IS : 2720 (Part XXXVIII) - 1976

(Reaffirmed 1997)

Indian Standard

METHODS OF TEST FOR SOILS

PART XXXVIII COMPACTION CONTROL TEST (*HILF METHOD*)

(First Reprint MARCH 1987)

UDC 624.131.378

INDIAN STANDARDS INSTITUTION

MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG

NEW DELHI 110002

Gr 7

August 1976

Indian Standard

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PART XXXVIII COMPACTION CONTROL TEST (*HILF METHOD*)

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Indian Standard

METHODS OF TEST FOR SOILS

PART XXXVIII COMPACTION CONTROL TEST (*HILF METHOD*)

0. FOREWORD

0.1 This Indian Standard (Part XXXVIII) was adopted by the Indian Standards Institution on 16 February 1976, after the draft finalized by the Soil Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 The field density tests covered in IS : 2720 (Part XXVIII)-1974*, IS : 2720 (Part XXIX)-1975†, IS : 2720 (Part XXXIII)-1971‡ and IS : 2720 (Part XXXIV)-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 VII)-1974|| and IS : 2720 (Part VIII)-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.

0.2.1 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.

*Methods of test for soils: Part XXVIII Determination of dry density of soils, in-place, by the sand replacement method (*first revision*).

†Methods of test for soils: Part XXIX Determination of dry density of soils in-place by the core-cutter method (*first revision*).

‡Methods of test for soils: Part XXXIII Determination of the density in-place by the ring and water replacement method.

§Methods of test for soils: Part XXXIV Determination of density of soil in-place by rubber-balloon method.

||Methods of test for soils: Part VII Determination of water content-dry density relation using light compaction (*first revision*).

¶Methods of test for soils: Part VIII Determination of water content-dry density relation using heavy compaction (*first revision*).

(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 built of cohesive soils.

0.3 In the preparation of this standard, assistance has also been taken from the following publications:

ASA 89.21-1973 Australian Standard methods of testing soils for engineering purposes: Part V — Soil compaction tests, Test 21. Compaction control test (Hilf method). Standards Association of Australia.

Earth Manual. Designation E-25 Rapid compaction control. US Bureau of Reclamation

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

1. SCOPE

1.1 This standard (Part XXXVIII) 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 VII)-1974† and IS : 2720 (Part VIII)-1974‡ using a 1 000 cm^3 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 XXVIII) - 1974§ and IS : 2720

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

†Methods of test for soils: Part VII Determination of water content-dry density relation using light compaction (*first revision*).

‡Methods of test for soils: Part VIII Determination of water content-dry density relation using heavy compaction (*first revision*).

§Methods of test for soils: Part XXVIII Determination of dry density of soils, in-place, by the sand replacement method (*first revision*).

(Part XXIX)-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 XXVIII)-1974† and IS : 2720 (Part XXIX)-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 VII)-1974‡, or IS : 2720 (Part VIII)-1974§ of volume 1 000 cm^3 (*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 110·00±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 cm^3), 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 VII)-1974‡ or IS : 2720 (Part VIII)-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 VII)-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.

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*Methods of test for soils: Part XXIX Determination of dry density of soils in-place by the core-cutter method (*first revision*).

†Methods of test for soils: Part XXVIII Determination of dry density of soils, in place, by the sand replacement method (*first revision*).

‡Methods of test for soils: Part VII Determination of water content-dry density relation using light compaction (*first revision*).

§Methods of test for soils: Part VIII Determination of water content-dry density relation using heavy compaction (*first revision*).

2.4 Balance — of 10 kg capacity readable and accurate to 5 g (*see* Note).

NOTE — For test using 1 500 cm^3 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 II)-1973*.

2.6 Sieves — 25-mm, 20-mm and 10-mm IS Sieves; 300-mm in diameter and conforming to IS : 460-1962† 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 the 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/cm^3 or less, the drying process can be eliminated by a procedure given in the reference in **0.2.1**.

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.

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

NOTE 1 — A sample yielding 10 kg mass (minimum) passing the specified IS Sieve is usually required when using a mould of 1 000 cm^3 capacity, or 15 kg mass (minimum) when using a mould of 1 500 cm^3 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 climatic 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 VII)-1974* or IS : 2720 (Part VIII)-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 VII)-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 II)-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 cm^3 capacity and 3·7 kg of soil for moulds of capacity 1 500 cm^3. 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 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

$$\frac{(100 + \text{percent change in water content})}{100}$$

*Methods of test for soils: Part VII Determination of water content-dry density relation using light compaction (*first revision*).

