



NIGERIAN BUILDING AND ROAD RESEARCH INSTITUTE
(FEDERAL MINISTRY OF INNOVATION, SCIENCE AND TECHNOLOGY)

LABORATORY MANUAL FOR SOIL TESTING IN ROAD CONSTRUCTION

**INTERNATIONAL WORKSHOP ON
GLOBAL TRENDS IN DESIGN & CONSTRUCTION OF DURABLE ROAD
PAVEMENTS
(24TH TO 28TH NOVEMBER, 2025)**

1.0 Natural Moisture Content (BS 1377: part 2,1990, ASTM D 2216)

1.1 Scope of the test

The objective of the test is to determine the water content of a soil sample as it was sampled in the field or at the moment of testing for the accurate determination of in-situ water content, the sampling, storage, transporting and handling precautions should be such that the water content remains within 1% of the in-situ value.

1.2 Apparatus used

- balance accurate to 0.01 gr.
- sample container (watch glasses or tins)
- oven (Capable of controlled heating at 105°C to 115°C) or
- desiccator

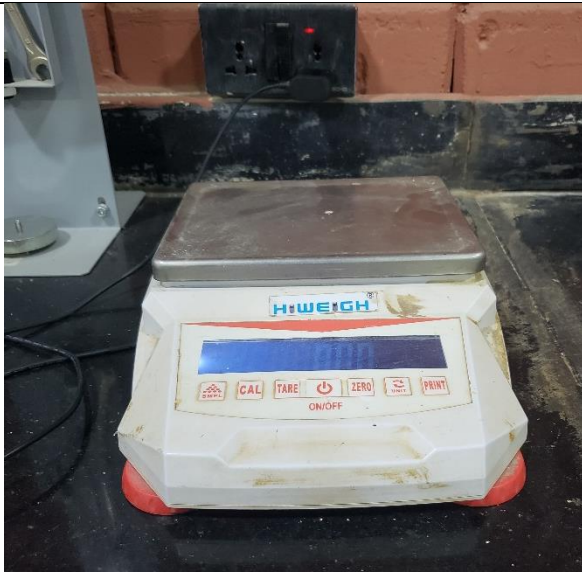
1.3 Sample preparation

The quantity of the soil sample required for an accurate measurement of the natural water content is dependent upon the particle size of the sample.

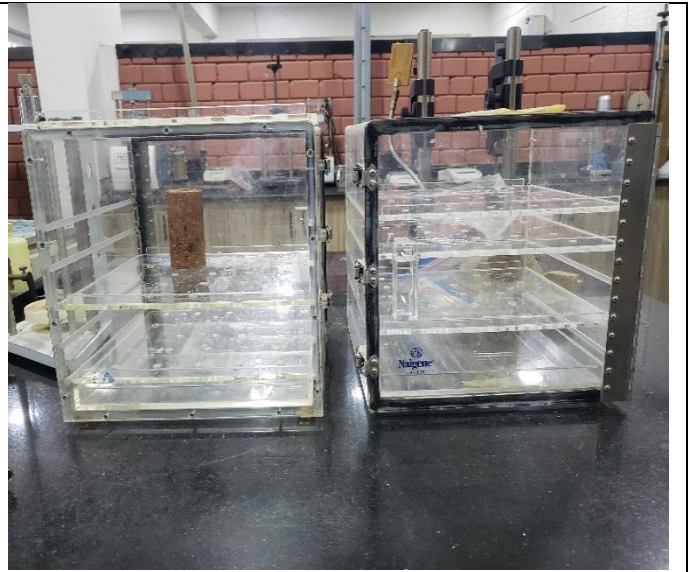
- fine grained material 30 g
- medium grained material 300 g
- coarse grained material 3000 g

1.4 Execution of the test

- weigh the sample container to 0,01 gr. accuracy M_1
- add the material to be tested and weigh again M_2
- place container with sample in the oven for 24 hours at a controlled temperature of 105 °C (BS) or 110 ± 5 °C
- cool the sample in the desiccator
- weigh the oven dry and cooled sample M_3



Weighing scale



Desiccator



Moisture cans



Laboratory Oven

Plate 1: Typical apparatus set for Moisture Content determination

1.5 Calculations

$$\text{Moisture content } W = \frac{\text{mass of water}}{\text{dry mass of sample}} = \frac{M2 - M3}{M3 - M1} * 100\%$$

2.0 SIMPLE DRY SIEVING (BS 1377: Part 2:1990, ASTM D422)

2.1 Scope of the test

Dry sieving is the simplest of all methods of particle size analysis. According to the British Standard dry sieving may be carried out only on materials for which this procedure gives the same results as the wet sieving procedure. This means that it is applicable only to clean granular materials, which usually implies clean sandy or gravelly soils (i.e. soils containing negligible amounts of particles of silt or clay size). If in doubt about the validity of the dry-sieving method, the wet-sieving procedure should be followed instead.

If particles of medium gravel size or larger are present in significant amounts, the initial size of the sample required may be such that riffing is necessary at some stage to reduce the sample to a manageable size for fine sieving. The procedure is then referred to as "composite sieving".

2.2 Sample preparation

- The specimen to be used for the test is obtained from the original sample by riffing, or by subdivision using the cone-and-quarter method. The appropriate minimum quantity of material depends upon the maximum size of particles present, and is indicated in Table 2.2-1 and 2.2-2 according to BS 1377 and ASTM D 422 respectively.
- The specimen is placed on a tray and is allowed to dry, preferably overnight, in an oven maintained at 105-110 °C (According to BS 1377) or $110 \pm 5^\circ \text{C}$ (According to ASTM D 422)
- After drying to constant weight, the whole specimen is allowed to cool, and is weighted to an accuracy within 0.1% or less of its total mass (M_1).

Table 2.1-1 Minimum quantities for particle size test (BS 1377)

Maximum size of material present in substantial proportion retained on BS sieve (mm)	Minimum mass of sample to be taken for sieving
Pass 2 mm or smaller	100g
6.3	200g
10	500g
14	1kg
20	2kg
28	6kg
37.5	15kg
50	35kg
63	50kg
75	70kg
100	150kg
150	500kg
200	1000kg

Table 2.1-2 Minimum quantities for particle size test (ASTM D 422)

Maximum particle size	Minimum weight of sample, g
75 mm	6000
50 mm	4000
25 mm	2000
10 mm	1000
Finer than 4.75 mm	200
Finer than 2 mm	100

2.3 Execution of the test

2.3.1 Selection of sieves.

- The complete range of sieves specified by the British Standard is given in Table 2.1-3 It is not necessary to use all sieves for every test, but the sieves used should adequately cover the range of aperture sizes for each particular soil. For classification purposes we can use a short set. Also, a series of sieves complying to ASTM E 11 as shown in 2.1-4 is used according to ASTM D 422.
- The sieves to be used are selected to suit the size of sample and type of material.
- Sieve frames must not be out of true, and should fit snugly one inside the other, to prevent escape of dust. Sieves are nested together with the largest aperture sieve at the top, and a receiving pan under the smallest aperture sieve at the bottom.



