IS : 9214 - 1979
(Reaffirmed 1997)

Indian Standard
METHOD OF DETERMINATION OF MODULUS OF SUBGRADE REACTION (*K*-VALUE) OF SOILS IN FIELD

First Reprint AUGUST 1997

(Incorporating Amendment No. 1)

UDC 624.131.522

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

Gr 6

May 1980

Indian Standard

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Indian Standard

METHOD OF DETERMINATION OF MODULUS OF SUBGRADE REACTION (*K*-VALUE) OF SOILS IN FIELD

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 5 June 1979, after the draft finalized by the Soil Engineering and Rock Mechanics Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 The 'modulus of subgrade reaction test', usually known as *K*-value test, is essentially a plate bearing test. This test is used for the design of pavement structures and raft foundations.

0.3 Like all other soil strength tests, *K*-value test will not provide a representative measurement of subgrade strength unless performed under the conditions that would be expected after equilibrium of the subgrade with the environmental influences of moisture, density, frost, drainage and traffic. Equilibrium is not attained until the structure has been superimposed upon it for some time.

0.4 In the formulation of this standard due weightage has been given to international co-ordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country.

0.5 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 deals with the method for the determination of modulus of subgrade reaction of the soil in place (generally known as *K*-value of the subgrade), for evaluation of strength of subgrade for roads, runway pavements and raft foundations.

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

2. TERMINOLOGY

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

2.1 Modulus of Subgrade Reaction — 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 diameter or smaller loading plate with corrections for size of plate used.

2.2 Deflection — The amount of downward vertical movement of a horizontal surface due to the application of a load to the surface.

2.3 *K*-value — If the assumption that the reaction of the subgrade is proportional to the deflection is entirely correct, the curve in Fig. 1 should be straight line and the slope of this line should give the modulus of subgrade reaction measured in MPa/cm (kgf /cm²/cm). The results, however, usually give a curve which is convex upwards and which has no straight portion even initially, *K*-value is, therefore, taken as the slope of the line passing through the origin and the point on the curve corresponding to 1·25 mm settlement (*see* Fig. 1):

$$K = \frac{p}{0{\cdot}125}\ \text{MPa/cm} = \frac{10p}{0{\cdot}125}\ \text{kgf/cm}^2\text{/cm}$$

where

p = load intensity corresponding to settlement of plate of 1·25 mm.

Alternatively, the *K*-value may be defined as a pressure of 0·07 MPa (0·70 kgf/cm²) divided by the corresponding settlement. That is when a standard 75 cm diameter steel bearing plate is subjected to a load of 3 100 kgf, say $K = \frac{0{\cdot}07}{d}$ MPa/cm

$$\left[K = \frac{0{\cdot}70}{d}\ \text{kgf/cm}^2\text{/cm} \right]$$

where

d = settlement in cm.