†Methods of test for soils: Part VIII Determination of water content-dry density relation using heavy compaction (*first revision*).

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

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 $\frac{\text{wet density}}{1{\cdot}02}$. If, on the other hand, the water content change is $-2{\cdot}5$ percent, that is, the soil has been made drier, then converted wet density is equal to $\frac{\text{wet density}}{0{\cdot}975}$. 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 (page 16) 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).

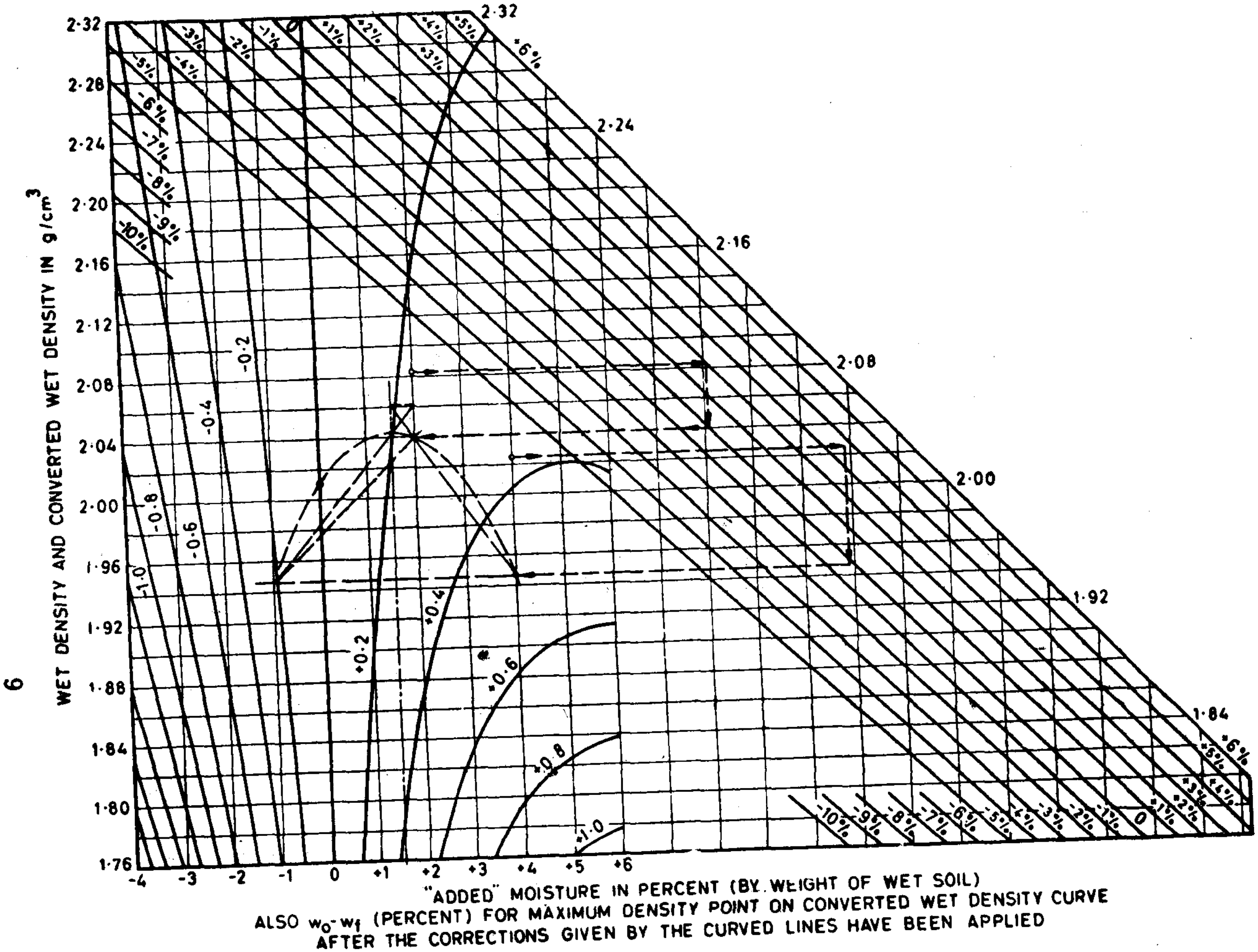
3.4.1 *Point (2) Higher Than Point (1)*—Weigh the appropriate amount of soil at field water content (*see* Note 1 under **3.2**). Add 4 percent of water (by mass of wet soil) (*see* Note under **3.3**), compact into a cylinder in the appropriate manner and determine the wet density. Reduce this wet density 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 (page 20) 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:

Percentage of water loss $=$ (Dried mass of soil $-$ $2{\cdot}50$) $\times$ 40, when moist soil taken is $2{\cdot}50$ kg.

