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EXPERIMENT NO: 01

DETERMINATION OF AGGREGATE IMPACT VALUE

(BS: 812: 1975 (PART 1, 2, 3))



1.1 GENERAL

The aggregate impact value gives a relative measure of the resistance of an aggregate to "sudden shock or impact", which in some aggregates differs from its resistance to a slowly applied compressive load. With aggregate of aggregate impact value (AIV) higher than 30 the result may be anomalous. Also aggregate sizes larger than 14 mm are not appropriate to the aggregate impact test.

The standard aggregate impact test shall be made on aggregate passing a 14. mm BS test sieve and retained on a 10.0 mm BS test sieve. If required, or if the standard size is not available, smaller sizes may be tested but owing to the non-homogeneity of aggregates the results are not likely to be the same as those obtained from the standard size. In general, the smaller sizes of aggregate will give a lower impact value but the relationship between the values obtained with different sizes may vary from one aggregate to another.

1.2 APPARATUS

The following apparatus is required.

1.2.1 An impact testing machine of the general form and complying with the followings,

(a) Total mass not more than 60 kg or less than 45 kg.
The machine shall have a circular metal base weighing between 22 kg and 30 kg., with a plane lower surface of not less than 300 mm diameter, and shall be supported on a level and plane concrete or stone block or floor at least 450 mm thick. The machine shall be prevented from rocking either by fixing it to the block or floor or by supporting it on a level and plane metal plate cost into the surface of the block or floor.

(b) A cylinder steel cup having an internal diameter of 102 mm and an internal depth of 50 mm. The walls shall be not less than 6 mm thick and the inner surfaces shall be case hardened. The cup shall be rigidly fastened at the center of the base and be easily removed for emptying.

(c) A metal hammer weighing 13.5 kg to 14.0 kg the lower end of which shall be cylindrical in shape, 100.00 mm diameter and 50 mm long, with a 1.5 mm chamfer at the lower edge, and case hardened. The hammer shall slide freely between vertical guides so arranged that the lower (cylindrical) part of the hammer is above and concentric with the cup.

(d) Means or raising the hammer and allowing it to fall freely between the vertical guides from a height of 380±5 mm on to the test sample in the cup, and means for adjusting the height of fall within 5 mm.

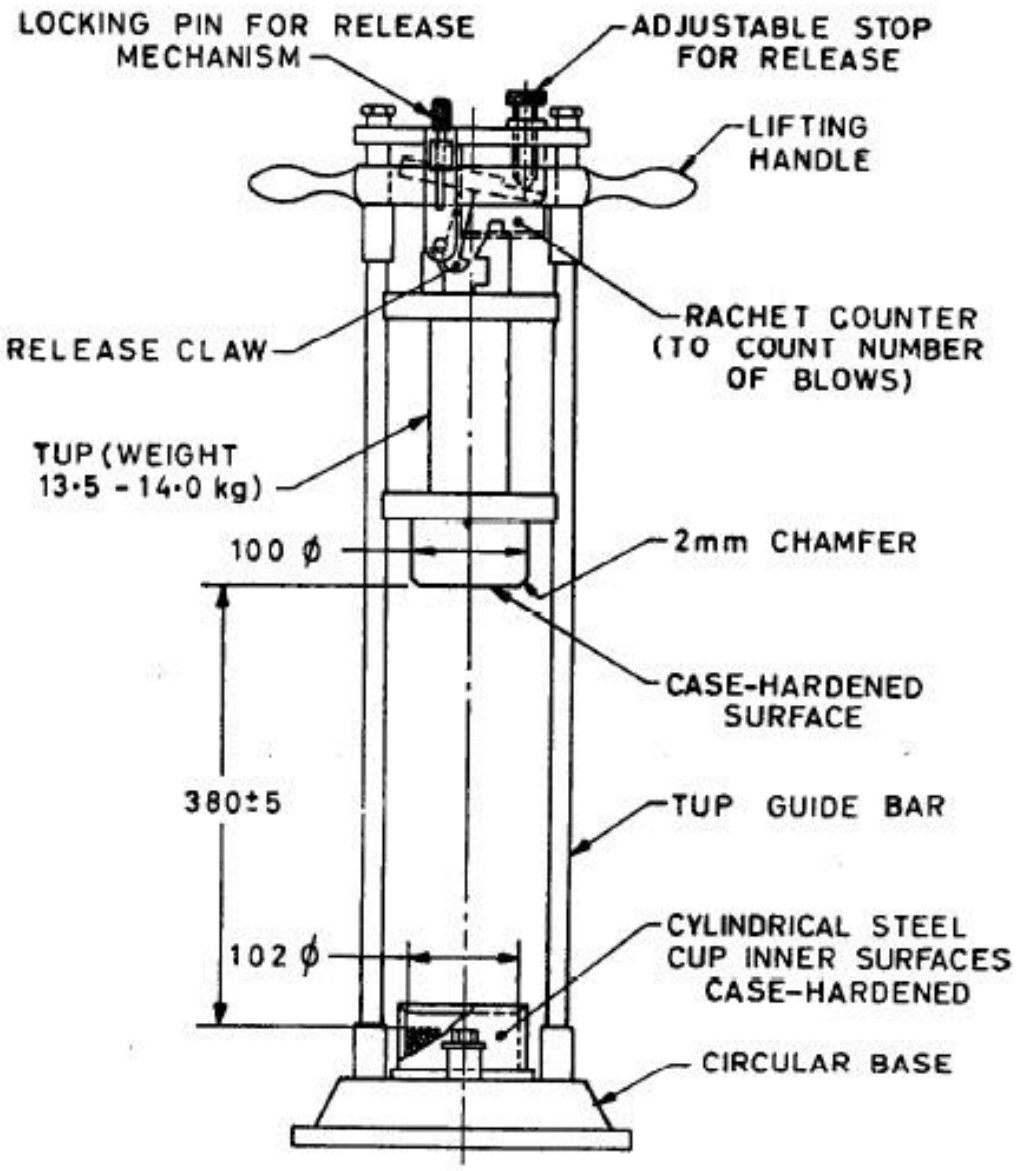


Figure1.1 Aggregate Impact Test machine

(e) Means for supporting the hammer whilst fastening or removing the cup.

NOTE: Some means for automatically recording the number of blow is desirable.

1.2.2 BS test sieves of aperture size 14.0 mm, 10.0 mm and 2.36 mm for a standard test.

1.2.3 A cylindrical metal measure of sufficient rigidity to retain its form under rough usage and with an internal diameter of 75 $\pm$ 1 mm and an internal depth of 50$\pm$ 1 mm.

1.2.4 A straight metal tamping rod of circular cross section, 10 mm diameter, 230 mm long, rounded at one edge.

1.2.5 A balance of capacity not less than 500 gm, and accurate to 0.1 gm.

1.3 PREPARATION OF THE TEST SAMPLE

The material for the standard test shall consist of aggregate passing a 14.0 mm BS test sieve and retained on a 10.00 mm BS test sieve and shall be thoroughly separated on these sieves before testing. For smaller sizes the aggregate shall be prepared in a similar manner using the appropriate sieves given in Table 1. The quantity of aggregate sieved out shall be sufficient for two tests.

The aggregate shall be tested in a surface dry condition. If dried by heating, the period of drying shall not exceed 4 h, the temperature shall not exceed 110^0C and the samples shall be cooled to room temperature before testing.

The measure shall be filled about one third full with the aggregate by means of a scoop, the aggregate being discharged from a height not exceeding 50mm above the top of the container. The aggregate shall then be tamped with 25 blows of the rounded end of the tamping rod, each blows being given by allowing the tamping rod to fall freely from a height of about 50 mm above the surface of the aggregate and the blows being evenly distributed over the surface. A further similar quantity of aggregate shall be added in the same manner and a further tamping of 25 times and the surplus aggregate removed by rolling the tamping rod across, and in contact with, the top of the container, any aggregate which impedes its progress being removed by hand and aggregate being added to fill any obvious depressions. The net mass of aggregates in the measure shall be recorded (mass A) and the same mass used for the second test.

1.4 TEST PROCEDURE

Rest the impact machine, without wedging or packing, upon the level plate, black or floor, so that it is rigid and the hammer guide columns are vertical. Fix the cup firmly in position on the base of the machine and place the whole of the test sample in it and compact by a single tamping of 25 strokes of the taming rod as above.

Adjust the height of the hammer so that its lower face is 380± 5 mm above the upper surface of the aggregate in the cup and then allow it to fall freely on to the aggregate. Subject the test sample to a total of 15 such blows, each being delivered act an interval of not less than 1 s. No adjustment for hammer height is required after the first blow.

Then remove the crushed aggregate by holding the cup over a clean tray and hammering on the outside with a suitable rubber mallet until the sample particles are sufficiently disturbed to enable the mass of the sample to fall freely on to the tray. Transfer fine particles adhering to the inside of

the cup and the underside of the hammer to the tray by means of a stiff bristle brush. Sieve the whole of the sample in the tray, for the standard test, on the 2.36 mm BS test sieve until no further significant amount in 1 min. When testing sizes smaller than the standard separate the fines on the appropriate sieve given in the 'for separating fines' column in table 1.1.

Weigh the fraction passing and retained on the sieve to an accurately of 0.1 gm (mass B and mass C respectively) and if the total mass B+C is less than the initial mass (mass A) by more than 1 gm, discard the result and make afresh test.
Repeat the whole procedure starting from the beginning using a second sample of the same mass as the first sample.

Table 1.1 Particulars of BS test sieves for testing standard and non-standard sizes of aggregates

Sample size	Nominal aperture sizes of BS test sieves complying with the requirements of BS410 (full tolerance)			
	for sample preparation		for separating fines	
	Passing	Retained		
Non-standard	mm	mm	mm	μ
	28.0	20.0	5.00	-
	20.0	14.0	3.35	-
Standard	14.0	10.0	2.36	-
Non-standard	10.0	6.30	1.70	-
	6.30	5.00	1.18	-
	5.00	3.35	-	85
	3.35	2.36	-	60

NOTE: Aggregate sizes larger than 14.0 mm are not appropriate to the aggregate impact test.

1.5 CALCULATIONS

The ratio of the mass of fines formed to the total sample mass in each test shall be expressed as a percentage, the result being recorded to the first decimal place.

Percentage fines: $B/A \times 100$

Where,
A is the mass of surface dry sample (gm)
B is the fraction passing the sieve for separating the fines (gm)

1.6 REPORTING OF RESULTS

The mean of the two results shall be reported to the nearest whole number as the aggregate impact value.

Experiment No: 01
Determination of Aggregate Impact Value

Name : **Student No**:

Type of material : Brick Chips/ Stone Chips/ Gravels/ Boulder/ Rock
Sample Size : 14 mm to 10 mm
Test Method : Bs 812 (part 3) 1975

Test No / Data	1	2	3
Wt. of Sample (Surface Dry), A (gm)			
Wt. of materials retained on 2.36 mm sieve, C (gm)			
Wt. of materials passing 2.36 mm sieve, B (gm)			
Aggregate Impact Value (%) = B/A x 100% (to the first decimal place)			
Average Aggregate Impact Value (AIV) = (to the nearest whole number)			

Calculation:

Average Aggregate Impact Value (AIV):

_____
Signature of the Course Teacher

EXPERIMENT NO: 02

DETERMINATION OF AGGREGATE CRUSHING VALUE

(BS: 812: 1975 (PART 1, 2, 3))



2.1 GENERAL

The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. With aggregate of an aggregate crushing value higher than 30 the result may be anomalous, and in such cases the ten percent fines value (clause 8) should be determined instead.

The standard aggregate crushing test shall be made as described in section 2.3 to section 2.7 on aggregate passing a 14.0 mm BS test sieve and retained on a 10.0 m BS test sieve. If required, or if the standard size of aggregate is not available, the test shall be made according to section 2.8.

2.2 SAMPLING

The sample for this test shall be taken in accordance with clause 5 of part 1 of this standard (BS 812).

2.3 APPARATUS

The following apparatus is required for the standard test.

2.3.1 An open ended steel cylinder of nominal 150 mm internal diameter with plunger and base plate, of the general from and diameter shown in the figure. The surfaces in contact with the aggregate shall be machined and case hardened, and shall be maintained in a smooth condition.

2.3.2 A straight metal tamping rod of circular cross section, 16 mm diameter and 450 mm to 600 mm long. One end shall be rounded.

2.3.3 A balance of at least 3 kg capacity and accurate to 1 gm.

2.3.4 BS test sieves of sizes 14.0 mm, 10.0 mm and 2.36 mm.

2.3.5 A compression testing machine capable of applying a force of 400 KN and which can be operated to give a uniform rate of loading so that this force is reached in 10 minute.

2.3.6 A cylindrical metal measure (optional) for measuring the sample, of sufficient rigidity to remain its form under rough usage and having an internal diameter of 115 mm and an internal depth of 180 mm.

Note. See Table 2.1

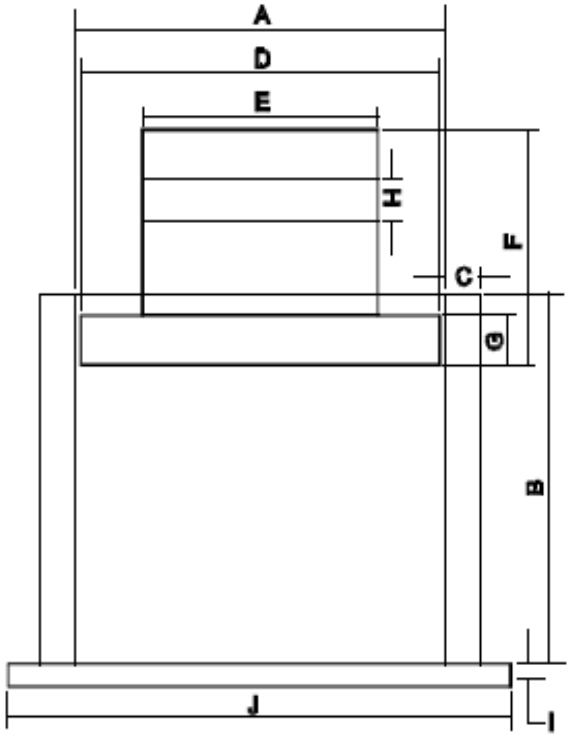


Figure 2.1 Outline of the cylinder and plunger apparatus for the crushing value

Table 2.1 Dimensions of the cylinder and Plunger apparatus for the crushing value.

Component	Dimensions See Figure	Nominal 150 mm internal diameter of cylinder, mm	Nominal 75 mm internal diameter of cylinder mm
Cylinder	Internal diameter, A Internal height, B Minimum wall thickness, C	154±0.5 mm 125 to 140 mm Not less than 16.0 mm	78±0.5 mm 70.0 to 85.0 mm Not less than 8.0 mm
Plunger	Diameter of piston, D Diameter of stem, E Overall length of piston plus stem, F Minimum depth of piston, G Diameter of hole, H	152±0.5 mm 95 to 155 100 to 115 mm Not less than 25.0 20.0±0.1 mm	76.0±0.5 mm 45.0 to 80.0 60.0 to 80.0 mm Not less than 19.0 10.0±0.1 mm
Base-plate	Minimum thickness, I Length of each side of square, J	10 mm 200 to 230 mm	10 mm 110 to 115 mm

NOTE: As a temporary measure, apparatus complying with the requirements of BS 812: 1967 (now withdrawn) shall be deemed to comply with this requirement.

2.4 PREPARATION OF TEST SAMPLE

The material for the standard test shall consist of aggregate passing the 14.0 mm BS test sieve and retained on the 10.0 mm BS test sieve and shall be thoroughly separated on these sieves before testing. The quality of aggregate shall be cooled to room temperature before testing.

The aggregate shall be tested in a surface-dry condition. If dried by heating the period of drying shall not exceed 4 h, the temperature shall not exceed 110^0C and the aggregate shall be cooled to room temperature before testing.

The quantity of aggregate for one test shall be such that the depth of the material in the cylinder shall be 100 mm after tamping.

The appropriate quantity may be found conveniently by filling the cylindrical measure in three layers of approximately equal depth, each layer being tamped 25 times from a height of approximately 50 mm above the surface of the aggregate with the rounded end of the tamping rod and finally leveled off, using the tamping rod as a straight edge.

The mass of material comprising the test sample shall be determined (mass A).

2.5 TEST PROCEDURE

Put the cylinder of the test apparatus in position on the base plate, and add the test sample in thirds, each third being subjected to 25 strikes from the tamping rod distributed evenly over the surface of the layer and dropping from a height approximately 50 mm above the surface of the aggregate. Carefully level the surface of the aggregate and insert the plunger so that it rests horizontally on this surface, taking care to ensure that the plunger does not jam in the cylinder.

Place the Apparatus, with the test sample and plunger in position, between the plates of the testing machine and load it at as uniform a rate as possible so that the required force is reached in 10 minutes. The required force shall be 400 KN.

Release the load and remove the crushed material by holding the cylinder over a clean tray and hammering on the outside with a suitable rubber mallet until the sample particles are sufficiently disturbed to enable the mass of the sample to fall freely on to the tray. Transfer fine particles adhering to the inside of the cylinder, to the base-plate and the underside of the plunger to the tray by means of a stiff bristle brush. Sieve the whole of the sample on the tray on the 2.36 mm BS test sieve until no further significant amount passes in 1 minute. Weight the fraction passing the sieve (mass B). Take care in all of these operations to avoid loose of the fines.
Repeat the whole procedure, starting from the beginning of 2.5, using a second sample of the same mass as the first sample.

2.6 CALCULATION

The ratio of the mass of fines formed to the total mass of the sample in each test shall be expressed as a percentage, the result being recorded to the first decimal place.
Percentage Fines: B/A x 100

Where,
A is the mass of surface dry sample (gm)
B is the mass of the fraction passing the 2.36 mm BS test sieve (gm)

2.7 REPORTING OF RESULTS

The mean of the two results shall be reported to the nearest whole number as the aggregate crushing value.

2.8 DETERMINATION OF AGGREGATE CRUSHING VALUE FOR NON-STANDARD SIZES OF AGGREGATE

2.8.1 General

If required, or if the standard size is not available, tests may be made on aggregates of other sizes larger than the standard up to a size which passes a 28.0 mm BS test sieve, using the standard apparatus. Alternatively, tests may be made on aggregates smaller than the standard down to a size which is retained on a 2.36 mm BS test sieve, using either the standard apparatus or that described in 2.8.2 which is referred to as the smaller apparatus.

Owing to the non-homogeneity of aggregates the results of tests on non-standard sizes are not likely to be the same as those obtained from standard tests. In general, the smaller sizes of aggregate will give a lower aggregate crushing value and the larger sizes a higher value, but the relationship between the values obtained will vary from one aggregate to another. However, the results obtained with the smaller apparatus have been found to be slightly higher than those with the standard apparatus and the errors for the smaller sizes of aggregate tested in the smaller apparatus are therefore compensator.

2.8.2 Apparatus

The following apparatus is required for the standard test

2.8.2.1 An open-ended steel cylinder, with plunger and base plate, generally as described in 2.3.1, with a nominal internal diameter of 75 mm the general form and dimensions of the cylinder and of the plunger are shown in Fig. 2.1

2.8.2.2 A balance of at least 500g capacity and accurate to 0.2g.

2.8.2.3 BS 410 test sieves of appropriate sizes given in Table 1.1 (see section 2.1.3.1 of Part 1 of this standard.)

2.8.2.4 A compression testing machine generally as described in 2.3.5 except that it shall be capable of applying force of 100 KN, and of being operated to' give a uniform rate of loading so that this force is reached in 10 min.

2.8.2.5 A cylindrical metal measure generally as described in 2.3.6 except that it shall have an internal diameter of 57 mm and an internal depth of 90 min.

2.8.3 Preparation of test sample

The material for tests on non-standard sizes shall consist of aggregate passing and retained on corresponding BS test sieves given in Table 1.1.

The procedure shall in other respects follow that given in section 2.4. except that in tests with the smaller apparatus the quantity shall be such that the depth of material in the nominal 75.0 mm internal diameter cylinder shall be 50 mm after taping with the smaller rod. The appropriate quantity may be found conveniently by using the smaller measure and taping rod.

2.8.4 Test procedure

Tests on non-standard sizes shall follow, the procedure given in 2.5 except that, when using the smaller apparatus, the smaller tamping rod shall be used and the total force shall be 100 KN. Take particular care with the larger sizes of aggregate to ensure that the plunger does not jam in the cylinder. Sieve the material removed from the cylinder on the appropriate sieve given in the “for separating fines” column in Table 1.1.

2.8.5 Calculations

Calculations for tests on non-standard sizes shall follow the method given in section2.6 substituting in the description of mass B the test sieve of appropriate size.

2.8.6 Reporting of results

Results of tests on non-standard sizes shall be reported as in 2.7 with, additionally, a report on the size of the aggregate tested and, if smaller than the standard size, the nominal size of the cylinder used in the test.

Experiment No: 02
Determination of Aggregate Crushing Value

Name : **Student No**:

Type of material : Brick Chips/ Stone Chips/ Gravels/ Boulder/ Rock
Sample Size : 14 mm to 10 mm
Test Method : Bs 812 (part 3) 1975

Test No / Data	1	2	3
Wt. of Sample (Surface Dry), A (gm)			
Wt. of materials retained on 2.36 mm sieve, C (gm)			
Wt. of materials passing 2.36 mm sieve, B (gm)			
Aggregate Crushing Value (%) = B/A x 100% (to the first decimal place)			
Average Aggregate Crushing Value (ACV) = (to the nearest whole number)			

Calculation:

Average Aggregate Crushing Value:

Signature of the Course Teacher

EXPERIMENT NO: 03

DETERMINATION OF THE TEN PERCENT FINES VALUE

(BS: 812: 1975 (PART 1, 2, 3))



3.1 GENERAL

The ten percent fines value gives a measure of the resistance of an aggregate to crushing which is applicable to both weak and strong aggregate.

The standard ten percent fines shall be made as described in section 3.3 to section 3.7 on aggregate passing a 14.0 mm BS test sieve and retained on a 10.0 mm BS test sieve. If required, or if the standard size of aggregate is not available, the test shall be made in accordance with section 3.8.

3.2 SAMPLING

The sample for this test shall be taken in accordance with clause 5 of part 1 of this standard (BS 812).

3.3 APPARATUS

The following apparatus is required for the standard test.
3.3.1 An open-ended steel cylinder with plunger, and base plate, as described in section2.3.1.

3.3.2 A tamping rod as described in section2.3.2.

3.3.3 A balance as described in section2.3.3.

3.3.4 BS 410 test sieves as described in section2.3.4.

3.3.5 A compression testing machine as described in section2.3.5, except that the forces which is to be applied may vary from 5 KN to 500 KN.

3.3.6 A cylindrical metal measure as described in section2.3.6:

3.3.7 (if required; see note in section 3.5), a means of measuring to the nearest 1 mm the reduction in distance between the platens of the testing machine during the test (e.g. a dial gauge).

3.4 PREPARATION OF THE TEST SAMPLE

The preparation of the test sample shall be as described in 2.4 except that, in the case of weak materials, particular care shall be taken not to break the particles when filling the measure and the cylinder.
NOTE: Sufficient test sample for three of more tests may be necessary.

3.5 TEST PROCEDURE

Put the cylinder of the test apparatus in position on the base-plate and add the test sample in thirds, each third being subjected to 25 strokes from the tamping rod distributed evenly over the surface of the layer and dropping from a height approximately 50 mm above the surface of the aggregate, particular care being taken in the case of weak materials not to break the particles. Carefully level the surface of the aggregate and insert the plunger so that it rests horizontally on this surface, taking care to ensure that the plunger does not jam in the cylinder.

Then place the apparatus, with the test sample and plunger in position, between the plates of the testing machine. Apply forces at as uniform a rate as possible so as to cause a total penetration of the plunger in 10 min of about:

a) 15 mm for rounded or partially rounded aggregate (e.g. uncrushed gravels)
b) 20 mm for normal crushed aggregate
c) 24 mm for honeycombed aggregate (e.g. some slags)

The figures may be varied according to the extent of the rounding or honeycombing.
NOTE: When an aggregate impact value is available, the force required for the first ten percent fines test can be estimated by means of the following more conveniently than by the use of the dial gauge.

Required force (KN) = 4000/ Aggregate Impact Value

This value of force will nearly always give a percentage fines within the required range of 7.5 to 12.5.

Record the maximum force applied to produce the required penetration. Release the force and remove the crushed material by holding the cylinder over a clean tray and hammering on the outside with a suitable rubber mallet until the sample particles are sufficiently disturbed to enable the mass of the sample to fall freely on to the tray. Transfer fine particles adhering to the inside of the cylinder and the underside of the plunger to the tray by means of a still bristle brush. Sieve the whole of the sample in the tray on the 2.36 mm BS test sieve until no further significant amount passes in 1 minute. Weight the fraction passing the sieve, and express this mass as percentage of the mass of the test sample. Normally this percentage of fines will fall within the range 7.5 to 12.5, but if it does not, make a further test loading to a maximum value adjusted as seems appropriate to bring the percentage fines within the range of 7.5 to 12.5. The formula given in 3.6 may be used for calculating the force required.

In all of these operations take care to avoid loss of the fines. Make a repeat test at the maximum force that gives a percentage fines within the range 7.5 to 12.5.

3.6 CALCULATIONS

The mean percentage fines from the two tests at this maximum force shall be used in the following to calculate the force required to produce ten percentage fines.

Force required to produce ten percent fines = 14 x / (y+4)
Where,
x is the maximum force (KN)
y is the mean percentage fines from two tests at "x" KN forces.

3.7 REPORTING AND RESULTS

The force required to produce ten percent fines shall be reported, to the nearest 10 KN for forces of 100 KN or more or the nearest 5 KN for loads of less than 100 KN, as the ten percent fines value.

3.8 DETERMINATION OF THE TEN PERCENT FINES VALUE FOR NON-STANDARD SIZES OF AGGREGATE

3.8.1 General

If required, or if the standard size is not available, test may be made on aggregates of other sizes which pass a 28.0 mm BS test sieve and are retained on a 2.36 mm BS test sieve. Because of the lack of experience of the testing sizes other than the standard it has not been possible to give any indication as to how the results obtained on non-standard sizes would compare with those obtained in the standard test as in the case of the aggregate crushing value.

3.8.2 Apparatus

The apparatus shall be as described in section 3.3.1 to section 3.3.3 and section 3.3.5 to section 3.3.7.

