DETERMINATION OF THE CALIFORNIA BEARING RATIO OF A SOIL: STANDARD LABORATORY METHOD FOR A REMOULDED SPECIMEN

1 SCOPE

This method sets out the procedure for the determination of the California Bearing Ratio (CBR) of a soil when compacted and tested in the laboratory.

2 SAFETY

This method does not attempt to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this method to establish appropriate occupational health and safety practices that meet statutory regulations.

3 REFERENCED METHODS

Australian Standards

AS 1152 Specification for test sieves

AS 2103 Dial gauges and dial test indicators

AS 2193 Methods for calibration and grading of force-measuring systems of testing machines

AS 1289.5.2.1 Determination of the dry density/moisture content relation of a soil using modified compactive effort

WA Test Methods

WA 105.1 Preparation of Disturbed Soil and Granular Pavement Material Samples for Testing.

WA 110.1 Soil and Granular Pavement Material Moisture Content: Convection Oven Method.

WA 115.1 Particle Size Distribution: Sieving and Decantation Method

WA 115.2 Particle Size Distribution: Abbreviated Method for Coarse Materials

WA 132.1 Dry Density/Moisture Content Relationship: Standard Compaction. Fine and Medium Grained Soils

WA 133.1 Dry Density/Moisture Content Relationship: Modified Compaction. Fine and Medium Grained Soils

WA 134.1 Dry Density Ratio (Percent)

WA 136.1 Moisture Ratio (Percent)

4 DEFINTIONS

Laboratory moisture ratio – the ratio of the moisture content of the specimen to the optimum moisture content of the material as determined on material prepared in accordance with Procedure 6.1(b), expressed as a percentage.

Laboratory density ratio – the ratio of the dry density of the specimen to the maximum dry density of the material as determined on material prepared in accordance with Procedure 6.1(b), expressed as a percentage.

5 APPARATUS

(a) **Steel penetration piston** with a 49.6 ± 0.1 mm diameter over the length of penetration. The length of the piston will depend upon the number of surcharges and the depth of penetration required.

(b) **Loading machine** equipped with –

i. A moveable head or base capable of travelling at a uniform (not pulsating) rate of 1 ± 0.2 mm/min for use in forcing the penetration piston into the specimen; and

ii. A force-measuring device meeting the accuracy and repeatability requirements of AS 2193 Grade "C" testing machines for the range of forces used in the test. The force-measuring device shall be also capable of indicating seating loads of approximately 50 N and 250 N.

NOTE: The indicator points of the force-measuring device at the seating loads of approximately, but not greater than, 50 N (for expected CBR values equal to or less than 30) and 250 N (for expected CBR values greater than 30) need not necessarily meet the Grade "C" requirements of AS 2193 but should be displayed as definite numbers or marks.

(c) **Thermostatically controlled oven** with good air ventilation capable of maintaining a temperature within the range of 105ºC to 110ºC.

(d) **Cylindrical metal mould** (Figure 1) of known volume with an internal diameter 152 ± 1 mm, height 178 ± 1 mm and wall thickness of at least 5 mm, provided with a metal extension collar and a perforated metal baseplate.

(e) **Steel spacer disc** (Figure 2) of 150 ± 1 mm diameter and 61 ± 0.25 mm high, fitted with a removable handle for lifting the disc from the mould.

(f) **Compaction apparatus** complying with the requirements of WA 132.1 or WA 133.1, as applicable.

(g) **Metal stem and perforated plate** with a mass of 1.00 ± 0.025 kg (Figure 3).

(h) **Metal surcharges**, with each surcharge having a mass of 2.25 ± 0.025 kg, a diameter of 150 ± 0.5 mm and with a centre hole of 55 ± 1.0 mm diameter (Figure 4).

NOTE: During penetration the surcharge in contact with the soil should meet the tolerances as specified. Other surcharges may be slotted and may be outside the tolerances provided the total surcharge mass is within the required tolerances and there is no contact with the side of the mould and the penetration piston.

(i) **Device for measuring swell (DMS)**, consisting of a dial gauge or similar capable of measuring the expected range of travel, graduated to at least 0.01 mm and meeting the accuracy and repeatability requirements of AS 2103 and a metal tripod (Figure 5)

(j) **Setting piece**, a length of bar to suit the device for measuring swell.

(k) **Balance** of at least 15 kg capacity readable to 1 g, with a Limit of Performance (F) of not more than 5 g.

(l) **Jack, lever, frame** or other suitable device, which may be used for extruding specimens from the cylinder (optional).

(m) **Sieves**, 19 mm and, if required, a 4.75 mm sieve, complying with AS 1152

(n) **Water tank** or container capable of maintaining water at a level above the moulds, during soaking.

(o) **Other apparatus** such as a mixing bowl, straightedge, filter paper and dishes.