Percentage of water loss $= \left(\frac{\text{Dried mass of soil} \times 3{\cdot}70}{3{\cdot}70}\right) \times 100$, when moist soil taken is $3{\cdot}70$ kg.



Example:

RC = 99·3%

C = 101·0%

$w_o - w_f$ = 1·7% (1·5 from the plot + 0·2 from the moisture correction curves)

Field moisture content. w_f	=	16·5%
Field dry density*	=	1·74 g/cm³
Lab. maximum dry density	=	1·76 ,,
Cylinder dry density	=	1·72 ,,
Optimum moisture content, w_o	=	18·2%†

* 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

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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 (page 23) 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 Solution 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):

a) Designate each point successively from left to right as *A*, *B* and *C*.

b) 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 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 co-ordinates 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 II)-1973*, calculate the field dry density, the cylinder dry density, the laboratory maximum dry density, and the optimum moisture content, as follows:

1) $$\text{Field dry density} = \frac{\text{field wet density}}{\left(1 + \frac{w_f}{100}\right)}$$

2) $$\text{Cylinder dry density} = \frac{\text{wet density of first specimen}}{\left(1 + \frac{w_f}{100}\right)}$$

3) $$\text{Laboratory maximum dry density} = \frac{\text{maximum converted wet density}}{\left(1 + \frac{w_f}{100}\right)}$$

4) $$\text{Optimum moisture content (OMC)} = w_f + \left(1 + \frac{w_f}{100}\right) Z_m$$

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 **0.2.1**.)

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 II)-1973*. Hence, a correction is needed to allow for this fact. The correction curves plotted in Fig. 1 are employed for making the necessary adjustments. These curves are for standard compaction and cover a wide range of soils.

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

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 **0.2.1**.

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 for 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; and

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):

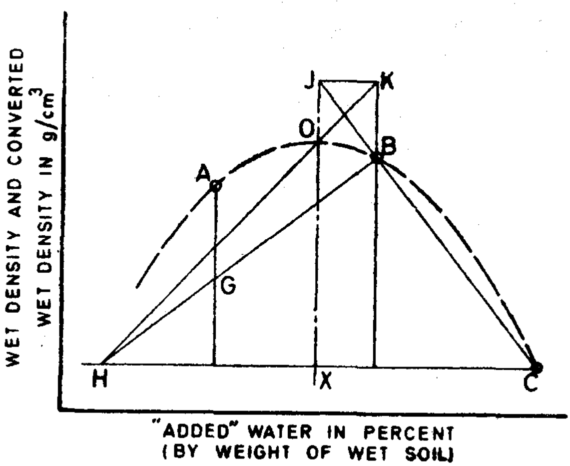

FIG. 2 GRAPHICAL SOLUTION GIVEN THREE POINTS EQUALLY SPACED HORIZONTALLY

a) Draw a horizontal base line through the right point *C*.

b) Find *G*, the mid point on the vertical between the base line and the left point *A*.

c) 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.

d) Find *J*, the intersection of the axis and the extension of *CB*. Project *J* horizontally to *K* on the vertical through *B*.

e) 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):

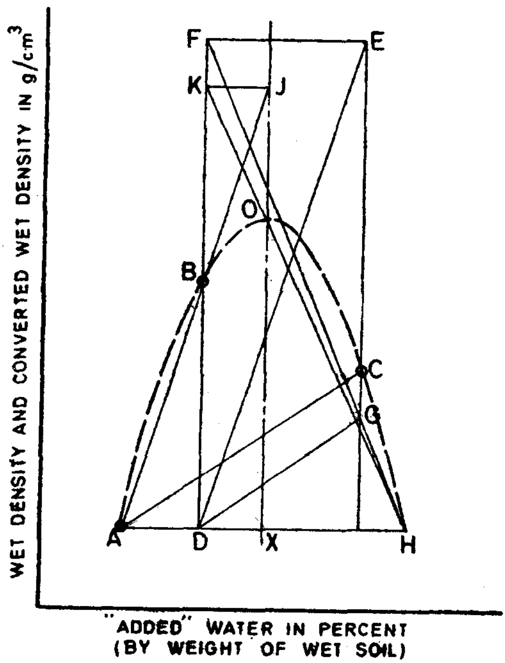

FIG. 3 GRAPHICAL SOLUTION GIVEN THREE POINTS UNEQUALLY SPACED HORIZONTALLY

a) Draw a horizontal base line through the left point *A*. Find *D* on the base line vertically below *B*.

