



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

LABORATORY MANUAL FOR ASPHALT AND SOIL TESTING IN ROAD CONSTRUCTION

INTERNATIONAL WORKSHOP ON
GLOBAL TRENDS IN DESIGN & CONSTRUCTION OF DURABLE ROAD PAVEMENTS
(24TH TO 28TH JUNE 2024)

1. Penetration Test

Scope: This test method covers determination of the penetration of semi-solid and solid bituminous materials. This test is conducted in accordance with **ASTM D5/D5M - 20**

Definition: The penetration of bituminous material is its consistency expressed as the distance in tenths of a millimetres that a standard needle penetrates vertically into a specimen of the material under specified conditions of temperature, load and duration of loading

Theory: The penetration test is widely used world over for classifying the bitumen into different grade. The ASTM has standardized the penetration test equipment and the procedure, Figure 1. Even though is recognized that the empirical tests like penetration, softening point etc. cannot fully qualify the – binder for its temperature susceptibility characteristic, the simplicity and quickness of operation of the test cannot be ignored for common use

Significance and Use

Test Penetration test is the most commonly adopted test on bitumen to grade the material in terms of its hardness. Depending upon the climatic condition and type of construction, bitumen of different penetration grades is used, 80/100 bitumen denotes that the penetration value ranges between 80 and 100. The penetration value of various types of bitumen used in pavement construction in this country range between 20 and 225. For bituminous macadam and penetration macadam IRC suggests bitumen grades 30/40, 60/70 & 80/100. In warmer regions lower penetration grades are preferred and in colder regions bitumen with higher penetration values are used.

Apparatus: It consists of items like container, needle, water bath penetrometer, stop watch etc. Following are the standard specifications as per ISI for the above apparatus.

(a) Container: A flat bottomed cylindrical metallic container 55 mm in diameter and 35mm or 57 mm in height.

(b) Needle: A straight, highly polished cylindrical hard steel needle with conical end, having the shape and dimensions. The needle is provided with a shank approximately 3.0 mm in diameter into which it is immovably fixed

(c) Water-bath: A water bath is maintained at 25 ± 1 °C containing not less than 10 litres of water, the sample is immersed to depth not less than 100 mm from the top and supported on a perforated shelf not less than 50 mm from the bottom of the bath.

(d) Penetrometer: It is an apparatus which allows the needle assembly of gross weight 100 g to penetrate without appreciable friction for the desired duration of time. The dial is accurately calibrated to give penetration value in units of one tenth of a mm. Electrically operated automatic penetrometers are also available.

(e) Transfer tray: A small tray which can keep the container fully immersed in water during the test.

Test Procedure:

- a. The bitumen is softened to a pouring consistency between 75°C and 100°C above the approximate temperature at which bitumen softens
- b. The bitumen is thoroughly stirred to make it homogenous & free from air bubbles & water
- c. The sample material is then poured into the container to a depth at least 15 mm more than the expected penetration
- d. The sample containers are cooled in atmosphere of temperature not lower than 13°C for one hour
- e. Then they are placed in temperature-controlled water bath at a temperature of 25°C for a period of one hour
- f. The sample container is placed in the transfer tray with water from the water bath and placed under the needle of the penetrometer
- g. The weight of needle, shaft and additional weight are checked
- h. The total weight of this assembly should be 100g using the adjusting screw
- i. The needle assembly is lowered and the tip of the needle is made contact to the top surface of the sample
- j. The needle assembly is clamped in this position. The contact of the tip of the needle is checked
- k. The initial reading of the penetrometer dial is either adjusted to zero or the initial reading is taken before releasing the needle
- l. The needle is released exactly for a period of 5.0 secs by pressing the start button and the reading is taken on the screen. At least three measurements are made on sample
- m. After each test, the needle is disengaged and cleaned with benzene and carefully dried
- n. The sample container is also transferred in the water bath before next testing is done so as to maintain a constant temperature of 25°C. The test procedure is repeated to obtain an average value.



Fig. 1: Penetration Testing Equipment



Fig. 2: Penetration Needle



Fig. 3: Penetration Cup

For penetrations below 200 mm:

Diameter 55 mm

Internal depth 35 mm

For penetrations between 200 and 350 mm

Diameter 70 mm

Internal depth 45 mm

Calculation:

The penetration is given by:

Penetration = (Initial dial gauge reading (mm) - Final dial gauge reading (mm)) x 10

The three penetration values obtained on the sample must agree to within the following limits: -

Penetration	0 – 49	50 – 149	150 – 249	250
Maximum difference between highest and lowest determination	2	4	6	8

If the differences exceed the above values, the results are ignored and the test must be repeated on the second sample. If the differences are again exceeded by the second sample, the results must be ignored and the test completely repeated. If the determinations are within the above tolerances, the penetration is quoted as the average of the individual results.

Test report:

The report shall contain at least the following information:

- Identification of the material tested
- A reference to the test method used
- A statement of any deviation from the method stated for 25°C/100g/5 seconds.
- The test results

2. Softening Point Test

Scope: This test method covers the determination of the softening point of bitumen in the range from 30 to 157 °C [86 to 315 °F] using the ring-and-ball apparatus immersed in distilled water [30 to 80 °C] or USP glycerin (above 80 to 157 °C). This test is conducted in accordance with **ASTM D36/D36M- 14 (Reapproved 2020)**

Definition: The softening point is the temperature at which the bitumen attains a particular degree of softening under specified conditions of the test. The Softening point test of bitumen sample is carried out in the Ring and Ball test apparatus

Theory: Bitumen does not suddenly change from solid to liquid state ,but as the temperature increases it gradually becomes softer until it flows readily .A semi solid state bitumen grades need sufficient fluidity before they are used for application with the aggregate mix .For this purpose bitumen is sometimes cut back with a solvent like kerosene .The common procedure however is to liquefy the bitumen by heating .The softening point is the temperature at which the substance attains particular degree of softening under specified condition of test . For bitumen it usually determined by Ring and Ball test. Brass ring test containing the test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed upon the bitumen and liquid medium is then heated at a specified distance below the ring is recorded as the softening point of a particular bitumen. The apparatus and test procedure are standardized by ISI. It obvious but harder grade bitumen possess higher softening point than softer grade bitumen. The concept of determining the softening point by Ring and Ball apparatus

Summary of Test Method

Two horizontal disks of bitumen, cast in shouldered brass rings, are heated at a controlled rate in a liquid bath while each supports a steel ball. The softening point is reported as the mean of the temperatures at which the two disks soften enough to allow each ball, enveloped in bitumen, to fall a distance of 25 mm [1.0 in.].



Ring-and-Ball Apparatus

Significance and Use

- i. Bitumen are viscoelastic materials without sharply defined melting points; they gradually become softer and less viscous as the temperature rises. For this reason, softening points must be determined by an arbitrary and closely defined method if results are to be reproducible.
- ii. The softening point is useful in the classification of bitumen, as one element in establishing the uniformity of shipments or sources of supply, and is indicative of the tendency of the material to flow at elevated temperatures encountered in service.