6 PROCEDURE

6.1 PREPARATION OF THE TEST INCREMENT

(a) Using the 19 mm sieve, sieve a representative sample of the soil prepared in accordance with the procedure described in Test Method WA 105.1. Determine the percentage of material retained on the sieve. Only the material passing the 19 mm sieve is to be used for the test.

NOTES:

1. Where it is obvious that all material passes the 19.0mm sieve (e.g. sand), testing by WA 115.1 or WA 115.2 is not necessary. It is sufficient to record that the material passes the 19.0mm sieve by visual assessment.

2. The removal of small amounts of stone retained on the 19 mm sieve will affect the CBR obtained only by amounts comparable with experimental error involved in measuring CBR. The exclusion of a large portion of stone coarser than 19 mm (such as is present, for example, in a gravel of 75 mm maximum size) may have a major effect on CBR 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 testing, or of calculation, for dealing with this difficulty in comparing laboratory CBR test results with CBR values obtained in the field.

3. Material, which has been compacted previously in the laboratory, should not be re-used, as breakdown of the material during compaction can lead to misleading results.

(b) Determine the dry density/moisture content relationship on a representative sample passing the 19 mm sieve in accordance with Test Method WA 133.1.

(c) Obtain a representative test increment from the CBR test portion. Determine the hygroscopic moisture content (w_H) in accordance with Test Method WA 110.1.

(d) Select the dry density (ρ_d)/ moisture content (w_C) condition at which the test increments are to be moulded.

(e) Calculate the dry mass (DM_{TI}) of the test increment using the equation:

$$DM_{TI} = \frac{WM_{TI} \times 100}{100 + w_H}$$

Where:

DM_{TI} = dry mass of test increment in grams

WM_{TI} = wet mass of test increment in grams

w_H = hygroscopic moisture content as a percentage

(f) Calculate the mass of water (m_{WR}) to be added to bring the test increment to the desired moisture content using the equation:

$$m_{WR} = \frac{(w_c - w_H)DM_{TI}}{100}$$

Where:

m_{WR} = mass of water to be added to the test increment in grams

w_c = moisture content (%) condition at which the test increments are to be moulded.

w_H = hygroscopic moisture content (%) of the test increment

DM_{TI} = dry mass of test increment in grams

Thoroughly mix the test increment with a suitable amount of potable water to bring the test increment to the required moisture content.

(g) Wet and thoroughly mix the test increment with the quantity of water calculated in 6.1(f). If there are coarse particles in the test increments, screen the test increment on a 4.75 mm sieve. Wet and mix the fraction retained on the 4.75 mm sieve to ensure complete wetting of the coarse particles prior to curing. Follow by remixing with the fraction passing the 4.75 mm sieve to ensure complete wetting of the whole test increment.

(h) Cure the test increment at room temperature for a minimum period as prescribed in Table 1. Liquid Limit may be estimated by visual and tactile assessed from an experience technician. Record the duration of curing.

TABLE 1
MINIMUM CURING TIME

Plasticity	Initial Moisture Condition	
	≤2% from OMC	>2% from OMC
Sands and granular material*	2 hours	2 hours
Liquid Limit ≤ 35%	24 hours	48 hours
Liquid Limit 36% - 50%	48 hours	4 days
Liquid Limit > 50%	4 days	7 days

**These can include naturally occurring sands and gravels, crushed rocks and manufactured materials with material passing 75µm typically less than 12%.*

NOTE: It is important that the water is thoroughly mixed into and uniformly distributed through the soil since inadequate mixing gives rise to variable results. It is desirable to keep the soil in a sealed container to allow the water to become more uniformly distributed through the soil before compaction

6.2 PREPARATION OF THE TEST SPECIMEN

(a) Calculate the desired wet density of the test specimen using of the following equation:

$$\rho_w = \frac{\rho_d \times (100 + w_c)}{100}$$

Where:

ρ_w = desired wet density of test specimen in t/m³

ρ_d = desired dry density of test specimen in t/m³

w_c = moulding moisture content of the test specimen as a percentage

(b) Calculate the desired wet mass of the test specimen using the following equation:

$$m_{TS} = \rho_w \times V_1$$

Where:

m_{TS} = desired wet mass of the test specimen in grams

ρ_w = desired wet density of test specimen in t/m³

V_1 = volume of the mould in cm³

(c) Calculate the wet mass of each layer that is to be compacted in the mould using the equation:

$$m_L = \frac{m_{TS}}{5}$$

Where:

m_L = wet mass of soil per layer in grams

m_{TS} = wet mass of test specimen in grams

(d) Determine the mass of the mould and perforated baseplate (m_1).

(e) Insert the spacer disc, clamp the mould (with the extension collar attached) to the baseplate and place a filter paper on top of the spacer disc.

(f) Immediately prior to compaction thoroughly mix the cured soil and determine the moisture content (w_1) of a representative fraction of the test portion in accordance with Test Method WA 110.1.