b) Draw *DE* parallel to *AB*. *E* is on the vertical through *C*. Project *E* horizontally to *F* on the vertical through *B*.

c) Draw *DG* parallel to *AC*. *G* is on the vertical through *C*.

d) 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.

e) Find *J*, the intersection of the axis and the extension of *AB*. Project *J* horizontally to *K* on the vertical through *B*.

f) 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.

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 (1)	96 (2)	98 (3)	102 (4)	104 (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

(*Continued*)

TABLE 1 CONVERTED WET DENSITY, GIVEN WET DENSITY AND 'ADDED' MOISTURE — *Contd*

x (1)	96 (2)	98 (3)	102 (4)	104 (5)
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	1·563
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	1·644
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
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

(*Continued*)

TABLE 1 CONVERTED WET DENSITY, GIVEN WET DENSITY AND 'ADDED' MOISTURE — *Contd*

x (1)	96 (2)	98 (3)	102 (4)	104 (5)
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*

x (1)	96 (2)	98 (3)	102 (4)	104 (5)
2·000	2·083	2·041	1·961	1·923
2·005	2·089	2·046	1·966	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

(Continued)

TABLE 1 CONVERTED WET DENSITY, GIVEN WET DENSITY AND 'ADDED' MOISTURE — *Contd*

x (1)	96 (2)	98 (3)	102 (4)	104 (5)
2·200	2·292	2·245	2·157	2·115
2·205	2·297	2·250	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

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		

(*Continued*)

TABLE 2 PERCENTAGE WATER LOSS CORRESPONDING TO MASS OF DRIED SOIL — *Contd*

B. For 3·70 kg of moist soil

Dried Mass (1)	Percent (2)	Dried Mass (1)	Percent (2)
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 Y