BS test sieves of appropriate sizes shall be as given in Table 1.1.

3.8.3 Preparation of test sample

The material for tests on non-standard sizes shall consist of aggregate passing and retained on corresponding BS test sieves given in Table 1.1.

The procedure shall in other respects follow that given in section 3.4.

3.8.4 Test procedure

Test on non-standard sizes shall follow the procedure given in 3.5 using the appropriate separating sieve given in table 1.1, it should be noted that the penetration of the plunger may not accord with the values given in 3.5.

3.8.5 Calculations

Calculations for non-standard sizes shall follow the method given in 3.6.

3.8.6 Reporting of results

Results of tests on non-standard sizes shall be reported as in 3.7 with, additionally, a report on the size of the aggregate tested.

Experiment No: 03
Determination of the Ten Percent Fines Value

Name : **Student No**:

Type of material : Brick Chips/ Stone Chips/ Gravels/ Boulder/ Rock
Sample Size : 14 mm to 10 mm
Test Method : Bs 812 (part 3) 1975

Force required to produce T.F.V = 4000 KN / A.I.V = KN.
Used Force = x = KN

Test No / Data	1	2	3
Wt. of Sample (Surface Dry), A (gm)			
Wt. of materials retained on 2.36 mm sieve, C (gm)			
Wt. of materials passing 2.36 mm sieve, B (gm)			
Percent Fines = B/A x 100% (to the first decimal place)			
Mean percentage fines (y), at x = KN force			

Calculation:

Ten Percent Fines Value (T.F.V) = 14x / (y+4) =
(to the nearest 5 KN, if < 100 KN
& 10KN, if ≥ 100 KN)

Ten Percent Fines Value (T.F.V):

Signature of the Course Teacher

EXPERIMENT NO: 04

DETERMINATION OF FLAKINESS INDEX

(BS: 812: 1975 (PART 1, 2, 3))



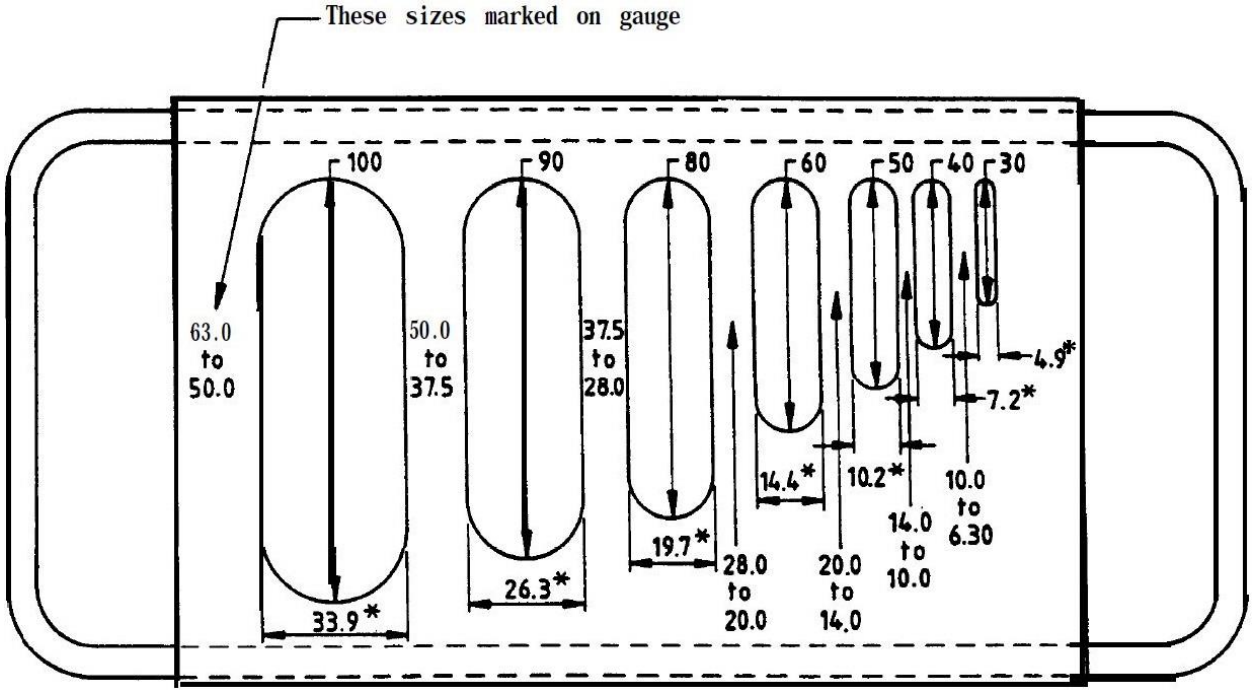
4.1 GENERAL

This method is based on the classification of aggregate particles as flaky when they have a thickness (smallest dimension) of less than 0.6 of their nominal size, this size being taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs. The flakiness index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test is not applicable to material passing a 6.30 mm BS test sieve or retained on a 63.0 mm BS test sieve.

4.2 APPARATUS

The following apparatus is required.

4.2.1 A metal thickness gauge of the pattern shown in figure 4.1 or special sieves having elongated apertures shown in figure 4.2. The width of the apertures and the thickness of the sheet used in the gauge or sieve shall be as specified in the following figures.



Dimensions are in mm
(Tolerances are given on essential dimensions as shown)

Figure 4.1 Thickness gauge



Figure 4.2 Sieves having elongated apertures

4.2.2 BS test sieves as shown in Table 4.1 (see also 7.1.3.1 of BS 812 Part 1:1975).

4.2.3 A balance accurate to 0.5% of the mass of the test sample.

4.3 SAMPLE FOR TEST

The sample for this test shall be taken in accordance with clause 5 of this part of this standard. It shall comply with the appropriate minimum mass given in Table 4.1, for sieve analysis with due allowance for later rejection of the particles retained on a 63.0 mm BS test sieve and passing 6.30 mm BS test sieve. The sample shall be taken from the laboratory sample by quartering or by means of a sample divider as described in 5.2.4 of BS 812 Part 1. Before testing it shall be brought to a dry condition in accordance with 5.1.4 of BS 812 Part 1.

Table 4.1 Dimensions of thickness gauges

Aggregate size fraction		Thickness gauge Width of slot of (Average x 0.6)	Minimum mass for subdivision
BS test sieve nominal aperture size			
100% passing	100% retained		
mm	mm	mm	Kg
63.0	50.0	33.9 ±0.3	50
50.0	37.5	26.3 ±0.3	35
37.5	28.0	19.7 ±0.3	15
28.0	20.0	14.4 ±0.15	5
20.0	14.0	10.2 ±0.15	2
14.0	10.0	7.2 ±0.10	1
10.0	6.30	4.9 ±0.1	0.5

4.4 PROCEDURE

Carry out a sieve analysis in accordance with BS 812: section 105.1using the sieve given in Table 4.1.

Discard all aggregate retained on the 63.0 mm BS test sieve and all aggregate passing the 6.30 mm BS test sieve.

Then weigh each of the individual size fractions retained on the sieves, other than the 63 mm BS test sieve and store them in separate trays with their size marked on the trays.

NOTE: Where the mass of any size fraction is considered to be excessive, i.e. more than the appropriate mass given in Table 4.1. Provided that the mass of the sub-divided fraction is not less than half the appropriate mass given in Table4.1. Under such circumstances the rest of the procedure should be suitably modified and the appropriate correction factor applied to determine the mass of flaky particles that would have been obtained had the whole of the original size fraction been gauged.

From the sums of the masses of the fractions in the trays (M_1), calculate the individual percentage retained on each of the various sieves. Discard any fraction of which the mass is, 5% of less of mass M_1. Record the mass remaining (M_2).

Gauge each fraction by one of the following procedures:

(a) Using the gauge: select the thickness gauge appropriate to the size-fraction under test (see Table 4.1) and gauge each particle separately by hand, or

(b) Using the special sieves: select the special sieve appropriate for the size-fraction under test. Place the whole of the size-fraction into the sieve which shall then be shaken until the majority of flaky particles have passed through the slots. Then gauge the particles retained individually by hand.

Combine and weigh all the particles passing the gauges or special sieves (M_3).

4.5CALCULATIONS AND REPORTING

Flakiness index = M_3/M_2 X 100

The flakiness index shall be reported to the nearest whole number. The sieve analysis obtained in this test shall also be reported.

Experiment No: 04
Determination of the Flakiness Index

Name : **Student No**:

Type of material : Brick Chips/ Stone Chips/ Gravels/ Boulder/ Rock
Test Method : Bs 812 (part 1) Clause 7.3 & 7.4

Sieve size (mm)	Gauge size used, (mm)	Wt. of the material retained (gm)	Percent of the material retained	Check if greater than 5% (ok/ not ok)	Flaky Particles (amount passed) gm
63.0	-	x	x		
50.0	33.9				
37.5	26.3				
28.0	19.7				
20.0	14.4				
14.0	10.2				
10.0	7.2				
6.3	4.9				
		M_1 =	**M_2 =**		**M_3 =**

Calculation:

Flakiness index (F.I) = M_3/M_2 X 100% = % (to the nearest whole number)

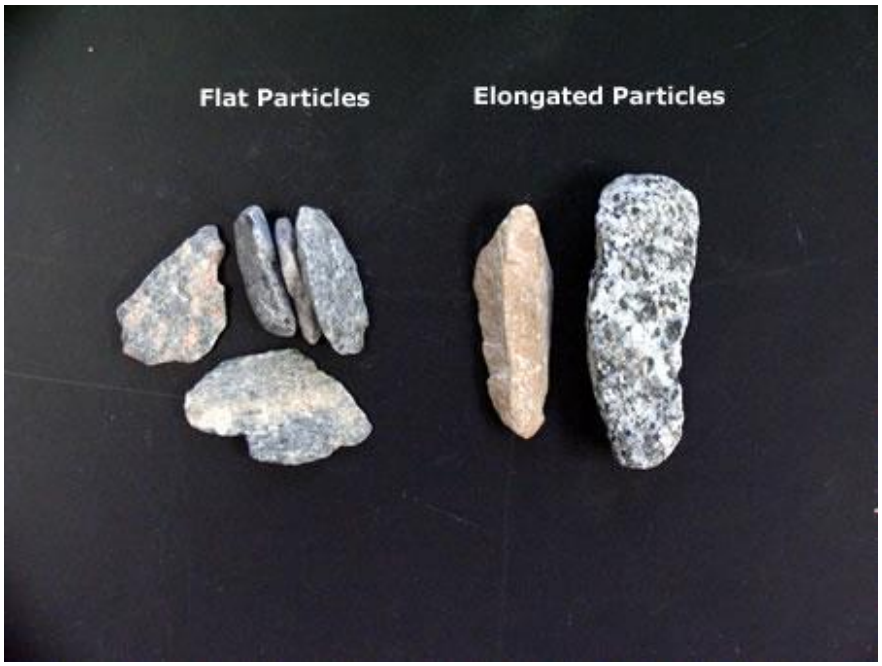
Signature of the Course Teacher

EXPERIMENT NO: 05

DETERMINATION OF ELONGATION INDEX

(BS: 812: 1975 (PART 1, 2, 3))





5.1 GENERAL

This method is based on the classification of aggregate particles as elongated when they have a length (greatest dimension) of more than 1.8 of their nominal size, this size being taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs.

The elongation index of an aggregate sample is found by separating the elongated particles and expressing their mass as a percentage, of the mass of the sample tested. The test is not applicable to material passing a 6.30 mm BS test sieve or retained on a 50 mm BS test sieve.

5.2 APPARATUS

The following apparatus is required.

5.2.1 A metal length gauge of the pattern shown in figure 5.1. The gauge lengths shall be those specified in the length gauge column of table 5.1.

5.2.2 BS test sieves as shown in Table 5.1 as appropriate (see also 7.1.3.1 of BS Part 1:1975).

5.2.3 A balance accurate to 0.5% of the mass of the test sample.

5.3 SAMPLE FOR TEST

The sample for this test shall be taken in accordance with clause 5 of this Part of this standard. It shall comply with the appropriate minimum mass given in Table 5 of BS 812 Part 1:1975, for sieve analysis, with due allowance for later rejection of particles retained on a 50.0 mm BS test sieve and passing a 6.30 mm BS test sieve. The sample shall be taken from the laboratory sample by quartering or by means of a sample divider as described in 5.2.4 of BS 812 Part 1:1975. Before testing it shall be brought to a dry condition in accordance with 7.1.4 of BS 812 Part 1:1975.

Table 5.1 Dimensions of length gauges

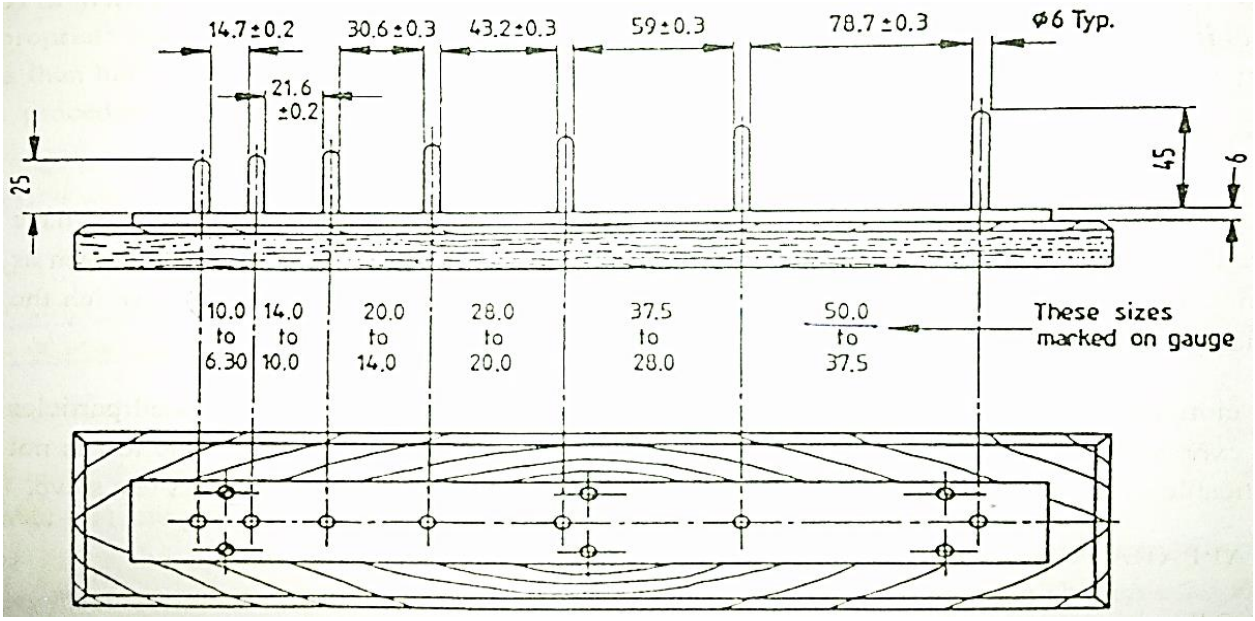
Aggregate size fraction BS test sieve nominal aperture size		Length gauge Gap between pins (Average x 1.8)	Minimum mass for subdivision
100% passing	100% retained		
mm	mm	mm	Kg
63.0	50.0	-	50
50.0	37.5	78.0 ± 0.3	35
37.5	28.0	59.0 ± 0.3	15
28.0	20.0	43.2 ± 0.3	5
20.0	14.0	30.6 ± 0.3	2
14.0	10.0	21.6 ± 0.2	1
10.0	6.30	14.7 ± 0.2	0.5

5.4 PROCEDURE

Carry out a sieve analysis in accordance with BS 812: section 105.2using the sieves shown in Table 5.1.

Discard all aggregate retained on the 50.0 mm BS test sieve and all aggregate passing the 6.30 mm BS test sieve.

Weigh and store each of the individual size-fractions retained on the other sieves in separate trays with their size marked on the tray.



Dimensions are in mm
(Tolerances are given on essential dimensions as shown)

Figure 5.1 Metal length gauge

NOTE: Where the mass of any size fraction is considered to be excessive, i.e. more than the appropriate mass given in Table 5.1, the fraction may be subdivided by the methods described in 5.2.4 of BS 812 Part 1:1975 provided that the mass of the subdivided fraction is not less than half the appropriate mass given in Table 5.1. Under such circumstances the rest of the procedure should be suitably modified and the appropriate correction factor applied to determine the mass of elongated particles that would have been obtained had the whole of the original size-fraction been gauged.

From the sum of the masses of the fractions in the trays (M_1), calculate the individual percentages retained on each of the various sieves. Discard any fraction whose mass is 5% or less of mass M_1. Record the mass remaining (M_2).

Select the length gauge appropriate to the size-fraction under test (see Table 5.1) and gauge each particle separately by hand. Elongated particles are those whose greatest dimension prevents them from passing through the gauge. Combine and weigh all elongated particles (M_3).

5.5CALCULATIONS AND REPORTING

Elongation index = M_3/M_2 X 100

The elongation index shall be reported to the nearest whole number. The sieve analysis obtained in this test shall also be reported.

Experiment No: 05
Determination of the Elongation Index

Name : **Student No**:

Type of material : Brick Chips/ Stone Chips/ Gravels/ Boulder/ Rock
Test Method : Bs 812 (part 1) Clause 7.3 & 7.4

Sieve size (mm)	Gauge size used, (mm)	Wt. of the material retained (gm)	Percent of the material retained	Check if greater than 5% (ok/ not ok)	Elongated Particles (amount retained) gm
50.0	-	x	x		
37.5	78.0				
28.0	59.0				
20.0	43.2				
14.0	30.6				
10.0	21.6				
6.3	14.7				
		M_1 =	M_2 =		M_3 =

Calculation:

Elongation index (E.I) = M_3/M_2 X 100% = % (to the nearest whole number)

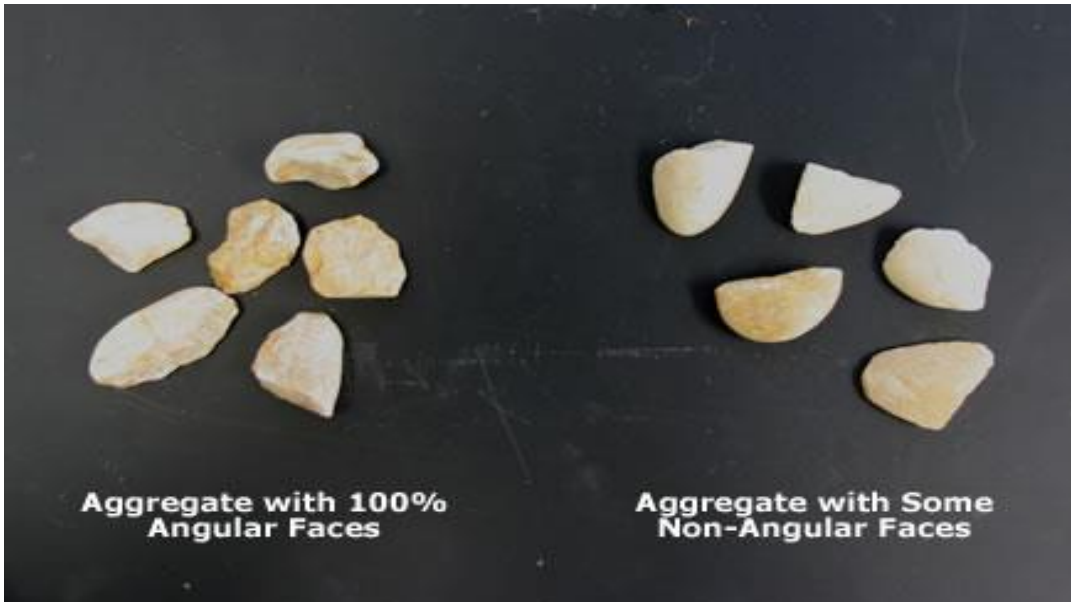
Signature of the Course Teacher

EXPERIMENT NO: 06

DETERMINATION OF ANGULARITY NUMBER

(BS: 812: 1975 (PART 1, 2, 3))





6.1 GENERAL

The angularity number is determined from the proportion of voids in a sample of aggregate after compaction in the specified manner. This property is used mainly in the design of mix proportions and in research.

Angularity or absence of rounding of the particles of an aggregate is a property which is of importance because it affects the ease of handling of a mixture of aggregate and binder (e.g. the workability of concrete) or the stability of mixtures that rely on the interlocking of the particles. The least angular (most rounded) aggregates are found to have about 33% voids and the angularity number is defined as the amount by which the percentage of voids exceeds 33. The angularity number ranges from 0 to about 12.

Since considerably more compactive effort is used than in the test for bulk density and voids (see 6.1 of part 2) the percentage of voids will be different. Weaker aggregates may be crushed during compaction and the results will be anomalous if this method is applied to any aggregate which breaks down during the test.

6.2 SAMPLING

The sample for this test shall be taken in accordance with clause 5 of this part of this standard.

6.3 APPARATUS

The following apparatus is required:

6.3.1 A metal cylinder closed at one end , of about 0.003 m^3 volume, the diameter and height of which should be approximately equal (e.g. 150 mm and 150 mm).

The cylinder shall be made from metal of a thickness not less than 3 mm and shall be of sufficient rigidity to retain its shape under rough usage.

6.3.2 A straight metal tamping rod of circular cross section 16 mm in diameter and 600 mm long rounded at one end.

6.3.3 A balance or scale of capacity 10 kg, accurate to 1 g.

6.3.4 A metal scoop approximately 200 mm x 120 mm x. 50 mm (i.e. about 1 liter heaped capacity).

6.3.5 BS perforated plate test sieves from 20.0 mm to 5.0 mm aperture size (but see note to section 3.5.5(a)).

6.4 CALIBRATION OF THE CYLINDER

The cylinder shall be calibrated by determining to the nearest mass of water (gm) at $20^0 \pm 2^0$C required to fill it up so that no meniscus is present above the rim of the container (mass C).

6.5 PREPARATION OF THE TEST SAMPLE

The sets sample shall be prepared as follows.

a) The amount of aggregate available shall be sufficient to provide, after separation on the appropriate pair of sieves, at least 10 kg of the predominant size as determined by sieve analysis on the BS test sieves.

The test sample shall consist of aggregate retained between the appropriate pair of BS test sieves from the following list:

20.0 mm and 14.0 mm; 14.0 mm and 10.0 mm; 10.0 mm and 6.3 mm; 6.3 mm and 5.0 mm.

Note: In testing aggregates larger than 20.0 mm the volume of the cylinder should be greater than 0.003 m^3, but for aggregates smaller than 5.0 mm a smaller cylinder may be used. The procedures should be the same as with the 0.003 m^3 cylinder, except that the amount of compactive effort (mass) should be proportioned to the volume of the cylinder used.

b) The aggregate to be tested shall be dried for at least 24 hr in shallow trays in a well-ventilated oven at a temperature of 105 ± 5^0C, cooled in an air tight container and tested.

6.6 TEST PROCEDURE

Fill the scoop and heap it to overflowing with the aggregate, which shall be placed in the cylinder by allowing it to slide gently off the scoop from the least height possible.

Subject the aggregate in the cylinder to 100 blows of the tamping rod at a rate of about two blows per second. Apply each blow by holding the rod vertical with its rounded end 50 mm above the surface of the aggregate and releasing it so that it falls freely. Do not apply any force to the rod. Evenly distribute the 100 blows over the surface of the aggregate.

Repeat the process of filling and tamping exactly as described above with a second and third layer of aggregate; the third layer shall contain just sufficient aggregate to fill the cylinder level with the top edge before tamping.

After the third layer of aggregate has been tamped, fill the cylinder to overflowing, and strike off the aggregate level with the top, using the tamping rod as a straight-edge.

Then add individual pieces of aggregate and roll them in, to the surface by rolling the tamping rod across the upper edge of the cylinder, and continue this finishing process as, long as the aggregate does not lift the rod off the edge of the cylinder on either side. Do not push in or otherwise force down the aggregate, and apply no downward pressure to the tamping rod, which shall roll in contact with the metal on both sides of the cylinder. Then weigh the aggregate in the cylinder to the nearest 5 gm.

Make three separate determinations and calculate the mean mass of aggregate in the cylinder (mass M). If the result of any one determination differs from the mean by more than 25 g, three additional determinations shall immediately be made on the same material, and the determinations calculated (mass M).

6.7CALCULATIONS

The angularity number of the aggregate shall be calculated from the equation:

Angularity number = $67 - \frac{100\,M}{CG}$

Where,

M is the mean mass of aggregate in the cylinder (gm);
C is the mass of water required to fill the cylinder (gm);
G is the relative density on an oven-dried basis of the aggregate determined in accordance with clause 5 of part 2 of this standard.

6.8 REPORTING OF RESULTS

The angularity number shall be reported to the nearest whole number.

Experiment No: 06
Determination of Angularity Number

Name : **Student No**:

Type of material : Brick Chips/ Stone Chips/ Gravels
Test Method : Bs 812; Part 1 Clause: 7.5 & BS 812, Part 2 Clause: 5

Serial No.	Mass of Aggregate in Cylinder (gm)	Mean Mass of Aggregate in the Cylinder, (M) (gm)	Relative Density of the Aggregate (Oven dry basis) (G)	Water Required to Fill the Cylinder, (C) (gm)	Angularity Number (A.N)
1					
2					
3					

Calculation:

Angularity Number (A.N) = $67 - \frac{100\,M}{CG}$ = **(to the nearest whole number)**

Signature of the Course Teacher

EXPERIMENT NO: 07

DETERMINATION OF ROADWAY CAPACITY

(Highway Capacity Manual (HCM)-1994, FHA, USA)



7.1 INTRODUCTION

The capacity of a roadway is its ability to accommodate traffic. It is usually expressed as the number of vehicles that can pass a given point in a certain time at a given speed.

Of course roadways are not ideal and prevailing roadway and traffic conditions those reduce ability of a road to accommodate traffic must be taken into consideration in highway capacity estimation. In determining highway capacities for uninterrupted flow conditions the general procedure, described below, is to apply appropriate empirically based adjustments for prevailing roadway and traffic conditions. The capacity of a given section of roadway stated either as unidirectional or both directions for a two lane or three lane roadway, may be defined as maximum number of vehicle that has a reasonable expectation of passing over a given section of roadway during a given time period under prevailing roadway and traffic condition.