2.4 Stiffening Plates — Nest of plates stacked on the bearing test plate for stiffening it.

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

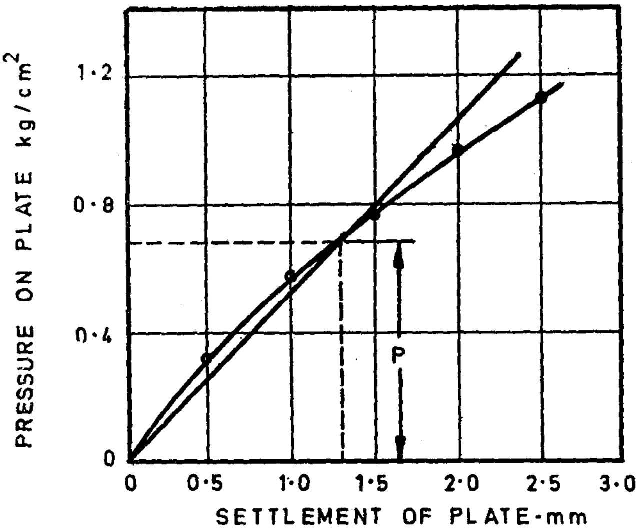


FIG. 1 RESULT OF PLATE BEARING TEST ON NATURAL SUBGRADE

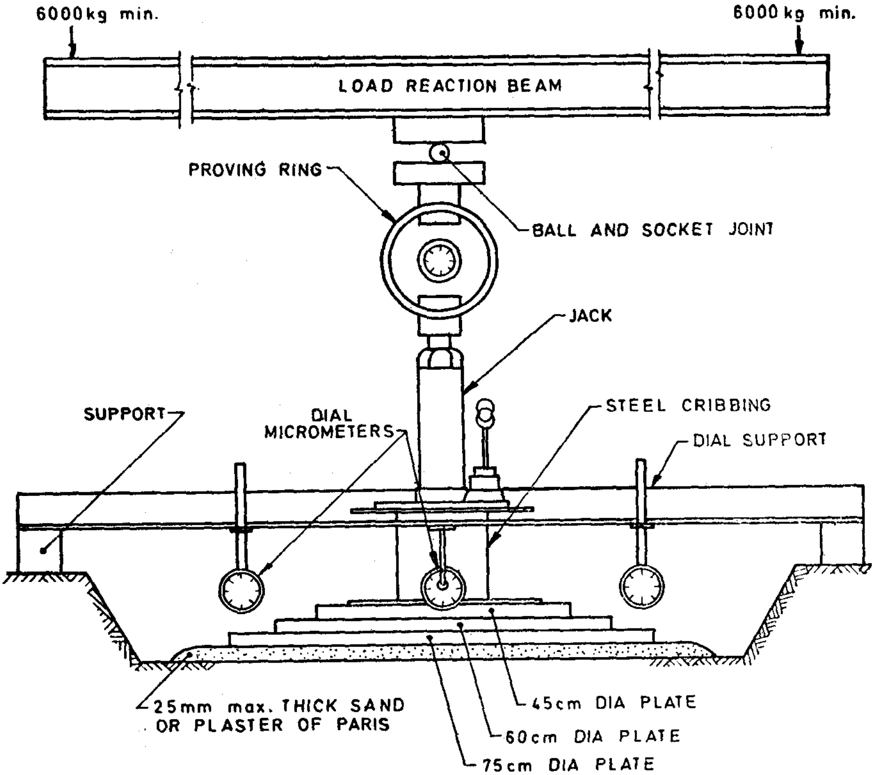
3. APPARATUS — (*see* Fig. 2).

3.1 Bearing Plates — It is a circular mild steel plate of 75 cm diameter and 25 mm thickness. Smaller bearing plates of 45, 40 or 30 cm may also be used.

3.2 Loading Attachment — Loads are applied by means of a hydraulic jack or a screw jack working against a reaction frame through bearing plates. The loading attachment should have a capacity of at least 150 kN (15 000 kgf) equipped with ball and socket joint between the test load and the jack to avoid eccentricity. The device should have an arrangement for attaching to a truck, trailer, truss or any other equipment load reaction.

3.3 Jacks — Hydraulic or screw jack of 150 kN (15 000 kgf) capacity.

3.4 Proving Ring — One calibrated proving ring of capacity 150 kN (15 000 kgf) with dial gauge to read to an accuracy of 0·002 mm. The proving ring should have an accuracy of one-half percent of the load measured.



NOTE — Support for load reaction shall be 240 cm minimum from bearing plates.

FIG. 2 SCHEMATIC DIAGRAM OF PLATE BEARING TEST

3.5 Loading Reaction — The reaction for jacking can be provided by a truck, trailer or anchor frame such that its reaction shall be at least 2·5 m away from the centre of the bearing plates. When the test is to be conducted on granular subgrades, a reaction of at least 150 kN (15 000 kgf) will be required. For cohesive soils a 50 kN (5 000 kgf) reaction may be sufficient.

3.6 Measuring Deformation — The vertical movement resulting from applied loads will be measured by at least three dial gauges uniformly spaced 120° apart, preferably four uniformly placed at 90° apart, and placed at about 10 mm away from the rim of 75-cm plate. The gauges will be supported by an independent datum bar such that their positions are unaffected by the loading operations. These supports should be at least 2·4 m from the plates and the wheels. The settlement of the plate is taken as the average of the readings of the dial gauges used for the purpose. Gauges with an accuracy of 0·002 mm are desirable; however, gauges with an accuracy of 0·01 mm may be used if time-readings are made.

3.7 Jack-Pads — Due to variation in the depth of test points some distance pieces, for example, spacers, will be required between jack and proving ring. These can be solid cylindrical pieces of aluminium alloy or any other suitable material to withstand and help in transferring heavy loads on to the bearing plate. These spacers should be at least 15, 20 and 30 cm long. The exact requirement of these jack pads will vary from one test point to another according to depth of test point below ground surface.