Plate 2: Set of sieves for dry sieving

Table 2.1-3 Metric sieves (BS 1377)

Construction	Aperture size			Suitable sieve diameters		
	full set	Standard set	Short set			
	A	B	C	450mm	300mm	200mm
Perforated	75 mm	+		+		
Steel plated	63	+	+	+		
(Square holes)	50			+		
	37.5	+		+	+	
	28			+	+	
	20	+	+	+	+	
	14				+	
	10	+			+	
	6.3	+	+		+	
	5				+	
Woven wire	3.35	+			+	+
	2	+	+	(+)	+	+
	1.18	+				+
	600 μm	+	+	(+)	+	+
	425					+
	300	+				+
	212		+			+
	150	+				+
	63	+	+	(+)	+	+
Lid and receiver +		+	+			
19 sieves		13 sieves	7 sieves			

Table 2.1-4 Sieves arrangement for simple dry sieving (ASTM D422)

Full set		Standard set	
Alternative designation	Size (mm)	Alternative designation	Size (mm)
3-in.	75	3-in.	75
2-in.	50	1 ^{1/2} -in..	37.5
1 ^{1/2} -in.	37.5	3/4- in.	19
1 -in	25.0	3/8- in.	9.5
3/4- in.	19.0	No.4	4.75
3/8- in.	9.5	No. 8	2.36
No.4	4.75	No.16	1.18
No. 10	2.00	No.30	0.600
No. 20	0.850	No.50	0.300
No. 40	0.425	No.100	0.150
N0. 60	0.250	No.200	0.075
No. 140	0.106		
No. 200	0.075		

2.4 Test procedure.

- The dried soil sample is placed in the topmost sieve and is shaken long enough that all particles smaller than each aperture size can pass through. This can be achieved most conveniently by using a mechanical sieve shaker.
- The whole nest of sieves with receiving pan is placed in the shaker, the dried soil is placed in the top sieve, which is then fitted with the lid, and the sieves are securely fastened down in the machine.
- Agitation in the shaker should be for a minimum period of 10 min. Some shakers have a built-in timing device which can be pre-set to switch off the motor automatically after the desired period.

- Weighing, the material retained on each sieve is transferred to a weighed container. Any particles lodged in the apertures of the sieve should be carefully removed with a sieve brush, the sieve being first placed upside-down on a tray or a clean sheet of paper. These particles are added to those retained on the sieve. Weighing of each size fraction should be to an accuracy of at least 0.1% of the total initial test sample mass. The masses retained (M_{s1} , M_{s2} , etc.) are recorded against the sieve aperture size on the particle size test work sheet. The mass (M_p) passing the 63 μ m sieve is also measured and recorded.

2.5 Calculations

The mass retained on the first sieve is denoted as M_{s1} .

The mass passing the first sieve = $M_1 - M_{s1}$.

The percentage passing the first sieve is given by

$$P_1 = \frac{M_1 - M_{s1}}{M_1}$$

The mass passing the second sieve = $M_1 - M_{s1} - M_{s2}$. The percentage passing the second sieve is given by

$$P_2 = \frac{M_1 - (M_{s1} + M_{s2})}{M_1} \times 100$$

And so on.

The percentage passing any subsequent sieve can be written as

$$P = \frac{M_1 - \Sigma M}{M_1} \times 100$$

Where ΣM denotes the sum of the masses retained on all sieves down to and including the one in question: $\Sigma M = M_{s1} + M_{s2} + M_{s3} + \text{etc.}$

The calculated mass passing the last sieve should be equal, or very nearly equal, to the mass collected in the receiving pan. If this is denoted by M_p , the percentage of fines, P_p passing the last sieve is

$$P_p = \frac{M_p}{M_1} \times 100$$

3.0 Wet sieving – fine-grained soils (BS1377: Part 2:1990, ASTM D422)

3.1 Scope of the test

If soil contains silt or clay, or both, even in small quantities, it is necessary to carry out a wet sieving procedure in order to measure the proportion of fine material present. Even when dry, fine particles of silt and clay can adhere to sand-size particles and cannot be separated by dry sieving, even if prolonged. Washing is the only practicable means of ensuring complete separation of fines for a reliable assessment of their percentage. If clay is present, or if there is evidence of particles sticking together, the material should be immersed in a dispersant solution before washing. The dried representative sample is spread out on a tray and covered with water containing 2g/litre of sodium hexametaphosphate. The soil is allowed to stand for at least an hour according to BS 1377 or 2 to 24 hours according to ASTM D 422, depending on the nature of the soil, and is stirred frequently. This disperses the clay fraction so that clay and silt will not adhere to larger particles.

The procedure is described in detail below for non-cohesive soils containing little or no gravel.

3.2 Sample Preparation

- The specimen to be used for the test is obtained from the original sample by rifling, or by subdivision using the cone-and-quarter method. The appropriate minimum quantity of material depends upon the maximum size of particles present, and is indicated in Tables 2.1.1 and 2.1.2.
- The specimen is placed on a tray and is allowed to dry, preferably overnight, in an oven maintained at 105-110 °C (According to BS 1377) or $110 \pm 5^\circ \text{C}$ (According to ASTM D 422) After drying to constant weight, the whole specimen is allowed to cool, and is weighted to an accuracy within 0.1% or less of its total mass (M_1).

3.3 Execution of the test

3.3.1 Selection of sieves.

The complete range of sieves specified by the British Standard is given in Table 2.1.3 or 2.1.4, It is not necessary to use all sieves for every test, but the sieves used should adequately cover the range of aperture sizes for each particular soil. For classification purposes, we can use a short set.

3.3.2 Sieving coarse material

The sample is sieved on a large-diameter 20 mm sieve, with a portion being taken at a time, so as not to overload the sieve (see Table 2.1-5). Particles retained are brushed to remove finer material which may be adhering to them, but individual particles must not be broken down. The material retained on the 20 mm sieve, after drying, if necessary, is then sieved on appropriate larger aperture sieves and the amount retained on each is weighed.

The fraction passing the 20 mm sieve, including "brushings" from larger particles, is then oven dried and weighed (M_2). If M_2 is much more than 2 kg the sample is subdivided to give a convenient mass M_3 for the remainder of the sieving operation.

3.3.3 Washing.

The 2 mm according to BS 1377 or 4.75 mm according to ASTM D 422 sieve is nested in the 63 microns according to BS or 75 microns according to ASTM, but the lid and receiver are not used. An additional intermediate sieve may be included to protect the 2mm or 4.75 mm and 63 microns or 75 microns sieve from overloading if the soil contains a high proportion of coarse sand or gravel.

The soil is placed a little at a time on the 2 mm or 4.75 sieve and washed over a sink with a jet or spray of clean water. The silt and clay passing the 63- or 75-micron sieve is allowed to run to waste. When the material on the 2- or 4.75-mm sieve has been washed free of fines, washing on the 63- or 75-micron sieve is continued until the wastewater is seen to run clear.

During this operation the sieve must not be allowed to become overloaded with soil or to overflow with water. The mass of soil retained on the 63mm should not exceed 150 g at any one time. Table 2.1-5 gives the recommended maximum quantities that may be retained on each sieve. If this is likely to be exceeded, the material should be sieved in two or more portions.

Warning: The sink used for this operation should be fitted with a silt trap.

3.3.4 Drying

The whole of the material retained on each sieve is allowed to drain and is carefully transferred to trays or evaporating dishes. These are placed in an oven to dry at 105-110 °C (According to BS 1377) or $110 \pm 5^\circ \text{C}$ (According to ASTM D 422), preferably overnight.

3.3.5 Weighing

After cooling, the whole of the dried material is put together and weighed to an accuracy of 0.1% (M_4).

3.3.6 Sieving

The dry soil is passed through a nest of the complete range of sieves to cover the sizes of particles present, down to the 63- or 75-micron sieve. This operation may be carried out by hand or preferably on a sieve shaker, exactly as in the dry sieving procedure. Weigh the amount retained on each sieve to 0.1 % of its total mass.

If the fraction passing the 63- or 75-microns sieve is small, i.e. not more than 150 g, the sample may be sieved by dry sieving on the appropriate sieves down to and including the 63 or 75 μm test sieve. Weigh the amounts retained on each sieve, and any fines passing the 63 or 75 μm test sieve (M_f), to 0.1 % of its total mass.