Apparatus:

- a. Rings - Two square-shouldered brass rings
- b. Pouring Plate - A flat, smooth, brass plate approximately 50 by 75 mm [2 by 3 in.].
- c. Balls - Two steel balls, 9.5 mm [$\frac{3}{8}$ in.] in diameter, each having a mass of 3.50 ± 0.05 g.
- d. Ball-Centering Guides - Two brass guides for centering the steel balls
- e. Bath - A glass vessel, capable of being heated, not less than 85 mm in inside diameter and not less than 120 mm in depth from the bottom of the flare.

Note: An 800-mL, low-form Griffin beaker of heat-resistant glass meets this requirement.

- f. Ring Holder and Assembly - A brass holder designed to support the two rings in a horizontal position, conforming to the shape and dimensions. The bottom of the shouldered rings in the ring holder shall be 25 mm [1.0 in.] above the upper surface of the bottom plate, and the lower surface of the bottom plate shall be 16 ± 3 mm [$\frac{5}{8} \pm \frac{1}{8}$ in.] from the bottom of the bath.
- g. Thermometer: An ASTM Low Softening Point Thermometer, having a range from -2 to $+80$ °C or 30 to 180 °F, and conforming to the requirements for Thermometer 15C or 15F as prescribed in Specification E1. As an alternative, any other thermometric device used shall be at least: (1) of equal accuracy to that of the thermometer specified in Specification E1, (2) capable of indicating temperature to within 1 °C [2 °F], and (3) stable to within 1 °C [2 °F] for the duration of the exposure.
- h. An ASTM High Softening Point Thermometer, having a range from 30 to 200 °C or 85 to 392 °F, and conforming to the requirements for Thermometer 16C or 16F as prescribed in Specification E1. As an alternative, any other thermometric device used shall be at least: (1) of equal accuracy to that of the thermometer specified in Specification E1, (2) capable of indicating temperature to within 1 °C [2 °F], and (3) stable to within 1 °C [2 °F] for the duration of the exposure
- i. The appropriate thermometer shall be suspended in the assembly as shown in Fig. 1(d) so that the bottom of the bulb is level with the bottom of the rings and within 13 mm [0.5 in.] of the rings, but not touching them or the ring holder. Substitution of other thermometers shall not be permitted. As an alternative, any other thermometric device used shall be at least: (1) of equal accuracy to that of the thermometer specified in Specification E1, (2) capable of indicating temperature to within 0.5 °C [1.0 °F], and (3) stable to within 0.5 °C [1.0 °F] for the duration of the exposure

Test Procedure:

- a. At first the sample of bitumen is heated above 70 degree centigrade to 100 degree centigrade above the softening point
- b. Now take glass plate and prepare a mix of glycerin and Dexedrine
- c. Apply this mixture to the surface of glass to prevent bitumen from sticking
- d. Now, put the both ring on the glass surface and pour full of bitumen into it
- e. Allow it to cool for 30 minutes in air
- f. The excess bitumen from ring should be removed from upper portion of the ring
- g. After that put distilled water in the beaker at a temperature of 5 degree centigrade. The beaker is filled in beaker such that the surface is about 50 millimetre above the specimen
- h. Now assemble the ring and ball guide and place it on the middle plate of metallic frame
- i. Now, place the frame in water and leave it for 15 minutes
- j. After 15 minutes take steel ball which are previously cooled at the temperature at 5 degrees centigrade and placed on the top of the ball guide
- k. Again, place the whole assembly on the heating plate
- l. After that it is again heated at a rate of 50 C per minute till the bitumen softens & touches the bottom of the metal plate placed at a specified distance below the ring
- m. Note down the temperature when the ball along with bitumen just touches the lower plate
- n. Take individual data of temperature for both balls individually
- o. The difference between centigrade. the two readings should not exceed 1-degree centigrade for temperature ranges 40 degrees centigrade to 60 degrees centigrade
- p. and 1.5 degrees centigrade for temperature ranges 60 degrees centigrade to 80 degrees centigrade. otherwise, tests should be repeated
- q. Hence, the average value of the two temperatures of both balls is the softening point of bitumen
- r. Hence, the average value of the two temperatures of both balls is the softening point of bitumen
- s. ASTM has specified different criteria so; code should be followed before application of bitumen for specified load

Report of Test

Temperature for ball (A) = 46 degree centigrade

Temperature for ball (B) = 47 degree centigrade

Softening point of bitumen = $(A + B)/2 = (46 + 47)/2 = 46.5$ degree centigrade

The softening point of bitumen used in the pavement construction varies between 35° to 70°. It indicates how susceptible the bitumen with respect to the variation of temperature. Bitumen of the same penetration value with a higher softening point is less susceptible to temperature than of that same grade bitumen having less softening point

3. Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using Rotational Viscometer

Scope: This test method outlines a procedure for measuring the apparent viscosity of asphalt from 40 to 260 °C [100 to 500 °F] using a rotational viscometer and a temperature-controlled thermal chamber for maintaining the test temperature. This test is conducted in accordance with **ASTM D4402/D4402M – 23**

Summary of Test: A rotational viscometer, as described in this test method, is used to measure the apparent viscosity of asphalt at elevated temperatures. The torque on the apparatus-measuring geometry, rotating in a thermostatically controlled sample holder containing a sample of asphalt, is used to measure the relative resistance to rotation. The torque and speed are used to determine the viscosity of the asphalt in pascal seconds, millipascal seconds, or centipoise.



Rotational Viscometer

Significance and Use: This test method is used to measure the apparent viscosity of asphalts at handling, mixing, or application temperatures. Some asphalts may exhibit non-Newtonian behaviour under the conditions of this test method, or at temperatures within the range of this test method. Since non-Newtonian viscosity values are not absolute properties, but reflect the behaviour of the fluid within the particular measurement system, it should be recognized that measurements made by this test method may not always predict field performance under the conditions of use. 5.3 Comparisons between non-Newtonian viscosity values should be made only for measurements made with similar conditions of temperature, shear rate, and shear history.

Apparatus:

- Rotational Viscometer, capable of measuring the torque required to rotate the selected apparatus-measuring geometry at a selected constant speed while submerged in asphalt at constant desired test temperature, and with the capability to convert the torque

measurement to viscosity in pascal seconds, millipascal seconds, or centipoise. This calculation may need to be done manually for some instruments.