While the maximum number of vehicle that can be accommodated remains fixed under similar roadway and traffic conditions, there is a range of lesser volumes which can be handled under differing operating conditions. Operation at capacity provides the maximum volume, but as both volume and congestion decrease there is an improvement in the level of service.

Level of service denotes any of an infinite number of differing combinations of operating conditions that can occur on a given lane or roadway when it is accommodating various traffic volumes.

Six levels of service (LOS), Level A through F, define full range of driving conditions from the best to worst in that order.

Level of service “A” represent free flow at low densities with no restriction due to traffic conditions. Level “B”, the lower limit of which is often used for the design of rural highways, is the zone of stable flow with some slight restriction of driver freedom. Level “C” denotes some of stable flow with more marked restriction in driver’s selection of speed and with reduced ability to pass. The conditions of level “D” reflect little freedom for driver maneuverability and condition approaches unstable flow. Level “E” area of unstable flow, is the zone of low operating speed and volume. Level “F” is the level of service provided by the familiar traffic jam, with frequent interruptions and breakdown of flow as well as volumes below capacity, coupled with low operating speed.

7.2 CAPACITY UNDER UNINTERRUPTED CONDITION

The capacity of roadway under uninterrupted flow condition can be obtained by modifying the capacity of the roadway under ideal conditions. Table 7.1 shows capacity of highway under ideal conditions according to Highway Capacity Manual (HCM)-1994 (USA).

These ideal conditions comprise uninterrupted flow, with no interference by side traffic or obstructions, a vehicle stream composed solely of passenger vehicles, 12 ft wide traffic lane, and should be capable of providing operation at 70 mph, with no restriction of passing sight distance.

Table 7.1: Capacity of roadway as per HCM-1994.

Roadway Type	**Capacity (passenger Vehicle/hr)**
Multi-lane Free Flow	2000 per lane
Two lane, two way	2000 total both direction
Three lane , two way	4000 total both direction

The adjustment factors used in modifying the capacity under ideal conditions to give capacity and service volumes under prevailing conditions may be grouped under

1. Roadway factors

2. Traffic factors

Table 7.2 gives the scale of operating characteristics established for various levels of service on 2 lane highways and summarizes general level of service criteria during uninterrupted flow conditions. Included, in addition to operating speeds and basic volume/capacity ratios for ideal alignment, are approximate measures of the influences of passing sight distance, expressed as a percentage of the total section that is adequate if greater than 1500 ft and of average highway speeds on volume/capacity ratios.

Table 7.2: Operating characteristics for various levels of service on 2 lane highways and general level of service criteria during uninterrupted flow conditions.

Level of Service	Traffic Flow Condition		Passing Sight Distance (%)	Basic Limiting Value for AHS* of 70 mph	Maximum service value under ideal condition
	Description	Operating Speed (mph)	>1500 ft		
A	Free Flow	≥ 60	100 80 60 40 20 0	0.20 0.18 0.15 0.12 0.08 0.04	400
B	Stable	≥ 50	100 80 60 40 20 0	0.45 0.42 0.38 0.34 0.30 0.24	900
C	Approaching unstable flow	≥40	100 80 60	0.70 0.68 0.65	1400

			40 20 0	0.62 0.59 0.54	
D	Approaching unstable flow	≥ 35	100 80 60 40 20 0	0.85 0.84 0.83 0.82 0.81 0.80	1700
E	Unstable Flow	30	Not Applicable	<=<1	2000
F	Forced Flow	<30	Not Applicable	Not Meaningful	Widely Variable (0 to capacity)

*AHS = Average highway speed

7.2.1 ROADWAY FACTORS

The roadway factors make allowances for the effects of design elements such as lane width, lateral clearances at the edge of lanes, alignment and grades. Table 7.3 shows the effect of reduced lane widths on capacity and Table 7.4 shows the effect of edge clearance. Under both conditions the driver has a feeling of restricted movement with limited clearance resulting reduced capacity and lower level of service.

Capacity of a roadway is also highly influence by width of shoulder. For safe operation and to develop full traffic capacity well maintained shoulder is required. Outside shoulder should be at least 10 ft preferably 12 ft and free of all obstructions for heavily traveled, high speed roadways. Fully implemented, firm and smooth shoulders increase traffic lane-width by 2 ft.

Table 7.3: Effect of lane width on capacity for uninterrupted flow conditions

Lane Width (ft)	Capacity %	
	Two-lane Roadways	Multi Lane Roadways
12	100	100
11	88	97
10	81	91
09	76	81

Table 7.4: Effective roadway width due to restricted lateral clearance under uninterrupted flow as per HCM-1994

Clearance from Pavement to Observation, Both Sides (ft)	Effective Width of Two 12-ft lane (ft)	Capacity of Two 12-ft Lanes (%)
6	24	100
4	22	92
2	20	83
0	17	72

7.2.2 TRAFFIC FACTORS

In addition to roadway factors, traffic factors (such as many trucks and buses in the traffic stream and variation of flow) affect the capacity and service columns of a road way. Trucks and busses, because of their restricted maneuverability, reduce the number of vehicles that a facility can handle. This reduction in vehicle is represented by the term passenger can equivalent (PCE), which indicates the equivalent number of passenger cars that have been displaced by the presence of each truck or bus, Table 7.5 shows passenger car equivalents for different types of vehicles as mentioned by the Roads and Highways Department.

Table 7.5: PCU values for different types of vehicles.

Vehicle Type	Passenger Car Unit (PCU) Value
Truck	3
Bus	3
Mini-bus	2
Passenger car	1
Utility	1
C.N.G, Baby taxi	0.75
Motorcycle	0.5
Bicycle	0.5
Cycle Rickshaw	2

Bullock Cart	4

*Source: Geometric Design Standards for Roads & Highways Department, Draft version-4, October 2004, Page-4

The method of estimation of highway capacity described in this article is applicable to rural highway situation only. In urban conditions, the roadway capacity mainly depends on the discharge capacity of the intersections. The commonly used intersections are: signalized, priority-controlled un-signalized and roundabout/traffic circles. However, considering the difficulties in arranging a field data collection trip to a representative rural highway section, required data will be collected from city roads. Therefore, it is suggested that an intersection free long stretch of road should be taken as the field site in order to get closer to the rural highway situation.

EXAMPLE

Find the capacity of a roadway section for the following data:

1. Roadway pattern : Two lane two way
2. Lane width : 11 ft
3. Shoulder condition: 4 ft on both side of roadway smooth and well maintained
4. Operating speed : 40 mph
5. % of passing sight distances: 80
6. Level of service C

Solution:

From Table 1 and Table 2
Capacity of two lane two way = 2000× 0.68 = 1360 veh/hr.

From Table 3,
Capacity reduction factor for 11 ft lane width =0.88

From Table 4,
Capacity reduction factor for 4 ft shoulder = 0.92
Therefore, actual roadway capacity = 1360×0.88×0.92 = 1101 passenger veh/hr. (total in both direction)

Experiment No: 07
Determination of Roadway Capacity

Name : **Student No**:

Find the capacity of a roadway section for the following data:

1. Roadway pattern :

2. Lane width :

3. Shoulder condition :

4. Operating speed :

5. % of passing sight distances :

6. Level of service :

Calculation:

Signature of the Course Teacher

EXPERIMENT NO: 08

A METHOD FOR MEASURING SATURATION FLOW AT TRAFFIC SIGNALS

(THE ROAD NOTE 34)



8.1 INTRODUCTION

When the green period at a traffic signal commences vehicles take a few seconds to accelerate to normal running speed, but after this initial period the queue discharges at a more or less constant rate. This rate is called the saturation flow and is usually expressed in vehicles per hour of green time. While the signal is green, vehicles continue to pass through the intersection at the saturation rate of flow, subject to the existence of stable queue. Some vehicles, but not all, make use of the amber period to cross the intersection and the average discharge rate falls to zero toward the end of this period.

The green plus the amber period can thus be divided, theoretically, into an "effective green time" during which traffic flows at the 'saturation' rate and a 'lost time' during which no flow occurs. The Road Note 34 describes a practical method of measuring saturation flow and lost time. The method consists of recording the number of vehicles discharged from a waiting queue in successive short intervals of the green period. The Note gives practical hints on how to decide when saturation flow ceases and on the treatment of non-standard intersections.

The analysis of data from a typical field data sheet is followed step by step. Passenger Car Equivalence of vehicles is given in order to be able to convert the saturation flow to passenger car units if the composition of the traffic is known.

8.2 BASIS OF THE ROAD NOTE 34 METHOD

In this method, the time "green period" refers to the green plus the amber period, i.e. the period when no red signal is shown.

A typical example of the variation of flow past the stop-line in successive short intervals of a fully saturated green period (i.e. a green period during which the queue is not fully discharged) is given in Figure 8.1. The effects on flow of starting delays and of the amber period are clearly shown. The average level of flow in these saturated intervals of the green period but excluding the beginning and end intervals is taken as the saturation flow. The graph can be simplified to the rectangular form shown by the broken line, the height of which is equal to the saturation flow and the area to the total number of vehicles discharged during a fully saturated green period. The width of the rectangle is called the effective green time and the difference between the actual green period (including amber) and this quantity is the lost time. This method of representing the discharge of the queue simplifies the calculation of delay and capacity because the number of vehicles discharged in a fully saturated green period is then directly proportional to the effective green time. Values calculated on this basis have been found to be in good agreement with those observed.

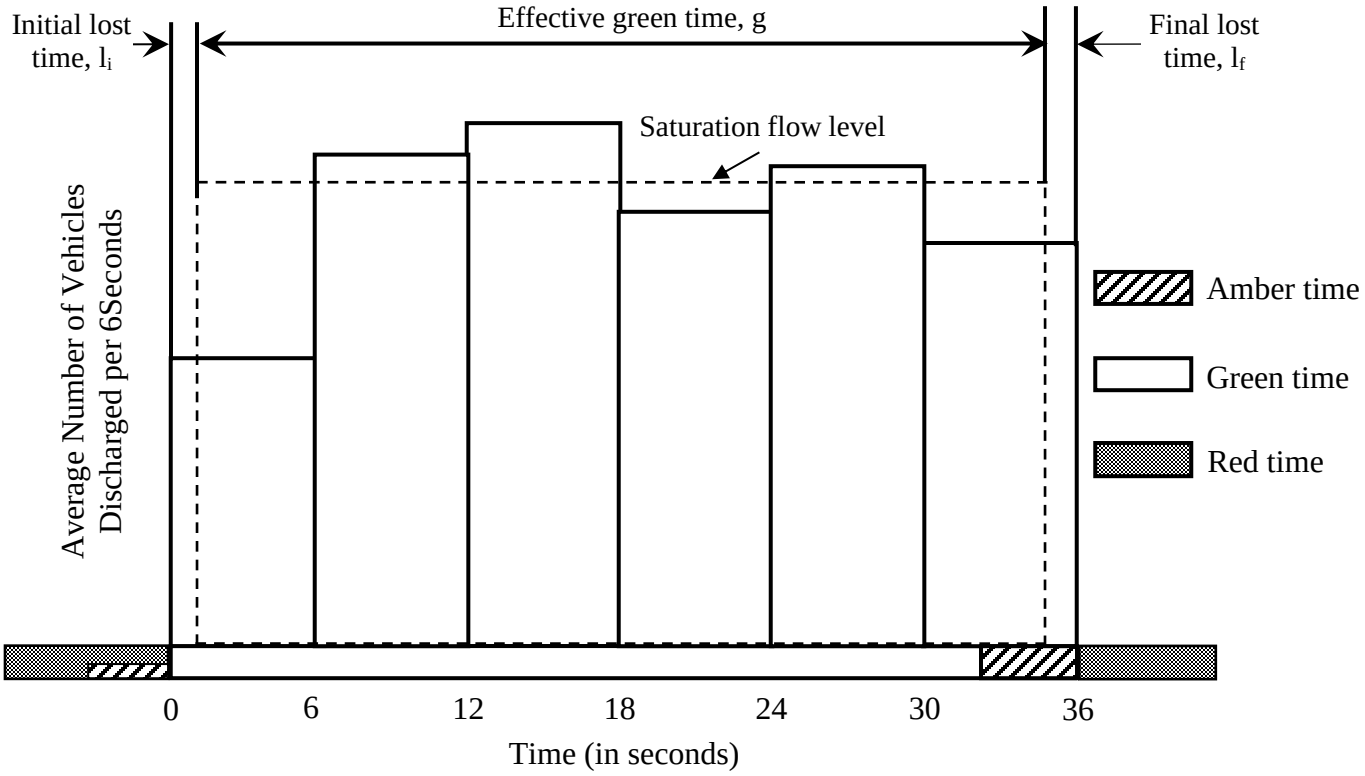


Figure 8.1 A typical example for fixed-time signals showing the variation of average discharge rate during a fully saturated green period

8.3 DATA COLLECTION PROCEDURE

- ❖ Select a suitable approach of an intersection where
  - flow condition is at the saturation level
  - at the road side and near the stop line of the approach there is a convenient place for collecting data

- ❖ Take total cycle time and green + amber period. Divide the combined green plus amber time by 6 in order to find the number of 6 sec intervals and the duration of last interval.

- ❖ Counting should be taken at the stop line (if there is no slop line a convenient reference line should be marked on the road).

- ❖ Start counting at the commencement of green signal and continue till the end of amber period.

- ❖ For each 6 sec interval, the classified vehicle counts should be recorded on the given form.

(See Table 8.1 for vehicle classification)

- For counting purpose, when rear wheel of a vehicle will cross the stop line, it should be included in the count for that particular interval.

- Recording of the flows should be discontinued, when the flow is no longer at the saturation level. (End of saturation level means — when queue disappears and vehicles discharges without stopping).

- Although the counting must stop at the end of the amber, any vehicle crossing on the red must be included in the last interval.

- Any vehicle that cross the observation point but fails to complete their journey through the intersection must not be counted until the next green period has started.

- Repeat vehicle counts for at least 10 cycles.

- Using Table 8.3, convert vehicles in terms of PCU values for each interval.

- Determine average PCU for each interval

- Draw histogram (i.e. discharge profile)

- Determine saturation flow by taking the height of the rectangle in each interval (excluding the first and last)

- Calculate lost times, $l = t - (n/s)$

  where, n = no. of vehicles discharges in initial/final interval (in PCU)

  s = saturation flow, PCU/sec

  t = duration of initial/final interval (in seconds)

- Calculate effective green lime, $g = G+A-(l_i + l_f)$

  where, G = observed green period

  A = observed amber period

  l_i = Initial lost time

  l_f = final lost time

Approach Capacity = $g/c \times s$ Where, c = cycle time

Table 8.1: Short description of various types of vehicles.
(ROADS AND HIGHWAYS DEPARTMENT)

Category	Type	Description
1	Heavy Truck	Three or more axles. Includes multi-axle tandem trucks, container carriers and other articulated vehicles.
2	Medium Truck	All 2-axle rigid trucks over three tonnes payload. Typical medium trucks are the Hindustan Bedford, "English" Bedford and Hino trucks of about 10 tonnes gross vehicle weight. Agricultural tractors and trailers are also included in this category.
3	Light Truck	Small trucks up to 3 tonnes payload. The most typical example is the Jeep based conversion.
4	Large Bus	More than 40 seats on 36 foot or longer chassis. Includes double decker buses.
5	Minibus	Between 16 and 39 seats. Typical minibuses are the TATA 909 and Hindustan Mascot.
6	Microbus	Up to 16 seats. Typical microbuses are the 12/15 seat Toyota Hi-ace, and the Mitsubishi L300.
7	Utility	Pick-ups, jeeps and four wheels drive vehicles, such as Pajero's and Land Rover's.
8	Car/Taxi	All types of car used either for personal or taxi services.
9	Baby-taxi	Includes Baby taxi and Mishuks
10	Tempo	Auto-Tempo and Auto-Vans.
11	Motor Cycle	All two wheeled motorized vehicles.
12	Bicycle	All pedal cycles.
13	Rickshaw Standard	Three wheeled cycle rickshaws (not rickshaw vans)
14	Rickshaw Van	Rickshaw vans
15	Cart	All animal and manually drawn/pushed carts.

Table 8.2: Vehicle identification sheet

No.	CATEGORY	CHARACTERISTICS	TYPICAL VEHICLES (TRUCKS AND BUSES)		
1	HEAVY TRUCK	3 OR MORE AXLES			
2	MEDIUM TRUCK	2 AXLES OVER THREE TONNES UNLOADED WEIGHT			
3	LIGHT TRUCK	2 AXLES UNDER THREE TONNES UNLOADED WEIGHT			
4	LARGE BUS	OVER 39 SEATS			
5	MINI BUS	16-39 SEATS			
No.	CATEGORY	CHARACTERISTICS	TYPICAL VEHICLES (LIGHT MOTORISED VEHICLES)		
6	MICROBUS	LESS THAN 16 SEATS			

7	UTILITY	PICK UPS AND FOUR WHEEL DRIVE VEHICLES			
8	CAR	ALL CARS AND TAXIS			
9	AUTO RICKSHAW	ALL THREE WHEELED MOTORISED VEHICLES			
10	MOTOR CYCLE	ALL TWO WHEELED MOTORISED VEHICLES			
No.	CATEGORY	CHARACTERISTICS	TYPICAL VEHICLES (NON MOTORISED VEHICLES)		
11	BICYCLE	PUSH BICYCLE			
12	CYCLE RICKSHAW	ALL THREE WHEELED NON MOTORISED VEHICLES			
13	CART	ALL ANIMAL AND PERSON DRAWN/PUSHED CARTS			

Table 8.3 (a): PCU estimates without non-motorized vehicles in the traffic stream

Proportion of NMV 0%	6 seconds intervals			
	3.5m	7.0m	10.5m	14.0 m
Motor-Cycle	0.02	0.06	0.03	0.01
Auto-Rickshaw	0.70	0.36	0.41	0.44
Tempo	0.76	0.41	0.51	0.55
Mini- Bus/Truck	1.43	1.45	1.53	1.40
Truck	1.99	1.97	2.12	2.28
Bus	1.96	1.95	1.99	2.09

Table 8.3 (b): PCU estimates with 10% non-motorized vehicles in the traffic stream

Proportion of NMV 10%	6 seconds intervals		
	7.0m	10.5m	14.0 m
Cycle	0.18	0.59	0.63
Rickshaw	1.23	1.12	0.91
Push-cart	2.77	2.76	2.24
Motor-Cycle	0.01	0.11	0.00
Auto-Rickshaw	0.20	0.22	0.30
Tempo	0.27	0.28	0.38
Mini- Bus/Truck	1.02	1.12	1.18
Truck	1.69	1.98	2.07
Bus	1.45	1.93	1.77

Table 8.3 (c): PCU estimates with 20% non-motorized vehicles in the traffic stream

Proportion of NMV 20%	6 seconds intervals		
	7.0 m	10.5 m	14.0 m
Cycle	0.31	0.41	0.38
Rickshaw	0.76	0.81	0.85
Push-cart	1.48	1.58	1.71
Motor-Cycle	0.64	0.12	0.04
Auto-Rickshaw	0.24	0.36	0.37
Tempo	0.32	0.42	0.41
Mini- Bus/Truck	1.01	1.06	1.04
Truck	1.25	1.14	1.66
Bus	1.14	1.16	1.23

Table 8.3 (d): PCU estimates with 30% non-motorized vehicles in the traffic stream

Proportion of NMV 30%	6 seconds intervals		
	7.0 m	10.5 m	14.0 m
Cycle	0.19	0.24	0.21
Rickshaw	0.60	0.53	0.48
Push-cart	1.28	1.71	1.10
Motor-Cycle	0.22	0.24	0.06
Auto-Rickshaw	0.17	0.29	0.22
Tempo	0.23	0.36	0.38
Mini- Bus/Truck	0.84	0.92	0.90
Truck	1.69	1.46	1.59
Bus	1.41	1.60	1.66

(Source: Roads and highways department)

Experiment No: 08

A Method for Measuring Saturation Flow at Traffic Signals

Name : **Student No**:

TRAFFIC COUNT FOR SATURATION FLOW CALCULATION
OF ……..…… INTERSECTION

C =

G =

A =

No. of vehicles per …….. Sec interval		1	2	3	4	5	No. of Vehicles in total 5 cycle	PCU factor	Converted PCU in total 5 cycle	Total PCU	Sample	Average
0												
……												
…….												

.....												
.....												
.....												

…….....												
……												

EXPERIMENT NO: 09

SPECIFIC GRAVITY OF SEMI-SOLID BITUMINOUS MATERIAL

AASHTO DESIGNATION: T 228-93
(ASTM DESIGNATION: D 70-76)



1. SCOPE

1.1 This method covers the determination of the specific gravity of semi-solid bituminous materials, asphalt cements, and soil tar pitches by use of a pycnometer.

2. SPECIFIC GRAVITY

2.1 The specific gravity of semi-solid bituminous materials, asphalt cements, and soft tar pitches shall be expressed as the ratio of the mass of a given volume of the material at 25^0C(77^0F) or at 15.6°C (60°F) to that of an equal volume of water at the same temperature, and shall be expressed thus:

Specific gravity, 25/25°C (77/77^0F) or 15.6/15.6°C (60/60°F)

3. APPARATUS

3.1 Pycnometer, glass, consisting of a cylindrical or conical vessel carefully ground to receive an accurately fitting glass stopper 22 to 26 mm in diameter. The stopper shall be provided with a hole 1.0 to 2.0 mm in diameter, centrally located in reference to the vertical axis. The top surface of the stopper shall be smooth and substantially plane and the lower surface shall be concave in order to allow all air to escape through the bore. The height of the concave section shall be 4.0 to 18.0 mm at the centre. The stoppered pycnometer shall have a capacity of 24 to 30 ml, and shall weigh not more than 40 g.

3.2 Water Bath- Constant temperature, capable of maintaining the temperature within 0.1^0C (0.2^0F) of the test temperature.

3.3 Thermometers- Calibrated liquid-in-glass of suitable range with graduations at least every 0.2°F (0.1°C) and a maximum scale error of 0.2°F (0.1°C) as prescribed in ASTM specification on El. Thermometers commonly used are 63°F or 63°C. Any other thermometer of equal accuracy may be used.

NOTE-1: Other ASTM thermometers (such as the ASTM 17°C) which have sub-divisions and scale errors equal to or smaller than those specified for the ASTM 63^0C and 63^0F may also be used.

3.4 Balance - a balance conforming to the requirements of M 231, Class B.

4. MATERIALS

4.1 Distilled Water - Freshly boiled and cooled distilled water shall be used to fill the pycnometer and the beaker.
NOTE-2: For the purpose of this lest, freshly boiled and cooled distilled, a mineralized or deionized water may be used.

5. PREPARATION OF EQUIPMENT

5.1 Partially fill a 600 ml or larger Griffin low-form beaker with freshly boiled and cooled distilled water to a level that will allow the top of the pycnometer to be immersed to a depth of not less than 40 mm.

5.2 Partially immerse the beaker in the water bath to a depth sufficient to allow the bottom of the beaker to be immersed to a depth of not less than 100 mm, while the top of the beaker is above the water level of the bath. Clamp the beaker in place.

5.3 Maintain the temperature of the water bath within 0.1°C(0.2°F) of the test temperature.

6. CALIBRATION OF PYCNOMETER

6.1 Thoroughly clean, dry, and weigh the pycnometer to the nearest 1 mg. Designate this mass as "A".

6.2 Fill the pycnometer with freshly boiled distilled water at test temperature and place the stopper in the pycnometer. Do not allow any air bubbles to remain in the pycnometer.

6.3 Allow the pycnometer to remain in the water for a period of not less than 30 min. Remove the pycnometer, immediately dry the top of the stopper with one stroke of a dry towel (Note 3), then quickly dry the remaining outside area of the pycnometer and weigh to the nearest 1 mg. Designate the mass of the pycnometer plus water as "B".

Note-3: Do not re-dry the top of the stopper even if a small droplet of water forms due to expansion. If the top is dried at the instant of removing the pycnometer from the water, the proper mass of the contents at the test temperature will be recorded. If moisture condenses on the pycnometer during weighing, quickly re-dry the outside of the pycnometer (excluding the top) before recording the mass.
Note-4: Calibration should be done at the specific temperature. A pycnometer calibrated at one temperature cannot be used at a different temperature without recalibration, at that temperature.

Table 9.1: Precision of specific Gravity Data for Semi-Solid Bituminous Materials

	deg C (deg F)	Single-Operator			Multilaboratory		
		Degrees of Freedom	(IS)	(D2S)	Degrees of Freedom	(LS)	(D2S)
Asphalt	15.6(60)	54	0.0011	0.0032	24	0.0018	0.0051
	25.0(77)	54	0.00080	0.0023	24	0.0024	0.0068
Soft tar pitch	15.6(60)	72	0.0013	0.0038	27	0.0029	0.0083
	25.0(77)	72	0.00083	0.0023	27	0.0017	0.0048
Pooled	15.6(60)	114	0.0013	0.0035	51	0.0024	0.0067
	25.0(77)	114	0.00082	0.0023	51	0.0019	0.0053

7. PROCEDURE

7.1 Preparation of Sample - Heat the sample with care, stirring to prevent local overheating, until the sample has become sufficiently fluid to pour. In no case should the temperature be raised to more than 56^0C (100°F) above the expected softening point for tar, or to more than 111°C (200°F) above the expected softening point for asphalt. Do not heat for more than 30 minutes over a flame or hot plate or for more than 2 hours in an oven, and avoid incorporating air bubbles in the sample.

7.2Pour enough sample into the clean, dry, warmed pycnometer to fill it about three-fourth to its capacity. Take precautions to keep the material from touching the sides of the pycnometer above the final level, and to prevent the inclusion of air bubbles (Note 5). Allow the pycnometer and its contents to cool to ambient temperature for a period of not less than 40 minutes, and weigh with the stopper to the nearest 1 mg. Designate the mass of the pycnometer plus sample as “C”.

NOTE-5: If any air bubbles are inadvertently included, remove by brushing the surface of the asphalt in the pycnometer with a high "soft" flame of a Bunsen burner. In order to avoid overheating, do not allow the flame to remain in contact with the asphalt more than a few seconds at any one time.

7.3 Fill the pycnometer with freshly boiled distilled water at test temperature and place the stopper in the pycnometer. Do not allow any air bubbles to remain in the pycnometer.