If the fraction passing the 63- or 75-microns sieve is large i.e. substantially greater than 150 g, it should be accurately weighed (M_5) and then subdivided to give a sample of 100-150 g.

Weigh this fraction (M_6) and then sieve on the appropriate sieves down to and including the 63 or 75 μm test sieve. Weigh the amounts retained on each sieve, and any fines passing the 63 μm test sieve,

(M_e)

If riffing is not necessary, (M_6) is the same as (M_5).

- Weighing

The portion retained on each sieve is weighed, each to an accuracy of 0.1%.

3.4 Calculations

- Calculation for the particles larger than 20mm in size, calculate the proportion by mass of material retained on each of the coarse series of sieves as a percentage of M_1

For example:

$$\text{Percentage retained on 28 mm sieve} = \left\{ \frac{M(28\text{mm})}{M_1} \right\} 100$$

Calculate the corrected mass of material retained on each of the sieves between 20 mm and 6.3 mm

by multiplying by $\frac{M_2}{M_3}$, then calculate this mass as a percentage of M_1

For example:

$$\text{Percentage retained on 10 mm sieve} = M(10\text{mm}) \left(\frac{M_2}{M_3} \right) \left(\frac{100}{M_1} \right)$$

- Calculate the corrected mass of material retained on each of the sieves finer than the 6.3 mm sieve by multiplying by $\left(\frac{M_2}{M_3}\right)\left(\frac{M_5}{M_6}\right)$, then calculate this mass as a percentage of M_1

For example:

$$\text{Percentage retained on 300 } \mu\text{m sieve} = M(300 \mu\text{m}) \left(\frac{M_2}{M_3}\right) \left(\frac{M_5}{M_6}\right) \left(\frac{100}{M_1}\right)$$

- Calculate the cumulative percentage by mass of the sample passing each of the sieves from the general relationship:

$$(\% \text{ passing this sieve}) = (\% \text{ passing previous sieve}) - (\% \text{ retained on this sieve})$$

Calculate the fraction passing the 63 μm test sieve by difference. The mass of fines lost by washing is equal to $(M_3 - M_4)$. To this is added the mass of any fine material (M_f) passing the 63 μm test sieve when dry sieved.

$$\text{Percentage passing 63 } \mu\text{m sieve} = \left\{ \frac{(M_3 - M_4) + M_f}{M_3} \right\} \left(\frac{M_2}{M_1}\right) 100$$

4.0 Hydrometer test (ASTM D422)

Basically, the behaviours of fine-grained soils are influenced by the shape, arrangement of particles and geological history. However, there are some cases in which the grain size distribution of these soils is required, for example, in the design of filters for drainage systems and the rise of water in the capillary opening. The behaviour of expansive soils is also a function of the proportion of clay fraction in the soil. Hydrometer analysis is a method used to determine the grain size distribution of fine-grained soil having particle sizes smaller than $75\mu\text{m}$ using a Hydrometer. It is based on the Stoke's law, which says that the larger the grain size, the greater its settling velocity in a fluid.

4.1 Equipment

- Soil Hydrometer: There are two types of hydrometer. One is graduated in specific gravity of fluids and is calibrated to read 1.000 g/cm^3 in pure water at 20°C (ASTM 151H). The other is graduated in grams of soil and is calibrated at 0g/l in pure water at 20°C (ASTM 152H).
- Two sedimentation cylinders of glass, marked for a volume of 1000ml .
- Mechanical stirrer; Thermometer, ranging from 0 to 50°C , accurate to 0.5°C .
- 0°C ; stopwatch; Balance accurate to 0.01g ; Oven; Desiccator; Evaporating Dish; Wash bottle; Glass rod about 12mm in diameter and about 400mm long; Water bath; Sieve $75\mu\text{m}$; Scale; 500ml of hydrogen peroxide, 500ml of a stock solution of sodium hexametaphosphate with a concentration of 40g per liter of distilled or demineralized water. This solution should be prepared frequently and should be less than a month old: 3l of distilled or demineralized water.

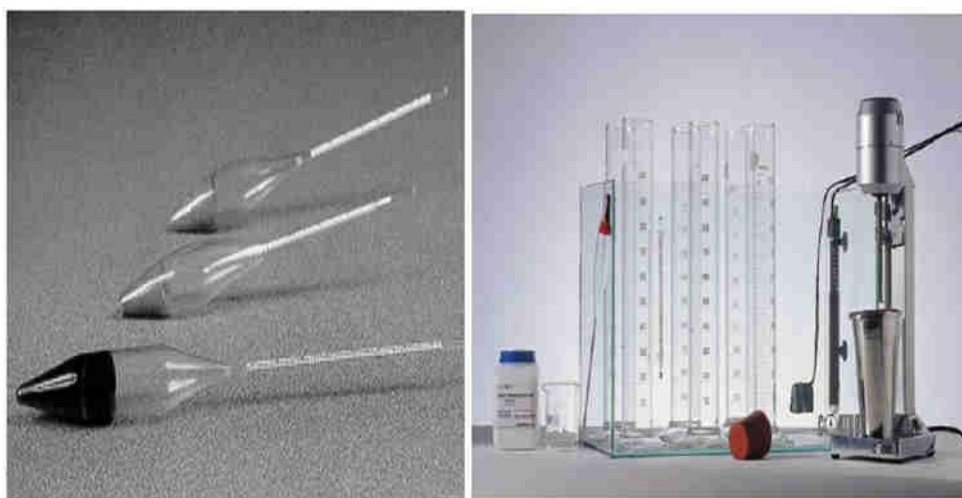


Plate 3: Hydrometer analysis apparatus

4.2 Preparation and pretreatment of Sample

- The test specimen is obtained from the fraction of sample soil that smaller than 75 μ m. The approximate weight of the dry specimen may be selected as shown in the table below.

Table 4.1 - Approximate Quantity of Material for Sedimentation Analysis

Soil type	Dry weight (g)
Fat clay	30.0
Lean clay and silty soil	50.0

- Organic soils must be treated with chemicals to remove organic matter. The organic matter is removed from soils by oxidation and accomplished by mixing the soil sample with a solution of 30% hydrogen peroxide.
- Very fine soil grains will normally tend to flocculate in suspension (i.e., will adhere to each other and settle together). A dispersing agent is added to all samples to prevent grains from flocculating. Hydrometer and Cylinder calibration
- Prior to the hydrometer test, the hydrometer and the sedimentation cylinder are calibrated.

4.3 Test Procedure

- Take the required mass from dried soil passing the 75 μ m sieve. And determine the specific gravity of solids using the remaining soil sample.
- Place the sample in the 250-ml beaker and cover it with 125 ml of sodium hexametaphosphate solution at 5%.
- Stir until the solution is thoroughly wetted. Allow to soak at least 16 hours.
- Transfer the material into the dispersing apparatus, taking care that no particle is left in the beaker by cleaning it with distilled water.
- Add distilled water, if necessary, so that the cup is more than half full.
- Stir for a period of 1min.