Values of Y_s		−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
0	X_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
	Y_m	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
0·005	X_m	1·11	1·12	1·13	1·13	1·14	1·15	1·17	1·18	1·20	1·22	1·25	1·29	1·33	1·40	1·50	1·67
	Y_m	0·014	0·013	0·013	0·012	0·011	0·011	0·010	0·010	0·009	0·008	0·008	0·007	0·007	0·006	0·006	0·005
0·010	X_m	1·20	1·21	1·22	1·24	1·25	1·27	1·29	1·31	1·33	1·36	1·40	1·44	1·50	1·57	1·67	1·80
	Y_m	0·018	0·017	0·017	0·016	0·016	0·015	0·014	0·014	0·013	0·013	0·012	0·012	0·011	0·011	0·010	0·010
0·015	X_m	1·27	1·29	1·30	1·32	1·33	1·35	1·38	1·40	1·43	1·46	1·50	1·55	1·60	1·67	1·75	1·86
	Y_m	0·022	0·022	0·021	0·021	0·020	0·019	0·019	0·018	0·018	0·017	0·017	0·016	0·016	0·016	0·015	0·015
0·020	X_m	1·33	1·35	1·36	1·38	1·40	1·42	1·44	1·47	1·50	1·53	1·57	1·62	1·67	1·73	1·80	1·89
	Y_m	0·027	0·026	0·026	0·025	0·025	0·024	0·023	0·023	0·023	0·022	0·022	0·021	0·021	0·021	0·020	0·020
0·025	X_m	1·38	1·40	1·42	1·43	1·45	1·48	1·50	1·53	1·56	1·59	1·63	1·67	1·71	1·77	1·83	1·91
	Y_m	0·031	0·031	0·030	0·030	0·029	0·029	0·028	0·028	0·027	0·027	0·026	0·026	0·026	0·025	0·025	0·025
0·030	X_m	1·43	1·44	1·46	1·48	1·50	1·52	1·55	1·57	1·60	1·63	1·67	1·71	1·75	1·80	1·86	1·92
	Y_m	0·036	0·035	0·035	0·034	0·034	0·033	0·033	0·032	0·032	0·032	0·031	0·031	0·031	0·030	0·030	0·030
0·035	X_m	1·47	1·48	1·50	1·52	1·54	1·56	1·58	1·61	1·64	1·67	1·70	1·74	1·78	1·82	1·88	1·93
	Y_m	0·040	0·040	0·039	0·039	0·038	0·038	0·038	0·037	0·037	0·036	0·036	0·036	0·036	0·035	0·035	0·035
0·040	X_m	1·50	1·52	1·53	1·55	1·57	1·59	1·62	1·64	1·67	1·70	1·73	1·76	1·80	1·84	1·89	1·94
	Y_m	0·045	0·045	0·044	0·044	0·043	0·043	0·042	0·042	0·042	0·041	0·041	0·041	0·041	0·040	0·040	0·040
0·045	X_m	1·53	1·55	1·56	1·58	1·60	1·62	1·64	1·67	1·69	1·72	1·75	1·78	1·82	1·86	1·90	1·95
	Y_m	0·050	0·049	0·049	0·048	0·048	0·048	0·047	0·047	0·047	0·046	0·046	0·046	0·045	0·045	0·045	0·045
0·050	X_m	1·56	1·57	1·59	1·61	1·63	1·65	1·67	1·69	1·71	1·74	1·77	1·80	1·83	1·87	1·91	1·95
	Y_m	0·054	0·054	0·054	0·053	0·053	0·052	0·052	0·052	0·051	0·051	0·051	0·051	0·050	0·050	0·050	0·050
0·055	X_m	1·58	1·59	1·61	1·63	1·65	1·67	1·69	1·71	1·73	1·76	1·79	1·81	1·85	1·88	1·92	1·96
	Y_m	0·059	0·059	0·058	0·058	0·058	0·057	0·057	0·057	0·056	0·056	0·056	0·056	0·055	0·055	0·055	0·055
0·060	X_m	1·60	1·62	1·63	1·65	1·67	1·69	1·71	1·73	1·75	1·77	1·80	1·83	1·86	1·89	1·92	1·96
	Y_m	0·064	0·064	0·063	0·063	0·062	0·062	0·062	0·062	0·061	0·061	0·061	0·061	0·060	0·060	0·060	0·060
0·065	X_m	1·62	1·63	1·65	1·67	1·68	1·70	1·72	1·74	1·76	1·79	1·81	1·84	1·87	1·90	1·93	1·96
	Y_m	0·069	0·068	0·068	0·068	0·067	0·067	0·067	0·066	0·066	0·066	0·066	0·066	0·065	0·065	0·065	0·065
0·070	X_m	1·64	1·65	1·67	1·68	1·70	1·72	1·74	1·76	1·78	1·80	1·82	1·85	1·88	1·90	1·93	1·97
	Y_m	0·074	0·073	0·073	0·073	0·072	0·072	0·072	0·071	0·071	0·071	0·071	0·070	0·070	0·070	0·070	0·070
0·075	X_m	1·65	1·67	1·68	1·70	1·71	1·73	1·75	1·77	1·79	1·81	1·83	1·86	1·88	1·91	1·94	1·97
	Y_m	0·078	0·078	0·078	0·077	0·077	0·077	0·077	0·076	0·076	0·076	0·076	0·075	0·075	0·075	0·075	0·075
0·080	X_m	1·67	1·68	1·70	1·71	1·73	1·74	1·76	1·78	1·80	1·82	1·84	1·86	1·89	1·91	1·94	1·97
	Y_m	0·083	0·083	0·083	0·082	0·082	0·082	0·081	0·081	0·081	0·081	0·081	0·080	0·080	0·080	0·080	0·080

Values of Y_t (Negative values)

(Continued)