(g) Compact the specimen uniformly into the mould, using a modified or standard compaction hammer, to the specified laboratory density ratio in five layers so that the compacted height of the soil in the mould is 23 ±2mm in the first layer, 47 ±2mm in the second layer, 70 ±2mm in the third layer, 94 ±2mm in the fourth layer and the fifth layer shall be compacted such that the surface of the specimen is flush with the top of the mould as is best practicable.

NOTE: A suitable pattern of blows is eight (8) blows around the perimeter of the specimen (with minimal overlap) and one (1) blow in the centre of the layer until the required depth is obtained.

Discard specimens that do not meet the above requirements.

The laboratory moisture ratio shall be within 5.0 percent of the specified moisture ratio and laboratory density ratio shall be within 1.0 percent of the specified density ratio.

(h) Free the material from around the inside of the collar and carefully remove the collar.

(i) While the base plate is still attached trim the surface of the compacted specimen level with the top of the mould by means of a straightedge. Use fines to patch any holes developed in the surface during trimming.

(j) Carefully remove the mould with compacted soil from the baseplate so as to not disturb the compacted soil. Place a filter paper on the baseplate and carefully invert the mould with compacted soil and replace onto the baseplate. Securely re-fasten the mould to the baseplate.

(k) Remove the spacer disc from the mould and determine the mass of the mould plus compacted soil (m_2).

(l) If soaking is not required, perform the penetration test (Procedure 6.4).

6.3 SOAKING THE TEST SPECIMEN

(a) Determine the mass of the baseplate plus mould plus specimen (m_3).

(b) Place a filter paper and the stem and perforated plate on the compacted soil specimen in the mould. Apply a surcharge in accordance with Figure 7; the minimum shall be 4.5 kg.

NOTE: Surcharges may be applied to simulate the confining effects of the overlying material layer (see Figure 7).

(c) Obtain and record an initial reading (r_1) using the device for measuring swell (DMS) and the setting piece.

(d) Place the DMS onto the top of the mould and mark the position so that it can be replaced in the original position.

(e) Obtain and record the initial reading before soaking (h_1) and remove the DMS.

(f) Place the specimen in the water tank and allow the water to have free access to the top and the bottom of the specimen. Soak for 4 days or other specified soaking period. Maintain the water level above the mould during this period.

NOTE: A shorter soaking period is permissible for soils that take up moisture readily provided tests have shown that the shorter period do not affect the results. Some specimens may require longer soaking periods to account for expected in service conditions.

(g) After soaking is completed obtain and record a final reading (r_2) using the DMS and the setting piece. If $r_2 \neq r_1$ reset the DMS so that $r_2 = r_1$

(h) Place the DMS on the points of contact marked in Procedure 6.3(d) and record the reading after soaking (h_2).

(i) Remove the specimen from the water and tilt the specimen to remove the surface water. Return the mould to the vertical position and allow the specimen to drain downward for approximately 15 minutes. Do not disturb the surface of the specimen during the removal of water.

(j) Remove the surcharges, stem and perforated plate and determine the mass of the baseplate plus mould plus specimen (m_4).

(k) Perform the penetration test (Procedure 6.4) as soon as practicable.

6.4 PENETRATION TEST

(a) Place the 2.25 kg annular surcharge on the specimen and then place the mould plus specimen plus baseplate in the loading machine. Seat the penetration piston with the smallest possible load, not exceeding 50 N for expected CBR values ≤ 30 and 250 N for expected CBR values > 30. Apply surcharges as required. Unless otherwise specified the surcharge mass shall be 4.5 kg. If the specimen was soaked, apply surcharges equivalent in mass to those applied during soaking.

NOTES:

1. This initial load is required to ensure satisfactory seating of the piston and is considered as the zero load when plotting the load-penetration curve.

2. Refer to Note in Procedure 6.3(b)

(b) Read, or set to zero, the force-measuring device and the displacement measuring device used to measure penetration. The penetration measured shall be that of the piston relative to the mould.

NOTE: The dial gauge should be mounted such that no other displacements in the equipment influence the actual measured penetration.

(c) Apply the load with a constant rate of penetration of 1 ± 0.2 mm/min. Record load readings at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5 mm.

NOTE: With manually operated loading devices, it may be necessary to take load readings at closer intervals to control the rate of penetration.

(d) The test may be terminated after 7.5 mm penetration if the penetration is proceeding without any increase in the load or the limits of the equipment are reached.

(e) Remove the soil from the mould and determine the moisture content of the top 30 mm layer (w_{30}) and that of the remaining specimen (w_r) in accordance with Test Method WA 110.1.

7 CALCULATONS

Calculate the following:

(a) Plot the load-penetration curve (see Figure 6). When the load-penetration curve is concave upward initially (because of surface irregularities or other causes) adjust the zero point as shown in Figure 6, curve 3. If the correction is greater than 2 mm the load-penetration curve shall be presented in the test report.