- b. Apparatus-Measuring Geometry, of various shapes and sizes, for measurement of various viscosities of asphalt.
- c. Temperature-Controlled Thermal Chamber Heater, for maintaining the sample of asphalt at the test temperature.
- d. Sample Chambers, reusable or disposable.
- e. Temperature Controller, capable of maintaining the specimen temperatures to 61.0 °C [62.0 °F] for test temperatures between 38 and 150 °C [100 to 300 °F] and to 62.0 °C [64.0 °F] for test temperatures between 150 and 260 °C [300 to 500 °F].
- f. Balance, readable to 0.1 g, for determining the mass of asphalt sample.
- g. Platinum Resistance Thermometer (PRT), with a probe which conforms to the requirements of Specification E1137/ E1137M, for measuring the temperature of the thermal chamber. The PRT shall have a three- or four-wire connection configuration and overall sheath length shall be at least 50 mm [2 in.] greater than the immersion depth. Calibrate the PRT system (probe and readout) in accordance with Test Methods E644.

Test Procedure:

- a. Allow the instrument electronics to warm up for at least 5 min before conducting any calibrations or analyses.
- b. Set the temperature controller to the desired test temperature, taking into account any offset determined
- c. Select an apparatus-measuring geometry that will develop a resisting torque between 10 and 98 % of the instrument capacity at the selected speed. Generally, measurements will be more accurate at higher torque readings.
- d. Preferably, preheat the sample chamber and the selected apparatus-measuring geometry until temperature equilibrium has been obtained for at least 15 min. If filled asphalts are being measured, this step is mandatory.
- e. Add the volume of sample specified by the manufacturer for the apparatus-measuring geometry to be used to the sample chamber. A convenient way for measuring the volume is by weighing out the amount calculated from approximate density data for the sample and then returning the sample chamber to the temperature-controlled chamber heater. Thoroughly stir filled asphalts to obtain a representative sample before weighing
- f. Do not overfill the sample chamber, but ensure that the measuring portion of the apparatus-measuring geometry will be completely immersed. The sample volume is critical to meet the system calibration standard.
- g. Insert the selected preheated apparatus-measuring geometry into the liquid in the chamber and couple it to the viscometer, following the manufacturer's instructions for proper alignment.
- h. Bring the asphalt sample to the desired temperature within 30 min and allow it to equilibrate at the desired test temperature for a minimum of 10 min before beginning the measurement. In the case of filled asphalts, start the motor rotation immediately.

- i. Start the motor rotation of the viscometer at a speed that will develop a resisting torque that is between 10 and 98 % of the full-scale instrument capacity. Maintain this speed and allow the sample to equilibrate for an additional 5 min. Temperature should not deviate more than 61.0 °C [62.0 °F] during this conditioning period.
- j. Measure either the viscosity or the torque at 1-min intervals for a total of 3 min. The instrument may perform this measurement automatically.
- k. Repeat steps h – j for each test temperature required. If filled asphalts are being measured, a new, freshly stirred sample will be required for each test temperature.
- l. If torque readings are above 98 % of the instrument capacity at the lowest test temperature, decrease the speed of rotation of the apparatus-measuring geometry and continue with the test, or repeat steps d – j with a smaller diameter geometry and the appropriate volume of sample.
- m. If the torque reading is below 10 % of the instrument capacity at the highest test temperature, increase the speed of rotation of the apparatus geometry, or repeat steps d - j with a larger diameter geometry and the appropriate volume of sample.
- n. If the instrument does not read out directly in viscosity units, multiply the torque readings by the appropriate factor to obtain the viscosity values

Calculation:

If the instrument does not automatically average three readings, then calculate the result as the arithmetic average of the three readings taken at 1-min intervals, rounded to three significant figures. If the rotational viscometer has a digital output displaying viscosity in centipoise (cP), multiply by 0.001 to obtain the viscosity in pascal seconds (Pa·s). For instruments that offer automation, the results of a 3-min integration shall be acceptable. If required, multiply the average reading by the calibration constant determined in 9.2. If the instrument does not display shear rate, determine the shear rate from the geometry and rotational speed.

Report of test:

Report the following information:

Test Temperature	°C
Apparatus-measuring geometry	Geometry designation
Type and size	Geometry diameter
Torque	mNm or % instrument capacity
Rotational speed	r/min
Shear rate	sec ⁻¹
Viscosity result	mPa·s

4. Dynamic Shear Rheometer (DSR)

Scope: This test method covers the determination of the complex shear modulus and phase angle of asphalt binders when tested in dynamic (oscillatory) shear using parallel plate geometry. This test is conducted in accordance with **ASTM D7175 – 23**

Definition: The dynamic shear rheometer (DSR) is used to characterize the viscous and elastic behaviour of asphalt binders at medium to high temperatures. This characterization is used in the Superpave PG asphalt binder specification. As with other Superpave binder tests, the actual temperatures anticipated in the area where the asphalt binder will be placed determine the test temperatures used.

This test method covers the determination of the dynamic shear modulus and phase angle of asphalt binder when tested in dynamic (oscillatory) shear using parallel plate test geometry

Summary of Test Method

Test specimens are formed between parallel metal plates and one of the parallel plates is oscillated with respect to the other at pre-selected temperatures, frequencies, and rotational strain amplitudes. The required amplitudes are specified to ensure that the measurements are within the region of linear behavior. The test specimen is maintained at the test temperature by positive heating and cooling of the upper and lower plates or by enclosing the upper and lower plates in a thermally controlled environment or test chamber. Specification testing is performed at a test frequency of 10 rad/s. The complex modulus (G^*) and phase angle (δ) are calculated automatically as part of the operation of the rheometer using proprietary computer software supplied by the instrument manufacturer.

Significance and Use

The complex shear modulus is an indicator of the stiffness or resistance of asphalt binder to deformation under load. The phase angle is a measure of the relative portion of the response to an applied load that is elastic (recoverable) or viscous (nonrecoverable). The test procedure is applicable to measurements in the linear region where the measured modulus and phase angle are independent of the amplitude of the strain. The complex modulus and the phase angle are used to calculate performance-related criteria in accordance with Specification D6373 or D8239.



Dynamic Shear Rheometer (DSR)



Specimen Mold

Apparatus:

- a. Dynamic Shear Rheometer (DSR) Test System: Consisting of parallel metal plates, an environmental chamber, a loading device, and a control and data acquisition system.
- b. Specimen Mold (Optional): The overall dimensions of the silicone rubber mould for forming asphalt binder test specimens may vary but the thickness shall be greater than 5 mm. If the mould is a single sample mould, the following dimensions have been found suitable: For a 25-mm test plate with a 1-mm gap, a mould cavity approximately 18 mm in diameter and 2.0 mm deep. For an 8-mm test plate with a 2-mm gap, a mould cavity approximately 8 mm in diameter and 2.5 mm deep.
- c. Specimen Trimmer: With a straightedge at least 4 mm wide.
- d. Wiping Material: Clean cloth, paper towels, cotton swabs, or other suitable material as required for wiping the plates.
- e. Cleaning Solvents: Mineral oil, citrus-based solvents, mineral spirits, toluene, or similar solvent as required for cleaning the plates. Acetone for removing the solvent residue from the surfaces of the plates is also necessary.
- f. Reference Thermometer: Either NIST-traceable liquid-in-glass thermometer(s) or NIST-traceable electronic thermometric device(s).
- g. Portable Thermometer: A standardized portable thermometer consisting of a resistive detector, associated electronic circuitry, and digital readout. The thickness of the detector shall be no greater than 2.0 mm such that it can be inserted between the test plates. The reference thermometer may be used for this purpose if its detector fits within the dummy specimen.