3.8 Stiffening Plates — These are mild steel plates of 60, 45 and 30 cm diameter and 25 mm thickness.

3.9 Miscellaneous Apparatus — Datum bar of 5 m length with suitable dial gauge attachments, pick axes, showel, trowel, spatula, spirit level and plumb bob.

4. TEST PROCEDURE

4.1 Two alternative test procedures may be followed. More accurate tests are made with a 75-cm plate, and a load reaction arrangement, a loading jack, a proving ring to measure the load and three dial gauges placed diagonally apart about 10 mm from the rim to measure the vertical deflection.

4.2 Preparation of Test Area — *K*-value tests should be conducted on representative area. Most soils exhibit a marked reduction in the modulus of subgrade reaction with increase in moisture content, which cannot be generalized. Conditions of moisture content, density, and type of material all enter into the interpretation of test results to give a design value which will represent the condition of equilibrium that ultimately will exist in the subgrade. Generally, subgrade is composed of either natural ground or fill-material. Preparation of an area for testing will depend on composition of subgrade.

4.2.1 *Preparation of Test Area for Natural Ground* — Strip off an area equal to twice the area of the bearing plate to the proposed elevation of the subgrade surface. In any case, it is necessary to remove the top 25 cm of the soil before testing. The effect of surcharge can be eliminated by having supports of datum bar at least 1·25 m away from the nearest edge of bearing plates.

4.2.1.1 On fine grained soils the bearing plate, with its lower surface oiled, shall be placed and rotated. When the plate is removed the irregularities in the surface, being marked with oil shall be trimmed off. This process is repeated until the plate is in contact with the soil over the whole area.

4.2.1.2 When the test is made on granular subgrade, extreme care shall be taken not to disturb the natural condition of the subgrade while the test site is being prepared. Prior to placement of 75 cm diameter plate, the area should be cleared of loose material and levelled.

4.2.1.3 On gravely soils flat bearing surface can best be obtained with plaster of paris, which should be levelled with the plate before the plaster has set. The *K*-value test should not be started until the plaster has sufficiently hardened.

4.2.2 *Preparation of Filled-Up Area* — In case the test is to be conducted on subgrade composed of fill materials, a test embankment of about 75 cm height should be constructed, after necessary stripping. For design purposes the conditions of the moisture content and dry density of the test area should be those which are likely to exist when the subgrade has reached a state of relative equilibrium subsequent to the construction of pavement. Generally, the subgrade will be compacted at optimum moisture content and specified density. If ordinary compaction equipment is not available, approximate compaction may be obtained by hand tamping in layers.

4.2.2.1 The test should be conducted keeping in view elimination of bearing pressures of reaction frame and datum bar, as mentioned in **4.2.1**. The bearing plate with its lower surface oiled shall be placed on the prepared surface and rotated. When the plate is removed all proud portions indicated by oil marks shall be as levelled as possible. If levelling is difficult due to presence of granular material, a layer of fine dry sand at no place thicker than 5 mm may be laid and the plate seated properly.

4.3 Loading Procedure — There are two methods for determination of modulus of subgrade reaction as given in **4.3.1** and **4.3.2**.

4.3.1 *Method I* — The loading system and bearing plate should be seated by applying a load of 3·1 kN (310 kgf) (0·007 MPa for a standard 75 cm diameter plate), when the design thickness of pavement is less than 40 cm which is normally used for lightly loaded pavements. For heavy duty pavements a seating loading of 6·2 kN (620 kgf) should be used. The seating load will be allowed to remain until practically complete deformation has taken place, at this time a reading should be taken on the dial gauges and adjusted to 'zero' reading. Cyclic loading under 3·1 kN (310 kgf) or 6·2 kN (620 kgf) seating load, as required, may be used to assure good seating of the bearing plate. Then without releasing the seating load an additional 31 kN (3 100 kgf) [that is, a total 34·1 kN (3 410 kgf) or 37·2 kN (3 720 kgf) load depending on the type of the pavement] should be applied to the plates and held until practically complete settlement has taken place.

For recording observations, *pro forma* given at Appendix A should be used. Prior to releasing the 31 kN (3 100 kgf) load, a value of K_u will be computed for the average deflection at the plate rim by the formula:

$$K_u = \frac{0{\cdot}07}{d} \text{ MPa/cm, or}$$

$$K_u = \frac{0{\cdot}70}{d} \text{ kgf/cm}^2\text{/cm}$$

where

d = deflection in cm.

One of the procedures given in **4.3.1.1** and **4.3.1.2** should be then followed depending upon the type of subgrade and the value of uncorrected modulus of subgrade K_u.