7.4 Allow the pycnometer to remain in the water bath for a period of not less than 30 minutes. Remove the pycnometer from the bath. Dry and weigh using the same technique as that employed in Section 6.3. Designate this mass of pycnometer plus sample plus water as “D”.

8. CALCULATIONS

8.1 Calculate the specific gravity to the nearest third decimal as follows:

$$\text{Specific gravity} = \frac{(\mathrm{C}-\mathrm{A})}{[(B-A)-(D-C)]}$$

Where :

A = mass of pycnometer (plus stopper)
B = mass of pycnometer filled with water
C = mass of pycnometer partially filled with asphalt, and
D = mass of pycnometer plus asphalt plus water

9. REPORT

9.1 Report the specific gravity to the nearest third decimal at 25/25°C (77°F) or 15.6/15.6^{0}C (60/60°F).

10. PRECISION

1.1 Single-Operator Precision:

1.1.1 The single-operator standard deviation for semi-solid bituminous materials tested at 15.6^0 C (60^{0}F) has been found to be 0.0013 (Note 6). Therefore, results of two properly conducted tests by the same operator should not differ by more than 0.002 (Note 6).

1.2 Multi-laboratory Precision:

1.2.1 The multi-laboratory standard deviation for semi-solid bituminous materials tested at 15.6^{0}C (60^{0}F) has been found to be 0.0024 (Note 6). Therefore, results of two properly conducted tests from two different laboratories on samples of the same material should not differ by more than 0.007 (Note 6).

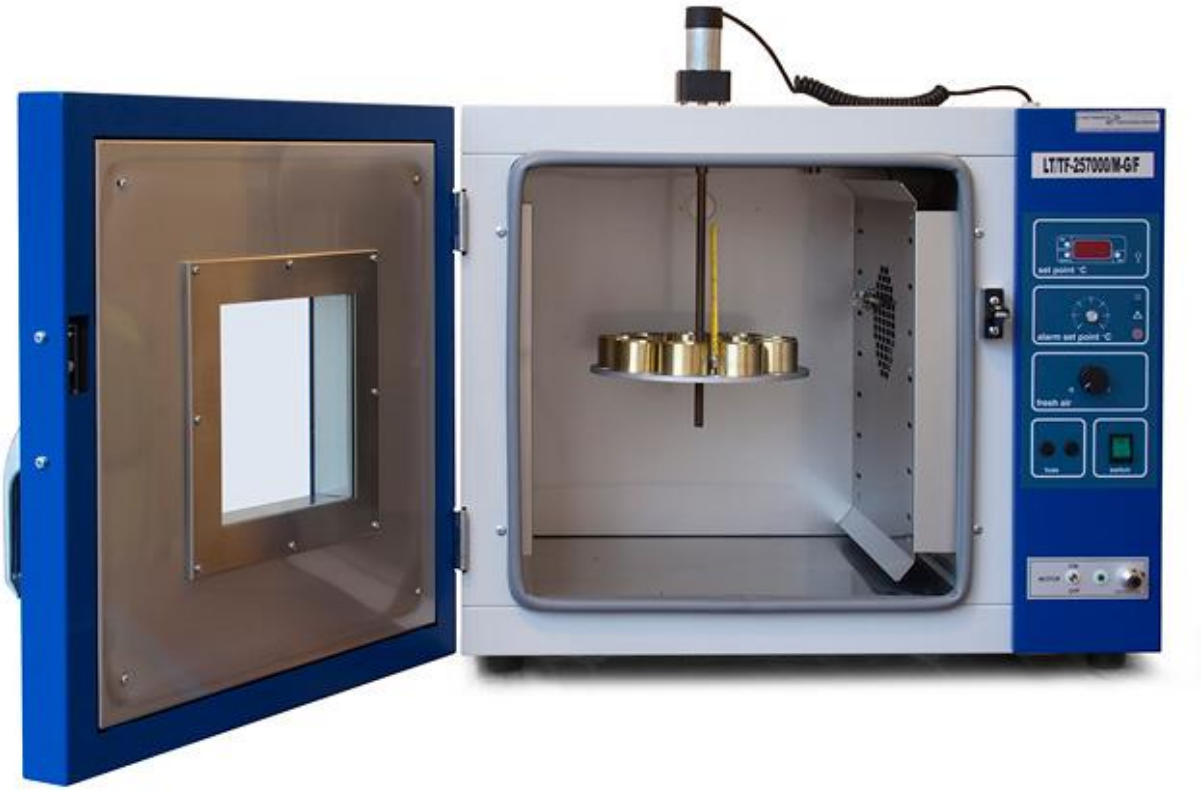
1.2.2 For materials tested at 25^{0}C (77^{0}F) the standard deviation has been found to be 0.0019 (Note 6). Therefore, results of two properly conducted tests from two different laboratories on samples of the same material should not differ by more than 0.005 (Note 6).

NOTE-6: These numbers represent, respectively, the (IS) and (D2S) limits as describe in AASHTO Recommended Practice R2, for Preparing Precision Statements for Test Methods for Construction Materials.

EXPERIMENT NO: 10

LOSS ON HEATING OF OIL AND ASPHALTIC COMPOUND

AASHTO DESIGNATION: T 47-83 (1993)
(ASTM DESIGNATION: D 6-80)



1. SCOPE

1.1 This method covers the determination of the loss in mass (exclusive of water) of oil and asphaltic compounds when heated as herein after prescribed.

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:

E1 Specification for ASTM Thermometers

E145 Specification for gravity-convection and forced-ventilation ovens

3. APPARATUS

3.1 Oven: The oven shall be electrically heated and shall conform to the performance requirements of ASTM specification E 145, for Gravity-Convection and Forced-Ventilation Ovens. It shall comply with the following requirements.

3.1.1 Construction: The oven shall be rectangular with minimum interior dimensions of 330 mm (13 in.) in each direction. The oven shall have in front a tightly fitting hinged door, which shall provide a clear opening substantially the same as the interior height and width of the oven. The door may contain a window with dimensions of a least 100 by 100 mm (4 by 4 in.), and with two sheets of glass separated by an air space, through which a vertical thermometer located in the oven, may be read without opening the door, or the oven may be provided with an inner glass door, through which the thermometer may be observed on opening the outer door momentarily. The oven shall be adequately ventilated by convection currents of air and for this purpose shall be provided with openings for the entrance of air and for the exit of heated air and vapors.

3.1.2 Rotating Shelf: The oven shall be provided with a circular metal shelf having a minimum diameter of 250 mm (9.8 in.). The shelf shall suspend by a vertical shaft and centered with respect to the horizontal interior dimensions. The shelf shall be provided with a mechanical means for rotating it at the rate of 5 to 6 rpm. The shelf shall be vertically located as close to the center of the oven as permitted by compliance with the requirements regarding to thermometer placement.

3.2 Thermometer: An ASTM Loss on Heating Thermometer graduated in Celsius degrees, having a range from 155 to 170°C, and conforming to the requirements for Thermometer as prescribed in the ASTM Specification E1, for ASTM Thermometers.

3.3 Container: The container in which the sample is to be tested shall be of metal or glass, cylindrical in shape, and shall have a flat bottom. It's inside diameter and depth shall be 55mm (2.17 in.) and 35 mm (1.38 in.) respectively.

4. PROCEDURE

4.1 First test the material under examination for water and if water is present, remove it by suitable methods of dehydration before subjecting the material to the loss on heating test, or obtain another sample that is free from water.

4.2 Place 50.0±0.5 gm of the sample of the water free material in a container, cool the sample to room temperature and weigh to the nearest 0.01 gm. Bring the oven to a temperature of 163°C (325°F) and place the container with the weighed sample on recesses if the recommended shelf is used. Close the oven and rotate the shelf during the entire test at a rate of 5 to 6 rpm. Maintain the temperature at 163 ± 1°C (325±1.8°F) for 5 hrs, start counting the time when the temperature reaches 162°C, and in no case shall the total time that a sample is in the oven be more than 5h and 15 min. At the conclusion of the heating period, remove the sample from the oven, cool to room temperature, and weigh to the nearest 0.01 gm.

5. CALCULATIONS

5.1 Calculate the percentage loss to the nearest second decimal as follows:

$$\% \text{ loss} = [(A-B)/A'] * 100$$

Where, A= initial weight of the container plus sample
B = final weight of the container plus sample after heating
A′ = initial weight of the sample

6. PRECAUTIONS

6.1 Under ordinary circumstances a number of samples having about the same degree volatility may be tested at the same time. Samples varying greatly in volatility should be tested separately. When extreme accuracy is required not more than one material should be tested at one time and duplicate samples of it should be placed simultaneously in the oven to check the accuracy of result. Samples showing evidences of foaming during the test shall be rejected.

7. Reproducibility of Results

7.1 Up to 5 percent loss in mass the results obtained may be considered as correct within 0.5. Above 5 percent loss in mass, the numerical limit of error increases 0.01 for every 0.5 percent increase in loss by volatilization as follows:

Table 10.1: Numerical limit of error for loss above 5 percent.

Volatilization Loss (%)	Numerical Correction	True Volatilization Loss, (%)
5.0	± 0.50	4.50 to 5.55
5.5	± 0.51	4.99 to 6.01
6.0	± 0.52	5.48 to 6.52
10.0	± 0.60	9.40 to 10.60
15.0	± 0.70	14.30 to 15.70
25.0	± 0.90	24.10 to 25.90
40.0	± 1.20	38.80 to 41.20

EXPERIMENT NO: 11

PENETRATION OF BITUMINOUS MATERIAL

AASHTO DESIGNATION: T 49-93′
(ASTM DESIGNATION: D 5-86)



1. SCOPE

1.1 This test method covers determination of the penetration of semi-solid and solid bituminous materials. Materials having penetrations below 350 can be tested by the standard apparatus and procedure described. Materials having penetrations between 350 and 500 can be determined using the special apparatus and modifications given in Section 9.3.

1.2 This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1 AASHTO standards:

T 53 Softening Point of Asphalt (Bitumen) and Tar in Ethylene Glycol (Ring-and-Ball)

2.2 ASTM Standards:

C 670 Practice for Preparing Precision Statements for Test Methods for Construction Materials
E1 Specification for ASTM Thermometers
E77 Method for Verification and Calibration of Liquid in Glass Thermometers.

2.3 ANSI Standard

B 46.1 Surface Texture
IP Standard Thermometers

3. DESCRIPTION OF TERM

3.1 The penetration of a bituminous material is the distance in tenths of a millimeter that a standard needle penetrates vertically into a sample of the material under fixed conditions of temperature, load and time.

4. SUMMARY OF METHOD

4.1 The sample is melted and cooled under controlled conditions. The penetration is measured with a penetrometer by means of which a standard needle is applied to the sample under specific conditions.

5. SIGNIFICANCE AND USE

5.1 The penetration test is used as a measure of consistency. Higher values of penetration indicate softer consistency.

6. APPARATUS

6.1 Penetration Apparatus - Any apparatus permitting movements of the spindle without appreciable friction and which is accurately calibrated to yield results in accordance With the description of the term penetration (see section 3.1) will be acceptable. The surface on which the sample container rests shall be flat and the axis of the plunger shall be at approximately 90 degrees to this surface. The spindle shall be detachable without the use of special toots, for checking its mass. When the needle is mounted in a ferrule, the mass of the moving spindle shall be 47.5 ± 0.05 g. Regardless of the type of mounting of the needle, the total mass of the needle and spindle assembly shall be 50.0 ± 0.05 g. Weights of 50.0 ± 0.05 g and 100.0 ± 0.05 g shall be provided for total loads of 100 g and 200 g (0.9 N and 2 N), depending upon the conditions of test to be applied.

NOTE: 1- The detachability of the spindle prescribed here is intended to apply to penetration apparatus acquired after January 1, 1976. Penetration apparatus acquired before January 1, 1976, may conform either to this standard or to the previous standard (T. 49-74).

6.2 Needle- The needle, Figure 1, shall be made from fully hardened and tempered stainless steel, grade 440 C or equal HRC 54 to 60. It shall be approximately 50 mm (2 in.) in length and 1.00 to 1.02 mm (0.039 to 0.040 in) in diameter. It shall be symmetrically tapered at one end to a cone whose angle shall be within the range of 8.7 to 9.7 deg over the entire length from full needle diameter, and whose axis shall be coincident with the needle axis within 0.0127 mm (0.005 in.) maximum run out (total indicator reading).

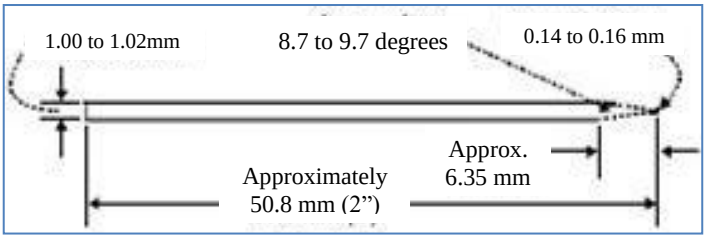


Figure 11.1: Needle for penetration test

After tapering, the point shall be ground off to a truncated cone, the smaller base of which shall be from 0.14 to 0.16 mm (0.0055 to 0.0063 in) in diameter. The truncation shall be square with the needle axis within 2 degree, and the edge shall be sharp and free from burrs.

6.2.1 When the surface texture of the tapered cone surface is measured in accordance with American National Standards Institute Standard B46.1, the surface roughness height shall be 0.2 to 0.3 μm (8 to 12 μ in.) arithmetic average.

6.2.2 The exposed length of the needle when mounted in the chuck of the penetration apparatus or in a ferrule shall be approximately 40 to 45 mm (1.57 to 1.77 in). When the needle is mounted in a ferrule, the ferrule shall be a cylindrical rod, 3.20 ± 0.05 mm (0.126 ± 0.002 in) in diameter and approximately 38 mm (1.5 in) long, made of stainless steel or brass, in which the needle shall be rigidly and coaxially mounted. The weight of the ferrule needle assembly shall be 2.50 ± 0.05 g. (A drill hole is permissible at the end of the ferrule to control weight). Individual identification markings shall be placed on the ferrule of each needle; the same markings shall not be repeated by a manufacturer within a 3year period.
NOTE 2- The manufacturer or commercial laboratories will certify the test needles for conformance to the permissible variations.

6.3 Container- A container, in which the sample is tested, made of metal or glass cylindrical in shape, and having a flat bottom. The container to be used for materials having a penetration of 200 or less shall have a nominal capacity of 3 oz (90 ml). Its inside dimensions shall be essentially as follows: 55 mm (2.17 in) in diameter and 35 mm (1.38 in) in depth. The container to be used for materials having a penetration over 200 shall have a nominal capacity of 6 oz (175 ml). Its inside dimensions shall be essentially as follows: 70 mm (2.75 in) in diameter and 45 mm (1.77 in) in depth.
NOTE 3- Containers known as tin boxes or as seamless ointment boxes may be obtained in dimensions conforming to the above requirements.

6.4 Water Bath - A water bath maintained at a temperature varying not more than 0.1°C (0.2°F) from the temperature of the test. The volume of water shall not be less than 10 liters. The bath shall have a perforated shelf supported in a position not less than 50 mm from the bottom of the bath

and not less than 100 mm below the liquid level in the bath. The water in the bath shall be substantially free from oil and slime or other organic growth. Brine may be used in the water bath for determinations at low temperatures. If penetration tests are to be made without removing the sample from the bath, a shelf strong enough to support the penetration apparatus shall be provided.

NOTE 4- The use of distilled, demineralized or deionized water is recommended for the bath. Care should be taken to avoid contamination of the bath water by surface active agents, release agents or other chemicals as their presence may affect the penetration values obtained.

6.5 Transfer Dish for Container- When used; the transfer dish for the container shall be a cylinder with a flat bottom made of glass, metal or plastic. It shall be provided with some means which will ensure a firm bearing and prevent rocking of the container. It shall have a minimum inside diameter of 90 mm (3.5 in) and a minimum depth above the bottom bearing of 55 mm (2.17 in).
NOTE 5- A magnetic strip in the bottom of the transfer dish may be used to prevent the ointment tin from rocking.

6.6 Thermometers for Water Bath- Calibrated Liquid-in-glass thermometers of suitable range with subdivisions and maximum scale error of 0.1°C (0.2°F) or any other thermometric device of equal accuracy, precision, and sensitivity shall be used.

The following thermometers conforming to the requirements of ASTM Specification E1, ASTM Thermometers are required:

6.6.1 For tests at 25°C (77°F) use an ASTM Saybolt Viscosity Thermometer 17°C (or 17°F) having a range of 19 to 27°C (66 to 80°F). The thermometer shall be immersed in the bath 150±15 mm.

6.6.2 For tests at 0°C (32°F) and 4°C (39.2°F) use ASTM Precision Thermometer 63°C (or 63°F) having a range of -8 to + 32°C (18 to 89°F). The thermometer shall be immersed in the bath 150±15 mm.

6.6.3 For tests at 46.1°C (115°F) use ASTM Precision Thermometer 64°C (or 64°F) having a range of 25 to 55°C (77 to 131°F). The thermometer shall be immersed in the bath 150 ± 15 mm.

6.6.4 Since the accuracy of the test results is dependent upon closely controlled temperature conditions, the thermometer used for the water bath should be calibrated by ASTM E77, Inspection, Test and standardization of Etched Stem Liquid-in-Glass thermometers.

6.7 Timing Device- For hand-operated penetrometers any convenient timing device such as an electric timer, a stop watch, or other spring-activated device may be used provided it is graduated in 0.1 second or less and is accurate to within ± 0.1 second for a 60 second interval. An audible second counter adjusted to provide 1 beat each 0.5 second may also be used. The time for a count interval must be 5 ± 0.1 second. Any automatic timing device attached to a penetrometer must be accurately calibrated to provide the desired test interval within ± 0.1 second.

6.8 Heater- An oven or hot plate, heated by electricity or gas, shall be provided for heating samples.

7. PREPARATION OF SAMPLE

7.1 Heat the sample with care to prevent local overheating until it has become fluid. Then with constant stirring, raise the temperature of the asphalt sample not more than 100°C or l80°F above its expected softening point or the tar pitch sample not more than 56°C or 100°F above its softening point determined in accordance with the Method of test for Softening Point of Bituminous Materials (Ring and Ball Method), T 53. Avoid the inclusion of air bubbles. To reach the pouring temperature, do not heat the softened sample more than 30 minutes.

Then pour it into the sample container to a depth such that, when cooled to the temperature of test the depth of the sample is at least 10 mm greater than the depth to which the needle is expected to penetrate. Pour separate samples for each variation in test conditions.

7.2 Loosely cover each container and its contents as a protection against dust, and allow to cool in an atmosphere at a temperature not higher than 30°C or 86°F and not lower than 20°C or 68°F for not less than $1\frac{1}{2}$ hours nor more than 2 hours when the sample is in a 175 ml (6 oz) container and for not less than 1 nor more than $1\frac{1}{2}$ hours when the sample is in a 90 ml (3 oz) container. Then place the sample in the water bath maintained at the prescribed temperature of test, along with the transfer dish if used, and allow it to remain for not less than $1\frac{1}{2}$ hours nor more than 2 hours when the sample is in the 175 ml (6 oz) container, and for not less than 1 nor more than $1\frac{1}{2}$ hours when the sample is in a 90 ml (3 oz) container.

8. TEST CONDITIONS

8.1 Where the conditions of test are not specifically mentioned, the temperature, load, and time are understood to be 25°C (77°F), 100 g, 5 second, respectively.

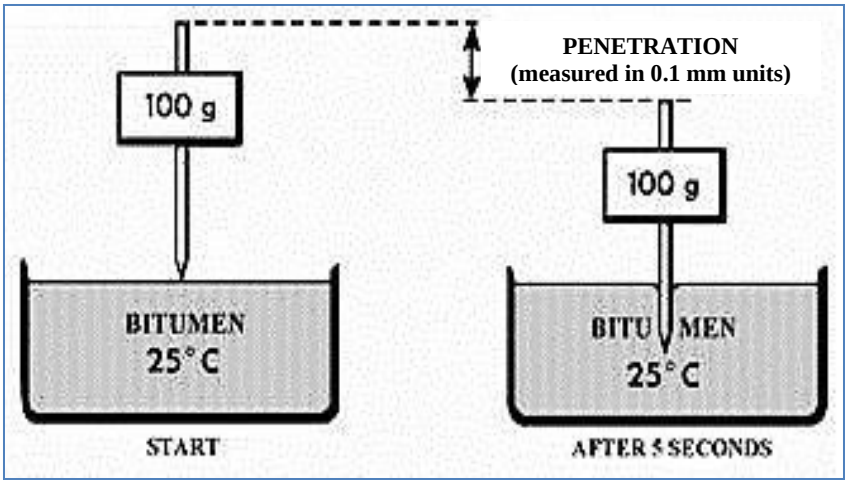


Figure 11.2: Penetration test

Other conditions of temperature, load and time may be used for special testing, such as:

Table 11.1: Temperature and Time for different loads of penetration needle assembly.

Temperature	Load, g	Time
0°C/(32°F)	200	60
4°C/(39.2°F)	200	60
46.1^0C/(115^0F)	50	5

In such cases, the specific conditions of test shall be reported.

9. PROCEDURES

9.1 Examine the needle holder and guide to establish the absence of water and other extraneous matter. Clean a penetration needle with toluene or other suitable solvent, dry with a clean cloth, and insert the needle in the penetrometer. Unless otherwise specified, place the 50 g weight above the needle, making the total load of 100 g $\pm$ 0.1g for the needle and attachment. If tests are made with the penetration apparatus mounted in the bath, place the sample container directly on the submerged stand of the penetration apparatus. If tests are made with the sample in the bath and the penetration apparatus outside the bath, place the containers on the shelf provided in the bath. In the above procedures the container shall be kept completely submerged during the complete test. If tests are made using the transfer dish with the penetration apparatus outside the bath, place the sample in a dish filled with water from the bath to a depth to cover completely the sample container. Then place the transfer dish containing the sample on the stand on the penetration apparatus and penetrate immediately. In each case, adjust the needle loaded with the specified weight to just make contact with the surface of the sample. Accomplish this by making contact of the actual needle point with its image reflected by the surface of the sample from a properly placed source of light (Note 8). Either note the reading of the dial or bring the pointer to zero. Then quickly release the needle for the specified period of time and adjust the instrument to measure the

distance penetrated. Observe the sample container as the needle is applied, and if any movement of the container is noted, ignore the result.
NOTE 6- For certain types of asphalt erratic results are sometimes obtained. When this occurs, pre-treat the needles by immersing them for 5 minutes in a 1 percent solution of olene acid prior to drying and running the test.
NOLL 7- For reference tests, penetrations at temperature other than 25^0C (77^0F) should be made without removing the sample from the bath.
NOTE 8- The positioning of the needle can be materially aided by using an illuminated methyl methacrylate rod.

9.2 Make at least three penetrations at points on the surface of the sample not less than 10 mm (3/8 in) from the side of the container and not less than 10 mm (3/8 in) apart. If the transfer dish is used, return the dish and sample to the water bath after each penetration. Before each test, clean the needle with a clean cloth moistened with toluene or other suitable solvent to remove all adhering bitumen, and then wipe with a clean dry cloth. For penetration values greater than 200, use at least three needles, leaving them in the sample until completion of the penetrations.

9.3 The needles, containers, and other conditions described in this method provide for determinations of penetrations up to 350. However, the method may be used for direct determinations up to 500 provided special containers and needles are used. The container shall be at least 60 mm in depth. The overall volume of material in the container should not exceed 125 ml to permit proper temperature adjustment of the sample.

9.3.1 Specially made needles for such determination shall meet all the requirements of Section 6.2 for dimensions and weight except that the minimum exposed length of the needle shall be 50 mm.

9.3.2 An approximation of the penetration of such high penetration materials may also be obtained by determining the penetration using the standard needle and 6 oz container but with a 50 g loading. The penetration is then calculated by multiplying the result for the 50 g load by the square root of 2. That is:

Penetration under 100g load = (Penetration under 50g load) x 1.414

The report of results obtained by this procedure shall indicate the basis of the test.

10. REPORT

10.1 Report to the nearest whole unit the average of at least three penetrations whose values do not differ by more than the amount shown:

Table 2: Limit of penetration values for different penetration range.

Penetration	0-49	50-149	150-249	≥ 250
Maximum difference between highest and lowest determinations	2	4	6	8

10.1.1 If the appropriate tolerance is exceeded, ignore all results and repeat the test.

11. PRECISION

11.1 Repeatability- Two results obtained by the same operator on the same

	Standard Deviation Within Laboratory	Standard Deviation Between Laboratory
Asphalt at 25^0C (77^0F) below 50 penetration	0.35 units	1.4 units
Asphalt at 25^0C (77^0F) 50 penetration and above	1.1 percent of their mean	2.8 percent of their mean
Tar pitches at 25^0C (77^0F)	5.2 percent of their mean	1.4 units

Sample in the same apparatus, and on different days should be considered suspect if they differby more than the following amounts:

Asphalt at 25^0C (77^0F) below 50 penetration	1 units
Asphalt at 25^0C (77^0F) 50 penetration and above	3 percent of their mean
Tar pitches at 25^0C (77^0F)	15 percent of their mean

For pitches estimates of precision are based on results from 2 pitches with penetration of 7 and24 estimates may not be applicable to appreciably harder or softer materials

11.2 Reproducibility- Two results obtained by different operators in different laboratories ondifferent days should be considered suspect if they differ by more than the following amounts:

Asphalt at 25^0C (77^0F) below 50 penetration	4 units
Asphalt at 25^0C (77^0F) 50 penetration and above	8 percent of their mean
Tar pitches at 25^0C (77^0F)	4 units*

NOTE: 9- Values show above was obtained by multiplying the estimates of the following population standard deviation (0'p) by 2 v 2.