Sample Preparation

- i Material Selection: Choose the appropriate sample materials based on the testing requirement (e.g. bitumen, polymer-modified bitumen)
- ii Sample Conditioning: Ensure the test sample is heated to the appropriate temperature around 135°C to achieve a homogeneous liquid state
- iii Mould Preparation: clean and dry mould should be use and ensure the mould are compatible with the testing apparatus
- iv Filling the mould: Pour the conditioned sample into the mould carefully to avoid air bubbles and ensure the mould is completely filled
- v Levelling: The sample surface should be using a clean flat spatula to ensure uniformity and remove excess material if necessary
- vi Cooling: Allow the sample to cool in the mould in a fridge or to the desired testing temperature
- vii Sample Removal: Carefully remove the sample from the mould, ensuring it retains its shape and integrity

Test Procedure

- a. Bring the specimen to the test temperature
- b. Set the temperature controller to the desired test temperature, including any offset as required. Allow the temperature indicated by the RTD to come to the desired temperature. The test shall be started only after the temperature has remained at the desired temperature ± 0.1 °C for at least 10 minutes
- c. Strain Control Mode—When operating in a strain-controlled mode, determine the strain value according to the value of the complex modulus. Control the strain within 20 percent of the target value calculated by Equation below
$$\gamma, \text{ percent} = 12.0 / (G^*)^{0.29}$$
where: γ = shear strain in percent, and G^* = complex modulus in kPa.
- d. Stress Control Mode - When operating in a stress-controlled mode, determine the stress level according to the value of the complex modulus. Control the stress within 20 percent of the target value calculated by Equation below
$$\tau, \text{ percent} = 12.0 / (G^*)$$
where: τ = shear stress in kPa, and G^* = complex modulus in kPa
- e. When the temperature has equilibrated, condition the specimen by applying the required strain for a recommended 10 cycles or a required range of 8 to 16 cycles at a frequency of 10 rad/s. Obtain a test measurement by recording data for an additional recommended 10 cycles or a range of 8 to 16 cycles. Reduce the data obtained for the second set of cycles to produce a value for the complex modulus and phase angle. Typically, a Fast Fourier Transform (FFT) is used to reduce the data
- f. The data acquisition system specified automatically calculates G^* and from test data acquired when properly activated
- g. Initiate the testing immediately after preparing and trimming the specimen. The testing at subsequent temperatures should be done as quickly as possible to minimize the effect of molecular associations (steric hardening) that can cause an increase in modulus if the specimen is held in the rheometer for a prolonged period of time. When testing at multiple temperatures all testing should be completed within four hours

Report of test:

- a. Provide a complete identification and description of the material tested including name, grade, and source
- b. Describe the instrument used for the test including the model number
- c. The strain and stress levels specified have been selected to ensure a common reference point that has been shown to be within the linear region for neat and modified asphalt binders. Some systems may not be linear within this region. When this situation is observed, report the modulus at the recommended stress or strain levels but also report that the test conditions were outside the linear region
- d. For each test, report the following:
 - i Test plate diameter, nearest 0.1 mm, and test gap, nearest 1 mm
 - ii Test temperature, nearest 0.1 °C
 - iii Test frequency, nearest 0.1 rad/s

- iv Strain amplitude, nearest 0.01 percent, or torque, nearest mN•m
- v Complex modulus (G^*) for the 10 measurements, kPa to three significant figures

5. Marshall Stability and Flow, Volumetric Parameters

Scope: This test method covers measurement of resistance to plastic flow of 4 in. (102 mm) cylindrical specimens of asphalt mixture loaded in a direction perpendicular to the cylindrical axis by means of the Marshall apparatus. This test method is for use with dense-graded asphalt mixtures prepared with asphalt binder (modified and unmodified) with maximum size aggregate up to 1 in. (25 mm) in size (passing 1 in. (25 mm) sieve). This test is conducted in accordance with **ASTM D6927 – 22**

Definition: The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method. Marshall stability is the peak resistance load obtained during a constant rate of deformation loading sequence.

Marshall flow is a measure of deformation (elastic plus plastic) of the asphalt mixture determined during the stability test.

Summary of Test Method

Marshall stability and flow values along with density, air voids in the total mix, voids in the mineral aggregate, or voids filled with asphalt binder, or both, filled with asphalt binder are used for laboratory mix design and evaluation of asphalt mixtures. In addition, Marshall stability and flow can be used to monitor the plant process of producing asphalt mixture. Marshall stability and flow may also be used to relatively evaluate different mixes and the effects of conditioning such as with water.

- a. Marshall stability and flow are asphalt mixture characteristics determined from tests of compacted specimens of a specified geometry. The Marshall Test can be conducted with two different types of equipment: (1) Method A - using a loading frame with a load ring and a dial gauge for deformation or flow meter (Traditional Method); or (2) Method B - using a load-deformation recorder in conjunction with a load cell and linear variable differential transducer (LVDT) or other automatic recording device (Automated Method)



Marshall Stability and Flow Equipment

Apparatus:

- a. Mold Assembly: cylindrical moulds of 10 cm diameter and 7.5 cm height consisting of a base plate and collar extension
- b. Sample Extractor: for extruding the compacted specimen from the mould
- c. Compaction pedestal and hammer.
- d. Breaking head: The testing head shall consist of upper and lower cylindrical segments of cast gray or ductile iron, cast steel, or annealed steel tubing. The lower segment shall be mounted on a base having two perpendicular guide rods or posts (minimum 1/2 in. (12.5 mm) in diameter) extending upwards. Guide sleeves in the upper segment shall direct the two segments together without appreciable binding or loose motion on the guide rods.
- e. Compression Loading Machine: The compression loading machine (Fig. 3) may consist of a screw jack mounted in a testing frame and shall be designed to load at a uniform vertical movement of 2.00 $\pm$ 0.15 in./min (50 $\pm$ 5 mm/min). The design in Fig. 3 shows power being supplied by an electric motor. A mechanical or hydraulic compression testing machine may also be used provided the rate of loading can be maintained at 2.00 $\pm$ 0.15 in./min (50 $\pm$ 5 mm/min) Flow meter, water bath, thermometers
- f. Flow Meter: The Marshall flow meter consists of a guide sleeve and a gage (Fig. 4). The activating pin of the gage shall slide inside the guide sleeve with minimal friction and the guide sleeve shall slide freely over the guide post (see Fig. 4) of the breaking head. These points of frictional resistance shall be checked before tests. Graduations of the flow meter gage shall be increments of 0.01 in. (0.25 mm) or finer. Instead of a flow meter, other devices such as an indicator dial or linear variable differential transducer (LVDT) connected to a loaded formation recorder or computer may be used. These alternate devices should be capable of indicating or displaying flow(deformation) to the required sensitivity. These devices must be designed to measure and record the same relative movement between the top of the guide post and the upper breaking head.
- g. Water Bath: The water bath shall be deep enough to maintain the water level a minimum of 1.25 in. (30 mm) above the top of specimens. The bath shall be thermostatically controlled so as to maintain the specified test temperature 62 °F (1 °C) at any point in the tank. The tank shall have a perforated false bottom or be equipped with a shelf for supporting specimens 2 in. (50 mm) above the bottom of the bath and be equipped with a mechanical water circulator. The air bath for mixtures containing cutback asphalt binder shall be thermostatically controlled and shall maintain the air temperature at 77 $\pm$ 2 °F (25 $\pm$ 1 °C).
- h. Load Measuring Device: As a minimum, a calibrated nominal 5000 lb (20 kN) ring dynamometer (Fig. 3) with a dial indicator to measure ring deflection for applied loads is required. The 5000 lb (20 kN) ring shall have a minimum sensitivity of 10 lb (50 N). The dial indicator should be graduated in increments of 0.0001 in. (0.0025 mm) or finer. The ring dynamometer should be attached to the testing frame should be provided to transmit load to the breaking head. The ring dynamometer assembly may be replaced with a load cell connected to a load deformation recorder or computer provided capacity and sensitivity meet above requirements

Sample Preparation:

The Marshall method, like other mix design methods, uses several trial aggregate-asphalt binder blends (typically 5 blends with 3 samples each for a total of 15 specimens), each with a different asphalt binder content. Then, by evaluating each trial blend's performance, an optimum asphalt binder content can be selected. In order for this concept to work, the trial blends must contain a range of asphalt contents both above and below the optimum asphalt content. Therefore, the first step in sample preparation is to estimate an optimum asphalt content. Trial blend asphalt contents are then determined from this estimate.

Test Procedure:

In the Marshall test method of mix design three compacted samples are prepared for each binder content. At least four binder contents are to be tested to get the optimum binder content. All the compacted specimens are subject to the following tests:

- Bulk density determination:** The bulk density of the sample is usually determined by weighting the sample in air and in water. It may be necessary to coat samples with paraffin before determining density. The specific gravity G_{bcm} of the specimen is given by $G = \frac{W_a}{W_a - W_w}$
where, W_a = weight of sample in air (g)
 W_w = weight of sample in water (g)
- Stability and flow test:** In conducting the stability test, the specimen is immersed in a bath of water at a temperature of $60^\circ \pm 1^\circ\text{C}$ for a period of 30 minutes. It is then placed in the Marshall stability testing machine and loaded at a constant rate of deformation of 5 mm per minute until failure. The total maximum in kN (that causes failure of the specimen) is taken as Marshall Stability. The stability value so obtained is corrected for volume. The total amount of deformation is units of 0.25 mm that occurs at maximum load is recorded as Flow Value. The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds.
- Density and voids analysis**

Report of Test:

- Bulk specific gravity of aggregate (G_{bam}):**
Since the aggregate mixture consists of different fractions of coarse aggregate, fine aggregate, and mineral filler with different specific gravities, the bulk specific gravity of the total aggregate in the paving mixture is given as

$$G_{bam} = \frac{\frac{P_{ca} + P_{fa} + P_{mf}}{G_{bca} + \frac{P_{fa}}{G_{bfa}} + \frac{P_{mf}}{G_{bmf}}}}$$

where, G_{bam} = bulk specific gravity of aggregates in paving mixtures.

P_{ca} , P_{fa} , P_{mf} = percent by weight of coarse aggregate, fine aggregate, and mineral filler in paving mixture.

G_{bca}, G_{bfa}, G_{bm}f = bulk specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively

b. Maximum specific gravity of aggregate mixture (G_{bam}):

The maximum specific gravity of aggregate mixture should be obtained as per ASTM D2041, however because of the difficulty in conducting this experiment an alternative procedure could be utilized to obtain the maximum specific gravity using the following equation:

$$G_{bam} = \frac{\frac{P_{ca} + P_{fa} + P_{mf}}{G_{bca} + \frac{P_{fa}}{G_{bfa}} + \frac{P_{mf}}{G_{bm}f}}}{1}$$

where,

G_{mp} = maximum specific gravity of paving mixtures.

P_{ca}, P_{fa}, P_{mf} = percent by weight of coarse aggregate, fine aggregate, and mineral filler in paving mixture.

G_{bca}, G_{bfa}, G_{bm}f = bulk specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively.

c. Percent voids in compacted mineral aggregate (VMA):

The percent voids in mineral aggregate (VMA) is the percentage of void spaces between the granular particles in the compacted paving mixture, including the air voids and the volume occupied by the effective asphalt content

$$VMA = 100 - \frac{G_{bcm}P_{ta}}{G_{bam}}$$

where,

VMA = percent voids in mineral aggregates.

G_{bcm} = bulk specific gravity of compacted specimen

G_{bam} = bulk specific gravity of aggregate.

P_{ta} = aggregate percent by weight of total paving mixture.

d. 4 Percent air voids in compacted mixture (P_{av}): Percent air voids is the ratio (expressed as a percentage) between the volume of the air voids between the coated particles and the total volume of the mixture.

$$P_{av} = 100 \frac{G_{mp} - G_{bcm}}{G_{mp}}$$

where,

P_{av} = percent air voids in compacted mixture

G_{mp} = maximum specific gravity of the compacted paving mixture

G_{bcm} = bulk specific gravity of the compacted mixtures

- e. Determination of optimum binder content: Five separate smooth curves are drawn with percent of asphalt on x-axis and the following on y-axis
- unit weight
 - Marshall stability
 - Flow
 - VMA
 - Voids in total mix (P_{av})

Optimum binder content is selected as the average binder content for maximum density, maximum stability and specified percent air voids in the total mix.

6. Standard Method of Test for Cantabro Abrasion Loss of Asphalt Mixture Specimens

Scope: Use this test procedure to determine the abrasion loss of compacted hot-mix asphalt specimens

Definition: Cantabro abrasion loss refers to the amount of material loss from an asphalt mixture specimen due to repeated abrasion.

