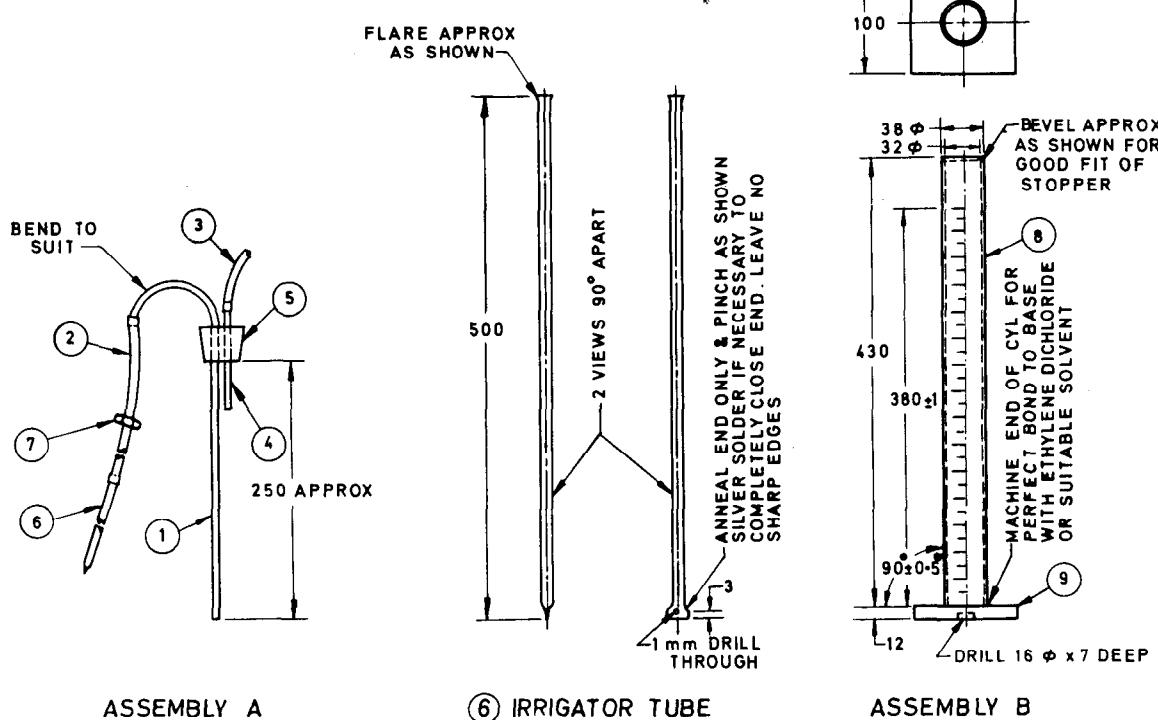
3.11.2 Manually Operated — capable of producing an oscillating motion at a rate of 100 complete cycles in 45 ± 5 seconds, with a hand-assisted half stroke length of 125 ± 5 mm.