These estimates of precision are based on the following data (see table entitled "Estimates of Precision"):

	Asphalt at below 50 penetration	Asphalt 50 penetration and above	Tar pitches
Samples	2	7	2
Laboratories	16	27	19
Replicates per sample	3	3	3
Degrees of freedom:			
Within laboratories	32	185	38
Between laboratories	14	89	17

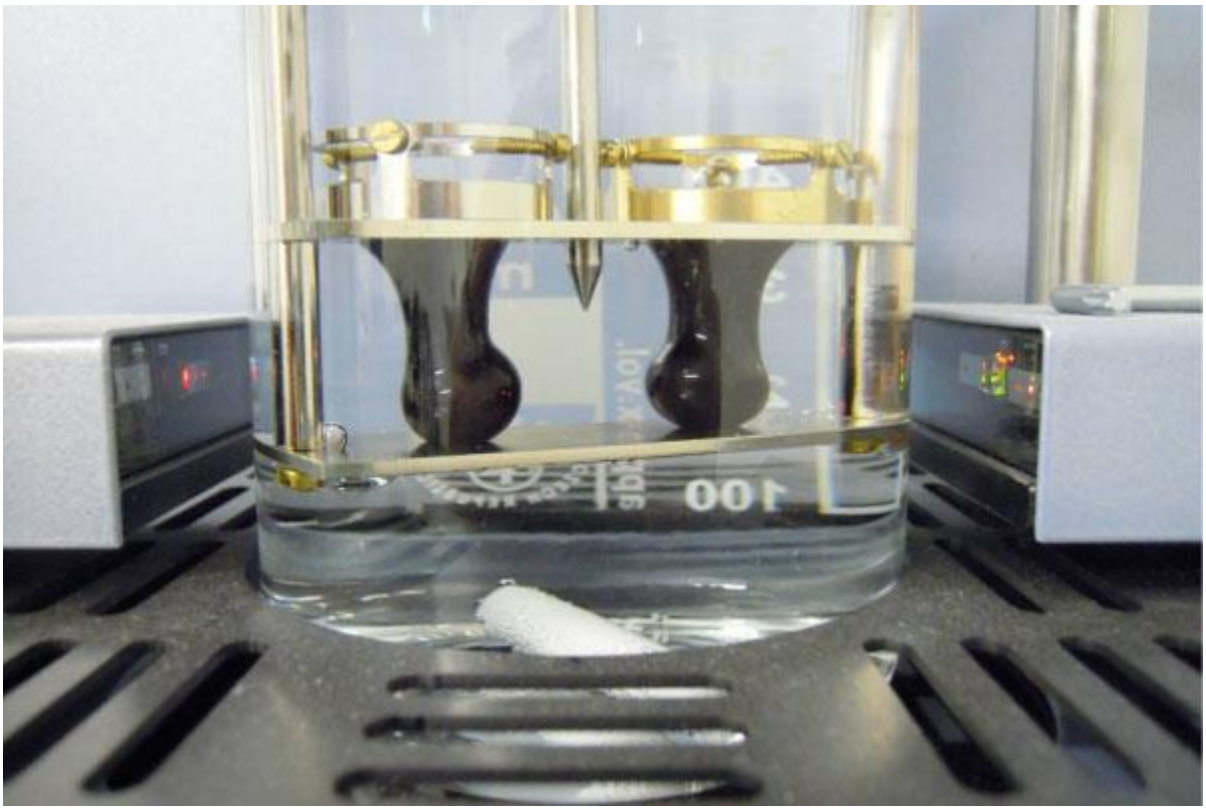
* For definitions of terms and recommended used of precision indexes see ASTM RecommendedPractice E77, for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material.

EXPERIMENT NO: 12

SOFTENING POINT OF BITUMINOUS MATERIAL

(RING AND BALL METHOD)

AASHTO DESIGNATION: T 53-92
(ASTM DESIGNATION: D 36-89)



1. SCOPE

1.1 The ring and ball softening point is extensively used to evaluate the consistency of bituminous binders. It is a very simple one, consisting of placing a 3/8 in diameter steel ball on a binder sample placed in a steel ring and immersed in a water bath. Heat is applied to the water and its temperature is raised until a value is reached when the test sample has become sufficiently soft to allow the ball, enveloped in binder to fall down. The water temperature at which this occurs is called the ring and ball softening point.

The softening point is not a melting point; bituminous binders do not melt but instead gradually change from semi-solids to liquids on the application of heat. It is useful for determining the temperature susceptibilities of bitumen which are to be used in thick films, such as in crack fillers. When two bitumen have the same penetration value, the one with the higher softening point is normally less susceptible to temperature changes.

2. REFERENCED DOCUMENTS

2.1 Standards

C 670 Practices for Preparing Precision Statements for Test Methods for Construction materials

E 1 Specification for ASTM Thermometers

T 40 Methods of Sampling Bituminous Materials

T 48 Test Method for Flash and Fire Points by Cleveland Open cup

3. APPARATUS AND MATERIALS

3.1 Ring- A brass ring of 15.875 mm (5/8 in) inside diameter, 6.35 mm (1/4 in) depth and thickness of wall is 2.38 mm (3/32 in). This ring shall be attached in a convenient manner to a brass with (diameter 1.85 mm = 0.072 in).

3.2 Ball - A steel ball 9.53 mm (3/8 in) in diameter having a mass of 3.50 ± 0.05 g.

3.3 Container - A glass vessel, not less than 8.5 cm (3.34 in) in diameter and measuring 10.5 cm (4.13 in.) in depth from the bottom of the flare (a 600 ml beaker, low form, meets this requirement).



Figure 12.1 Ring and Ball apparatus

3.4 Thermometer - ASTM Low Softening point Thermometer having a range of -2 to +80°C or 30°to 180°Fis specified.

4. REAGENTS AND MATERIALS

4.1 Bath liquids:
4.1.1 Freshly boiled distilled water.
4.1.2 USP Glycerin, or
4.1.3 Ethyl Glycol, with a boiling point between 195 and 197°C (383 and 387°F).

5. PREPARATION OF SAMPLE

Melt and thoroughly stir the sample avoiding incorporating air bubbles in the mass and then pour it into the ring. The ring, while being filled, should rest on a brass plate which has been amalgamated to prevent the bituminous material from adhering to it. Allow the excess material to cool for 1 hr then cut it off cleanly with a slightly heated knife.

6. PROCEDURE FOR MATERIALS HAVING SOFTENING POINTS 80^0C (176^0F) OR BELOW

6.1 Fill the glass vessel to a depth of substantially 8.25 cm (3.25 in) with freshly boiled, distilled water at 5°C (41°F).

6.2 Suspend the ring containing the sample in the water so that the lower surface of the filled ring is exactly 2.54 cm (1 in) above the bottom of the glass vessel and its upper surface is 5.08 cm (2 in) below the surface of the water.

6.3 Place the ball in the water but not on the specimen.

6.4 Suspend the thermometer so that the bottom of the bulb is level with the bottom of the ring and within 0.635 cm (3/4 in) but not touching the ring. Maintain the temperature of the water at 5°C (41°F) for 15 min.

6.5 With suitable force, place the ball in the center of the upper surface of the bitumen in the ring, thus completing the assembly.

6.6 Apply the heat in such a manner that the temperature of the water is raised 5°C (9°F) each minute.

7. SOFTENING POINT

Report the temperature recorded by the thermometer at the instant the bituminous material touches the bottom of the glass vessel as the softening point. No correction shall be made for emergent stem of the thermometer.

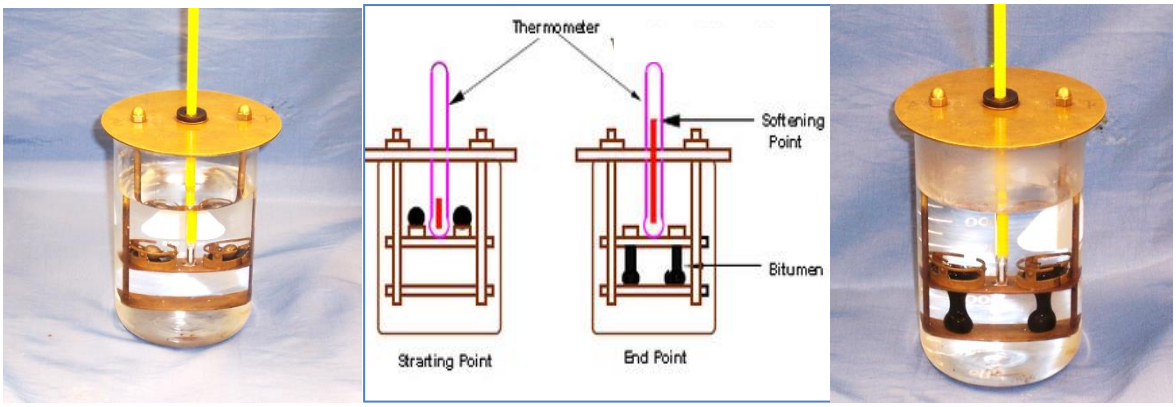


Figure 12.2 Illustration of softening point

8. PERMISSIBLE VARIATION IN RISE OF TEMPERATURE

The rate of rise of temperature shall be uniform and shall not be averaged over the period of the test. The maximum permissible variation for any minute period after the first three minutes shall be 0.5°C (0.9°F). All tests in which the rate of rise in temperature exceeds these limits shall be rejected.

9. PROCEDURE FOR MATERIALS HAVING SOFTENING POINTS ABOVE 80^0C (176^0F)

Thermometer- An ASTM high softening point Thermometer having a range of 30 to 200°C or 85 to 392°F is specified Modifications for Hard Materials.

Employ the same procedure as described above except that U.S.P., Glycerin shall be used instead of water, and the starting point of the Glycerin bath shall be 32°C (89.6°F). Bring the bath to this temperature and thoroughly agitate it, then place the apparatus and specimens in the bath, which shall be maintained, under agitation at the starting temperature for 15 min. In applying the heat, place the ring apparatus of the center of the container and place the burner midway between the center and edge of the beaker away from the specimen.

10. PRECAUTIONS

10.1 The use of freshly boiled distilled water is essential as otherwise air bubbles may form on the specimen and affect the accuracy of the results. Rigid adherence to the prescribed rate of heating is absolutely essential in order to secure accuracy of results.

A sheet of paper placed on the bottom of the glass vessel and conveniently weighted will prevent the bituminous material from sticking to the glass vessel, thereby saving considerable time and trouble in cleaning.

11. ACCURACY

The limit of accuracy of the test is 0.5°C (0.9°F).

EXPERIMENT NO: 13

SOLUBILITY OF BITUMINOUS MATERIAL

AASHTO DESIGNATION: T 44-93
(ASTM DESIGNATION: D 2042-81)



1. SCOPE

1.1 This method covers the determination of the degree of solubility in trichloroethylene or 1, 1, 1 trichloroethylene of asphalt minerals having little or no mineral matter.

2. SUMMARY OF METHOD

2.1 The sample is dissolved in trichloroethylene or 1, 1, 1 trichloroethylene and filtered through a filter mat. The insoluble material is washed, dried, and weighed.

3. SIGNIFICANCE AND USE

3.1 This method is a measure of the solubility of asphalt in trichloroethylene or 1, 1, 1 trichloroethylene. The portion that is soluble in trichloroethylene or 1, 1, 1 trichloroethylene represents the active cementing constituents.

4. APPARATUS AND MATERIALS

4.1 The assembly of the filtering apparatus is illustrated in Figure 13.1. Details of the component parts are as follows:

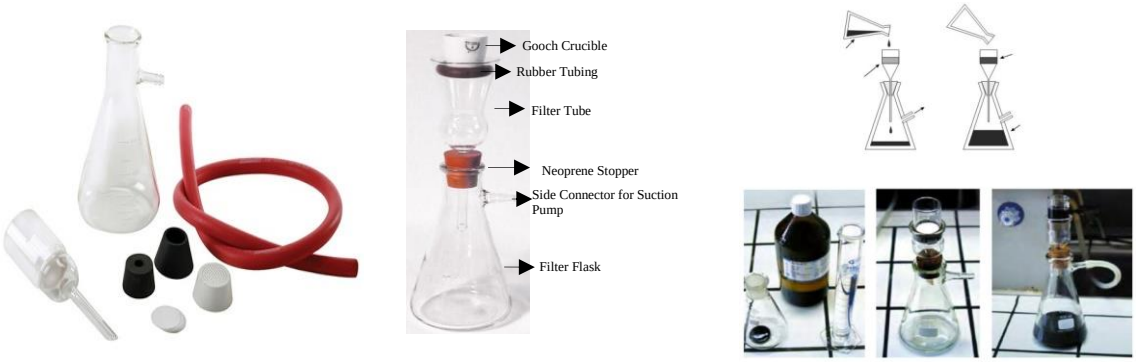


Figure 13.1: Component parts of the filtering apparatus

4.1.1 Gooch Crucible, glazed inside and outside with the exception of outside bottom surface. The approximate dimensions shall be a diameter of 44 mm at top, tapering to 36 mm at bottom and a depth of 28 mm.

4.1.2 Glass Fiber Pad of 3.7 cm in diameter.

4.1.3 Filter Flask, heavy-wall, with side tube, 250 ml, capacity or larger.

4.1.4 Filter Tube, 40 to 42 mm inside diameter.

4.1.5 Rubber Tubing or Adapter, for holding the Gooch crucible on the filter tube.

NOTE 1- Other suitable assemblies permitting vacuum filtration with a Gooch crucible may be used.

4.2 Erlenmeyer Flask, 125 ml, or other suitable container.

4.3 Oven, capable of maintaining a temperature or 110±5°C (230 ± 9°F).

4.4Desiccator, of suitable size, charged with an effective desiccant.

4.5 Analytical Balance, class A conforming to the requirements of an AASHTO Specification M 231.

5. SOLVENT

5.1 Technical grade, Type 1, Trichloroethylene or technical grade 1,1,1 trichloroethylene.

6. SAFETY PRECAUTIONS

6.1 "Trichloroethylene or 1,1,1 trichloroethylene are toxic material and strict adherence to instructions in Material Safety Data Sheets are to be followed". Caution: Trichloroethylene or 1,1,1 trichloroethylene in the presence of heat and moisture may form acids that are extremely corrosive.

7. PREPARATION OF GOOCH CRUCIBLE

7.1 Assemble the filtering apparatus. Place filter pad into the gooch crucible, moisten the pad with solvent and seat firmly in the bottom of the crucible with light suction. Place in an oven at 110 ± 5°C (230 ± 9° F) for at least 20 minutes, cool in desiccator and weigh to the nearest 0.1 mg. Repeat the drying and weighing until constant mass (± 0.3 mg) is obtained. Store in a desiccator until ready for use.

8. SAMPLE PREPARATION

8.1 If the sample is not fluid, heat to any convenient temperature, but in any case, not more than 100°C or 180°F above the softening point.

9. PROCEDURE

9.1 Note safety precautions in Section 6. Transfer approximately 2 g of the sample into a tared 25 ml Erlenmeyer flask or another suitable container. Allow the container and its contents to cool to ambient temperatures and weigh to the nearest 1 mg. Add 100 ml of the trichloroethylene or 1,1,1 trichloroethylene to the container in small portions with continuous agitation until all lumps disappear and no undissolved sample adhere to the container. Stopper the flask or otherwise cover the container and set aside for at least 15 minutes.

Normally the temperature at which this test is run is not critical and it may be performed at the laboratory air temperature. For referee tests, however, the flask and sample in solution shall be placed in a water bath maintained at 37.8 ± 0.25°C (100 ± 0.5°F), for 1 hour before filtering.

9.2 Place the previously prepared and weighed Gooch crucible in the filtering tube.

Wet the filter pad with a small portion of clean solvent and decant the solution through the filter pad of the crucible with light suction.

When the insoluble matter is appreciable, retain as much of it as possible in the container until the solution has drained through the filter pad. Wash the container with a small amount of solvent and, using a stream of solvent from a wash bottle, transfer all insoluble matter to the crucible. Use a "policeman" if necessary to remove any insoluble matter adhering to the container, rinse the policeman and the container, thoroughly wash the insoluble matter in the crucible with solvent until the filtrate is substantially colorless, and then apply strong suction to remove the remaining solvent. Remove the crucible from the tube and wash the bottom free of any dissolved matter. Place in an oven at 110 ± 5°C (230 ± 9°F), for at least 20 min. Cool in a desiccator and weigh to the nearest 0.1 mg. Repeat the drying and weighing until constant weight (± 0.3 mg) is obtained. Fiber glass filter pads should be used only one time.

10. CALCULATIONS AND REPORT

10.1 Calculate either the total percentage of insoluble matter or the percentage of the sample soluble in the solvent used as follows:

Insoluble, percent = A/B x 100

Soluble, percent = 100 - (A/B x 100)

where,
A = total weight insoluble, and
B = total weight of sample.

10.1.1 For percentage of insoluble less than 1.0, report to the nearest 0.01 percent; for percentage of insoluble 1.0 or more report to the nearest 0.1 percent.

11. PRECISION

11.1 estimates of standard deviation for this procedure and the criteria for judging the acceptability of results (95 percent confidence level) are indicated in the table entitled "Standard Deviations".

The estimates of standard deviation are based on the following:

	Asphalts
Materials	4
Replications	3
Solvents	4
Laboratories	26
Degree of freedom:	
within-laboratory	159
between Laboratory variability	81
Standard deviation (S) of data:	
within-laboratory variability	0.035
between laboratory variability	0.090

EXPERIMENT NO: 14

DUCTILITY OF BITUMINOUS MATERIAL

AASHTO DESIGNATION: T 51-93
(ASTM DESIGNATION: D 113-79)



1. SCOPE

1.1 The ductility of a bituminous material is measured by the distance to which it will elongated before breaking when two ends of a briquette specimen of the material, of the form describe in Section 2, are pulled apart at a specified speed and at a specified temperature. Unless otherwise specified, the test shall be made at a temperature of 77°±0.9°F (25°±0.5°C) and with a speed of 5 cm/min, + 5.0 percent. At other temperatures the speed should be specified.

2. APPARATUS

2.1 Mould - the mould shall be similar in design to that shown in Figure 14.1. Dimensions shown Figure 1 shall be as given with the permissible variations indicated. The mould shall be made of brass, the ends b and b' being known as clips, and the parts a and a' as sides of the mould. The dimensions of the mould shall be such that, when properly assembled, it will form a briquette specimen having the following dimensions:

Table 14.1: Dimensions of Ductility Test apparatus.

Total length	7.45 to 7.55 cm
Distance between clips	2.97 to 3.03 cm
Width at mouth of clip	1.98 to 2.02 cm
Width at minimum cross section (halfway between clips)	0.99 to 1.01 cm
Thickness throughout	0.99 to 1.01 cm

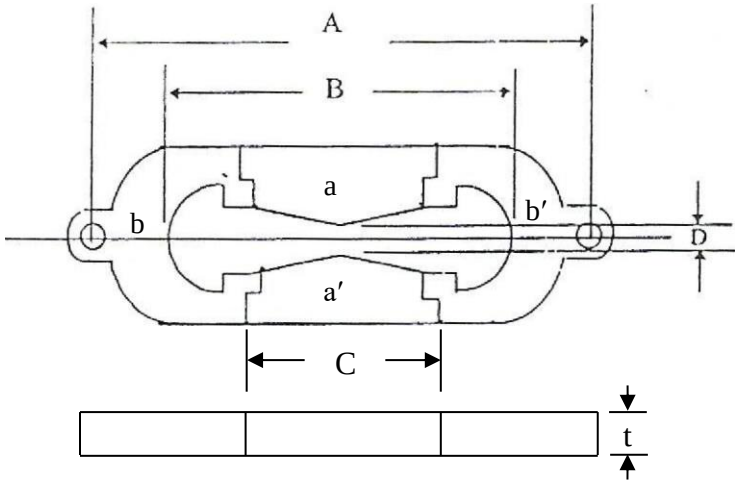


Figure 14.1 Mold for Ductility Test Specimen

Table 14.2: Dimensions of different parts of Ductility Test apparatus shown in Figure 14.1.

A	Distance between centers	111.5 to 113.5 mm
B	Total length of briquette	74.5 to 75.5 mm
D	Width at minimum cross section	9.9 to 10.1 mm
t	Thickness	9.9 to 10.1 mm

2.2 Water Bath - The water bath shall be maintained at the specified test temperature, varying not more than 0.18°F (0.1°C) from this temperature. They volume of water shall be not less than 10 liters, and the specimen shall be immersed to a depth of not less than 10 cm and shall be supported on a perforated shelf not less than 5 cm from the bottom of the bath.

2.3 Testing Machine - For pulling the briquette of bituminous material apart, any apparatus may be used which is so constructed that the specimen will be continuously immersed in water as specified in Section 3.3, while the two clips are pulled apart at a uniform speed, as specified, without under vibration. Figure 14.2 shows the ductility testing machine.



Figure 2: Ductility Testing Machine

2.4 Thermometer - A thermometer having a range as shown below and conforming to the requirements prescribed in Specification E1 for Standard Thermometer.

Table 14.3: Specifics of Standard Thermometer for Ductility Test.

Temperature Range	ASTM Thermometer No
-8 to 32°C	63°C
18 to 89°F	63°F

3. PROCEDURE

3.1 Molding Test Specimen - Heat the sample with care to prevent local overheating until it has become sufficiently fluid to pour. Strain the melted sample through a No. 50 sieve conforming to ASTM Specification E11, for Wire cloth Sieves for Testing Purposes, and, after a thorough stirring

pour it into the mold. Assemble the mold on a brass plate and, to prevent the material under test from sticking, thoroughly amalgamate the surface of the plate and interior surface of the sides a and a', Figure 1, of the mold or coat with a mixture of glycerin and dextrin, tale, or china clay. The plate upon which the mold is placed shall be perfectly flat and level so that the bottom surface of the mold will touch it throughout. In filling the mold, take care not to disarrange the parts and thus distort the briquette. In filling, pour the material in a thin stream back and forth from end to end of the mold until the mold is more than level full. Let the mold containing the material cool to room temperature or a period of from 30 to 40 min and then place it in the water bath maintained at the specified temperature of test for 30 min; then cut off the excess bitumen with a hot straight edged putty knife or spatula to make the mold just level full as shown in Figure 14.3.



Figure 14.3: Molding and Cutting of Test Specimen

3.1.1 Caution - Careless handling of mercury will create a definite health hazard. The rules prescribed as follows should be observed at all times:

1. Store the mercury in a closed jug in a cool place.
2. Strictly avoid spilling any mercury.
3. Remove mercury vapors by working under a ventilated hood.
4. Keep amalgamated brass plates and other apparatus at no higher than normal room temperature.

3.2 Keeping Specimen at Standard Temperature - Place the brass plate and mold, with briquette specimen, in the water bath and keep at the specified temperature for a period of from 85 to 95 min. Then remove the briquette from plate, detach the side pieces, and immediately test the briquette.

3.3 Testing - Attach the rings at each end of the clips to the pins or hooks in the testing machine and pull the two clips apart at a uniform speed as specified until the briquette ruptures as shown in Figure 14.4.

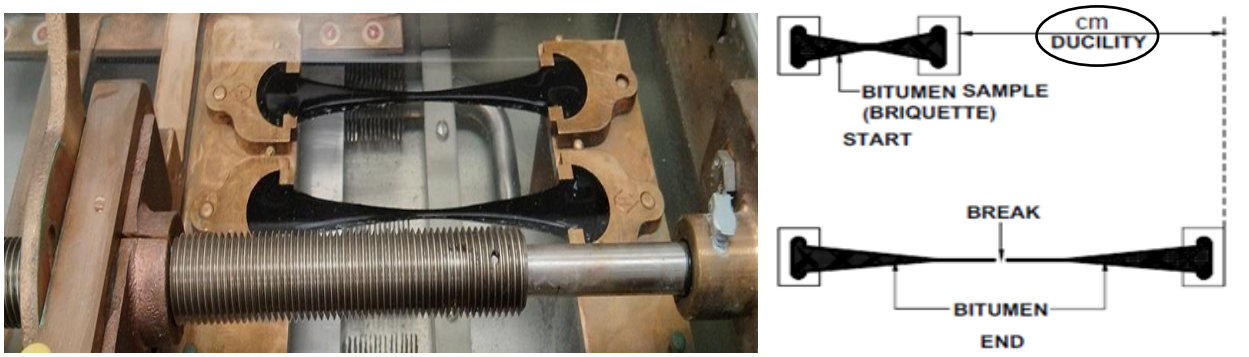


Figure 14.4: Ductility Testing

A variation of + 5 percent from the speed specified will be permissible. Measure the distance in centimeters through which the clips have been pulled to produce rupture. While the test is being made, the water in the tank of the testing machine shall cover the specimen both above and below it by at least 2.5 cm and shall be kept continuously at the temperature specified within +0.9°F (0.5°C).

4. REPORT

4.1 A normal test is one in which the material between the clips pulls out to a point or thread until rupture occurs at the point where the thread has practically no cross-sectional area. Report the average of three normal tests as the ductility of the sample.

4.2 If the bituminous material comes in contact with the surface of the water or the bottom of the bath, the test shall not be considered normal. Adjust the specific gravity of the bath by the addition of either methyl alcohol or sodium chloride so that the bituminous material neither comes to the surface of the water, nor touches the bottom of the bath at any time during the test.

4.3 If a normal test not obtainable on three terms, report the ductility as being unobtainable under the conditions of the test.

5. PRECAUTIONS

5.1 Owing to possible danger to health if mercury is handled carelessly, the following rules should be observed at all times:

5.1.1 Store the mercury in a closed jug in a cool place.
5.1.2 Strictly avoid spilling any mercury.
5.1.3 Remove mercury vapors by working under a suitable hood with good ventilation.
5.1.4 Keep amalgamated brass plates and other apparatus at not above normal room temperature.

EXPERIMENT NO: 15

FLASH AND FIRE POINTS OF BITUMINOUS MATERIAL (CLEVELAND OPEN CUP METHOD)

AASHTO DESIGNATION: T 48-91
(ASTM DESIGNATION: D 92-85)



1. SCOPE AND SIGNIFICANCE

This method describes a test procedure for determining the flash and fire points (Cleveland Open Cup Tester) of all petroleum products except fuel oils and those having an open cup flash below 175^0F. The flash point is the temperature at which a bituminous material, during heating, will evolve vapors that will temporarily ignites or flash when a small flame is brought in contact with them. The fire point is the temperature at which the evolved vapors will ignite and continue to burn.

To make the test, the material is heated in an open cup, and at intervals a small flame is applied near its surface. The lowest temperature at which application of the test flame causes the vapors to ignite is recorded as the flash point while the temperature at which the vapors ignited and burn for at least 5 seconds is recorded as the fire point. The flash and fire point test is purely a safety test. It indicates the maximum temperature to which the material can be safely heated.