Summary of Test: This test procedure measures the breakdown of compacted specimens utilizing the Los Angeles Abrasion machine. The percent of weight loss (Cantabro loss) is an indication of PFC durability and relates to the quantity and quality of the asphalt binder. The percentage of weight loss is measured and reported



Los Angeles Abrasion Machine

Significance and use:

- The procedure is applied to open-graded asphalt mixes with minimum grading size of less than 25mm
- This test is used to indirectly assess the cohesion, bonding and effects of traffic abrasion and suction

Apparatus:

- Los Angeles Abrasion Machine: Test procedure shall be conducted in accordance with test method C131/C131M
- Thermometers: to measure the temperature of the aggregate, binder and asphalt mix, metal temperatures with a scale up to 200 °C (390 °F) and an accuracy of ± 3 °C (± 5 °F) or better shall be used. To measure the test temperature, a thermometer with a scale from 0 °C (32 °F) to 50 °C (122 °F) and an accuracy of ± 0.5 °C (± 1 °F) shall be used
- Balance: with a capacity of 2kg and an accuracy of ± 0.1 g for weighing the samples

- d. General Material: Trays, pots, spatulas, asbestos gloves, grease pencil, curved scoops, filter paper rings and so forth

Sample Preparation:

- a. Prepare two specimens in accordance with Tex-241-F. Specimen diameter must be 5.9 in. (150 mm), and height must be 4.5 ± 0.2 in. (115 ± 5 mm)
- b. For PFC mixtures, mould test specimens to 50 gyrations (Ndesign). There is not a specific density requirement for PFC mixtures
- c. For other HMA mixtures, density of test specimens must be $93 \pm 1\%$
- d. For hot-mix cold-laid and LRA mixtures, mold samples to density in accordance with the specification

Test Procedure:

- a. Mould the specimens in accordance with specification
- b. Cool moulded specimens to room temperature and weigh. Record and designate the weight
- c. Calculate the density of the specimens
- d. Discard specimens not meeting the $93 \pm 1\%$ density requirement and mould new specimens
- e. Allow the specimens to stand at room temperature ($77 \pm 3^{\circ}\text{F}$) for a minimum of 24 hr. before testing
- f. Place the specimens in the temperature chamber or oven long enough to ensure a consistent temperature of $77 \pm 2^{\circ}\text{F}$ ($25 \pm 1^{\circ}\text{C}$) throughout the specimen before testing
- g. Test laboratory-moulded specimens within three days of moulding
- h. Place the test specimen in the Los Angeles testing machine
- i. Rotate the Los Angeles machine at a speed of 30 - 33 rpm for 300 revolutions
- j. After 300 revolutions, discard the loose material broken off the test specimen
- k. Without including any of the discarded material, weigh the test specimen. Record and designate this weight as B

Calculations:

Calculate the Cantabro Loss using the following formula:

$$CL = \frac{A-B}{A} \times 100$$

Where:

CL = Cantabro Loss, %

A = Initial weight of test specimen

B = Final weight of test specimen

Report of Test:

- a. Report the following for each specimen:
 - i. Initial weight
 - ii. Final weight
 - iii. Percent loss
- b. Report the average percent loss of the tested specimens to the nearest tenth

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

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.

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

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

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

Calculations

$$\text{Moisture content } W = \frac{\text{mass of water}}{\text{dry mass of sample}} = \frac{M_2 - M_3}{M_3 - M_1} * 100\%$$

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

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 gravely 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".

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

Execution of the test

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.

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	¾- in.	19
1 -in	25.0	3/8- in.	9.5
¾- 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 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.

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

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

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

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)

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.

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 Table 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).

Execution of the test

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.

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 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.

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.

5 Weighing

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

(M_4).

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%.

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:

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

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:

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

- 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 behaviour 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.

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
- 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.

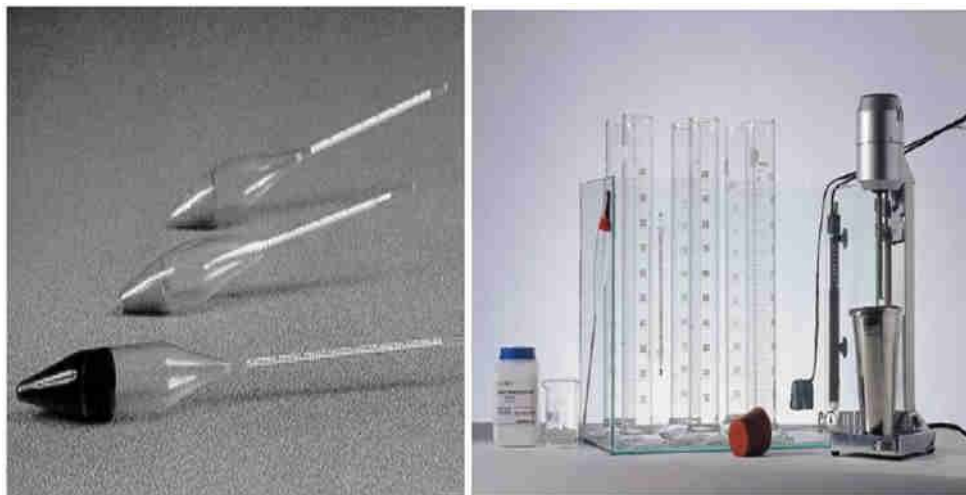


Figure 4.1 – Hydrometer analysis apparatus

Preparation and pretreatment of Sample

- The test specimen is obtained from the fraction of sample soil that smaller than $75\mu\text{m}$. 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.

Test Procedure

- Take the required mass from dried soil passing the $75\mu\text{m}$ 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.

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_o = 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.

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

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.