- Immediately after dispersion, transfer the soil-water slurry to the glass sedimentation cylinder.
- Add distilled water until the total volume is 1000ml. Shake the solution to complete the agitation of the slurry. About one minute before starting the test, take the cylinder in one end and, using the palm of the other hand or a suitable rubber cup as a stopper, shake the suspension vigorously for a few second to mix the sediment at the bottom of the cylinder into a uniform suspension. Repeat this agitation several times by turning the cylinder upside down.
- Set the cylinder in a convenient location and take hydrometer reading at the following interval of time (measured from the beginning of sedimentation) : 1min, 2, 5, 15, 30, 60, 120, ...1440. Reading taken up to 2min. can be performed without taking off the hydrometer from the cylinder. For the remaining readings slowly insert the hydrometer about 20-25 seconds before the reading is due. As soon as the reading is taken, carefully remove the hydrometer and place it in a cylinder with distilled water.
- After each reading take the temperature of the suspension by inserting the thermometer into the suspension. If the hydrometer test is conducting at constant temperature at which the hydrometer is calibrated (in constant temperature bath), this step is not required.

4.4 Computation and Plotting

1. For computation of diameter of grains

$$D = \sqrt{\frac{L}{T}}$$

Where

D = Grain-size, in mm

K = (See Appendix)

H = Viscosity of the water at temperature T in g/cm.sec

G_s = the specific gravity of the soil particles

ρ_w = The unit mass of water at temperature T in g/cm³

L = Effective depth corresponding to R' in cm

T = the time after the beginning of sedimentation, in min

2. The percentage p by weight of particles with diameter smaller than D is

For ASTM 152H: $P = a \frac{R''}{M_0} \times 100$

For ASTM 151H: $P = b \frac{R''-1}{M_0} \times 100$

Where

$$a = 0.6226 \frac{G_s}{G_s - 1}$$

$$b = V \frac{G_s}{G_s - 1}$$

M_0 = Oven-dried weight of soil per liter of suspension

R'' = Corrected hydrometer reading

G_s = Specific gravity of the soil particles and

V = Volume of suspension usually it is 1000cc.

3. Plot percentage finer versus grain size on semi-logarithmic graph.

5.0 The Atterberg limits

The Atterberg limits are the so-called consistency limits. Determining the Atterberg limits is a very useful method to classify cohesive soils. The concept is based on the fact that the consistency depends largely on its water content. The Atterberg limits comprise the liquid limit (W_L), the plastic limit (W_p) and the shrinkage limit (W_s). They define the boundaries between the four stages of soil. There are generally two methods for the determination of liquid limits, the fall cone penetration and Casagrande method. The fall cone method is preferred over the Casagrande method, this is because it gives a more reliable, consistent and reproducible result.

5.1 Liquid limit using the cone penetrometer BS 1377: Part 2:1990

5.1.1 Scope of the test

With this test, one can obtain the liquid limit. This value is often used in classification systems, together with particle size analysis.

It is based on the measurement of penetration into the soil of a standardized cone of specified mass. At the liquid limit the cone penetration is 20 mm.

Note: The results obtained with the cone penetrometer may differ slightly from those with the Casagrande apparatus, but in most cases up to a liquid limit of 100 these differences will not be significant.

5.1.2 Apparatus used

- Cone penetrometer with standard cone of mass 80 gr. see fig 5.4
- sample cup of diameter 55 mm and 40 mm deep - Flat glass plate about 500 mm square.
- 2 spatulas
- wash bottle
- drying oven
- mass balance accurate to 0.01 g



Plate 4: Digital cone penetrometer for Liquid Limit determination

5.1.3 Sample preparation

Wherever possible, the test shall be carried out on soil in its natural state. With many clay soils it is practicable and shall be permissible to remove by hand any coarse particles present, i.e. particles retained on a 425 μ m test sieve. Otherwise, these particles shall be removed by wet sieving.

5.1.3 (a) Sieve procedure

- Take a sample of the soil of sufficient size to give a test specimen weighing at least 300 g., which passes the 425 μ m test sieve.
- Take a representative sample and determine its moisture content, W_1 . (in %)
- Weight the remainder of the sample to an accuracy of within 0.01 g
- (M6) -Place the sample in a container under just enough distilled water to submerge it.

- Stir the mixture until it forms a slurry.
- Sieve the slurry through the 425 µm sieve with the minimum amount of distilled water until the water passing is virtually clear.
- Collect the material retained on the 425 µm sieve, dry it at 105 °C and weigh it to an accuracy of within 0.01 g (M7).
- Collect the fines in a receiver or large container if necessary, and let the fine particles settle.
- After a suitable interval, pour off any clear water above the suspension, and let it dry (warm air) until it forms a stiff paste.

5.1.3 (b) Calculation

From the sieved soil calculate the dry mass, M_d (in g), of the initial sample from the equation:

$$M_d = \left(\frac{100}{100 + W_n} \right) M_6$$

Where

W_n is the moisture content (in %)

M_6 is the mass of particles retained on 425 µm sieve (in g).

$$P_a = \left(\frac{M_d - M_7}{M_d} \right) 100\%$$

Where

M_7 is the dry mass of particles passing the 425 µm sieve (in g)

5.1.4 Execution of the test

- Thoroughly mix the sample on the glass plate using two spatulas, and if necessary, add distilled water, to form a plastic material.

- Place the paste into an airtight container and leave it standing for a curing period of 24 hour, or overnight, to allow water to permeate through the soil mass. For soil of low clay content, such as very silty soils, the curing period may be omitted.
- Remove the soil from the container and remix with the spatulas for at least 10 min. Some soils (heavy clays) up to 40 min.
- fill the sample cup with the soil and trim off excess material with the spatula to form a smooth even surface being careful not to trap any air bubbles
- bring the point of the cone to the surface of the sample lower the dial gauge pointer to the top of the cone and set the gauge to zero
- release the cone by pressing the release button for 5 seconds.
- lower the pointer to the new position of the cone.
- Take a reading to the nearest 0.1 mm, it should be approximately 15 mm for the first test.
- Lift out the cone and clear it carefully. Add a little more wet soil to the cup and take a second reading. If the second cone penetration differs from the first by less than 0.5 mm, the
- Average value is recorded, and the moisture content is measured. If the second penetration is between 0.5 and 1 mm different from the first, a third test is carried out, and provided the overall range does not exceed 1mm, the average of the three penetrations is recorded and the moisture content is measured. If the overall range exceed 1mm, the soil is removed from the cup and remixed, and the test is repeated.
- take a sample of approximately 10 grams from the cup and determine its moisture content
- To the remainder of the material add some distilled water and repeat the above procedure. This is done at least three more times to get a range (min. 4) of penetration values from about 15mm to 25 mm.
- N.B. One must be careful not to add too much water at one time.

5.1.5 Calculation

The moisture contents determined are plotted against the respective penetration depth, both on a linear scale. The liquid limit is defined as that moisture content where the cone penetrates 20 mm into the sample. This value is interpolated from a graph. See fig. 6.5.