NOTE 1- It is the practice in the United Kingdom and in any other countries to use IP Method 35, Flash Point (Open) and Fire Points by Means of the Pensky-Martens Apparatus unless T73. Test flash point by Pensky-Martens Closed Tester is specified. This Method may occasionally be specified for the determination of the fire point of a fuel oil. For the determination of Flash points of fuel oils, use AASHTO T 73 IP 34, T 73 should be used when it is desired to determine the possible presence of small but significant concentrations of lower flash points substances which may escape detection by T 48. T79, Flash Point with Tag Open Cup Apparatus, may be employed if the flash point is below 79°C (175^0F) as determined by T 48.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards:

T 73 Flash Point by Pensky-Martens Closed Tester

T 79 Flash Point with Tag Open-Cup Tester

2.2 ASTM Standards:

E 1 Specification for ASTM Thermometers

2.3 Other Methods:

IP Method 35 Flash Point (Open) and Fire Point by Means of the pensky-Martens Apparatus.

3. APPARATUS AND MATERIALS

3.1 Cleveland Open Tester - The apparatus consists of the test cup, heating plate, test flame applicator, heater, and support as shown in Figure 15.1.



Figure 15.1: Cleveland Open Cup Tester

3.2 Shield - A shield 18 inch (46 cm) square and 24 in, (61 cm) high, is recommended but not essential.

3.3 Thermometer - ASTM thermometer having a range of 20^0F to 760^0F (-6˚C to + 400˚C).

4. PROCEDURE

4.1 Support the tester on a level steady table in a draft free room or compartment and shield the spot of the tester from strong light by any suitable means.

4.2 Clean the cup with an appropriate solvent and remove all gums, carbon deposit, and oxide coating from the inside of the cup with fine steel wool until a bright metallic surface is presented.

4.3 Support the thermometer in a vertical position with the bottom of the bulb 1/4 inch (0.635 cm) from the bottom of the cup and above a point halfway between the center and back of the cup.
Note 2- The immersion line engraved on the thermometer will be 5/64 inch (0.20 cm) below level of the rim of the cup when the thermometer is properly positioned.

4.4 Fill the cup at any convenient temperature (Note 3) so that the top of the meniscus is exactly at the filling line. When too much sample has been added to the cup, remove the excess, using a spoon or other suitable device; however, if there is sample on the outside of the apparatus, empty, clean. Destroy any air bubbles appear on the surface of the sample.

Note 3- Viscous samples should be heated until they are reasonably fluid before being poured in to the cup; however, the temperature during heating must not exceed 100°F (65°C) below the probable flash point.

4.5 Light the test flame and adjust it to a diameter of 1/8 to 3/16 in. (0.08 cm).

4.6 Apply heat initially so that the rate of temperature rise of the sample is 25 to 30^0F (13.9 to 16.7°C) per minute. When the sample temperature is approximately 100°F (56^0C) below the anticipated flash point, decrease the heat so that the rate of temperature rises for the last 50^0F (27.8°C) before the flash point is 10 + 1°F (5.5 + 0.6°C) per minute.

4.7 Starting at least 50°F (2.8°C) mark pass the test flame across the center of the cup, at right angles to the diameter which passes through the thermometer. With a smooth, continuous motion apply the flame either in a straight line or along the circumference of a circle having a radius of at least 6 inch (15 cm). The center of the test flame must move in a plane not more than 5/6" inch (0.2 cm) above the plane of the upper edge of the cup. The time consumed in passing the test flame across the cup shall be about 1 sec.

4.8 Record as the flash point the temperature read on the thermometer when a flash appears at any point on the surface of the sample but do not confuse the true flash with the bluish halo that sometimes surrounds the test flame.

4.9 To determine the fire point, continue heating so that the sample temperature increases at rate of 10 ± 1°F (5.5± 0.6^0C) per minute. Continue the application of the test flame at 5^0F (2.8°C) intervals until the vapor ignites and continues to burn for at least 5 sec. Record the temperature at this point as the fire point.

5. CALCULATION AND REPORT

5.1 Observe and record the barometric pressure at the time of the test. When the pressure differs from 760 mm Hg, correct the flash or fire point, or both, by means of the following equations:

- Corrected flash or fire point, or both = F + 0.06(760-P) or
- Corrected flash or fire point, or both = C + 0.03(760-P)

Where:

F = observed flash or fire point, or both, to the nearest 5°F
C = observed flash or fire point, or both, to the nearest 2°C.
P = barometric pressure, mm Hg.

EXPERIMENT NO: 16

STANDARD TEST METHOD FOR CBR (CALIFORNIA BEARING RATIO) OF LABORATORY COMPACTED SOILS[1]

(ASTM DESIGNATION: D 1883-99)



1. SCOPE

1.1 This test method covers the determination of the CBR (California Bearing Ratio) of pavement sub-grade, sub-base and base/course materials from laboratory compacted specimens. The test method is primarily intended for but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than ¾ inch (19 mm).

NOTE 1 The agency performing this test can be evaluated in accordance with Practice D 3740. Notwithstanding statements on precision and bias contained in this Standard: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies which meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Users of this method are cautioned that compliance with Practice D 3740 does not in itself assure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means of evaluating some of those factors.

1.2 When materials having maximum particle sizes greater than ¾ inch (19 mm) are to be tested, this test method provides for modifying the gradation of the material so that the material used for tests all passes the ¾ inch sieve while the total gravel (No. 4 to 3 in.) fraction remains the same. While traditionally this method of specimen preparation has been used to avoid the error inherent in testing materials containing large particles in the CBR test apparatus, the modified material may have significantly different strength properties than the original material. However, a large experience base has developed using this test method for materials for which the gradation has been modified, and satisfactory design methods are in use based on the results of tests using this procedure.

1.3 Past practice has shown that CBR results for those materials having substantial percentages of particles retained on the No. 4 sieve are more variable than for finer materials. Consequently, more trials may be required for these materials to establish a reliable CBR.

1.4 This test method provides for the determination of the CBR of a material at optimum water content or a range of water content from a specified compaction test and a specified dry unit weight. The dry unit weight is usually given as a percentage of maximum dry unit weight from the compaction tests of Test Methods D 698 or D 1557.

1.5 The agency requesting the test shall specify the water content or range of water content and the dry unit weight for which the CBR is desired.

1.6 Unless specified otherwise by the requesting agency, or unless it has been shown to have no effect on test results for the material being tested, all specimens shall be soaked prior to penetration.

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests. Current edition approved Feb. 10, 1999. Published May 1999; Originally published as D 1883-61T; Last previous edition D 1883-94.

1.7 For the determination of CBR of field compacted materials, see Test Method D 4429.

1.8 The values stated in inch-pound units are to be regarded as the standard. The SI equivalents shown in parentheses may be approximate.

1.9 This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:

D 422 Test Method for Particle-Size Analysis of Soils[2]
D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]
D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 KN-m/m^3))[2]
D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 KN-m/m^3))[2]
D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[2]
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[2]
D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[2]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]
D 3740 Practice for Minimum Requirements of Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[2]
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[2]
D 4429 Test Method for CBR (California Bearing Ratios) of Soils in Place[2]

3. SUMMARY OF TEST METHOD

3.1 For tests performed on materials compacted to one water content, three specimens are prepared. The specimens are compacted using three different compaction efforts to obtain unit weights both above and below the desired unit weight. After allowing specimens to take on water by soaking, or other specified treatment such as curing, each specimen is subjected to penetration by a cylindrical rod. Results of stress (load) versus penetration depth are plotted to determine the CBR for each specimen. The CBR at the specified density is determined from a graph of CBR versus dry unit weight.

[2]Annual Book of ASTM Standards, Vol 04.08.

3.2 For tests in which the result is to be determined for a water content range, a series of specimens at each of three compaction efforts are prepared over the range of water content of interest. The compaction efforts are chosen to produce unit weights above and below the desired unit weight. After allowing the specimens to take on water by soaking, or other specified treatment such as curing, each specimen is penetrated. Results are plotted to obtain the CBR for each specimen. A plot of CBR versus unit weight for each water content is made to determine the minimum CBR for the water content range of interest.

4. SIGNIFICANCE AND USE

4.1 This test method is used to evaluate the potential strength of subgrade, subbase, and base course material, including recycled materials for use in road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods.

4.2 For applications where the effect of compaction water content on CBR is small, such as cohesion less, coarse grained materials, or where an allowance is made for the effect of differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort. The dry unit weight specified is normally the minimum percent compaction allowed by the using agency's field compaction specification.

4.3 For applications where the effect of compaction water content on CBR is unknown or where it is desired to account for its effect, the CBR is determined for a range of water content, usually the range of water content permitted for field compaction by using agency's field compaction specification.

4.4 The criteria for test specimen preparation of self-cementing (and other) materials which gain strength with time must be based on a geotechnical engineering evaluation. As directed by the engineer, self-cementing materials shall be properly cured until bearing ratios representing long term service conditions can be measured.

5. APPARATUS

5.1 Loading Machine: The loading machine shall be equipped with a movable head or base that travels at a uniform (not pulsating) rate of 0.05 in. (1.27 mm)/min for use in forcing the penetration piston into the specimen. The machine shall be equipped with a load indicating device that can be read to 10 lbf (44 N) or less. The minimum capacity of the loading machine shall be based on the requirements indicated in Table 16.1.

Table 16.1: Minimum Load Capacity

Maximum Measurable CBR	Minimum Load Capacity	
	lbf	KN
20	2500	11.2
50	5000	22.3
>50	10000	44.5

5.2 Mold: The mold shall be a rigid metal cylinder with an inside diameter of 6 ± 0.026 inch (152.4 ± 0.66 mm) and a height of 7 ± 0.018 inch (177.8 ± 0.46 mm). It shall be provided with a metal extension collar at least 2.0 inch (50.8 mm) in height and a metal base plate having at least twenty eight $\frac{1}{16}$inch (1.59 mm) diameter holes uniformly spaced over the plate within the inside circumference of the mold. When assembled with spacer disc in place in the bottom of the mold, the mold shall have an internal volume (excluding extension collar) of 0.075 ± 0.0009 ft (2124 ± 25 cm). Figure 1 shows a satisfactory mold design. A calibration procedure should be used to confirm the actual volume of the mold with the spacer disk inserted. Suitable calibrations are contained in Test Methods D 698 and D 1557.

5.3 Spacer Disk: A circular metal spacer disc (see Figure 1) having a minimum outside diameter of $5\frac{15}{16}$inches (150.8 mm) but no greater than will allow the spacer to easily slip into the mold. The spacer disc shall be 2.416 ± 0.005 inch (61.37 ± 0.127 mm) in height.

5.4 Rammer: A rammer as specified in either Test Methods D 698 or D 1557 except that if a mechanical rammer is used it must be equipped with a circular foot, and when so equipped, must provide a means for distributing the rammer blows uniformly over the surface of the soil when compacting in a 6 inch (152.4 mm) diameter mold. The mechanical rammer must be calibrated and adjusted in accordance with Test Methods D 2168.

5.5 Expansion Measuring Apparatus: An adjustable metal stem and perforated metal plate, similar in configuration to that shown in Figure 1. The perforated plate shall be $5\frac{7}{8}$ to $5\frac{15}{16}$ inch (149.23 to 150.81 mm) in diameter and have at least forty two $\frac{1}{16}$ inch (1.59 mm) diameter holes uniformly spaced over the plate. A metal tripod to support the dial gage for measuring the amount of swell during soaking is also required.

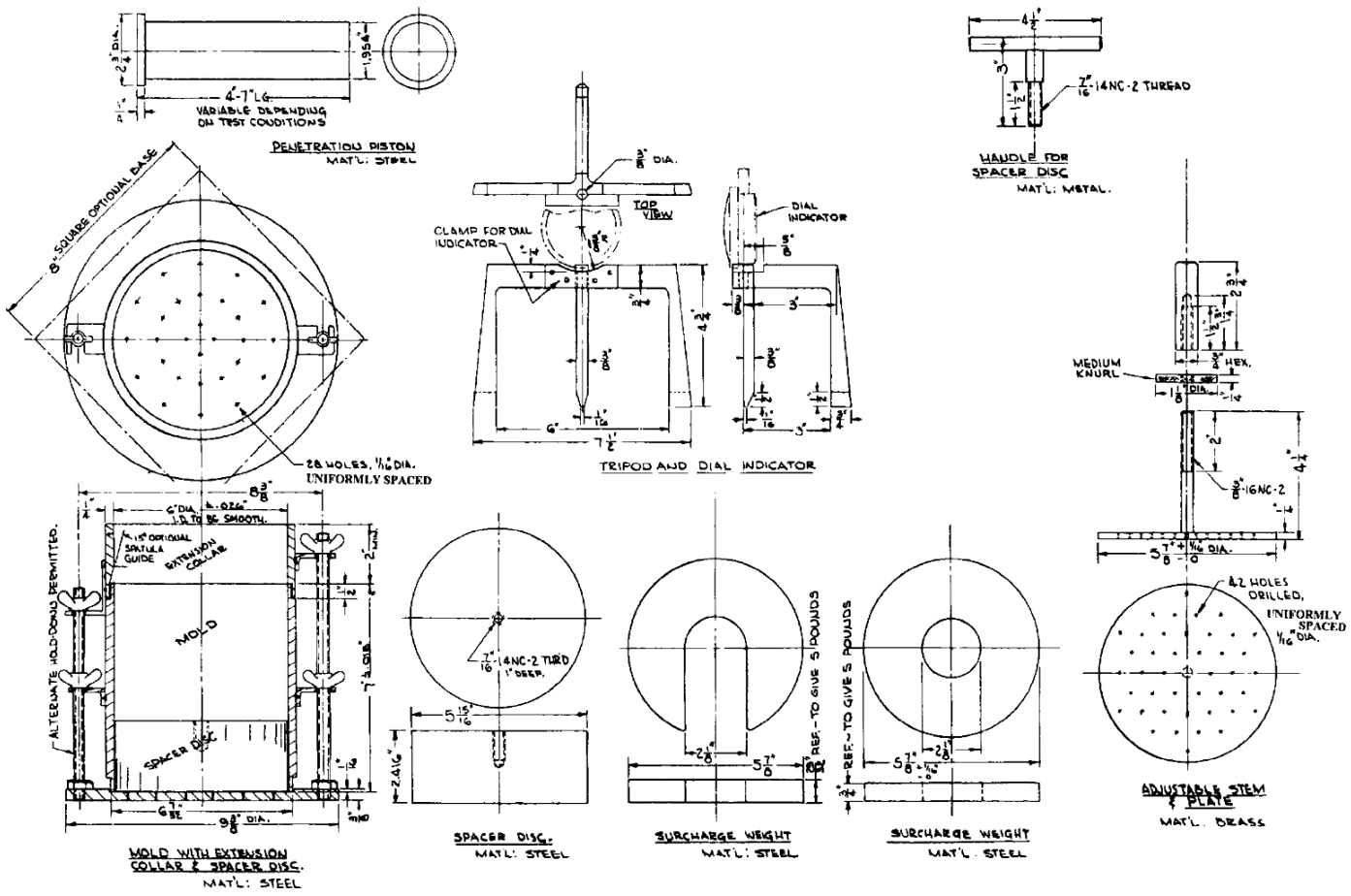


Figure 16.1: Bearing Ratio Test Apparatus (See Table 16.2 for metric equivalents)

5.6 Weights: One or two annular metal weights having a total mass of 4.54 ± 0.02 kg and slotted metal weights each having masses of 2.27 ± 0.02 kg. The annular weight shall be $5\frac{7}{8}$ to $5\frac{15}{16}$inches (149.23 to 150.81 mm) in diameter and shall have a center hole of approximately $2\frac{1}{8}$inch (53.98 mm).

5.7 Penetration Piston: A metal piston 1.954 ± 0.005 inch (49.63 ± 0.13 mm) in diameter and not less than 4 inch (101.6 mm) long (see Figure 16.1). If, from an operational standpoint, it is advantageous to use a piston of greater length, the longer piston may be used.

5.8 Gages: Two dial gages reading to 0.001 inch (0.025 mm) with a range of 0.200 minimum.

5.9 Miscellaneous Apparatus: Other general apparatus such as a mixing bowl, straightedge, scales, soaking tank or pan, oven, fast filtering high wet strength filter paper, dishes, and 2inch, $\frac{3}{4}$inch and No. 4 sieves.

Table 16.2 Metric Equivalents

Inch-Pound Units, in.	Metric Equivalent, mm	Inch-Pound Units, in.	Metric Equivalent, mm	Inch-Pound Units, in.	Metric Equivalent, mm
0.003	0.076	19⁄32	15.08	3 1⁄2	88.90
0.005	0.127	5⁄8	15.88	3 3⁄4	95.25
0.135	3.43	3⁄4	19.10	4 1⁄4	108.0
0.201	5.11	15⁄16	23.81	4 1⁄2	114.3
0.4375	11.11	1	25.40	4 3⁄4	120.7
0.4378	11.12	1 1⁄8	28.58	5 7⁄8	149.2
0.510	12.95	1 1⁄4	31.8	5 15⁄16	150.8
0.633	16.08	1 3⁄8	34.9	6	152.0
1.370	34.60	1 1⁄2	38.10	6 7⁄32	158.0
1.375	34.93	1 3⁄4	44.5	6 1⁄2	165.1
1.954	49.63	1 13⁄16	46.04	7	177.8
2.416	61.37	1 15⁄16	49.21	7 1⁄2	190.1
1⁄16	1.59	2	50.80	8 3⁄8	212.7
7⁄32	5.56	2 1⁄8	53.98	8 1⁄2	215.9
1⁄4	6.35	2 1⁄5	55.9	9 3⁄8	238.1
3⁄8	9.53	2 1⁄4	57.2	14 1⁄4	362.0
7⁄16	11.11	2 1⁄2	63.50	18	457.2
15⁄32	11.91	2 3⁄4	69.85	32 1⁄4	719.2
1⁄2	12.70	2 31⁄32	75.41	36 5⁄8	930.3
17⁄32	13.49	3	76.20	39	990.6

Inch-Pound Units, lb	Metric Equivalent, kg	Inch-Pound Units, psi	Metric Equivalent, MPa
0.04	0.02	200	1.4
0.05	0.02	400	2.8
0.12	0.05	600	4.1
0.59	0.27	800	5.5
0.71	0.32	1000	6.9
0.75	0.34	1200	8.3
3.20	1.45	1400	9.7
5.00	2.27		
10.00	4.54		

6. SAMPLE

6.1 The sample shall be handled and specimen(s) for compaction shall be prepared in accordance with the procedures given in Test Methods D 698 or D 1557 for compaction in a 6 inch (152.4 mm) mold except as follows:

6.1.1 If all material passes a ¾ inch (19 mm) sieve, the entire gradation shall be used for preparing specimens for compaction without modification. If there is material retained on the ¾inch (19 mm) sieve, the material retained on the ¾inch (19 mm) sieve shall be removed and replaced by an equal amount of material passing the ¾inch (19 mm) sieve and retained on the No. 4 sieve obtained by separation from portions of the sample not otherwise used for testing.

7. TEST SPECIMENS

7.1 Bearing Ratio at Optimum Water Content Only: Using material prepared as described in 6.1, conduct a control compaction test with a sufficient number of test specimens to definitely establish the optimum water content for the soil using the compaction method specified, either Test Methods D 698 or D 1557. A previously performed compaction test on the same material may be substituted for the compaction test just described, provided that if the sample contains material retained on the ¾inch (19 mm) sieve, soil prepared as described in 6.1 is used (Note 2).

NOTE 2 Maximum dry unit weight obtained from a compaction test performed in a 4 inch (101.6 mm) diameter mold may be slightly greater than the maximum dry unit weight obtained from compaction in the 6 inch (152.4 mm) compaction mold or CBR mold.

7.1.1 For cases where the CBR is desired at 100 % maximum dry unit weight and optimum water content, compact a specimen using the specified compaction procedure, either Test Methods D 698 or D 1557, from soil prepared to within ±0.5 percentage point of optimum water content in accordance with Test Method D 2216.

7.1.2 Where the CBR is desired at optimum water content and some percentage of maximum dry unit weight, compact three specimens from soil prepared to within ±0.5 percentage point of optimum water content and using the specified compaction but using a different number of blows per layer foreach specimen. The number of blows per layer shall be varied as necessary to prepare specimens having unit weights above and below the desired value. Typically, if the CBR for soil at 95 % of maximum dry unit is desired, specimens compacted using 56, 25, and 10 blows per layer is satisfactory. Penetration shall be performed on each of these specimens.

7.2 Bearing Ratio for a Range of Water Content: Prepare specimens in a manner similar to that described in 7.1 except that each specimen used to develop the compaction curve shall be penetrated. In addition, the complete water content unit weight relation for the 25 blows and 10 blows per layer compactions shall be developed and each test specimen compacted shall be penetrated. Perform all compaction in the CBR mold. In cases where the specified unit weight is at or near 100% maximum dry unit weight, it will be necessary to include a compaction effort greater than 56 blows per layer (Note 3).

NOTE 3 A semi-log log plot of dry unit weight versus compaction effort usually gives a straight-line relation when compaction effort in ft-lb/ft^3 is plotted on the log scale. This type of plot is useful in establishing the compaction effort and number of blows per layer needed to bracket the specified dry unit weight and water content range.

7.2.1 If the sample is to be soaked, take a representative sample of the material, for the determination of moisture, at the beginning of compaction and another sample of the remaining material after compaction. Use Test Method D 2216 to determine the moisture content. If the sample is not to be soaked, take a moisture content sample in accordance with Test Methods D 698 or D 1557 if the average moisture content is desired.

7.2.2 Clamp the mold (with extension collar attached) to the base plate with the hole for the extraction handle facing down. Insert the spacer disk over the base plate and place a disk of filter paper on top of the spacer disk. Compact the soil water mixture into the mold in accordance with 7.1, 7.1.1, or 7.1.2.

7.2.3 Remove the extension collar and carefully trim the compacted soil even with the top of the mold by means of a straightedge. Patch with smaller size material any holes that may have developed in the surface by the removal of coarse material. Remove the perforated base plate and spacer disk, weigh, and record the mass of the mold plus compacted soil. Place a disk of coarse filter paper on the perforated base plate, invert the mold and compacted soil, and clamp the perforated base plate to the mold with compacted soil in contact with the filter paper.

7.2.4 Place the surcharge weights on the perforated plate and adjustable stem assembly and carefully lower onto the compacted soil specimen in the mold. Apply a surcharge equal to the weight of the base material and pavement within 2.27 kg (5 lb), but in no case shall the total weight used be less than 4.54 kg (10 lb). If no pavement weight is specified, use 4.54 kg. Immerse the mold and weights in water allowing free access of water to the top and bottom of the specimen. Take initial measurements for swell and allow the specimen to soak for 96 hr. Maintain a constant water level during this period. A shorter immersion period is permissible for fine grained soils or granular soils that take up moisture readily, if tests show that the shorter period does not affect the results. At the end of 96 hr, take final swell measurements and calculate the swell as a percentage of the initial height of the specimen.

7.2.5 Remove the free water and allow the specimen to drain downward for 15 min. Take care not to disturb the surface of the specimen during the removal of the water. It may be necessary to tilt the specimen in order to remove the surface water. Remove the weights, perforated plate, and filter paper, and determine and record the mass.

8. PROCEDURE FOR BEARING TEST

8.1 Place a surcharge of weights on the specimen sufficient to produce an intensity of loading equal to the weight of the base material. If no pavement weight is specified, use 4.54 kg mass. If the specimen has been soaked previously, the surcharge shall be equal to that used during the soaking period. To prevent upheaval of soil into the hole of the surcharge weights, place the 2.27

kg annular weight on the soil surface prior to seating the penetration piston, after which place the remainder of the surcharge weights.

8.2 Seat the penetration piston with the smallest possible load, but in no case in excess of 10 lbf (44 N). Set both the stress and penetration gages to zero. This initial load is required to ensure satisfactory seating of the piston and shall be considered as the zero load when determining the load penetration relation. Anchor the strain gage to the load measuring device, if possible; in no case attach it to the testing machines support bars (legs).

NOTE 4At high loads the supports may torque and affect the reading of the penetration gage. Checking the depth of piston penetration is one means of checking for erroneous strain indications.

8.3 Apply the load on the penetration piston so that the rate of penetration is approximately 0.05 inch (1.27 mm)/min. Record the load readings at penetrations of 0.025 inch (0.64 mm), 0.050 inch (1.27 mm), 0.075 inch (1.91 mm), 0.100 inch (2.54 mm), 0.125 inch (3.18 mm), 0.150 inch (3.81 mm), 0.175 inch (4.45 mm), 0.200 inch (5.08 mm), 0.300 inch (7.62 mm), 0.400 inch (10.16 mm) and 0.500 inch (12.70 mm). Note the maximum load and penetration if it occurs for a penetration of less than 0.500 inch (12.70 mm). With manually operated loading devices, it may be necessary to take load readings at closer intervals to control the rate of penetration. Measure the depth of piston penetration into the soil by putting a ruler into the indentation and measuring the difference from the top of the soil to the bottom of the indentation. If the depth does not closely match the depth of penetration gage, determine the cause and test a new sample.

8.4 Remove the soil from the mold and determine the moisture content of the top 1 inch (25.4 mm) layer. Take a moisture content sample in accordance with Test Methods D 698 or D 1557 if the average moisture content is desired. Each moisture content sample shall weigh not less than 100 g for fine grained soils nor less than 500 g for granular soils.

NOTE 5 The load readings at penetrations of over 0.300 inch (7.6 mm) may be omitted if the testing machine's capacity has been reached.