4. MATERIALS

4.1 Stock Calcium Chloride Solution — The materials listed below will be required:

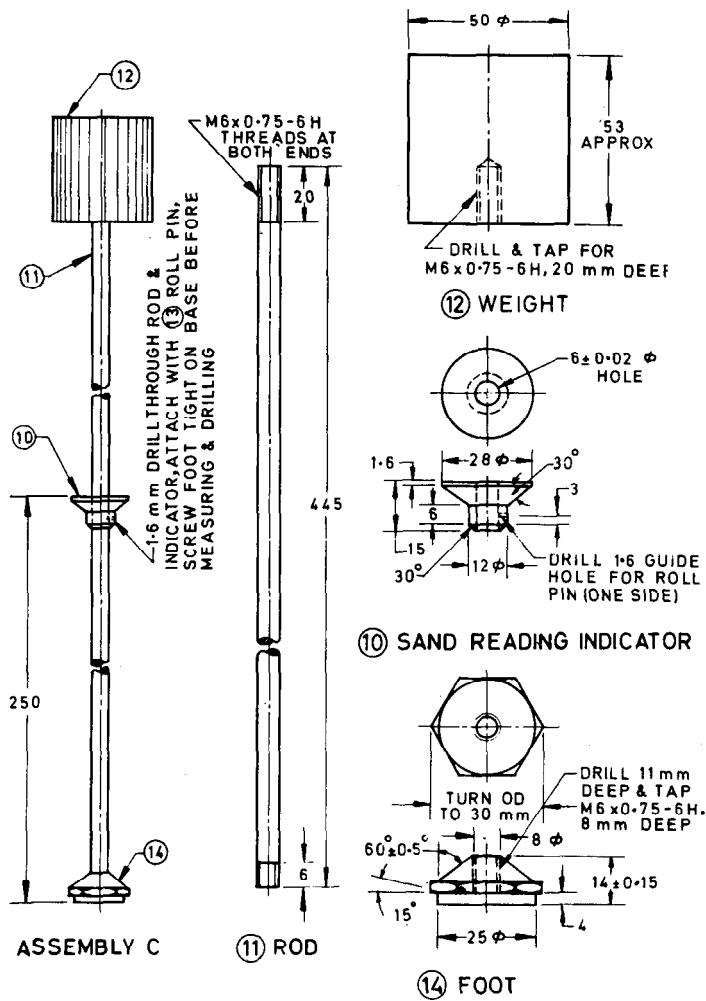
a) 480.4 g of technical grade anhydrous calcium chloride conforming to IS: 1314-1967 'Specification for calcium chloride.'

b) 2 179 g of glycerine (technical grade) conforming to IS: 1796-1961 'Specification for crude glycerine and refined glycerine.'



All dimensions in millimetres.

FIG. 1 SAND EQUIVALENT TEST APPARATUS—*Contd*



All dimensions in millimetres.

FIG. 1 SAND EQUIVALENT TEST APPARATUS

LIST OF MATERIALS

ASSEMBLY	PART NO.	DESCRIPTION	STOCK SIZE, mm	MATERIAL
<i>A Siphon Assembly</i>				
	1	Siphon tube	5 diameter, 410 length	Copper tube (may be plated)
	2	Siphon hose	3 ID, 1 220 length	Rubber tube, pure gum or equivalent
	3	Blow hose	3 ID, 50 length	Rubber tube, pure gum or equivalent
	4	Blow tube	5 diameter, 50 length	Copper tube (may be plated)
	5	2-hole stopper	To fit 4-litre bottle	Rubber
	6	Irrigator tube	6.4 OD wall, 500 length	Stainless steel tube
	7	Clamp	A suitable pinchcock	
<i>B Graduate Assembly</i>				
	8	Tube	38 OD, 450 length	Transparent acrylic plastic
	9	Base	12 × 100 × 100	Transparent acrylic plastic
<i>C Weighted Foot Assembly</i>				
	10	Sand reading indicator	28 diameter, 15 height	Nylon
	11	Rod	6 diameter, 445 height	Brass (may be plated)
	12	Weight	50 diameter, 53 height	Cold rolled steel (may be plated)
	13	Roll pin	1.6 diameter, 12 height	Corrosion-resistant metal
	14	Foot	17.5 hex, 14 height	Brass (may be plated)
	15	Solid stopper	To suit graduated cylinder	Rubber

NOTE 1 — Assembly C — weighted foot assembly should weigh $1\ 000 \pm 5$ g.

NOTE 2 — Graduations on graduate to be in mm. Centimetre marks should be numerically designated

NOTE 3 — Accuracy of scale ± 0.02 mm.

- c) 49.7 g of formaldehyde (40 percent by volume solution) conforming to IS: 3321-1973 'Specification for formaldehyde solution.'