4.3.1.1 For cohesive subgrades with K_u equal to 0·555 MPa/cm (5·55 kgf/cm²/cm) or less, the load will be released. For some clayey soils it may be necessary to plot a time-settlement curve to aid determination of practically complete settlement. In general, the load will be held until the rate of deflection of the bearing plate is less than 0·000 5 cm/min (that is, 0·005 cm in 10 minutes). This rate of settlement indicates that the major portion of the settlement has occurred.

4.3.1.2 For granular subgrades, or cohesive subgrade with K_u equal to 0·555 MPa/cm (5·55 kgf/cm²/cm) or more a load-deflection curve should be obtained by measuring the successive deformations caused by increasing the load in increments of 15·5 kN (1 550 kgf) to a maximum of 93 kN (9 300 kgf). The load should not be released between the increments of loading. Each increment of load shall be held for at least 15 minutes. The final load of 93 kN (9 300 kgf) shall be held until practically complete settlement is reached, but in not less than 15 minutes. In general the 0·21 MPa (2·1 kgf/cm²) load should be held until the rate of settlement of the plate is less than 0·000 2 cm/min (that is, 0·002 cm in 10 minutes). This rate indicates that the major portion of the settlement has taken place.

4.3.2 *Method II* — The plate shall first be seated by applying a load equivalent to a pressure of 0·007 MPa (0·07 kgf/cm²) and releasing it after a few seconds. A load sufficient to cause approximately a 0·85-mm settlement should be applied and when there is no perceptible increase in settlement or in the case of clayey soils, when the rate of increase in settlement is less than 0·025 mm/min the average of the readings of the deflection dial gauges should be noted. The load as measured by the pressure gauge attached to the jack or by the proving ring should be noted, both immediately before and after the deflection readings. The load should be increased until there is an additional settlement of approximately 0·25 mm and the load and deflection again noted when there is no perceptible increase in settlement. This procedure should be repeated until a total settlement of not less than 1·75 mm has been produced. For recording observations *pro forma* is given at Appendix B.

NOTE 1 — Rapid and less accurate tests may be made with a 45-cm or even a 30-cm diameter plate with a 5-tonne loaded lorry to provide the load reactions, a pressure gauge to measure the load and at least 3 dial gauges to measure the vertical deflection of the bearing plate. In such cases, the K_p value applied should be corrected for the standard 75 cm plate as explained in **5**.

NOTE 2 — The test may be conducted with a plate of diameter smaller than 75 cm when adequate reaction is not available. When a smaller plate is used, the K_p value should be corrected to get the K value corresponding to a standard 75 cm diameter plate as explained in **5**.

5. EVALUATION OF SUBGRADE TEST RESULTS

5.1 The corrections mentioned in **5.1.1** to **5.1.4** should be applied before a final value of subgrade reaction K is evaluated.

5.1.1 *Correction when Using Plates Smaller than 75 cm Diameter* — Theoretical relationship may be established between the modulus of subgrade reaction and the plate diameter. This value for a plate of particular diameter can be expressed as a percentage of the equivalent modulus of subgrade value of a 75-cm diameter from Fig. 3 and thus equivalent value of K_p for a 75-cm diameter plate can be evaluated.

5.1.2 *Correction of Load-Deflection Curve* — The correction should be necessary if the value of K_u is 0·555 MPa/cm (5·55 kgf/cm²/cm) or more. In such a case unit loads up to 93 kN (9 300 kgf) in 15·5 kN (1 550 kgf) increments should be applied and a load-deflection curve is plotted. In these cases the load-deflection curve shall not be a straight line and hence a correction should be made. Generally, the load-deflection curve shall approximate a straight line between unit loads of 31 kN (3 100 kgf) and 93 kN (9 300 kgf) [0·07 to 0·21 MPa (0·7 to 2·1 kgf/cm²)]. The correction should then consist of drawing a straight line parallel to the straight-line portion of the load-deflection curve through the origin. The deflection for computing the K_d value shall then be determined at a unit load of 31 kN (3 100 kgf) (0·07 MPa/0·7 kgf/cm²) and the K_d computed by the formula given in **4.3.1**. In case no straight portion on the curve is observed, then at least three points in the region having the least curvature should be selected (*see* Fig. 4).