9. CALCULATION

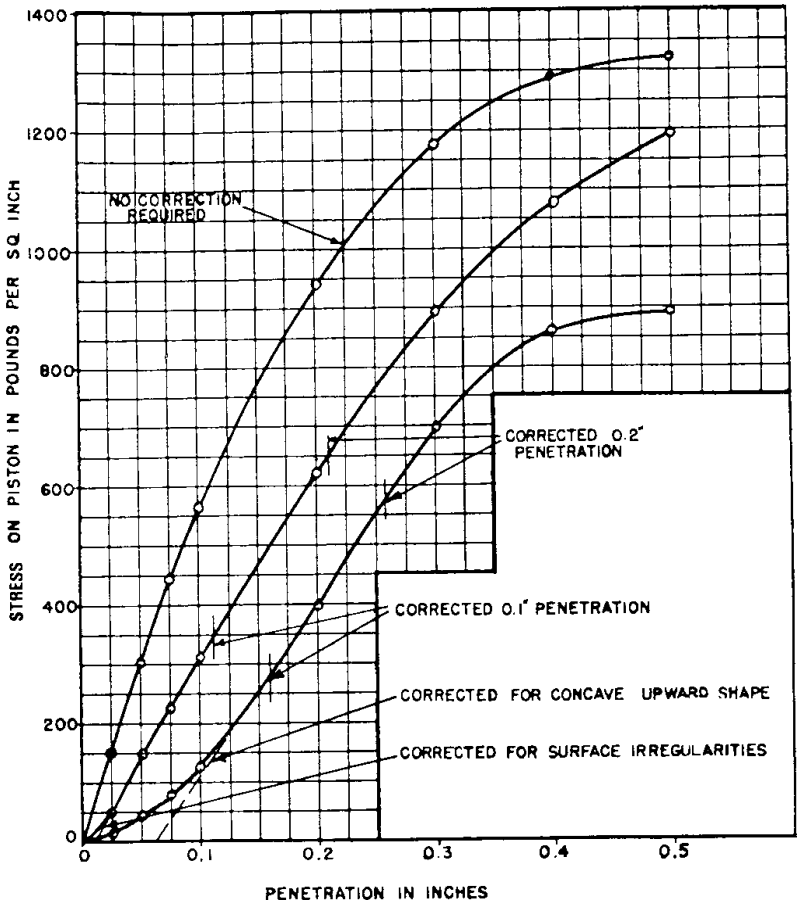
9.1 Load-Penetration Curve: Calculate the penetration stress in pounds per square inch or mega Pascals and plot the stress-penetration curve. In some instances, the stress-penetration curve may be concave upward initially, because of surface irregularities or other causes, and in such cases the zero point shall be adjusted as shown in Figure 16.2.

NOTE 6 Figure 2 should be used as an example of correction of load-penetration curves only. It is not meant to imply that the 0.2 inch penetration is always more than the 0.1 inch penetration.

9.2 Bearing Ratio: Using corrected stress values taken from the stress penetration curve for 0.100 inch (2.54 mm) and 0.200 inch (5.08 mm) penetrations, calculate the bearing ratios for each by

dividing the corrected stresses by the standard stresses of 1000 psi (6.9 MPa) and 1500 psi (10.3 MPa) respectively, and multiplying by 100. Also, calculate the bearing ratios for the maximum stress, if the penetration is less than 0.200 inch (5.08 mm) interpolating the standard stress. The bearing ratio reported for the soil is normally the one at 0.100 inch (2.54 mm) penetration. When the ratio at 0.200 inch (5.08 mm) penetration is greater, rerun the test. If the check test gives a similar result, use the bearing ratio at 0.200 inch (5.08 mm) penetration.

NOTE 7 If bearing ratio values at penetrations of 0.300 inch (7.62 mm), 0.400 inch (10.16 mm) and 0.500 inch (12.7 mm) are desired, the corrected stress values of these penetrations should be divided by the standard stresses of 1900 psi (13.1 MPa), 2300 psi (15.9 MPa), 2600 psi (17.9 MPa), respectively, and multiplied by 100.



NOTE: See Table 2 for metric equivalents

Figure 16.2: Correction of Load-Penetration Curves

9.3 Design CBR for One Water Content Only: Using the data obtained from the three specimens, plot the CBR versus molded dry unit weight relation as illustrated in Figure 3. Determine the design CBR at the percentage of the maximum dry unit weight requested.

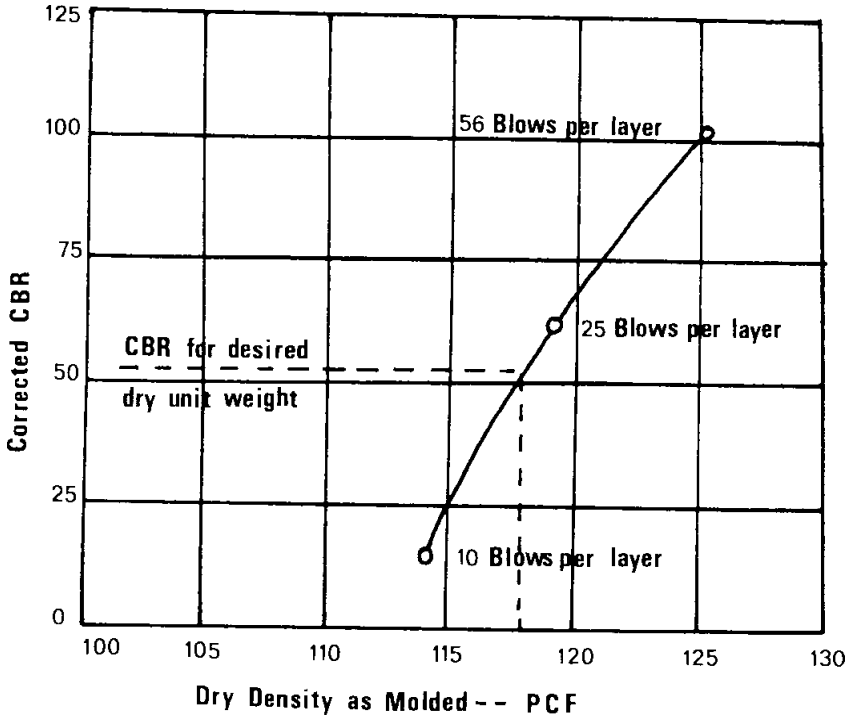
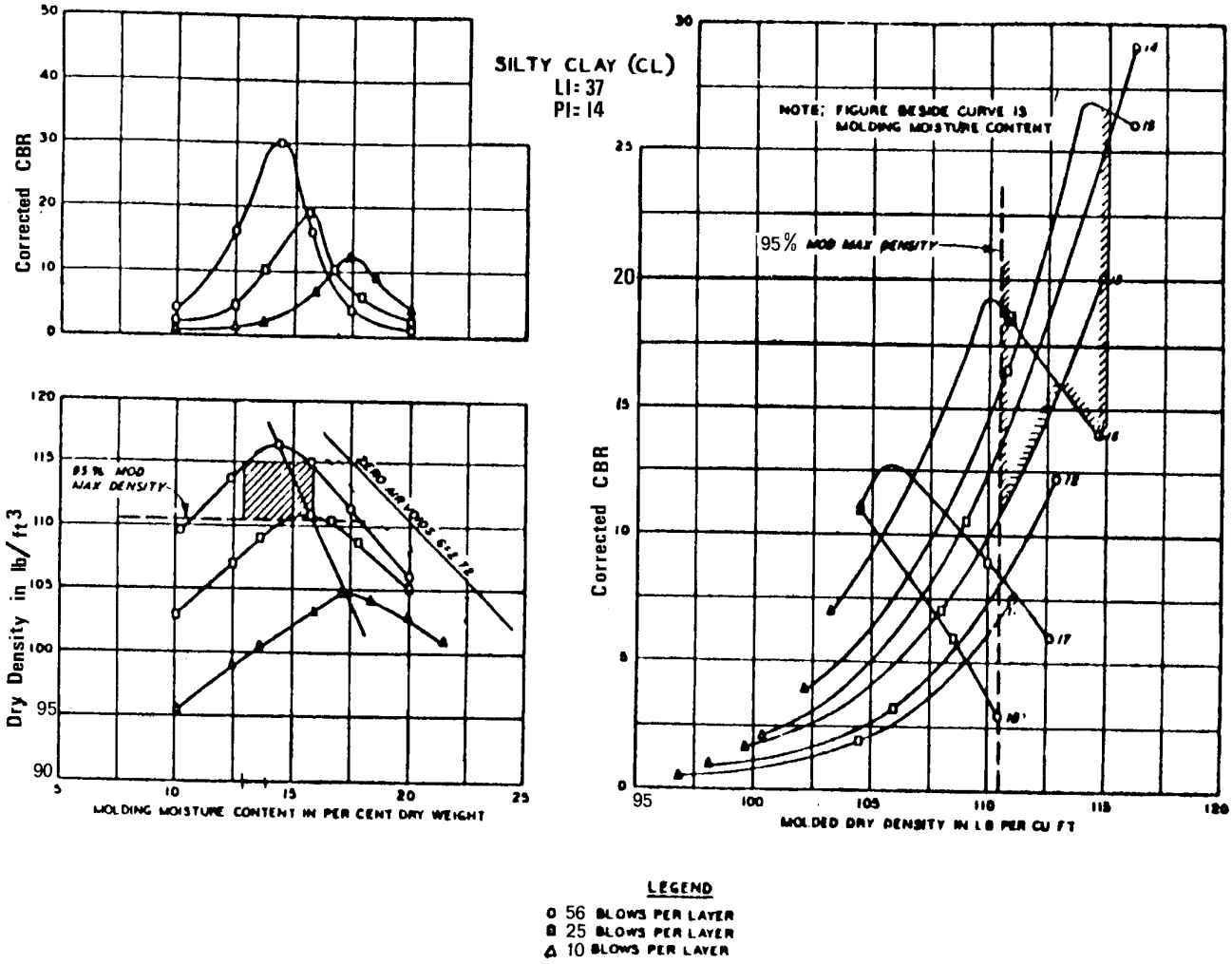


Figure 16.3 Dry Density Versus CBR

9.4 Design CBR for Water Content Range: Plot the data from the tests at the three compactive efforts as shown in Figure 16.4. The data plotted as shown represents the response of the soil over the range of water content specified. Select the CBR for reporting as the lowest CBR within the specified water content range having a dry unit weight between the specified minimum and the dry unit weight produced by compaction within the water content range.



NOTE Surcharge = 50 lb soaking and penetration. All samples soaked top and bottom four days. All samples compacted in 5 layers, 10-lb hammer, 18-in. drop in CBR mold.

Figure 16.4 Determining CBR for Water Content Range and Minimum Dry Unit Weight

10. REPORT

10.1 The report shall include the following:

10.1.1 Method used for preparation and compaction of specimen: Test Methods D 698 or D 1557, or other, with description.
10.1.2 Condition of sample (unsoaked or soaked).
10.1.3 Dry density (unit weight) of sample before soaking, kg/m^3 (lb/ft^3).
10.1.4 Dry density (unit weight) of sample after soaking kg/m^3 (lb/ft^3).
10.1.5 Moisture content of sample in percent:

10.1.5.1 Before compaction.
10.1.5.2 After compaction.
10.1.5.3 Top 1 inch (25.4 mm) layer after soaking.
10.1.5.4 Average after soaking.
10.1.6 Swell (percentage of initial height).
10.1.7 Bearing ratio of sample (unsoaked or soaked), percent.
10.1.8 Surcharge amount.
10.1.9 Any special sample preparation and testing procedures (for example: for self-cementing materials).
10.1.10 Sample identification (location, boring number, etc.).
10.1.11 Any pertinent testing done to identify the sample such as: soil classifications per Test Method D 2487, visual classification per Practice D 2488, Atterberg limits per Test Method D 4318, gradation per Method D 422 etc.
10.1.12 The percent material retained on the 19 mm sieve for those cases where scalping and replacement is used.

11. PRECISION AND BIAS

11.1 No available methods provide absolute values for the soil bearing strength derived by this test method; therefore, there is no meaningful way to obtain an evaluation of bias.

11.2 At present, sufficient data for determining the precision of this test method has not been gathered. Users are encouraged to submit data to the subcommittee for inclusion in the statement. One user, based on seven repetitions, has developed a IS % of 8.2 % (compacted per Test Method D 698) and 5.9 % (compacted per Test Method D 1557). See Appendix X1 for the data used.

Experiment No: 16
Standard Test Method for CBR of Laboratory Compacted Soils

Name: **Student No**:

Mold:	**Calibration of Proving Ring:**
Height of Mold = Diameter of Mold = **Spacer Disk :** Height of Spacer Disk = Compacted Height of Sample = Volume of Compacted Sample =	…… y = load in lb. x = load dial reading

Bulk Density of Sample:

Weight of Soil + Mold =

Weight of Mold =

Weight of Soil

Bulk Density = (Weight of Soil/Volume of Compacted Soil) =

Moisture Content of Sample:

Wet Weight of (Container + Soil) =

Dry Weight of (Container + Soil) =

Weight of Container =

Weight of wet soil, W_w =

Weight of dry soil, W_d=

Moisture Content = $(W_w - W_d)/W_d$ =

Penetration Stress Calculation

Diameter of Penetration Plunger =

Area of Penetration Plunger =

1	2	3	4
Penetration (inch)	**Proving Ring Dial Reading**	**Piston Load (lb)**	**Penetration Stress (psi)**
0			
0.025			
0.05			
0.075			
0.1			
0.125			
0.15			
0.175			
0.2			
0.3			
0.4			
0.5			

$CBR_{0.1''}$ =

$CBR_{0.2''}$ =

_____

Signature of Course Teacher

EXPERIMENT NO: 17

ASPHALT CONCRETE MIX DESIGN BY MARSHALL METHOD

(ASPHALT INSTITUTE MANUAL SERIES NO. 2 (MS-2), Ch. 4 & Ch. 6, SIXTH EDITION 1997)



VOLUMETRIC PROPERTIES OF COMPACTED PAVING MIXTURES

1.1 GENERAL

The volumetric properties of a compacted paving mixture [air voids (V_a), voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), and effective asphalt content (P_{be})) provide some indication of the mixture's probable pavement service performance. The intent of laboratory compaction is to simulate the in place density of HMA after it has endured several years of traffic. How well the laboratory compaction procedure simulates either the compacted state immediately after construction or after years of service can be determined by comparing the properties of an undisturbed sample removed from a pavement with the properties of a sample of the same paving mixture competed in the laboratory.

It is necessary to understand the definitions and analytical procedures described here to be able to make informed decisions concerning the selection of the design asphalt mixture. The information here applies to both paving mixtures that have been compacted in the laboratory, and to undisturbed samples that have been removed from a pavement in the field.

A comparison of field and laboratory compacted mix properties has been made in several research studies. Statistical analysis of these data has failed to establish one laboratory compaction method that consistently produces the closest simulation to the field for all of the measured properties. However, there is a trend toward the gyratory method of compaction based on these findings and other subjective factors. This is a very complicated issue. Compaction method, level of compaction, structural concerns, construction conditions and other influences can all make a difference in these comparisons. Assuming that a reasonable degree of simulation is achieved by whatever compaction procedures are used, it is universally agreed that the air void analysis is an important part of mix design.

1.2 DEFINITIONS

Mineral aggregate is porous and can absorb water and asphalt to a variable degree. Furthermore, the ratio of water to asphalt absorption varies with each aggregate. The three methods of measuring aggregate specific gravity take these variations into consideration. The methods are ASTM bulk, ASTM apparent and effective specific gravities. The differences among the specific gravities come from different definitions of aggregate volume.

Bulk Specific Gravity, G_{sb} - the ratio of the weight in air of a unit volume of permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of equal density of an equal volume of gas free distilled water at a stated temperature. See Figure 17.1.

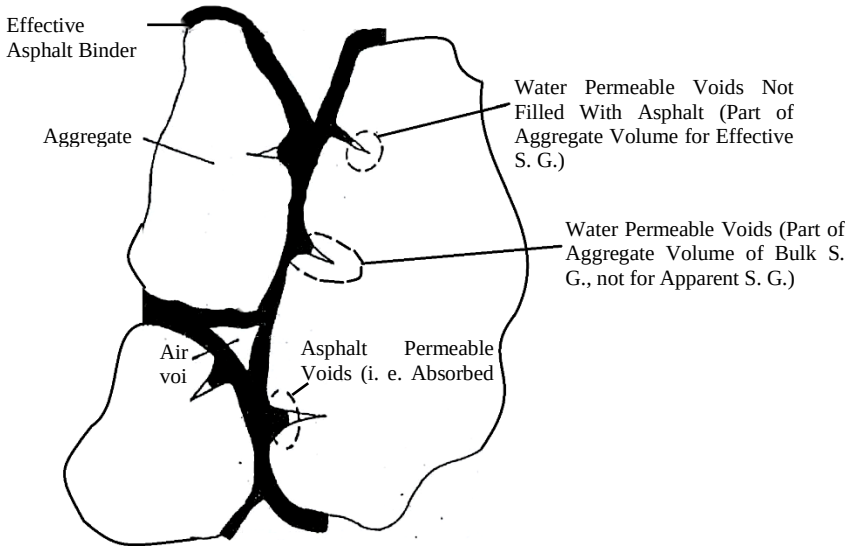


Figure 17.1 Illustrating bulk, effective, and apparent specific gravities; air voids and effective, asphalt content in compacted asphalt paving mixture

Apparent Specific Gravity, G_{sa} - the ratio of the weight in air of a unit volume of an impermeable material at a stated temperature to the weight in air of equal density of an equal volume of gas free distilled water at a stated temperature. See Figure 17.1.

Effective Specific Gravity, G_{se} - the ratio of the weight in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the weight in air of equal density of an equal volume of gas free distilled water at a stated temperature. See Figure 17.1.

NOTE: The accuracy of specific gravity measurements for mix design is important. Unless specific gravities are determined to four significant figures (three decimal places) an error in air voids value of as much as 0.8 percent can occur. Therefore, the Asphalt Institute recommends the use of weigh scales whose sensitivity will allow a mix batch weighing 1000 to 5000 grams to be measured to an accuracy of 0.1 gram.

V_{ma} = Volume of voids in mineral aggregate
V_{mb} = Bulk volume of compacted mix
V_{mm} = Void less volume of paving mix
V_{fa} = Volume of voids filled with asphalt
V_a = Volume of air voids
V_b = Volume of asphalt
V_{ba} = Volume of absorbed asphalt
V_{sb} = Volume of mineral aggregate (by bulk specific gravity)
V_{se} = Volume of mineral aggregate (by effective specific gravity)

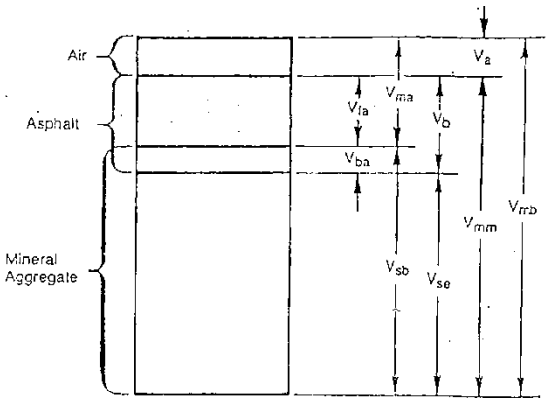


Figure 1.2 Representation of volumes in a compacted asphalt specimen

The definitions for voids in the mineral aggregate (VMA), effective asphalt content (P_{be}), air voids (V_a) and voids filled with asphalt (VFA) are:

Voids in the Mineral Aggregate, VMA - the volume of inter granular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the sample. See Figure 17.2.

Effective Asphalt Content, Pbe - the total asphalt content of a paving mixture minus the portion of asphalt that is lost by absorption into the aggregate particles. See Figure 17.2.

Air Voids, V_a - the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture. See Figure 17.2.

Voids Filled with Asphalt, VFA - the portion of the volume of intergranular void space between the aggregate particles (VMA) that is occupied by the effective asphalt. See Figure 17.2.

The Asphalt Institute recommends that VMA values for compacted paving mixtures should be calculated in terms of the aggregate's bulk specific gravity, G_{sb}. The effective specific gravity should be the basis for calculating the air voids in a compacted asphalt paving mixture.

Table 1 illustrates that the type of aggregate specific gravity used in the analysis of a compacted paving mixture can have a very dramatic effect on the values reported for air voids and VMA. These differences are enough to make it appear that a mixture may satisfy or fail the design criteria for air voids and VMA depending on the aggregate specific gravity used for analysis. Asphalt Institute mix design criteria do not apply unless VMA calculations are made using bulk specific gravity and air void content calculations are made using effective specific gravity.

Voids in the mineral aggregate (VMA) and air voids (V_a) are expressed as percent by volume of the paving mixture. Voids filled with asphalt (VFA) is the percentage of VMA that is filled by the effective asphalt. Depending on how asphalt content is specified, the effective asphalt content may be expressed either as percent by weight of the total weight of the paving mixture, or as percent by weight of the aggregate in the paving mixture.

Because air voids, VMA and VFA are volume quantities and therefore cannot be weighed, a paving mixture must first be designed or analyzed on a volume basis. For design purposes, this volume approach can easily be changed over to a weight basis to provide a job mix formula.

1.3 OUTLINE OF PROCEDURE FOR ANALYZING A COMPACTED PAVING MIXTURE

This list delineates all the measurements and calculations needed for a void analysis:
(a) Measure the bulk specific gravities of the coarse aggregate (AASHTO T 85 or ASTM C 127) and of the fine aggregate (AASHTO T 84 or ASTM C 128).
(b) Measure the specific gravity of the asphalt cement (AASHTO T 228 or ASTMD 70) and of the mineral filler (AASHTO T 100 or ASTM D 854).
(c) Calculate the bulk specific gravity of the aggregate combination in the paving mixture.
(d) Measure the maximum specific gravity of the loose paving mixture (ASTMD 2041).
(e) Measure the bulk specific gravity of the compacted paving mixture (ASTM D 1188 or ASTM D 2726).
(f) Calculate the effective specific gravity of the aggregate.
(g) Calculate the maximum specific gravity of the mix at other asphalt contents.
(h) Calculate the asphalt absorption of the aggregate.

Table 17.1: Influence of type of specific gravity on determination of VMA, VFA and air voids

Specific gravity Employed for Aggregate		Allowance For Absorption of Asphalt by Aggregate	Void Properties Compacted Mixture		
			Percent Voids in Mineral Aggregate	Percent Air Voids	Percent Voids Filled With Asphalt
ASTM Bulk	2.651	Yes	13.6	1.1	92
ASTM Bulk	2.651	No	13.6	-0.8	106
ASTM Bulk (sat. surf. dry)	2.716	Yes	15.6	3.2	79
ASTM Bulk (sat. surf. dry)	2.716	No	15.6	1.3	92
ASTM Apparent	2.834	No	19.1	4.9	74
Effective	2.708	No	15.4	1.1	93

Bulk Specific Gravity of Compacted Mixture, G_{mb} 2.436
Density of Compacted Mixture, W_r, Mg/m^3 (lb/ft^3) 2.435 (152.0)
Asphalt Content, percent by weight of total mix 5.9
Asphalt Absorbed by Aggregate Particles, percent 0.8
Specific Gravity of Asphalt Cement, G_b 1.011
(i) Calculate the effective asphalt content of the paving mixture.
(j) Calculate the percent voids in the mineral aggregate in the compacted paving mixture.
(k) Calculate the percent air voids in the compacted paving mixture.
(l) Calculate the percent voids filled with asphalt.

Equations for these calculations are found in Articles 1.5 through 1.11 and theirapplication may be expedited by use of the appropriate worksheet.

1.4 PAVING MIXTURE DATA FOR SAMPLE CALCULATIONS

Table 17.2 illustrates the basic data fora sample of paving mixture. These design data are used in the sample calculations used in the remainder of this chapter.

1.5 BULK SPECIFIC GRAVITY OF AGGREGATE

When the total aggregate consists of separate fractions of coarse aggregate, fine aggregate and mineral filler, all having different specific gravities, the bulk specific gravity for the total aggregate is calculated using:

$$G_{sb} = \frac{P_1 + P_2 + \ldots + P_n}{P_1/G_1 + P_2/G_2 + \ldots + P_n/G_n}$$

Where, G_{sb}= bulk specific gravity for the total aggregate
P_1, P_2, P_n= individual percentages by weight of aggregate
G_1, G_2, G_n= individual bulk specific gravities of aggregate

Table 17.2: Basic data for sample of paving mixture:

a) Constituents

Material	Specific Gravity				Mix Composition	
		Bulk	AASHTO Method	ASTM Method	Percent By Weight of Total Mix	Percent By Weight of Total Aggregate
Asphalt Cement	1.030 (G_b)		T 228	D 70	5.3 (P_b)	5.6 (P_b)
Coarse Aggregate		2.716 (G_1)	T 85	C 127	47.4 (P_1)	50.0 (P_1)
Fine Aggregate		2.689 (G_2)	T 84	C 128	47.3 (P_2)	50.0 (P_2)
Mineral Filler	----		T 100	D 854	----	----

b) Paving Mixture

Bulk specific gravity of compacted paving mixture sample, G_{mb} (ASTM D 2726) = 2.442
Maximum specific gravity of paving mixture sample, G_{mm} (ASTM D 2041) = 2.535

The bulk specific gravity of mineral filler is difficult to determine accurately. However, if the apparent specific gravity of the filler is substituted, the error is usually negligible.
Using the data in Table 17.2:

$$G_{sb} = \frac{50.0 + 50.0}{50.0/2.716 + 50.0/2.689} = 2.703$$

1.6 EFFECTIVE SPECIFIC GRAVITY OF AGGREGATE

When based on the maximum specific gravity of a paving mixture, G_{mm}, as measured using ASTM D 2041, the effective specific gravity of the aggregate, G_{se}, includes all void spaces in the aggregate particles except those that absorb asphalt. G_{se} is determined using:

$$G_{se} = \frac{P_{mm} - P_b}{P_{mm}/G_{mm} - P_b/G_b}$$

Where, G_{se} = effective specific gravity of aggregate
G_{mm} = maximum specific gravity (ASTM D 2041) of paving mixture (no air voids)
P_{mm} = percent by weight of total loose mixture = 100
P_b = asphalt content at which ASTM D 2041 test was performed, percent by total weight of mixture
G_b= specific gravity of asphalt

Using the data in Table 17.2:

$$G_{se} = \frac{100 - 5.3}{100/2.535 - 5.3/1.030} = 2.761$$

NOTE: The volume of asphalt binder absorbed by an aggregate is almost invariably less than the volume of water absorbed. Consequently, the value for the effective specific gravity of an aggregate should be between its bulk and apparent specific gravities. When the effective specific gravity falls outside these limits, its value must be assumed to be incorrect. The calculations, the maximum specific gravity of the total mix by ASTM D 2041, and the composition of the mix in terms of aggregate and total asphalt content should then be rechecked for the source of the error.
The apparent specific gravity, G_{sa}, of the total aggregate can be calculated by the same formula as the bulk by using the apparent specific gravity of each aggregate constituent.