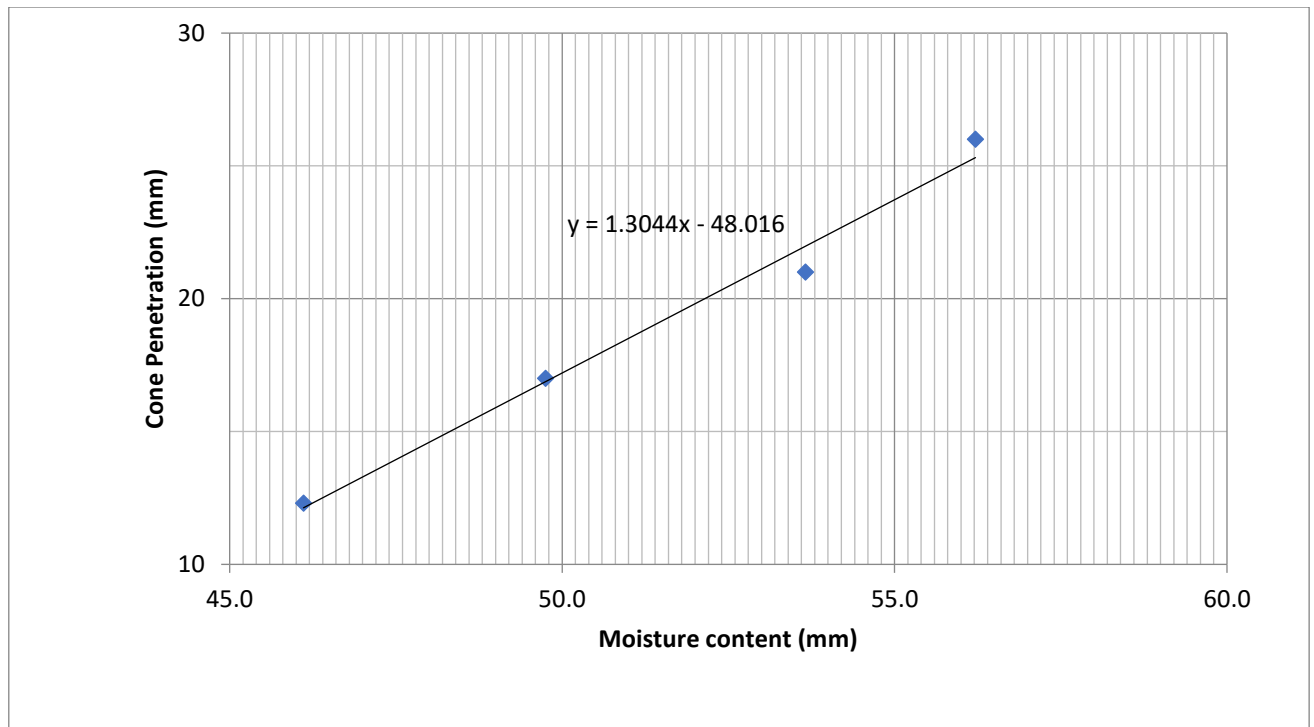


Fig 1: Typical penetration versus moisture content plot

5.2 Plastic limit BS 1377: Part 2:1990, ASTM D 4318

5.2.1 Scope of the test

The plastic limit is often used together with the liquid limit to determine the plasticity index, which, when plotted against the liquid limit on the plasticity chart, provides a means of classifying cohesive soils.

It is the empirically established moisture content at which soil becomes too dry to be plastic.

5.2.2 Apparatus

- glass plate
- 3 mm diameter metal rod
- spatulas
- drying oven - mass balance accurate to 0,01 gram.

5.2.3 Sample preparation

20 gram of material is needed. The sample may be a disturbed sample. We only use material passing the 425 μm sieve.

5.2.4 Execution of the test

- Thoroughly knead the sample and if necessary, mix with the distilled water for 10 min. to form a plastic ball.
- Mould the ball between the fingers and roll between the palms of the hands so that the warmth of the hands slowly dries it. When slight cracks begin to appear on the surface, divide the ball into two portions each of about 10 g. Further divide each into four equal parts, but keep each set of four parts together.
- One of the parts is formed into a thread about 6 mm diameter, using the finger and thumb of each hand. The thread must be intact and homogeneous. Using a steady pressure, roll the thread between the fingers of one hand and the surface of the glass plate. The pressure should reduce the diameter of the thread from 6 mm to about 3 mm after between five and ten back-and-forth movements of the hand. Some heavy clay may need more than this because this type of soil tends to become harder near the plastic limit. It is important to maintain a uniform rolling pressure throughout; do not reduce pressure as the thread diameter approaches 3 mm.
- Mould the soil between the fingers again to dry it further. Form it into a thread and roll out again as before. Repeat this procedure until the thread crumbles when it has been rolled to 3-mm diameter. The metal rod serves as a reference for gauging this diameter. By "crumbling" is meant shearing both longitudinally and transversally as it is rolled. Crumbling must be the result of the decreasing moisture content only, and not due to mechanical breakdown caused by excessive pressure, or oblique rolling or detachment of an excessive length beyond the width of the hand.
- The first crumbling point is the plastic limit. It may be possible to gather the pieces together after crumbling, to reform a thread and to continue rolling under pressure, but this should not be done.
- As soon as the crumbling stage is reached, gather the crumbled threads and place them into a weighed moisture content container.
- Repeat for the other three pieces of soil, and place in the same container. Weigh the container and soil as soon as possible, dry in the oven overnight, cool and weigh dry, as in the standard moisture content procedure.

- Repeat stages on the other set of four portions of the soil, using a second moisture content container.

5.2.5 Calculations

Calculate the moisture content of the soil in each of the two containers. Take the average of the two results. If they differ by more than 0,5% moisture content, the test should be repeated.

Remarks

From some soils the plastic limit cannot be determined. Crumbling occurs before you reach 3mm. or rolling of the soil is not possible.

6.0 Soil Compaction test BS 1377: Part 4: 1990, ASTM 698, 699

6.1 Scope of the test

Compaction of soil is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the soil. The dry density, which can be achieved, depends on the degree of compaction applied and on the amount of water present in the soil. For a given degree of compaction of a given cohesive soil there is an optimum moisture content at which the dry density obtained reaches a maximum value.

Two types of compaction test are described, each with procedural variations related to the nature of the soil:

- 1-Light compaction test (BSL according to BS 1377 or Standard proctor test according to ASTM D 698), using a 2.5 kg rammer.
- 2-Heavy compaction test (BSH according to BS 1377 or Modified proctor according to ASTM D 699), using a 4.5 kg rammer.

For both these tests a compaction mould of 1 L. internal volume is used for soil in which all particles pass a 20 mm test sieve (BS 1377) or $943 \pm 14 \text{ cm}^3$ if more than 30 % is passing sieve 9.5 mm (ASTM 698, 699).

But if there is a limited amount of particles up to 37.5 mm size or less than 30 % passes sieve 19.0 mm, equivalent tests are carried out in the larger CBR mould. Specifications for compaction by rammer in the CBR mould are based on the same compactive effort per unit volume of soil as in the smaller compaction mould. For a series of tests on a particular soil, one size of mould should be used consistently.

6.2 Apparatus used

- A cylindrical mould with an internal diameter 105 mm (BS) or $101.6 \pm 0.4 \text{ mm}$ (ASTM) and an internal effective height of 115.5 mm (BS) or $116.4 \pm 0.5 \text{ mm}$ (ASTM). Detachable base plate and removable extension collar.
- Metal rammer:

Light test: 50 mm diameter face, weight of 2.5 kg, sliding freely in a tube which controls the height of drop to 300 mm (BS) or 305 mm (ASTM).

Heavy test: 50 mm diameter face, weight of 4.5 kg, sliding freely in a tube, which controls the height of drop to 450 mm (BS) or 457 mm (ASTM).

- Jacking apparatus for extracting the compacted material from the mould.
- 20 mm and 37.5 mm British Standard sieves or 4.75, 9.5- and 19.0-mm ASTM mould.
- CBR mould, as described in the next chapter.
- Balance readable to 5 g.
- Watertight containers or strong polythene bags
- A drying oven capable of maintaining a temperature of 105 ° C to 1155 ° C.
- A steel straightedge, about 300 mm long and 3 mm thick, with one beveled edge.
- Mixer, min 5 liters.