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

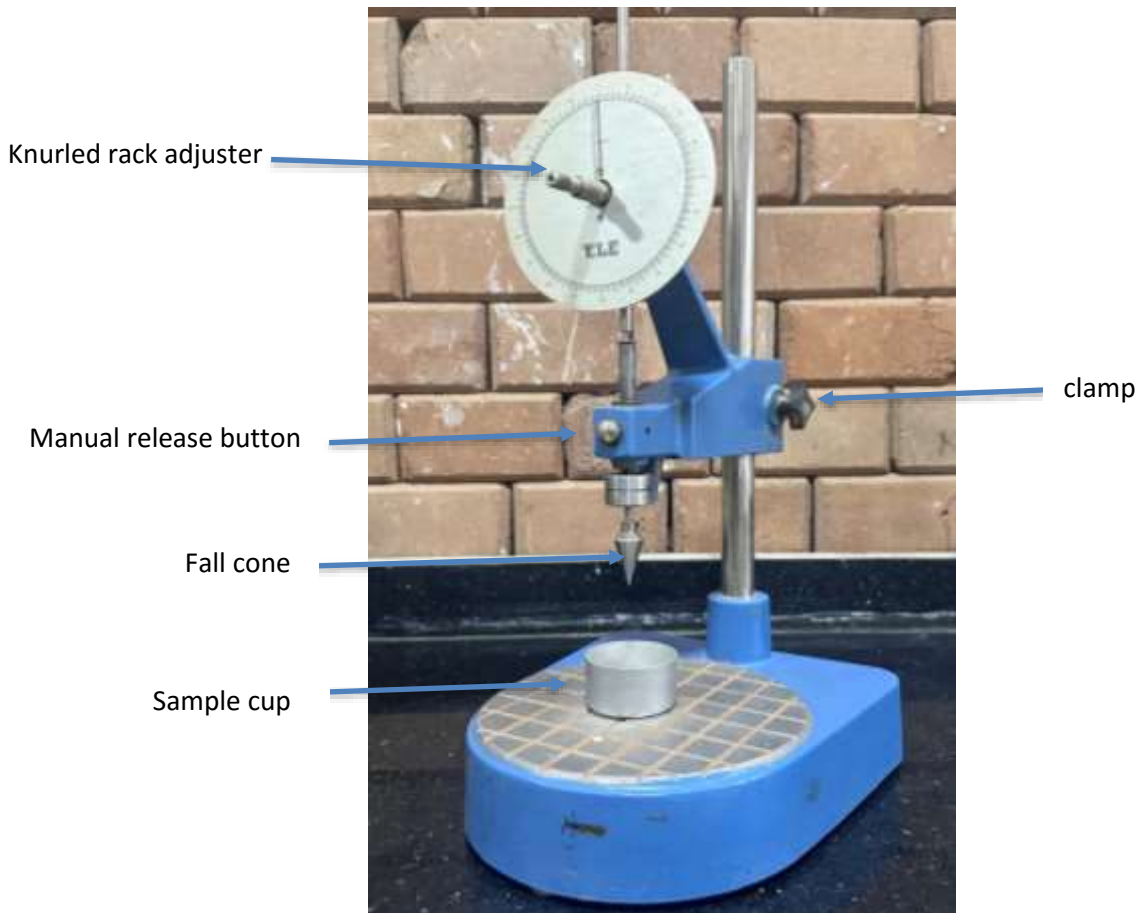


Fig.5.4 cone penetrometer

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 remove by wet sieving.

1 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 μ m sieve with the minimum amount of distilled water until the water passing is virtually clear.
- Collect the material retained on the 425 μ m 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.

2 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)

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.

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.

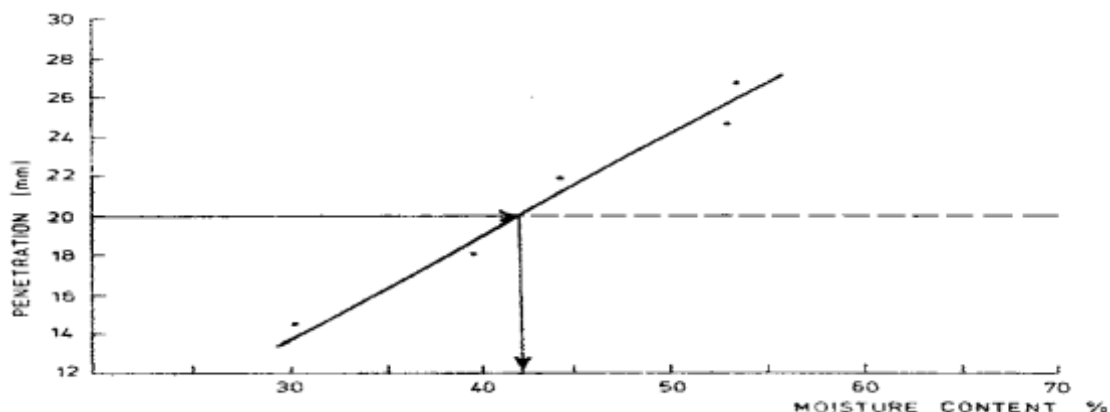


Fig 6.5 Typical penetration versus moisture content plot

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

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 empirical established moisture content at which soil becomes too dry to be plastic.

Apparatus

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

Sample preparation

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

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.

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

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.

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.

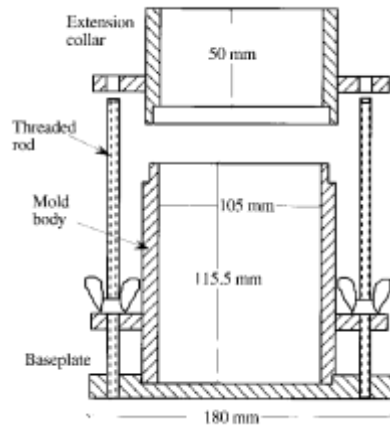


Fig. 6.1.1 British standard compaction mould

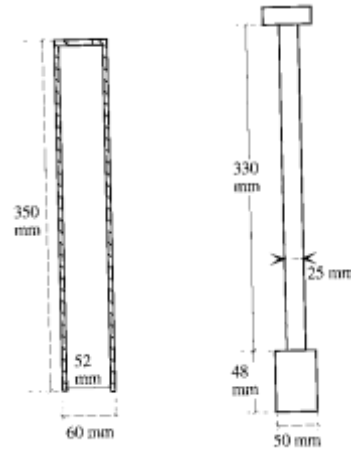


Fig 6.1.2 Ordinary test rammer

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 points, 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 onto 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 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 moisture throughout and then place on a separate covered container and allow standing prior to compaction in accordance with table below.

Table 6:2 - Required Standing Times of Moisturized Specimens

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

Execution of the test

- Weigh the mould = m_1
- 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. 6.1.3
- After this, the rammer should be moved, according to fig. 6.1.3 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 6.1.4)
- Remove the extension collar carefully and cut away the excess soil and level off the top of the mould. Any small cavities, resulting from removed stones, should be filled up with fine material.

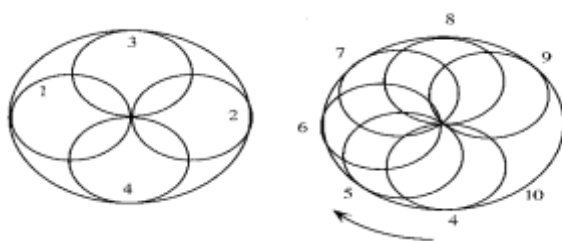


Fig. 6.1.3 Sequence of blows

compaction

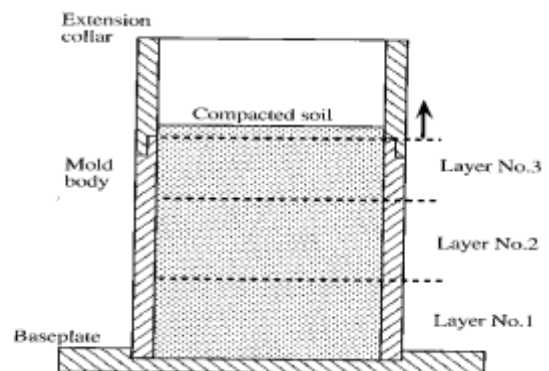


Fig. 6.1.4 After

-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.