4.1.1 Dissolve 480.4 g of calcium chloride in 2 litres of distilled water. Cool and filter through ready pleated rapid filtering filter paper. Add 2179 g of glycerine and 49.7 g of formaldehyde to the filtered solution, mix well and dilute to 4 litres.

4.2 Working Calcium Chloride Solution — Prepare the working calcium chloride solution by diluting 90 ml of the stock calcium chloride solution to 4 litres with water. Use distilled or demineralized water for the normal preparation of the working solution. However, if it is determined that the local tap water is of such purity that it does not affect the test results, it is permissible to use it instead of distilled or demineralized water.

NOTE — The effect of local tap water on sand equivalent test results may be determined by comparing the results of three sand equivalent tests using distilled water with the results of three sand equivalent tests using the local tap water. The six test specimens required for this comparison shall be prepared from the same sample of material and oven-dried as prescribed in this method.

5. SAMPLE PREPARATION

5.1 Obtain at least 1500 g of material passing 4.75-mm IS Sieve in the following manner.

5.1.1 Separate the sample on the 4.75-mm IS Sieve by means of a lateral and vertical motion of the sieve, accompanied by a jarring action so as to keep the sample moving continuously over the surface of the sieve. Continue the sieving until not more than one percent by mass of the residue passes the sieve during one minute. The sieving operation may be performed either by hand or by a mechanical apparatus. When thoroughness of mechanical sieving is being determined, test by the hand method described above using a single layer of material on the sieve.

5.1.2 Breakdown any lumps of material in the coarse fraction to pass the 4.75-mm IS Sieve. A mortar and rubber-covered pestle or any other means that will not cause appreciable degradation of the aggregate may be used.

5.1.3 Remove any coatings of fines adhering to the coarse aggregate. These fines may be removed by surface-drying the coarse aggregate, then rubbing between the hands over a flat pan.

5.1.4 Add the material passing the sieve as obtained in **5.1.2** and **5.1.3** to the separated fine portion of the sample.

5.2 Prepare test specimens from the material passing 4.75-mm IS Sieve portion of the sample by the procedure described in either **5.2.1** or **5.2.2**.

NOTE — Experiments show that, as the amount of material being reduced by splitting or quartering is decreased, the accuracy of providing representative portions is decreased. For this reason, it is imperative that extreme care be exercised when preparing the test specimens.

5.2.1 Split or quarter enough material to fill four can measures to the brim or slightly rounded above the brim in the following manner.

5.2.1.1 If it appears necessary, dampen the material to avoid segregation or loss of fines during the splitting or quartering operations. Use care in adding water to the sample to retain a free-flowing condition of the material.

5.2.1.2 Using the measuring can, dip out four of these measures from the sample. Each time a measure full of the material is dipped from the sample, tap the bottom edge of the measure on a work table or other hard surface at least four times and jog it slightly to produce a measure of consolidated material level-full or slightly rounded above the brim.

5.2.1.3 Determine and record the amount of material contained in these four measures either by mass or by volume in a dry plastic cylinder.

5.2.1.4 Return this material back to the sample and proceed to split or quarter the material making the necessary adjustments to obtain this predetermined mass or volume. When this mass or volume is obtained, two successive splitting or quartering operations without adjustment should provide the proper amount of material to fill the measure.

5.2.1.5 Dry each test specimen to constant mass at $105 \pm 5^\circ\text{C}$ and cool to room temperature before testing.

NOTE — Sand equivalent results on test specimens that have not been dried will generally be lower than the results obtained on identical test specimens that have been dried. As a time-saving expedient, it is permissible to test most materials without drying when the sand equivalent value is used to determine compliance with a specification giving a minimum acceptable test value. If the resulting test value is lower than that specified, however, it will be necessary to return the test on a dried test specimen. If the sand equivalent, determined from a test on one dried test specimen, is below the minimum specification limit, it will be necessary to perform two additional tests on dried test specimens from the same sample. The sand equivalent for a sample shall be determined in accordance with 8.