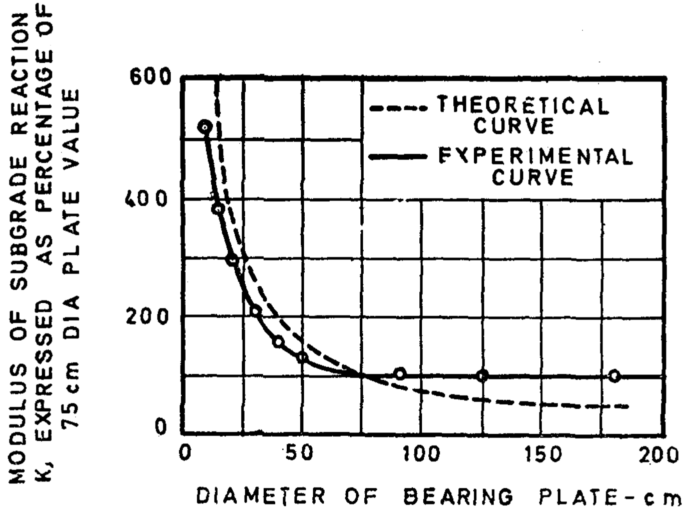


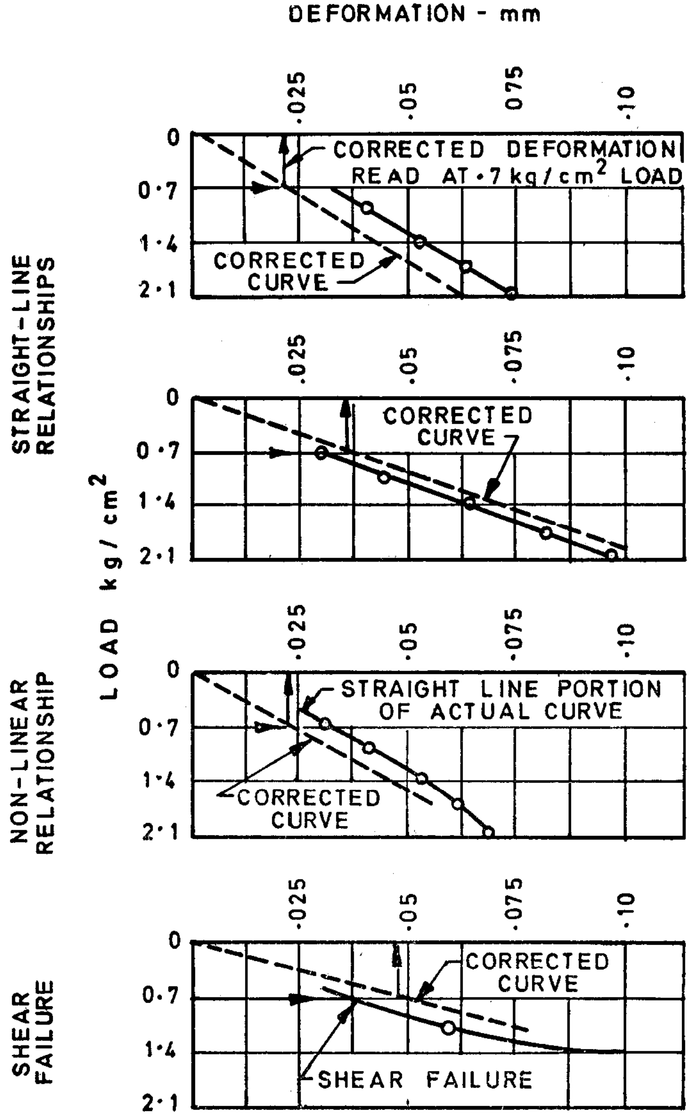
Fig. 3 Relationship Between Modulus of Subgrade Reaction and Diameter of Bearing Plate

5.1.3 *Correction for Bending of the Plates* — The bending of the bearing plate is greater at the centre than at the rims, even when nests of plates are used. A method for the correction of modulus of subgrade for plate bending is shown in Fig. 5.

The value of uncorrected subgrade reaction should be used as the ordinate to enter the curve in Fig. 5. The value obtained on the abscissa in the curve of Fig. 5 should be the K_b value corrected for bending of plate.

Note — When uncorrected value is less than 0·275 MPa/cm, the correction for plate bending is negligible and may be ignored.

5.1.4 *Correction for Saturation* — The moisture content of the subgrade at the time of the plate bearing test may increase after the pavement has been constructed and the worst condition may be covered by converting the value of modulus of subgrade obtained from bearing test to a value for the subgrade when soaked. It is impracticable to do this directly by artificially wetting the test area. Hence correction should be applied on the basis of consolidation tests on the subgrade material.