(b) Read from the load-penetration curve, corrected if required, the force value in kN at penetrations of 2.5 mm and 5.0 mm and calculate the bearing ratio for each by dividing by 13.2 kN and 19.8 kN, respectively, and multiplying by 100.

Record the greater of the calculated values as the CBR of the material.

(c) Calculate the mass of dry soil in the specimen (m_5) from the following equation:

$$m_5 = \frac{m_2 - m_1}{\left(1 + \frac{w_1}{100}\right)}$$

Where:

m_5 = mass of dry soil in the specimen, in grams

m_2 = mass of mould plus compacted soil, in grams

m_1 = mass of mould, in grams

w_1 = moisture content of the soil immediately prior to compaction, in percent

(d) Calculate the dry density of the specimen before soaking (ρ_d) from the following equation:

$$\rho_d = \frac{1}{V_1} \times m_5$$

Where:

ρ_d = dry density of the specimen, in grams per cubic centimetre

m_5 = mass of dry soil in the specimen

V_1 = volume of the specimen in cubic centimetres (volume of the mould less the volume occupied by the disc)

(e) Calculate the laboratory density ratio (LDR) of the specimen from the following equation:

$$LDR = \frac{\rho_d}{MDD} \times 100$$

Where:

LDR = laboratory density ratio, in percent

ρ_d = dry density of the specimen, in grams per cubic centimetre

MDD = maximum dry density of the soil, in grams per cubic centimetre.

(f) Calculate the laboratory moisture ratio (LMR) of the specimen from the following equation:

$$LMR = \frac{w_1}{OMC} \times 100$$

Where:

LMR = laboratory moisture ratio, in percent

w_1 = moisture content of the soil immediately prior to compaction, in percent

OMC = optimum moisture content of the soil, in percent

(g) If the specimen has been soaked, calculate the percent swell (S) from the following equation:

$$S = \frac{h_2 - h_1}{117} \times 100$$

Where:

S = the swell of the specimen, in percent

h_2 = the reading after soaking, in millimetres

h_1 = the reading before soaking, in millimetres

(h) If the specimen has been soaked calculate the moisture content of the specimen after soaking (w_w) from the following equation:

$$w_w = w_1 + \frac{m_4 - m_3}{m_5} \times 100$$

Where:

w_w = moisture content of the specimen after soaking, in percent

w_1 = moisture content of the soil immediately prior to compaction, in percent

m_4 = mass of baseplate plus mould plus specimen after soaking in grams

m_3 = mass of baseplate plus mould plus specimen before soaking, in grams

m_5 = mass of dry soil in the specimen, in grams

(i) If the specimen has been soaked calculate the volume of the specimen after soaking (V_2) from the following equation:

$$V_2 = V_1 \left(\frac{100 + S}{100}\right)$$

Where:

V_2 = the volume of the specimen after soaking, in cubic centimetres

V_1 = the volume of the specimen before soaking, in cubic centimetres

S = the swell of the specimen, in percent

(j) If the specimen has been soaked calculate the specimen dry density after soaking (ρ_{da}) from the following equation:

$$\rho_{da} = \frac{m_5}{V_2}$$

Where:

ρ_{da} = dry density of the specimen after soaking, in grams per cubic centimetre

m_5 = mass of dry soil in the specimen, in grams

V_2 = the volume of the specimen after soaking, in cubic centimetres

(k) If the specimen has been soaked, calculate the laboratory density ratio after soaking (LDR_a) as a percentage of maximum dry density.

$$LDR_a = \frac{\rho_{da}}{MDD} \times 100$$

Where:

LDR_a = laboratory density ratio after soaking

ρ_{da} = dry density of the specimen after soaking, in grams per cubic centimetre

MDD = maximum dry density of the soil, in grams per cubic centimetre.

(l) If the specimen has been soaked calculate the laboratory moisture ratio after soaking (LMR_a) of the specimen from the following equation:

$$LMR_a = \frac{w_w}{OMC} \times 100$$

Where:

LMR_a = laboratory moisture ratio, in percent

w_w = moisture content of the specimen after soaking, in percent

OMC = optimum moisture content of the soil, in percent

(m) Calculate the laboratory moisture ratio of the top 30 mm of the specimen after penetration (LMR_{30}) of the specimen from the following equation:

$$LMR_{30} = \frac{w_{30}}{OMC} \times 100$$

Where:

LMR_{30} = laboratory moisture ratio of the top 30 mm, in percent

w_{30} = moisture content of the top 30 mm the specimen.

OMC = optimum moisture content of the soil, in percent

(n) Calculate the laboratory moisture ratio of the remainder (i.e. excluding the top 30mm) of the specimen after penetration (LMR_r) of the specimen from the following equation:

$$LMR_r = \frac{w_r}{OMC} \times 100$$

Where:

LMR_r = laboratory moisture ratio of the remainder, in percent.

w_r = moisture content of the remainder of the specimen.