5.2.2 Prepare the desired number of test specimens from the sample as follows.

5.2.2.1 Maintaining a free-flowing condition, dampen the material sufficiently to prevent segregation or loss of fines.

5.2.2.2 Split or quarter out 1000 to 1500 g of the material. Mix thoroughly with a hand trowel in a circular pan by scoping toward the middle of the pan while rotating it horizontally. Mixing or remixing should be continued for at least 1 minute to achieve uniformity. Check the material for the necessary moisture condition by tightly squeezing a small portion of the thoroughly mixed sample in the palm of the hand. If a cast is formed that permits careful handling without breaking, the correct moisture range has been obtained. If the material is too dry, the cast will crumble and it will be necessary to add water and remix and retest until the material

forms a cast. If the material shows any free water, it is too wet to test and should be drained and air-dried, mixing it frequently to ensure uniformity. This overly wet material will form a good cast when checked initially, so the drying process should continue until a squeeze check on the drying material gives a cast which is more fragile and delicate to handle than the original. If the 'as received' water content is within the limits described above, the sample may be run immediately. If the water content is altered to meet these limits, the sample should be put in a pan, covered with a lid or with a damp trowel that does not touch the material and allowed to stand for a minimum of 15 minutes.

5.2.2.3 After the minimum curing time, remix for 1 minute without water. When thoroughly mixed, form the material into a cone with a trowel.

5.2.2.4 Take the can measure in one hand and push it directly through the base of the pile while holding the free hand firmly against the pile opposite the measure.

5.2.2.5 As the can travels through the pile and emerges, apply enough hand pressure to cause the material to fill the can to overflowing. Press firmly with the palm of the hand, compacting the material until it consolidated in the can. The excess material should be struck off level with the top of the can, moving the edge of the trowel in a sawing motion across the brim.

5.2.2.6 To obtain additional test specimens, repeat the procedures in **5.2.2.3** to **5.2.2.5**.

6. PREPARATION OF APPARATUS

6.1 Fit the siphon assembly to a 4-litre bottle of working calcium chloride solution. Place the bottle on a shelf 915 ± 25 mm above the work surface.

NOTE — Instead of the 4-litre bottle, a glass or plastic vat having a larger capacity may be used provided the liquid level of the working solution is maintained between 915 and 115 mm above the work surface.

6.2 Start the siphon by blowing into the top of the solution bottle through a short piece of tubing while the pinch clamp is open.

6.3 When using either the mechanical or the manually operated sand equivalent shaker, fasten the apparatus to a firm and level mount.

NOTE — If only a few sand equivalent tests are to be performed at one location, it is possible to hold the manually operated shaker by hand on a firm mount.

7. PROCEDURE

7.1 Siphon 100 ± 2 mm (indicated on the graduated cylinder) of working calcium chloride solution into the graduated cylinder.

7.2 Pour one of the test specimens into the graduated cylinder using the funnel to avoid spillage.

7.3 Tap the bottom of the cylinder sharply on the

palm of the hand several times to release air bubbles and to promote thorough wetting of the specimen.

7.4 Allow the wetted specimen and cylinder to stand undisturbed for 10 ± 1 minutes.

7.5 At the end of the 10-minute soaking period, stopper the cylinder; then loosen the material from the bottom by partially inverting the cylinder and shaking it simultaneously.

7.6 After loosening the material from the bottom of the cylinder, shake the cylinder and contents by any one of the following three methods.

7.6.1 Mechanical Shaker Method — Place the stoppered cylinder in the mechanical sand equivalent shaker, set the time, and allow the machine to shake the cylinder and the contents for 45 ± 1 seconds.

7.6.2 Manual Shaker Method — Secure the stoppered cylinder to the shaker and shake for 100 strokes, with half stroke length of 125 ± 5 mm.