TABLE 3 COORDINATES OF MAXIMUM DENSITY POINT ON CONVERTED WET DENSITY CURVE — *Contd*

B. Positive Values of Y_4

Values of Y_2		0	0·005	0·010	0·015	0·020	0·025	0·030	0·035	0·040	0·045	0·050	0·055	0·060	0·065	0·070	0·075	0·080
0	X_m Y_m	— —																
0·005	X_m Y_m	2·00 0·005	3·00 0·006															
0·010	X_m Y_m	2·00 0·010	2·33 0·010	3·00 0·011														
0·015	X_m Y_m	2·00 0·015	2·20 0·015	2·50 0·016	3·00 0·017													
0·020	X_m Y_m	2·00 0·020	2·14 0·020	2·33 0·020	2·60 0·021	3·00 0·023												
0·025	X_m Y_m	2·00 0·025	2·11 0·025	2·25 0·025	2·43 0·026	2·67 0·027	3·00 0·028											
0·030	X_m Y_m	2·00 0·030	2·09 0·030	2·20 0·030	2·33 0·031	2·50 0·031	2·71 0·032	3·00 0·034										
0·035	X_m Y_m	2·00 0·035	2·08 0·035	2·17 0·035	2·27 0·036	2·40 0·036	2·56 0·037	2·75 0·038	3·00 0·039									
0·040	X_m Y_m	2·00 0·040	2·07 0·040	2·14 0·040	2·23 0·040	2·33 0·041	2·45 0·041	2·60 0·042	2·78 0·043	3·00 0·045								
0·045	X_m Y_m	2·00 0·045	2·06 0·045	2·13 0·045	2·20 0·045	2·29 0·046	2·38 0·046	2·50 0·047	2·64 0·048	2·80 0·049	3·00 0·051							
0·050	X_m Y_m	2·00 0·050	2·05 0·050	2·11 0·050	2·18 0·050	2·25 0·051	2·33 0·051	2·43 0·052	2·54 0·052	2·67 0·053	2·82 0·055	3·00 0·056						
0·055	X_m Y_m	2·00 0·055	2·05 0·055	2·10 0·055	2·16 0·055	2·22 0·056	2·29 0·056	2·38 0·056	2·47 0·057	2·57 0·058	2·69 0·059	2·83 0·060	3·00 0·062					
0·060	X_m Y_m	2·00 0·060	2·04 0·060	2·09 0·060	2·14 0·060	2·20 0·061	2·26 0·061	2·33 0·061	2·41 0·062	2·50 0·063	2·60 0·063	2·71 0·064	2·85 0·066	3·00 0·068				
0·065	X_m Y_m	2·00 0·065	2·04 0·065	2·08 0·065	2·13 0·065	2·18 0·065	2·24 0·066	2·30 0·066	2·37 0·067	2·44 0·067	2·53 0·068	2·63 0·069	2·73 0·070	2·86 0·071	3·00 0·073			
0·070	X_m Y_m	2·00 0·070	2·04 0·070	2·08 0·070	2·12 0·070	2·17 0·070	2·22 0·071	2·27 0·071	2·33 0·071	2·40 0·072	2·47 0·073	2·56 0·073	2·65 0·074	2·75 0·076	2·87 0·077	3·00 0·079		
0·075	X_m Y_m	2·00 0·075	2·03 0·075	2·07 0·075	2·11 0·075	2·15 0·075	2·20 0·076	2·25 0·076	2·30 0·076	2·36 0·077	2·43 0·077	2·50 0·078	2·58 0·079	2·67 0·080	2·76 0·081	2·88 0·083	3·00 0·084	
0·080	X_m Y_m	2·00 0·080	2·03 0·080	2·07 0·080	2·10 0·080	2·14 0·080	2·19 0·081	2·23 0·081	2·28 0·081	2·33 0·082	2·39 0·082	2·45 0·083	2·52 0·084	2·60 0·085	2·68 0·086	2·78 0·087	2·88 0·088	3·00 0·090

Values of Y_4 (Positive values)

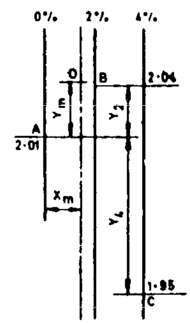
Tabulated values are coordinates (upper value X_m, lower value Y_m) of the peak point (maximum density point on converted wet density curve) of a parabola whose axis is vertical, given three points A, B, and C spaced 2 percent apart horizontally. The origin of coordinates is at point A, the extreme left point.

Y_2 is the ordinate of point B minus ordinate of point A. Y_4 is the ordinate of point C minus ordinate of point A. Y_4 may be negative.

Example:

$Y_2 = 2{\cdot}04 - 2{\cdot}01 = 0{\cdot}03$
$Y_4 = 1{\cdot}95 - 2{\cdot}01 = -0{\cdot}06$
From table, $X_m = 1{\cdot}5$; $Y_m = 0{\cdot}034$
Ordinate of point O = Ordinate of point $A + Y_m$
$= 2{\cdot}01 + 0{\cdot}034$
$= 2{\cdot}044 \approx 2{\cdot}04$
Abscissa of point O, Z_m = Abscissa of point $A + X_m$
$= 0 + 1{\cdot}5 = 1{\cdot}5\%$

NOTE — If abscissa of point A were -2%, Z_m would be $-2{\cdot}0 + 1{\cdot}5 = -0{\cdot}5\%$



(*Continued from page* 2)

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