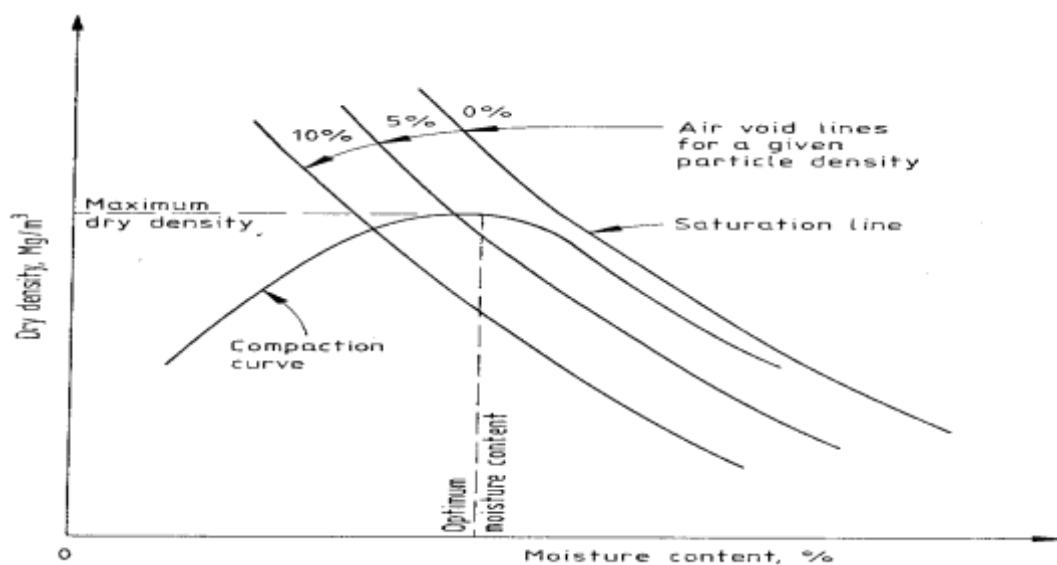


Fig 6.1.5: Graph of dry density-moisture content

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/m³)

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.

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

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-section 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.

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 standardized 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 liters

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:

$$M_1 = \frac{V_m}{100} (100 + W) \rho_d \frac{100\%}{1}$$

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 method 3 and 4 or to provide a specified compactive effort in methods 5 and 6.

- The sample has to be divided in equal parts of weights 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 7.1 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	Rammer		No. of layers	Blows per layers	
	Mass (kg)	drop (mm)			
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.

Execution of the test.

- The load-measuring device is connected to the compression machine.
- The cylindrical plunger, diameter 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 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.

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.

Correction

- The load-penetration curve is normally convex upwards. Figure 7.2, test 1
- If not, a correction has to be applied: figure 7.2, test 2
- From the inflection point, the tangent has to be drawn until it cuts the horizontal axis.
- This cutting point must then be taken as the new origin point and a new penetration scale, starting with zero at this new point, must be added.

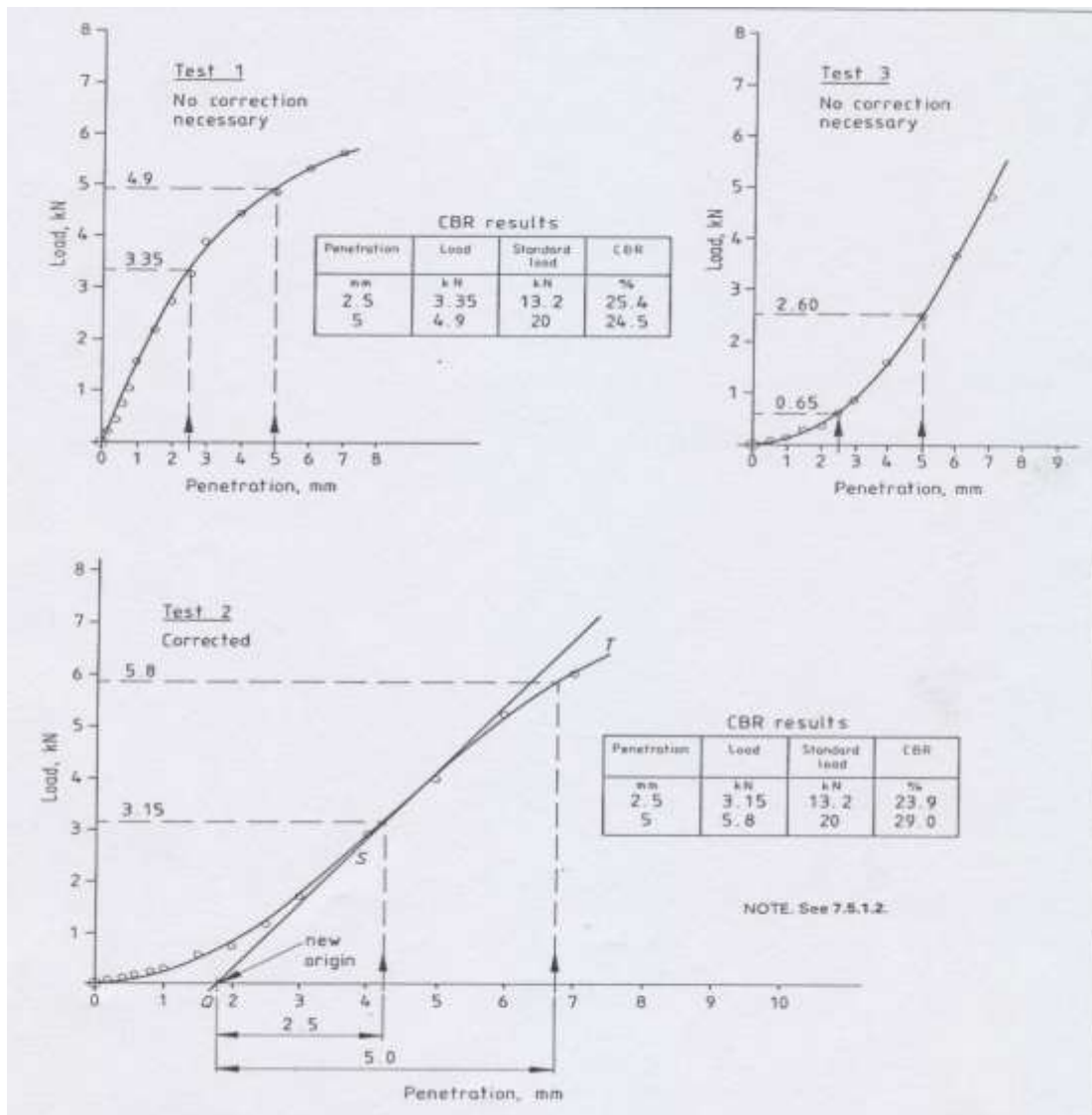


Fig 7.2 Three types of load penetration curve from CBR tests:

Test 1, no correction required

Test 2, correction required

Test 3, correction as (B) may not be valid.

References

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