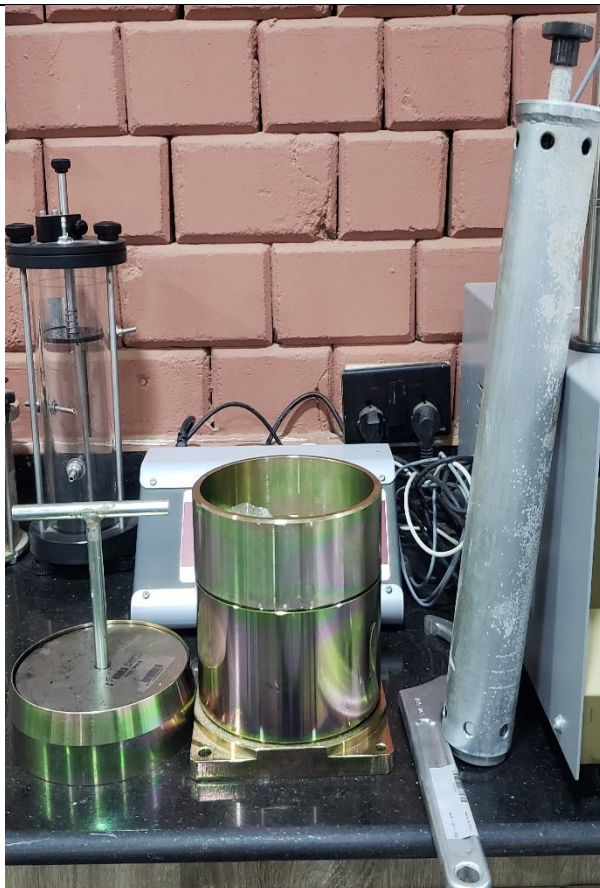


Plate 5: Typical apparatus set for Proctor compaction test

6.3 Sample preparation

A. BS 1377: Part 4: 1990

The quantity of soil required, depends on the size of the largest particles present and if the particles are susceptible to crushing during compaction.

Determine the approximate percentage by mass of particles in the soil sample passing the 20 mm and 37.5 mm test sieves.

For soils not susceptible to crushing, one sample only is required for test and it can be used several times.

- Original bulk sample, is air dried and weighed = w_1
- Particles larger than 20 mm should be removed by sieving with the 20 mm and 37.5 mm BS sieve.
- The amount of material retaining on the sieves has to be weighed and as a percentage from the total mass calculated.
- On the basis of these percentages the soil can be assigned to one of the grading zones (1) to (5) in Table 6.1, and the minimum mass of soil required can be determined.

Table 6.1 Quantity of soil required with particle sizes

Grading zone	Minimum Percentage passing test sieve		Minimum Mass of prepared soil required		Type of mould used
	20 mm	37.5 mm	A	B	
	%	%	kg	kg	
1	100	100	6	15	1 L
2	95	100	6	15	
3	70	100	15	40	CBR
4	70	95	15	40	
5	70	90	15	40	
x	Less than 70	Less than 90	Test not applicable		

A = Soil particles not susceptible to crushing.

B = Soil particles susceptible to crushing.

- Depending on the soil type, a suitable amount of water should be added

Light test: Sandy + gravely soils: 4-6% (200-300 ml water on 5 kg of soil)

Cohesive soils: 8-10 % below the plastic limit

Heavy test: Sandy + gravely soils: 3-5% (150-250 ml water on 5 kg of soil)

Cohesive soils: 15 % below the plastic limit

- Thorough mixing in of the water is essential.

B. ASTM D 698, 699

- ASTM recommends using a fresh soil sample for each test point, which requires about 16kg of soil for five test points. Therefore, the field sample should have a moist mass at least 23kg.
- After selecting a representative portion of quantity adequate for the test, prepare the specimen in accordance with either i or ii, the first is preferred.
 - i. Moist preparation method - Without previously drying the sample, pass it through a 4.75mm, 9.5mm, or 19.0mm sieve.
 - ii. Dry preparation method - If the sample is too damp to be friable, reduce the water content by air-drying or by the use of a drying apparatus, such that the temperature of the sample doesn't exceed 60 °C until the material is friable. Thoroughly break up the aggregations in such a manner as to avoid breaking individual particles. Pass the material through the appropriate sieve.
- Determine the percentage of the material retained on the 4.75mm, 9.5mm and 19.0mm sieves as appropriate for choosing procedure A or B.
- Prepare at least four (preferably five) specimens, each 2.3kg, having water contents such that they bracket the estimated optimum water content. A specimen having a water content close to optimum should be prepared first by trial addition of water and mixing (Typically, soil at optimum moisture content can be squeezed into lump that sticks together when hand pressure is released, but will break cleanly into two sections when "bent". At water content dry of optimum, soils tend to crumble; wet of optimum, soils tend to stick together in a sticky cohesive mass. Optimum water content is typically slightly less than the plastic limit. Select

water content for the rest of the specimens to provide at least two specimens wet and two dry of optimum, and water contents varying by about 2%. Some soil with very high optimum moisture content or a relatively flat compaction curve may require larger water content increments to obtain a well-defined maximum dry unit weight.

- Water content increments should not exceed 4%.
- Thoroughly mix each specimen to ensure even distribution of moisture throughout and then place on a separate covered container and allow standing prior to compaction in accordance with the table below.

Table 6:2 - Required Standing Times of Moisturised Specimens

Classification	Min. Standing time, hrs.
GW, GP, SW, SP	No requirement
GM, SM	3
All other soils	16

6.4 Execution of the test

- Weigh the mould = m1
- Connect the extension collar to the mould. Add loose soil to the mould.
Using the standard or CBR mould, place a quantity of moist soil in the mould that, when compacted it occupies a little over one-third of the height of the mould body for the "light" test and one-fifth for the "heavy" test
- Place the guide tube gently on the soil and hold it vertically.
- Now the soil should be compacted by 27 blows for the 1 L mould (BS) or 25 blows for the 4 in. mould (ASTM), and 62 or 56 blows for the CBR mould according to BS or ASTM, respectively.
- First 4 blows according to the pattern of Fig. 2
- After this, the rammer should be moved, according to Fig. 2, between the successive blows. With this, the blows are uniformly distributed over the whole area.
- Place a second, approximately equal, layer of soil in the mould and compact it in the same way as described above.

- Repeat with:
 - i. Light test (Standard proctor), third layer.
 - ii. Heavy test (Modified proctor), third, fourth and fifth layer.
- The compacted surface in the extension collar should be about 6 mm above the level of the mould body. (see Fig. 3)
- Remove the extension collar carefully and cut away the excess soil and level off the top of the mould. Any small cavities, resulting from the removed stones, should be filled up with fine material.

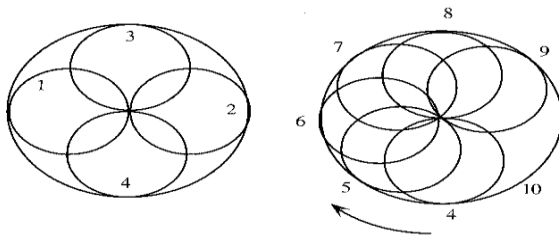


Fig. 2: Sequence of blows

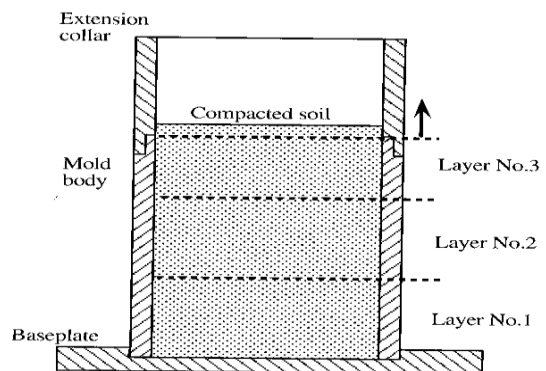


Fig. 3: After compaction

-Weigh the soil + mould (m_2).

Fit the mould onto the extruder and jack out the soil. Break up the sample on a tray.