OMC = optimum moisture content of the soil, in percent

8 REPORTING

Report the following:

(a) CBR of the specimen according to Table 2:

Table 2

CBR %	Report value to the nearest
< 5	0.5
5 to 20	1
>20 to 50	5
> 50	10

(b) The penetration at which the CBR was determined, in millimetres.

(c) The laboratory moisture content (w_1) and the moisture ratio (LMR) at which the specimen was compacted, to the nearest 0.1 percent.

(d) The desired moisture ratio to the nearest 0.1% at which the specimen was to be moulded.

(e) The laboratory dry density (ρ_d) and dry density ratio (LDR), at which the specimen was compacted, to the nearest 0.001 t/m³ and 0.1 percent respectively.

(f) The desired dry density ratio to the nearest 0.1% at which the specimen was to be moulded.

(g) The moisture content (w_{30}) and moisture ratio of the top 30 mm of the specimen after penetration, to the nearest 0.1 percent.

(h) The moisture content (w_r) and moisture ratio LMR_r of the remainder of the specimen after penetration, to the nearest 0.1 percent.

(i) If the specimen was soaked;

- The swell (S) of the specimen after soaking to the nearest 0.5 percent.
- The dry density ratio (LDR_a) of the specimen after soaking, to the nearest 0.1 percent.
- The moisture content (w_w) and moisture ratio LMR_a of the entire specimen after soaking, to the nearest 0.1 percent.

(j) The percentage by mass of the material retained on the 19 mm sieve.

(k) The mass of surcharges applied.

(l) The compactive effort used to compact the specimen in terms of the number of layers, the number of blows per layer and the mass of the rammer.

(m) The period of soaking.

(n) The period of curing

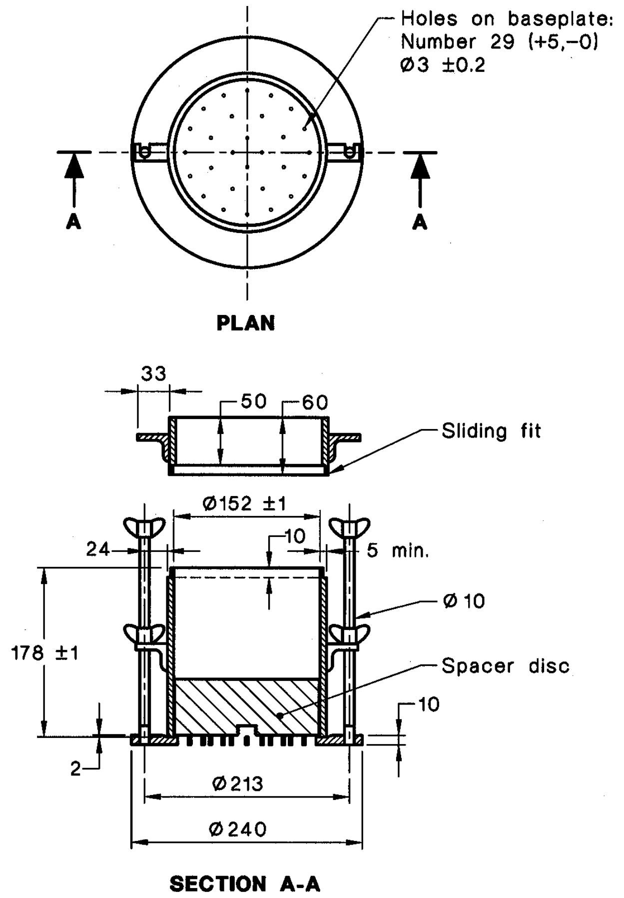
(n) The Identification and description of sample.

(o) The load-penetration curve with correction if applicable.

(p) Reference to this test method, i.e. Test Method WA 141.1.

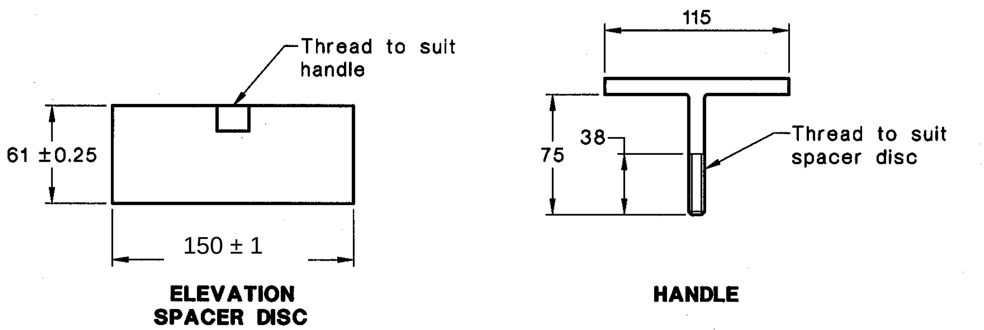
(q) The maximum dry density to the nearest 0.001 t/m³ and the optimum moisture content of the specimen to the nearest 0.1%.