7.6.3 Hand Method

7.6.3.1 Hold the cylinder in horizontal position and shake it vigorously in a horizontal linear motion from end to end.

7.6.3.2 Shake the cylinder 90 cycle in approximately 30 seconds using a throw of 230 ± 25 mm. A cycle is defined as a complete back and forth motion. To shake the cylinder at this speed properly, it will be necessary for the operator to shake with the forearms only, relaxing the body and shoulders.

7.7. Following the shaking operation, set the cylinder upright on the work table and remove the stopper.

7.8 Irrigation Procedure

7.8.1 During the irrigation procedure, keep the cylinder vertical and the base in contact with the work surface. Insert the irrigator tube in the top of the cylinder, remove the spring clamp from the hose, and rinse the material from the cylinder walls as the irrigator is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a gentle stabbing and twisting action while the working solution flows from the irrigator tip. This flushes the fine material into suspension above the coarser sand particles.

7.8.2 Continue to apply a stabbing and twisting action while flushing the fines upward until the cylinder is filled to the 380 mm graduation. Then rinse the irrigator tube slowly without shutting off the flow so that the liquid level is maintained at about the 380 mm graduation while the irrigator tube is being withdrawn. Regulate the flow just before the irrigator tube is entirely withdrawn and adjust the final level to the 380 mm graduation.

7.9 Allow the cylinder and contents to stand undis-

turbed for 20 minutes ± 15 seconds. Start the timing immediately after withdrawing the irrigator tube.

7.10 At the end of the 20-minute sedimentation period, read and record the level of the top of the clay suspension as prescribed in 7.12. This is referred to as the 'clay reading'. If no clear line of demarcation has formed at the end of the specified 20-minute sedimentation period, allow the sample to stand undisturbed until a clay reading can be obtained; then immediately read and record the level of the top of the clay suspension and the total sedimentation time. If the total sedimentation time exceeds 30 minutes, return the test using three individual specimens of the same material. Record the clay column height for the sample requiring the shortest sedimentation period as the clay reading.

7.11 Sand Reading Determination

7.11.1 After the clay reading has been taken, place the weighted foot assembly over the cylinder and gently lower the assembly until it comes to rest on the sand. Do not allow the indicator to hit the mouth of the cylinder as the assembly is being lowered.

7.11.2 As the weighted foot comes to rest on the sand, tip the assembly towards the graduations on the cylinder until the indicator touches the inside of the cylinder. Subtract 250 mm from the level indicated by the extreme top edge of the indicator and record this value as the 'sand reading'.

7.11.3 When taking the sand reading, take care not to press down on the weighted foot assembly since this could give an erroneous reading.

7.12 If clay or sand readings fall between 2-mm graduations, record the level of the higher graduation as the reading.

8. CALCULATIONS

8.1 Calculate the sand equivalent (*SE*) to the nearest 0.1 using the following formula:

$$SE = \frac{S_r}{C_r} \times 100$$

where

S_r = sand reading (see 7.11), and
 C_r = clay reading (see 7.11).

8.2 When the result of this calculation is not a whole number, the sand equivalent (*SE*) shall be the next higher whole number.

Example:

$$SE = \frac{84}{204} \times 100 = 41.2 = 42$$

8.3 If it is desired to average a series of sand equivalent values, average the whole number values determined as described in 8.2.

Example:

Calculated *SE* values 41.2, 43.8, 40.9 (see 8.1). After raising each to the next higher whole number; they become 42, 44, 41 (see 8.2). Average of these values is

$$\frac{42+44+41}{3} = 42.3$$

Since the average value is not a whole number, the sand equivalent value is 43 (see 8.3).

9. PRECISION

9.1 Before an operator is allowed to perform the sand equivalent test, he should be capable of obtaining consistent test results on representative samples of any given material when the test is performed in accordance with the prescribed procedure for the particular method used. An operator's test results are considered to be consistent if the individual results of three test performed by him on representative samples of the same material do not vary by more than ± 4 points from the average of these tests.