Now the moisture content has to be measured by taking three representative samples.

Break up what is left over from the compacted sample and mix it with the remainder of the prepared sample.

Add an increment of water, approximately as follows:

-Sandy+ gravely soils 1-2% (50-100 ml of water to 5 kg of soil).

-Cohesive soils: 2.4% (100-200 ml of water to 5 kg of soil).

Mix in the water thoroughly for each increment of water added.

Repeat the compaction part so that at least 5 compactions are made. Of course, the range of moisture contents should be such that the optimum moisture content is within that range.

6.5 Calculations

Calculate the Bulk density, ρ :

$$\text{Bulk density } \rho = \frac{M_2 - M_1}{V}$$

Where

m_1 = mass of mould and base plate

m_2 = mass of soil and mould and base

plate V = volume of the mould.

Calculate the average moisture content, W %, for each compacted specimen.

Calculate the corresponding dry density:

$$\rho_d = \frac{100\rho}{100+W}$$

Where;

ρ_d = the dry density (Mg/m^3)

W = the moisture content (%)

Plot each dry density, against the corresponding moisture content, W . Draw a curve of best fit to the plotted points and identify the position of the maximum on this curve. Read off the maximum dry density and the corresponding moisture content, which is the optimum moisture content for this degree of compaction.

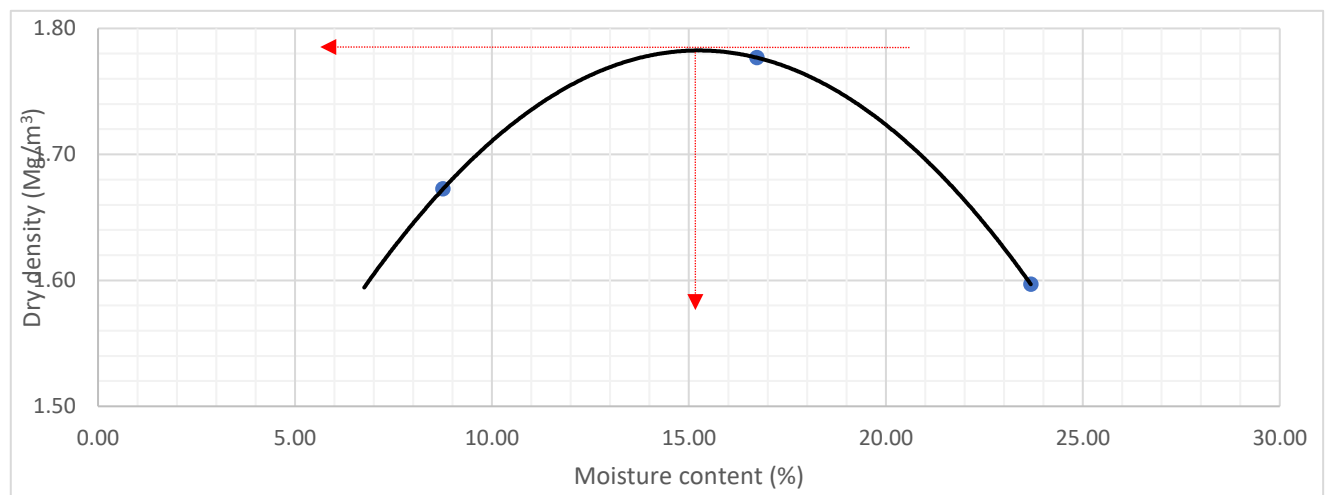


Fig 4: Graph of dry density-moisture content

6.6 Reporting

- Description of the soil
- The maximum dry density for the stated degree of compaction is reported to the nearest 0.001 Mg/m³.
- The optimum moisture content is reported as follows:
 - i. Below 5%: to the nearest 0.2%
 - ii. From 5% to 10%: to the nearest 0.5%
 - iii. Exceeding 10%: to the nearest 1%
- The percentage of stones retained on the 20mm sieve is reported to the nearest 1%.
- Which procedure was followed;
British or American Standard 2.5kg rammer method
British or American Standard 4.5kg rammer method
- Whether the test was carried out on a single sample or on separate batches.

7.0 Californian bearing ratio test BS 1377: Part 4: 1990, ASTM D 1883

7.1 Scope of the test

This method covers the laboratory determination of the California Bearing Ratio (CBR) of a compacted sample of soil.

The principle is to determine the relation between force and penetration when a cylindrical plunger with a standard cross-sectional area is made to penetrate the soil at a given rate.

At certain values of penetration, the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio (CBR).

The Californian Bearing Ratio test, or CBR test, is an empirical test which is used as an important criterion in pavement design. With this test, the bearing value of highway sub-bases and sub-grades can be estimated.

7.2 Apparatus used

- Motor-drive compression machine, with a constant penetration rate of 1 mm/min.
- The load-measuring device depends on the CBR value. With a CBR value up to 30%, a load ring with a range of 0-10KN is needed. A seating load of 50N has to be applied. With a CBR value above 30%, a load ring with a range of 0-50KN is needed. A seating load of 250N has to be applied.
- The displacement-measuring device must have a range of 25 mm and scale units of 0.01 mm.
- A standardised CBR mould, fittings and tools.
- 20 mm and 37.5 mm British Standard sieves.
- CBR mould, as described in section 7.0
- Balance, capable of weighing up to 25 kg, readable to 5 g.
- Watertight containers or strong polythene bags
- A drying oven capable of maintaining a temperature of 105 ° C to 115 ° C.
- A steel straightedge, about 300 mm long and 3 mm thick, with one beveled edge.
- Mixer, min 5 litres