9 FIGURES AND DRAWINGS



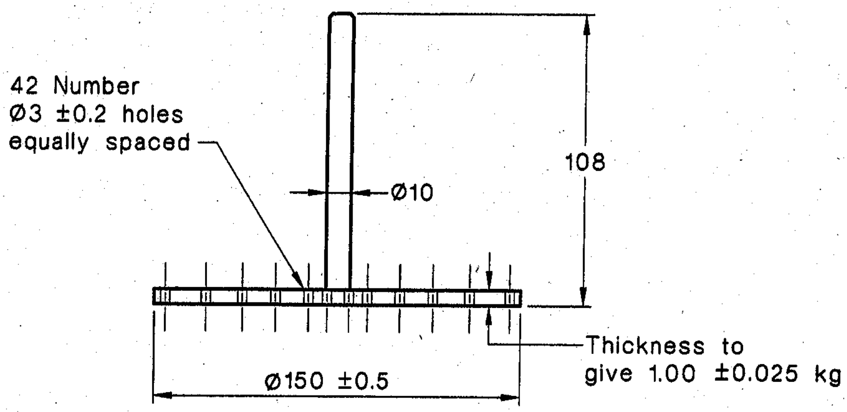
NOTES:
1 Essential dimensions are toleranced
2 All dimensions are in millimetres

FIGURE 1 MOULD



NOTES:
1 Essential dimensions are toleranced
2 All dimensions are in millimetres

FIGURE 2 SPACER DISC AND HANDLE

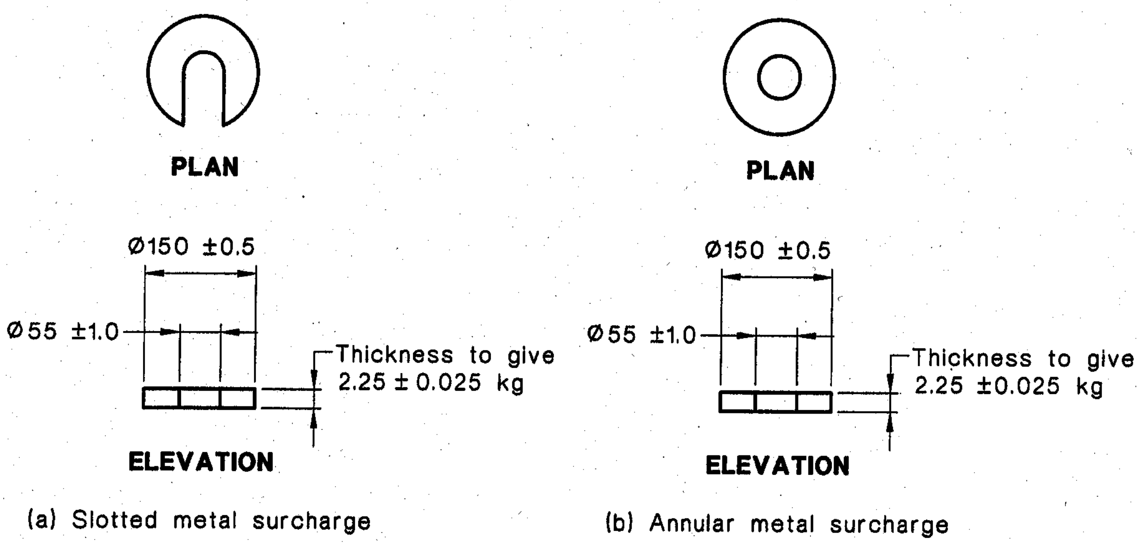


NOTES:

1 Essential dimensions are toleranced

2 All dimensions are in millimetres

FIGURE 3 STEM AND PLATE

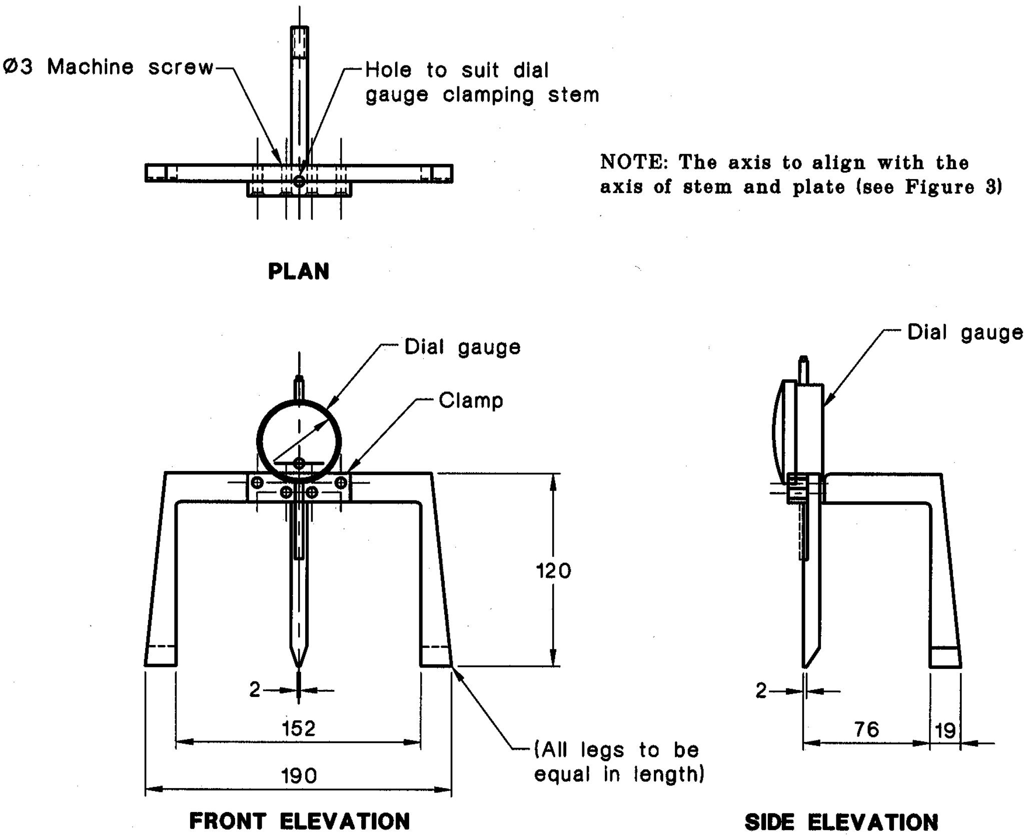


NOTES:

1 Essential dimensions are toleranced

2 All dimensions are in millimetres

FIGURE 4 SURCHARGES



NOTES:
1 Essential dimensions are toleranced
2 All dimensions are in millimetres

FIGURE 5 TYPICAL TRIPOD FOR MEASURING TEST SPECIMEN SWELL

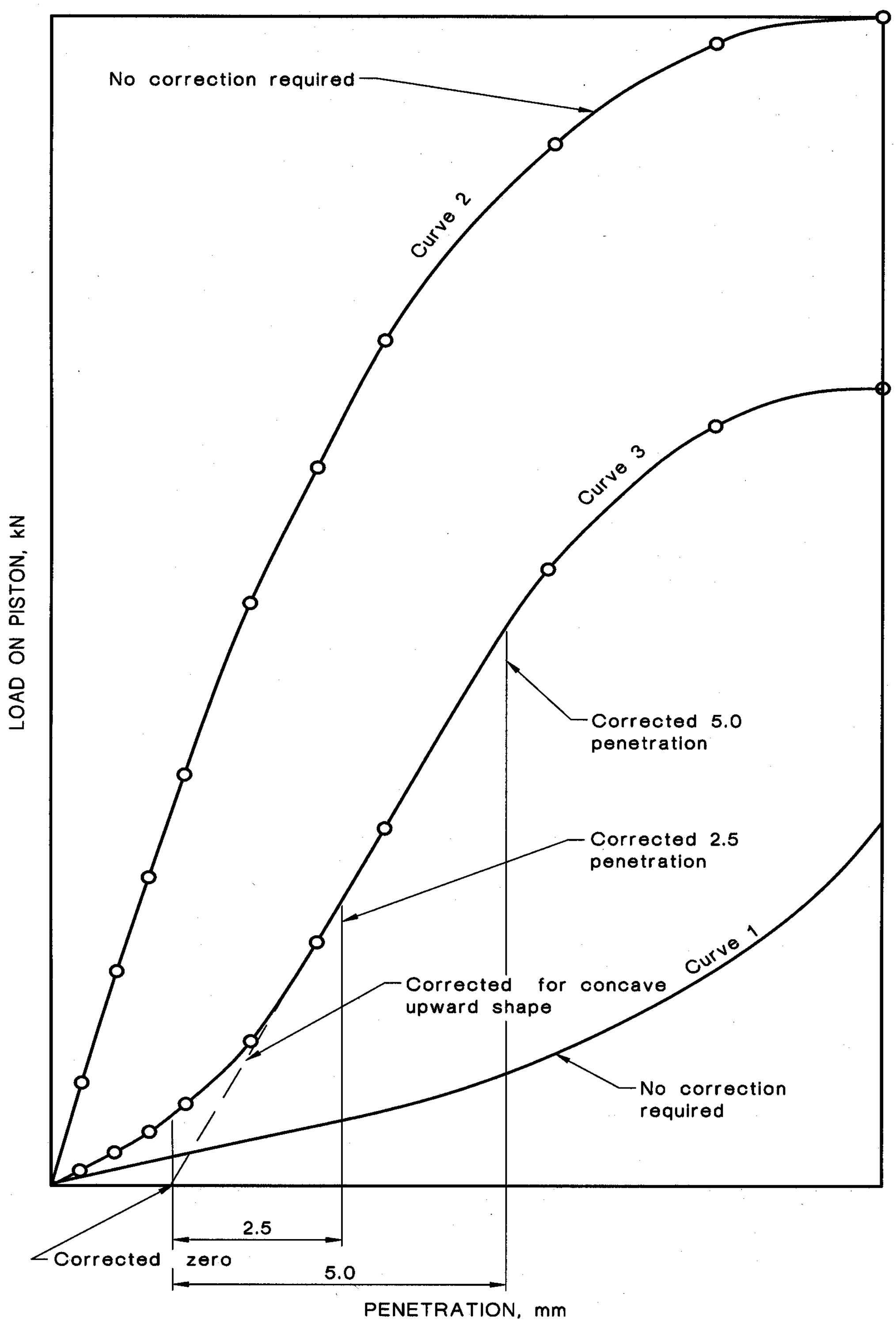


FIGURE 6 TYPICAL LOAD—PENETRATION CURVES

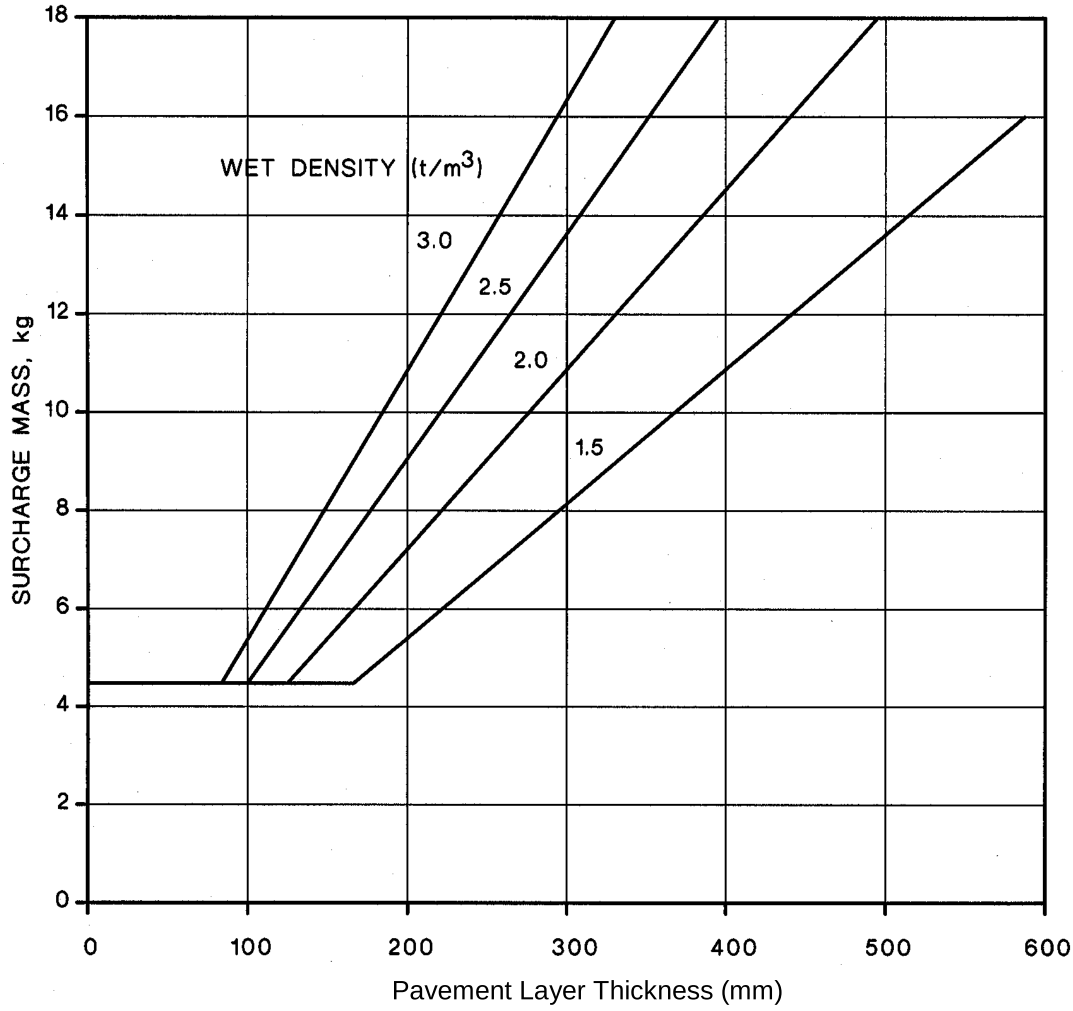


FIGURE 7 SELECTION OF SURCHARGE

10 ISSUING AUTHORITY

Document Owner
Pavements Manager

11 REVISION STATUS RECORD

Page No.	Section	Revision Description / Reference
3	6	Updated Table 1
1	3	Added AS 1289.5.2.1