NOTE — Corrected curve may lie above or below actual curve.

FIG. 4 CORRECTION OF LOAD-DEFLECTION CURVE

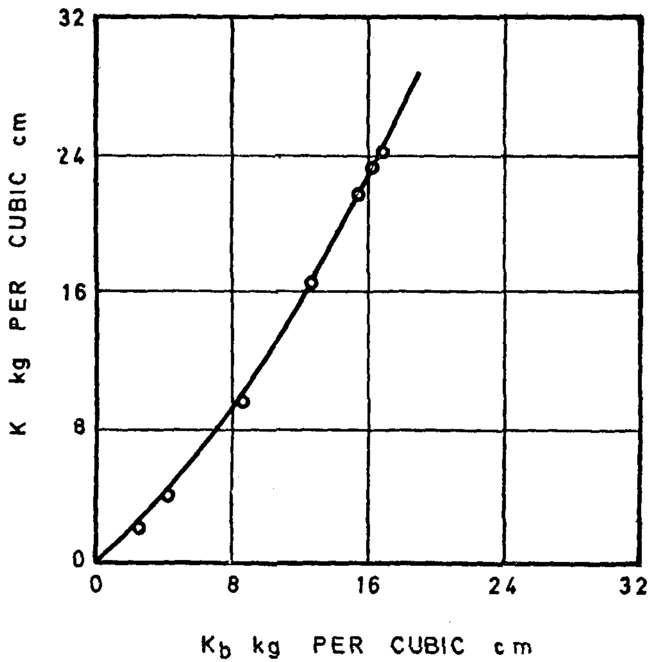


FIG. 5 CHART FOR CORRECTION FOR K_u FOR BENDING OF THE PLATE

5.1.4.1 The correction of subgrade saturation shall consist of loading two samples of the undisturbed subgrade materials in a consolidometer as follows:

a) One at the *in situ* moisture content, that is, at natural moisture content; and
b) The other at a saturated condition.

5.1.4.2 The two specimens in the consolidometer shall be applied the same seating load that was used in the field plate bearing tests (*see* **4.3.1**). The seating load shall be allowed to remain on the specimen having *in situ* water content until the vertical movement becomes stable, at this time a ' zero ' reading should be taken. Now apply an additional 31 kN (3 100 kgf) load. The total load should then be allowed to remain until the vertical dial gauge reading becomes stable.

5.1.4.3 The second specimen should be allowed to saturate under the seating load. After the vertical dial gauge does not show any movement, a 'zero' reading should be taken and an additional 31 kN (3 100 kgf) load should now be applied. Take down the readings when vertical dial shows stable reading.

5.1.4.4 The corrections for saturation should be applied in proportion to the deformations of the two specimens under a unit load of 31 kN (3 100 kgf) in addition to the seating load as follows:

$$K_s = \frac{d}{d_s} \times \text{uncorrected value of modulus subgrade}$$

where

K_s = corrected value of subgrade for saturation.

d = deformation of a specimen with natural moisture content under unit load of 31 kN (3 100 kgf).

d_s = deformation of a specimen when saturated under unit load of 31 kN (3 100 kgf).

If $\frac{d}{d_s} = 1$, this correction is inapplicable.

5.2 The corrections and order in which these should be applied are explained on a flow chart given in Appendix C.

5.2.1 For easy understanding of all the necessary corrections required to be applied in determination of *K*-value, a sample observations and calculations are given in Appendix D.

6. REPORT

6.1 The value shall be reported corrected to the second decimal place.

APPENDIX A

(*Clause* 4.3.1)

PRO FORMA FOR IN-PLACE *K*-VALUE — TEST METHOD I

Location... Tested by...
Material of test point............................. Date...
Depth of test...
Condition of test surface : Soaked/Unsoaked ....
Period of soaking, if any........... · ....
Moisture content.....................................
Density...
Method used for determination of density........
Dia of plate used :

Proving Ring Dial Gauge Readings	Load, kN (kgf)	Deflection Dial Gauge Readings				Average Deflection, mm	Cumulative Deflection, mm	*K*-value, kgf/cm²/cm MPa/cm					
		DG 1	DG 2	DG 3	DG 4			Uncorrected Value, K_u	Corrected for Load of Deflection, K_d	Corrected for Bending, K_b	Corrected for Saturation, K_s	Corrected for Size of Plate, K_p	Corrected *K*-value
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)

Rejected test with reason.............................