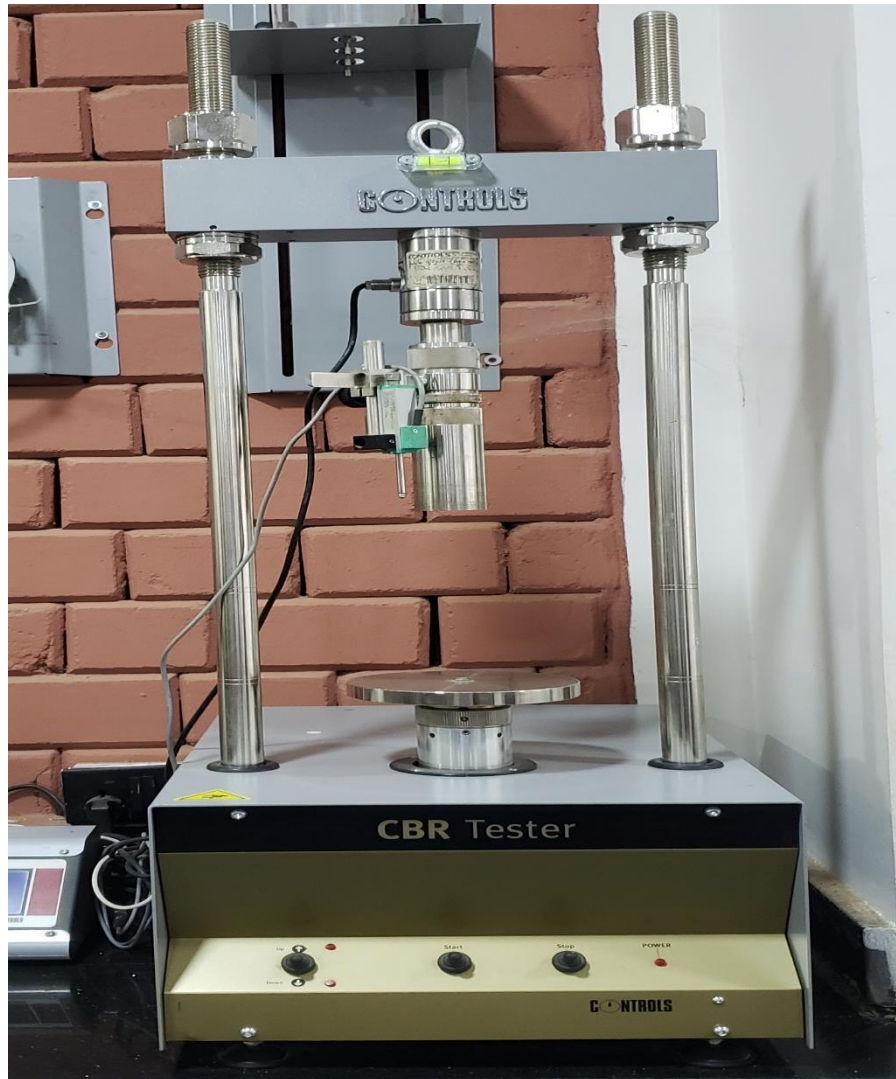


Plate 6: The Digital CBR tester

7.3 Sample Preparation.

The CBR test shall be carried out on material passing the 20 mm test sieve. If the soil contains particles larger than 20 mm, the test material must be sieved with the BS 20 mm sieve. If this fraction is more than 25 % the test is not applicable.

The moisture content of the soil shall be chosen to represent the design conditions for which the test results are required. Where a range of moisture contents is to be investigated, water shall be added or removed from the natural soil.

After bringing the sample to the required moisture content, the soil shall be thoroughly mixed and shall normally be sealed and stored for at least 24 h before starting compaction.

The mass of soil required for the test shall be calculated or estimated. When the density or air voids content of a compacted sample is specified, the exact amount of soil required for the test can be calculated as follows.

Dry density specification, the mass of soil M_1 (g), required to just fill the CBR mould of volume (cm^3) is given by the equation:

$$M_1 = \frac{V_m}{100} (100 + W) \rho_d 100\%$$

Where

W = the moisture content of the soil (%)

ρ_d = the specified dry density (Mg/m^3)

V_m = volume of the mould (m^3)

Compactive effort specification

About 6 kg of soil shall be prepared for each sample to be tested. The initial mass shall be measured so that the mass used for the test sample can be determined after compaction by difference, as a check.

To make comparison possible, the soil conditions (Bulk density, moisture content on dry density) have to be known.

Six methods are described in the British Standard for the preparation of disturbed samples for the CBR test. In methods 1 and 2, static compaction is used to achieve a specified density.

In the other methods, dynamic compaction by hand or mechanical rammer, or by vibrating hammer, is used, either to achieve a specified density in methods 3 and 4 or to provide a specified compactive effort in methods 5 and 6.

- The sample has to be divided into equal parts of weight according to the number of layers mentioned in Table 7.1. This is because the compaction takes place in stages, in order to get an optimal compaction.
- Dropping a certain weight several times, from a certain height, performs the compaction.
- Ensure that the blows are evenly distributed over the surface
- Table 8.1 gives the details of the compaction, depending on the required way of compaction.

Table 7.1 Compaction in CBR mould equivalent to BS compaction mould

Type of compaction	Mass (kg)	Rammer drop (mm)	No. of layers	Blows per layers	
BS' ordinary' (BS 1377)	2.5	300	3	62	
BS 'heavy' (BS 1377)	4.5	450	5	62	
Intermediate	4.5	450	5	30	
Vibrating hammer	30-40*	(vibration)	3	(60 s)	
ASTM 'Standard'	5.5 lb.	12 in	3	61	56
Modified AASHO	10.0 lb.	18 in	5	61	56

* Downward force (kgf) to be applied.

7.4 Execution of the test.

- The load-measuring device is connected to the compression machine.
- The cylindrical plunger, diameter of 50 mm and cross-sectional area of 1935 mm² and a length of 250 mm, is connected to the load-measuring device.
- The mould with the sample and the surcharge weights is placed in the machine. Each surcharge ring of 2 kg is equivalent to about 70 mm of thickness of superimposed construction.
- The plunger must be seated on top of the specimen and must be able to move freely from the surcharge weight.
- The seating load has to be applied by weight.
- Adjust the displacement-measuring device to read zero.
- Switch to motor drive and start the loading, with a loading rate of 1 mm/min.
- Reading of the load-measuring device has to be taken with every 0,25 mm displacement.

- After 7,5 mm penetration, the machine can be stopped.
- After removing the sample from the mould, the moisture content has to be determined.

7.5 Calculation

- The data, obtained with the test, have to be plotted in a load penetration diagram.
- The load at 2,5- and 5.0-mm penetration has to be read from this diagram.
- The same has to be done from the diagram of the standard CBR test, with a CBR value of 100%, (see figure 7.2.2) for the standard load for 2.5- and 5-mm penetration.
- The CBR-value is then:

$$CBR = \frac{\text{Load at 2.5mm penetration from test}}{\text{load at 2.5 mm penetration from standard}} \times 100\%$$

- The same calculation is done for 5 mm penetration.
- The highest of the two is then the CBR-value.

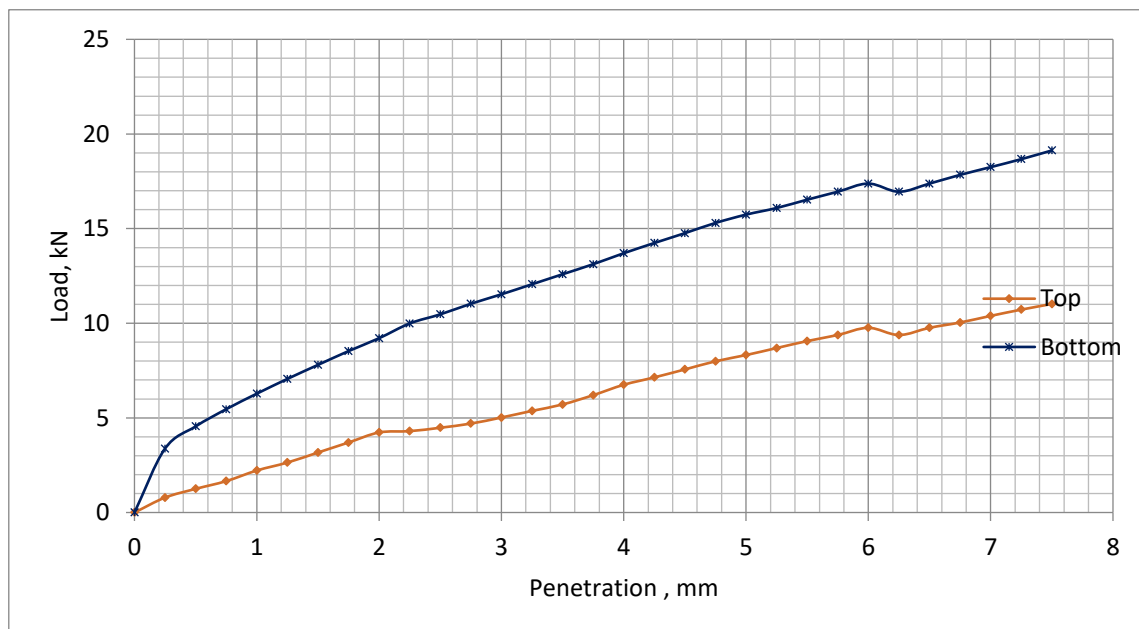


Fig 5: Graph of Load-penetration

References

- K.H. Head (1982), Manual of Soil Laboratory Testing
- Applicable ASTM standards for Soil testing
- Applicable BS 1377 standards