Result of repeat test if conducted...................

APPENDIX B

(*Clause* 4.3.2)

PRO FORMA FOR IN-PLACE *K*-VALUE (MODULUS OF SUBGRADE REACTION)— TEST METHOD II

Location .... Tested by ....

Material at test point... Date..

Depth of test ....

Condition of test surface : $\frac{\text{Soaked}}{\text{Unsoaked}}$ ....

Period of soaking, if any...................................

Moisture content ....

Density ....

Method used for determination of density.......

Dia of plate used :

Proving Dial Gauge Readings	Load, kN (kgf)	Deflection Dial Gauge Readings				Average Deflection, mm	Cumulative Deflection, mm	K_u MPa/cm (kgf/cm²/cm)	$K_b/K_p/K_s$ MPa/cm (kgf/cm²/cm)	Final Corrected *K*-value MPa/cm (kgf/cm²/cm)
		DG 1	DG 2	DG 3	DG 4					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

Note — Load increments to be loaded till the total deflection is 1·75 mm or more.

K-value to be computed from load/deflection plot.

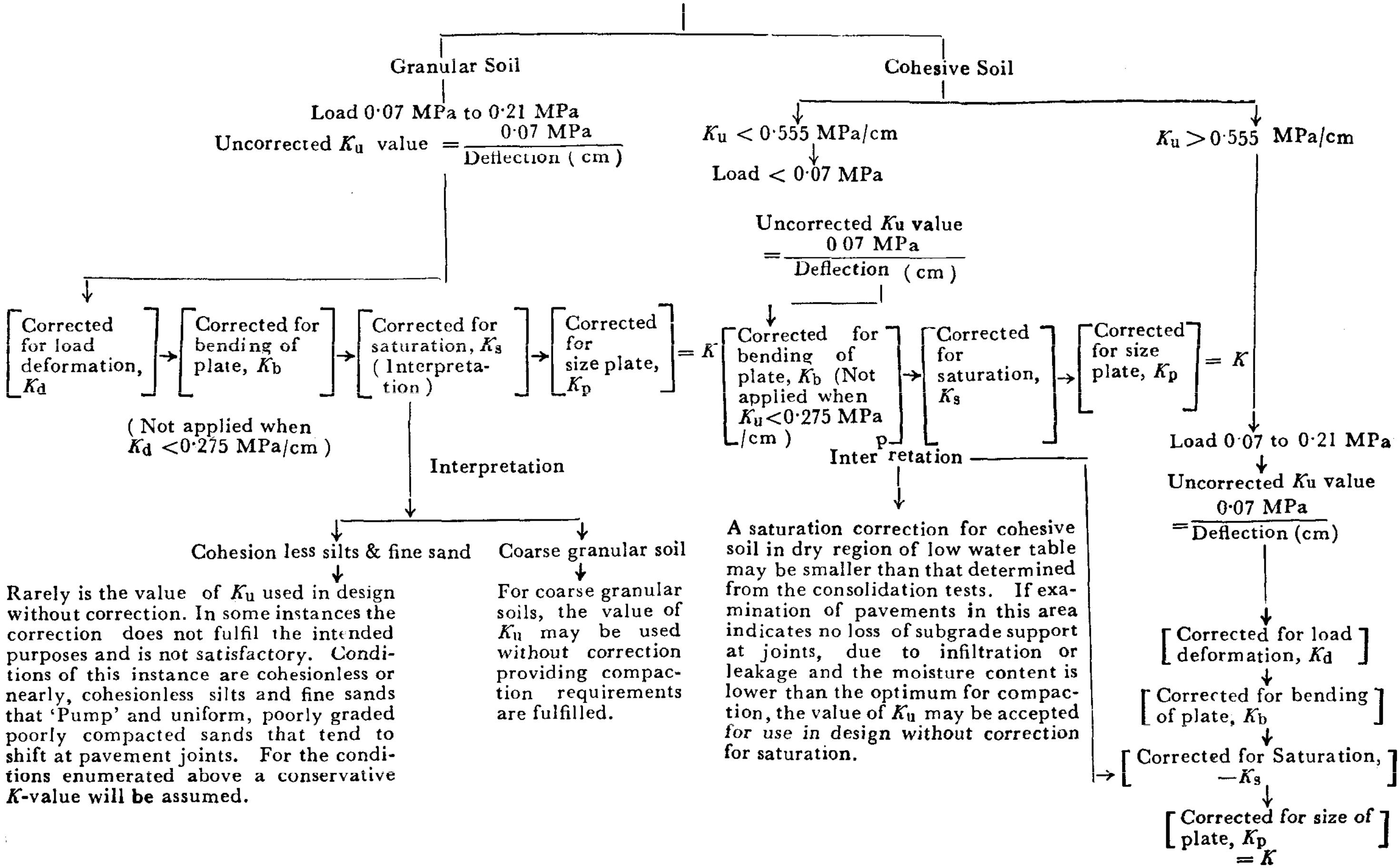
Rejected test with reasons ....

Result of repeat test if conducted ....

APPENDIX C

(*Clause* 5.2)

DETERMINATION OF *K*-VALUE ' FLOW CHART '



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APPENDIX D

(*Clause* 5.2.1)

SAMPLE OBSERVATION AND CALCULATIONS FOR DETERMINATION OF *K*-VALUE

Location : Tested by:

Material of test point 0 :

Depth of test : 0·50 cm Date:

Time:

Condition of test subgrade : Partly saturated

Period of soaking, if any :

Moisture content : 18 percent

Density : 1·8 g/cm^3

Dia of plate used : 75 cm

Proving Ring Dial Gauge Readings	Load in kN (kgf)	Deflection (mm) Dial Gauge Readings			Average Deflection, mm	K_u kg/cm^2/cm MPa/cm
		DG 1	DG 2	DG 3		
10·04	3·1 kN (310 kgf) (0·007 MPa)	26·00	15·10	11·26	17·45	
10·72	34·1 kN (3 410 kgf) (0·07 MPa)	25·72	14·62	10·88	17·07	18·5
11·06	49·6 kN (4 960 kgf) (·112 MPa)	25·37	14·52	11·73	16·87	
11·40	65·1 kN (6 510 kgf) (0·150 MPa)	25·00	14·00	10·36	16·45	
11·74	80·6 kN (8 060 kgf) (0·182 MPa)	24·70	13·90	10·16	16·25	
12·08	94·1 kN (9 410 kgf) (0·217 MPa)	24·77	13·85	9·99	16·20	

Calculations $K_u = \frac{0.07}{\text{[Total deflection in cm at 34.1 kN (3 410 kgf) Total deflection at 3.1 kN (310 kgf) load]}} = \frac{0.07}{0.038} = 1.85$ MPa/cm

or $\frac{0.7}{0.038} = 18.5$ kgf/cm²/cm.

CORRECTION FOR K-VALUE

Sl No.	Modulus of Subgrade MPa/cm (kgf cm²/cm)			
	Uncorrected value K_u for 75 cm ϕ	*Corrected for load deformation curve for 75 cm ϕ K_d	†Corrected for bending of plate of 75 cm ϕ K_b	‡Corrected for saturation 75 cm ϕ plate (to be done at the end) $K_s = \frac{d}{d_s} \times K_b$
1	1·85 (18·5)	1·555 (15·55)	1·21 (12·1)	0·97 (9·7)

*For applying correction to the K_u value obtained in the field using 75 cm dia plate for load deflection, plot load-deflection curves as explained in **5.2.2** and demonstrated in Fig. 4. Assuming that the curve obtained is for shear failure having concave shape upwards, draw a dotted correction curve passing through origin, parallel to the shear failure curve. Enter at the loading intensity of 0·07 MPa (0·7 kg/cm²) and determine corrected deflection. From Fig. 4, we obtain 0·045. Corrected value for load deflection is $K_d = \frac{0.07}{0.045} \left(\frac{0.7}{0.045} \right) = 1.555$ MPa/cm (15·55 kgf/cm²/cm).

†Correction for bending of plate of 75 cm dia shall be applied as shown in Fig. 5 (*see* **5.1.3**). Enter at $K = 1.555$ MPa/cm (15·55 kg/cm²/cm), and read the corrected values for bending of plate, that is $K_b = 1.21$ MPa/cm (12·1 kgf/cm²/cm).

‡Assuming $\frac{d}{d_s} = 0.8$ which is obtained from consolidation test result (refer **5.1.4**).

Substituting value of $\frac{d}{d_s}$ in equation $K_s = \frac{d}{d_s} \times K_u = 0.8 \times 1.21$ (0.8×12.1) = 0·97 MPa/cm (9·7 kgf/cm²/cm).

(*Continued from page* 2)

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Printed at New India Printing Press, Khurja, India