1.7 MAXIMUM SPECIFIC GRAVITY OF MIXTURES WITH DIFFERENT ASPHALT CONTENTS

In designing a paving mixture with a given aggregate, the maximum specific gravity, G_{mm}, at each asphalt content is needed to calculate the percentage of air voids for each asphalt content. While the maximum specific gravity can be determined for each asphalt content by ASTM D 2041, the precision of the test is best when the mixture is close to the design asphalt content. Also, it is preferable to measure the maximum specific gravity in duplicate or triplicate. After calculating the effective specific gravity of the aggregate from each measured maximum specific gravity (see Article 1.6) and averaging the G_{se} results, the maximum specific gravity for any other asphalt content can be obtained as shown below. For all practical purposes, the effective specific gravity

of the aggregate is constant because the asphalt absorption does not vary appreciably with variations in asphalt content.

$$G_{mm} = \frac{P_{mm}}{P_s/G_{se} + P_b/G_b}$$

Where, G_{mm} = maximum specific gravity of paving mixture (no air voids)
P_{mm} = percent by weight of total loose mixture = 100
P_s = aggregate content,percent by total weight of mixture
P_b = asphalt content,percent by total weight of mixture
G_{se} = effective specific gravity of aggregate
G_b= specific gravity of asphalt

Using the specific gravity data from Table 2, and the effective specific gravity, G_{se}, determined in article 1.6, the G_{mm} at an asphalt content, P_b, of 4 percent would be:

$$G_{mm} = \frac{100}{96/2.761 + 4/1.030}$$

1.8 ASPHALT ABSORPTION

Absorption is expressed as a percentage by weight of aggregate rather than as a percentage by total weight of mixture. Asphalt absorption, P_{ba}, is determined using:

$$P_{ba} = 100 \frac{G_{se} - G_{sb}}{G_{se}G_{sb}} G_b$$

Where, P_{ba} = absorbed asphalt, percent by weight of aggregate
G_{se} = effective specific gravity of aggregate
G_{sb}= bulk specific gravity of aggregate
G_b= specific gravity of asphalt

Using the bulk and effective aggregate specific gravities determined in Articles 1.5 and 1. 6 and the asphalt specific gravity from Table 17.2:

$$P_{ba} = 100 \left(\frac{2.761 - 2.703}{2.761 \text{ x } 2.703} \right) 1.030 = 0.8$$

1.9 EFFECTIVE ASPHALT CONTENT OF A PAVING MIXTURE

The effective asphalt content, P_{be}, of a paving mixture is the total asphalt content minus the quantity of asphalt lost by absorption into the aggregate particles. It is the portion of the total asphalt content that remains as a coating on the outside of the aggregate particles and it is the asphalt content which governs the performance of an asphalt paving mixture. The formula is:

$$P_{be} = P_b - \frac{P_{ba}}{100} P_s$$

Where, P_{be} = effective asphalt content, percent by total weight of mixture
P_b = asphalt content, percent by total weight of mixture
P_{ba} = absorbed asphalt, percent by weight of aggregate
P_s = aggregate content, percent by total weight of mixture
Using the data from Table 2 and Article 1.8:

$$P_{be} = 5.3 - \frac{0.8}{100} \text{x } 94.7 = 4.5$$

1.10 PERCENT VMA IN COMPACTED PAVING MIXTURE

The voids in the mineral aggregate, VMA, are defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The VMA is calculated on the basis of the bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted paving mixture. Therefore, the VMA can be calculated by subtracting the volume of the aggregate determined by its bulk specific gravity from the bulk volume of the compacted paving mixture. A method of calculation is illustrated for each type of mixture percentage content.

If the mix composition is determined as percent by weight of total mixture:

$$VMA = 100 - \frac{G_{mb} P_s}{G_{sb}}$$

Where, VMA = voids in mineral aggregate, percent of bulk volume
G_{sb} = bulk specific gravity of total aggregate
G_{mb} = bulk specific gravity of compacted mixture (AASHTO T 166; ASTM D 1188 or D 2726)
P_s = aggregate content, percent by total weight of mixture

Using the data from Table 2 and Article 1.5:

$$VMA = 100 - \frac{2.442 \text{ x } 94.7}{2.703} = 14.4$$

Or if the mix composition is determined as percent by weight of aggregate:

$$VMA = 100 - \frac{G_{mb}}{G_{sb}} \text{ x } \frac{100}{100 + P_b} 100$$

Where, P_b = asphalt content, percent by weight of aggregate

Using the data from Table 2 and Article 1.5:

$$VMA = 100 - \frac{2.442}{2.703} X \frac{100}{100 + 5.6} X\ 100 = 14.4$$

1.11 PERCENT AIR VOIDS IN COMPACTED PAVING MIXTURE

The air voids, V_a, in the total compacted paving mixture consist of the small air spaces between the coated aggregate particles. The volume percentage of air voids in a compacted mixture can be determined using:

$$V_a = 100 \text{ x } \frac{G_{mm} - G_{mb}}{G_{mm}}$$

Where, V_a= air voids in compacted mixture, percent of total volume
G_{mm} = maximum specific gravity of paving mixture (as determined in Article 1.7 or as measured directly for a paving mixture by ASTM D 2041)
G_{mb} = bulk specific gravity of compacted mixture (AASHTO T 166; ASTM D 1188 or D 2726)

Using data from Table 2:

$$V_a = 100 \text{ x } \frac{2.535 - 2.442}{2.535} = 3.7$$

1.12 PERCENT VFA IN COMPACTED PAVING MIXTURE

The voids filled with asphalt, VFA, is the percentage of the intergranular void space between the aggregate particles (VMA) that are filled with asphalt. VFA, not including the absorbed asphalt, is determined using:

$$VFA = \frac{100 (VMA - V_a)}{VMA}$$

Where, VFA = voids filled with asphalt, percent of VMA
VMA = voids in mineral aggregate, percent of bulk volume
V_a = air voids in compacted mixture, percent of total volume

Using the data from Table 2 and Articles 1.10 and 1.11:

$$VFA = 100 \text{ x } \frac{14.4 - 3.7}{14.4} = 74.3 \text{ percent}$$

MARSHALL METHOD OF MIX DESIGN

A. GENERAL

2.1 DEVELOPMENT AND APPLICATION

The concepts of the Marshall method of designing paving mixtures were formulated by Bruce Marshall, a former Bituminous Engineer with the Mississippi State Highway Department. The U.S. Army Corps of Engineers, through extensive research and correlation studies, improved and added certain features to Marshall's test procedure, and ultimately developed mix design criteria. The Marshall test procedures have been standardized by the American Society for Testing and Materials. Procedures are given by ASTM D 1559, *Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus*.* Testing procedures presented here are basically the same as those of the ASTM method.

The original Marshall method is applicable only to hot mix asphalt (HMA) paving mixtures containing aggregates with maximum sizes of 25 mm (1 inch) or less. A modified Marshall method has been proposed for aggregates with maximum sizes up to 38 mm (1.5 inch). The differences between this proposed method and the Original are discussed in Article 2.16. The Marshall method is intended for laboratory design and field control (Chapter 8, MS-2) of asphalt hot mix dense graded paving mixtures. Because the Marshall stability test is empirical in nature, the meaning of the results in terms of estimating relative field behavior is lost when any modification is made to the standard procedures. An example of such modification is preparing specimens from reheated or remolded materials.

**AASHTO T 245 "Resistance to plastic Flow of Bituminous Mixtures Using Marshall Apparatus" agrees with ASTM D 1559 except for provision for mechanically operated hammer. AASHTO T 245 Par. 2.3 Note 2- Instead of hand operated hammer and associated equipment, a mechanically operated hammer may be used provided it has been calibrated to give results comparable to the hand operated hammer.*

2.2 OUTLINE OF METHOD

The procedure for the Marshall method starts with the preparation of test specimens. Steps preliminary to specimen preparation are:

(a) All materials proposed for use meet the physical requirements of the project specifications.
(b)Aggregate blend combinations meet the gradation requirements of the project specifications.
(c) For performing density and voids analyses, the bulk specific gravity of all aggregates used in the blend and the specific gravity of the asphalt cement are determined.

These requirements are matters of routine testing, specifications, and laboratory technique that must be considered for any mix design method. Refer to Chapter 3 (MS-2), "Evaluation of Aggregate Gradation", for the preparation and analysis of aggregates.

The Marshall method uses standard test specimens of 64 mm (2 $\frac{1}{2}$ in.) height x 102mm (4 in.) diameter. These are prepared using a specified procedure for heating, mixing and compacting the asphalt aggregate mixture. The two principal features of the Marshall method of mix design are a density-voids analysis and a stability-flow test of the compacted test specimens.
The stability the test specimen is the maximum load resistance in Newton (lb.) that the standard test specimen will develop at 60^0 C (140^0 F) when tested as outlined.
The flow value is the total movement or strain, in units of 0.25 mm (1/100 in.) occurring in the specimen between no load and the point of maximum load during the stability test.

B. PREPARATION OF TEST SPECIMENS

2.3GENERAL

In determining the design asphalt content for a particular blend or gradation of aggregates by the Marshall method, a series of test specimens is prepared for a range of different asphalt contents so that the test data curves show well defined relationships. Tests should be planned on the basis of ½ percent increments of asphalt content, with at least two asphalt contents above the expected design value and at least two below this value.
The "expected design" asphalt content can be based on any or all of these sources: experience, computational formula, or performing the centrifuge kerosene equivalency and oil soak tests in the Hveem procedure. Another quick method to arrive at a starting point is to use the dust-to-asphalt ratio guideline (0.6 to 1.2). The expected design asphalt content, in percent by total weight of mix, could then be estimated to be approximately equivalent to the percentage of aggregate in the final gradation passing the 75 μm (No. 200) sieve.
One example of a computational formula is this equation:

$$P= 0.035a + 0.045b + Kc + F$$

Where: P = approximate asphalt content of mix, percent by weight of mix
a = percent* of mineral aggregate retained on 2.36mm (No. 8) sieve
b = percent* of mineral aggregate passing the 2.36mm (No. 8) sieve and retained on the 75 μm (No. 200) sieve
c = percent of mineral aggregate passing 75 μm (No. 200) sieve
K = 0.15 for 11-15 percent passing 75 μm (No. 200) sieve
0.18 for 6-10 percent passing 75 μm (No. 200) sieve
0.20 for 5 percent or less passing 75 μm (No. 200) sieve
F = 0 to 2.0 percent. Based on absorption of light or heavy aggregate. In the absence of other data, a value of 0.7 is suggested.

*Expressed as a whole number

To provide adequate data, at least three test specimens are prepared for each asphalt content selected. Therefore, a Marshall mix design using six different asphalt contents will normally require at least eighteen test specimens. Each test specimen will usually require approximately 1.2 kg (2.7 lb) of aggregate. Assuming some minor waste, the minimum aggregate requirements for one series of test specimens of a given blend and gradation will be approximately 23 kg (50 lb). About four liters (one gallon) of asphalt cement will be adequate.

2.4 EQUIPMENT

The equipment required for the preparation of test specimens is:

(a) Flat bottom metal pans for heating aggregates.
(b) Round metal pans, approximately 4 liter (4 qt.) capacity, for mixing asphalt and aggregate.
(c) Oven and Hot Plate, preferably thermostatically controlled, for heating aggregates, asphalt,and equipment.
(d) Scoop for batching aggregates.
(e) Containers: gill-type tins, beakers, pouring pots, or sauce pans, for heating asphalt.
(f) Thermometers: armored, glass, or dial type with metal stem, 10°C (50°F) to 235°C (450°F), for determining temperature of aggregates, asphalt and asphalt mixtures.
(g) Balances: 5 kg capacity, sensitive to 1 g, for weighing aggregates and asphalt and 2 kg capacity, sensitive 0.1 g, for weighing compacted specimens.
(h) Large Mixing Spoon or small trowel.
(i) Large spatula.
(j) Mechanical Mixer (optional): commercial bread dough mixer 4 liter (4 qt.) capacity or larger, equipped with two metal mixing bowls and two wire stirrers.
(k) Compaction Pedestal (Figure 2.1), consisting of a 200 x 200 x 460 mm (8 x 8 x 18 in.) wooden post capped with a 305 x 305 x 25 mm (12 x 12 x 1 in.) steel plate. The wooden post should be oak, pine or other wood having a dry weight of 670 to 770 kg/m^3 (42 to 48 pcf). The wooden post should be secured by four angle brackets to a solid concrete slab. The steel cap should be firmly fastened to the post. The pedestal should be installed so that the post is plumb, the cap level, and the entire assembly free from movement during compaction.
*(l) Compaction Mold, consisting of a base plate, forming mold, and collar extension. The forming mold has an inside diameter of 101.6 mm (4 in.) and a height of approximately 75 mm (3 in.); the base plate and collar extension are designed to be interchangeable with either end of the forming mold.
*(m) Compaction Hammer, consisting of a flat circular tamping face. 98.4 mm (3 $^7/_8$ in.) in diameter and equipped with a 4.5 kg (10 lb.) weight constructed to obtain a specified 457 mm (18 in.) height of drop.
*(n) Mold Holder, consisting of spring tension device designed to hold compaction mold centered in place on compaction pedestal.

(o) Paper disks, 100mm (4 in.), for compaction.
(p) Steel specimen extractor, in the form of a disk with a diameter not less than 100 mm (3.95 in.) and 13 mm (0.5 in.) thick for extruding compacted specimens from mold.
(q) Welders gloves for handling hot equipment. Rubber gloves for removing specimens from water bath.
(r) Marking Crayons, for identifying test specimens.

* Marshall test apparatus should conform to requirements of ASTM D 1559

(Note: See additional equipment requirements in Article 2.7)



Mechanical compaction hammer assembly Manual compaction hammer assembly

Figure 17.3 Pedestal, hammer and mold used in preparing Marshall test specimens

2.5 PREPARATION OF TEST SPECIMENS

These steps are recommended for preparing Marshall test specimens:

(a) Number of Specimens - Prepare at least three specimens for each combination of aggregates and asphalt content.

(b) Preparation of Aggregates - Dry aggregates to constant weight at 105°C to 110°C (220°F to 230°F) and separate the aggregates by dry sieving into the desired size fractions. These size fractions are recommended:

25.0 to 19.0 mm (1 to $^3/_4$ in.)

19.0 to 9.5 mm ($^3/_4$ to $^3/_8$ in.)

9.5 to 4.75 mm ($^3/_8$ in. to No. 4)

4.75 to 2.36 mm (No. 4 to No. 8)

passing 2.36 mm (No. 8)

(c) Determination of Mixing and Compaction Temperature - The temperature to which the asphalt must be heated to produce viscosities of 170 ± 20 centistokes kinematic and 280 ± 30 centistokes kinematic shall be established as the mixing temperature and compaction temperature, respectively. These temperatures can be estimated from a plot of the viscosity (log-log centistokes scale) versus temperature (log degrees Rankine scale, $^0R=^0F+459.7$) relationship for the asphalt cement to be used. An example plot is shown in Figure 2.2.

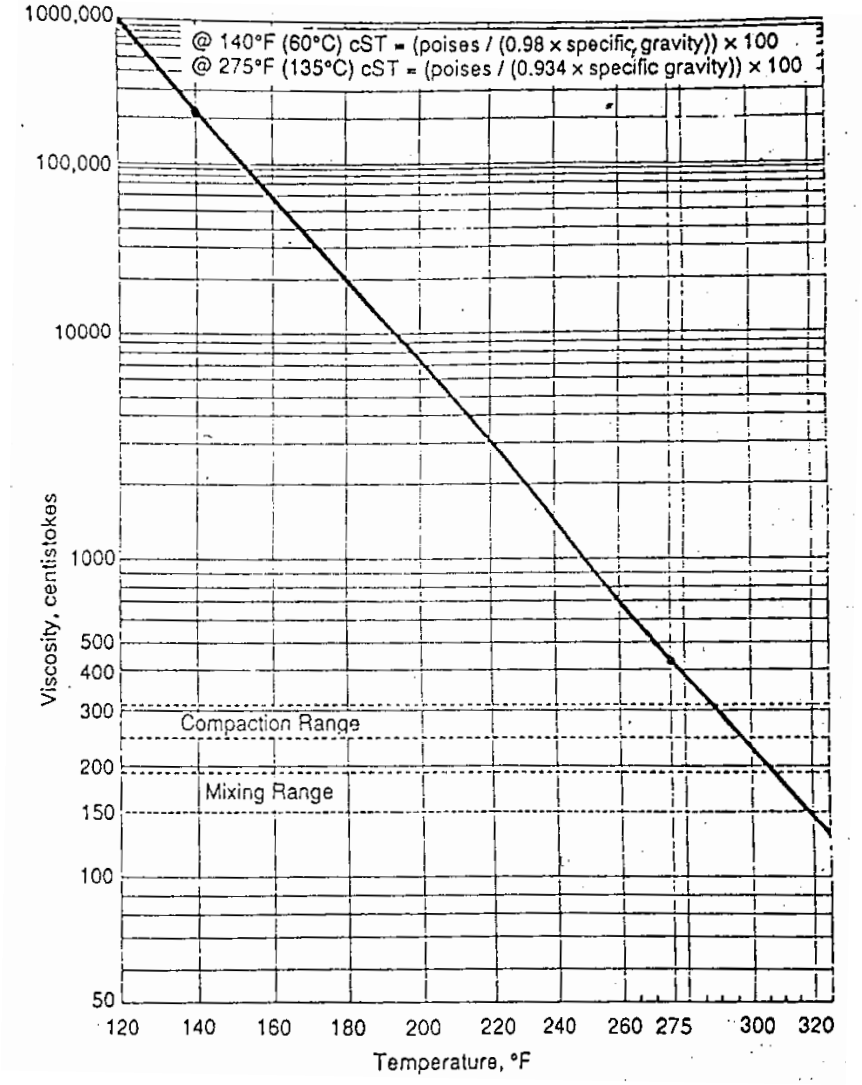


Figure 17.4 Determination of Mixing and Compaction Temperatures

(d) Preparation of Mold and Hammer - Thoroughly clean the specimen mold assembly and the face of the compaction hammer and heat them in a water bath or on the hot plate to a temperature between 95°C and 150°C (200°F and 300°F). Place a piece of filter or waxed paper, cut to size, in the bottom of the mold before the mixture is placed in the mold.

(e) Preparation of Mixtures - Weigh into separate pans for each test specimen the amount of each size fraction required to produce a batch that will result in a compacted specimen 63.5 ± 1.27 mm (2.5 ± 0.05 in.) in height. This will normally be about 1.2 kg (2.7 lb.). It is generally desirable to prepare a trial specimen prior to preparing the aggregate batches. If the trial specimen height falls outside the limits, the amount of aggregate used for the specimen may be adjusted using:

For International System of Units (SI),

*Adjusted mass of aggregate -63.5 (mass of aggregate used) / Specimen height (mm) obtained

U.S. Customary Units,

*Adjusted weight of aggregate - 2.5 (weight of aggregate used) / Specimen height (in.) obtained

Place the pans in the oven or on the hot plate and heat to a temperature not exceeding 28°C (50°F) above the mixing temperature specified in (c). (If a hot plate is used, provision should be made for dead space, baffle plate, or a sand bath beneath the pans and the hot plate to prevent local overheating) Charge the mixing bowl with heated aggregates and dry mix thoroughly. Form a crater in the dry blended aggregate and weigh the required amount of asphalt cement into the mixture in accordance with the calculated batch weights. At this point the temperature of the aggregate and asphalt must be within the limits of the mixing temperature established in paragraph (c). Asphalt cement should not be held at mixing temperatures for more than one hour before using. Mix the aggregate and asphalt cement, preferably with a mechanical mixer or by hand with a trowel, as quickly and thoroughly as possible to yield a mixture having a uniform distribution of asphalt.

Note: Currently, there is no standardized or recommended procedure for aging or curing the mixture prior to Marshall compaction. A number of suggested methods have been proposed; however, a consensus of opinion has not yet been reached. The Hveem procedure recommends a 2 to 3 hour cure period to allow for both aging and absorption to occur. If severe climates or absorptive aggregates are involved, some consideration should be given to this behavior.

(f) Packing the Mold - Place a paper disk in the mold. Place the entire batch in the mold, spade the mixture vigorously with a heated spatula or trowel 15 times around the perimeter and ten times over the interior. Smooth the surface to a slightly rounded shape. The temperature of the mixture immediately prior to compaction shall be within the limits of the compaction temperature established in paragraph (c); otherwise, it shall be discarded. In no case shall the mixture be reheated.

(g) Compaction of Specimens - Place a paper on top of the mix and place the mold assembly on the compaction pedestal in the mold holder. As specified according to the design traffic category (see Table 2.2), apply either 35, 50 or 75 blows with the compaction hammer using a free fall of 457 mm (18 in.). Hold the axis of the compaction hammer as nearly perpendicular to the base of the mold assembly as possible during compaction. Remove the base plate and collar, and reverse and reassemble the mold. Apply the same number of compaction blows to the face of the reversed specimen. After compaction, remove the base plate and the paper disks and allow the specimen to

cool in air until no deformation will result when removing it from the mold. When more rapid cooling is desired, electric fans may be used, but not water unless the specimen is in a plastic bag. Remove the specimen from the mold by means of an extrusion jack or other compression device, then place on a smooth level surface until ready for testing. Normally, specimens are allowed to cool overnight.

Note: ASTM D1559 specifies that hand lifting of a flat faced compaction hammer be used for specimen compaction. If variations (e.g. mechanical lift, slanted face, and rotating base) of the flat face, hand-lifted hammer are used, correlations with the standard Marshall compaction procedure must be made.

C. TEST PROCEDURE

2.6 GENERAL

In the Marshall method, each compacted test specimen is subjected to thesetestsand analysis in theorder listed:
(a) Bulk Specific Gravity Determination
(b) Stability and Flow Test
(c) Density and Voids Analysis

2.7 EQUIPMENT

The equipment required for the testing of the 102 mm (4 in.) diameter x 64 mm (2 $^1/_2$ in.) height specimens is:

*(a) Marshall Testing Machine, a compression testing device. It is designed to apply loads to test specimens through cylindrical segment testing heads (inside radius of curvature of 51 mm (2 in.)) at a constant rate of vertical strain of 51 mm (2 in.) per minute. Two perpendicular guide posts are included to allow the two segments to maintain horizontal positioning and free vertical movement during the test. It is equipped with a calibrated proving ring for determining the applied testing load, a Marshall stability testing head for use in testing the specimen, and a Marshall flow meter for determining the amount of strain at the maximum load in the test. A universal testing machine equipped with suitable load and deformation indicating devices may be used instead of the Marshall testing frame.

**Marshall test apparatus should conform to requirements of ASTM D 1559*

(b) Water Bath, at least 150 mm (6 in.) deep and thermostatically controlled to 60°C ± 1°C (140°F±1.8°F). The tank should have a perforated false bottom or be equipped with a shelf for suspending specimens at least 50 mm (2 in.) above the bottom of the bath.

2.8 BULK SPECIFIC GRAVITY DETERMINATION

The bulk-specific gravity test may be performed as soon as the freshly compacted specimens have cooled to room temperature. This test is performed according to ASTM D 1188, *Bulk Specific Gravity of Compacted Bituminous Mixtures Using Paraffin-coated Specimens* or ASTM D 2726, *Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens*.

2.9 STABILITY AND FLOW TESTS

After the bulk specific gravity of the test specimens have been determined, the stability and flow tests are performed:

(a) Immerse specimen in water bath at 60°C ± 1°C (140°F ± 1.8°F) for 30 to 40 minutes before test.

(b) If not using an automatic recording device (as shown in Figure 17.5). "Zero" the flow meter by inserting a 101.6 mm (4.00 in.) diameter metal cylinder in the testing head, placing the flow meter over the guide rod and adjusting the flow meter to read "zero."

Note: This adjustment should be made on the guide post marked with an "0" and with the side of the upper segment of the testing head marked with an "0" being placed on the same side as the guide post so marked. The same assembly of testing head and flow meter must then be used in testing the specimens. Specimens should be 101.6± 0.25 mm (4.00 in. ± 0.01 in.); otherwise, an initial and final reading of flow meter is required for the determination of the flow value.



Figure 17.5 Marshall stability and flow test

(c) Thoroughly clean the inside surfaces of testing head. Temperature of head shall be maintained between 21.1°to 37.8°C (70° to 100°F) using a water bath when required. Lubricate guide rods with a thin film of oil so that upper test head will slide freely without binding. If a proving ring is used

to measure applied load, check to see that dial indicator is firmly fixed and "zeroed" for the "no-load" position.

(d) With testing apparatus ready, remove test specimen from water bath and carefully dry surface. Place specimen in lower testing head and center; then fit upper testing head into position and center complete assembly in loading device. Place flow meter over marked guide rod as noted in (b) above.

(e) Apply testing load to specimen at constant rate of deformation, 51 mm (2 in.) per minute, until failure occurs. The point of failure is defined by the maximum load reading obtained. The total number of Newtons (lb.) required to produce failure of the specimen shall be recorded as its Marshall stability value.

(f)While the stability test is in progress, if not using an automatic recording device, hold the flow meter firmly in position over guide rod and remove as the load begins to decrease, take reading and record. This reading is the flow value for the specimen, expressed in units of 0.25 mm (1/100 in.). For example, if the specimen deformed 3.8 mm (0.15 in.) the flow value is 15.

(g) The entire procedure for both the stability and flow measurements, starting with the removal of the specimen from the water bath, shall be completed within a period of thirty seconds.

2.10 DENSITY AND VOIDS ANALYSIS

After the completion of the stability and flow test, a density and voids analysis is made for each series of test specimens.

(The calculations for the voids analysis are fully described in previous chapter)

(a) Average the bulk specific gravity values for all test specimens of given asphalt content; values obviously in error shall not be included in the average. These values of bulk specific gravity shall be used in further computations of voids data.

(b) Determine the average unit weight for each asphalt content by multiplying the average bulk specific gravity value by the density of water (1,000 kg/m^3 (62.4 pcf)).

(c) Determine the theoretical maximum specific gravity (ASTM D 2041) for at least two asphalt contents, preferably on mixes at or near the design asphalt content. An average value for the effective specific gravity of the total aggregate is then calculated from these values. This value may then be used for calculation of the maximum specific gravity of mixtures with different asphalt contents, as discussed in previous chapter.

(d) Using the effective and bulk specific gravity of the total aggregate, the average bulk specific gravities of the compacted mix, the specific gravity of the asphalt, and the maximum specific gravity of the mix determined above in (c), calculate the percent absorbed asphalt by weight of dry aggregate, percent air voids (V_a), percent voids filled with asphalt (VFA) and percent voids in mineral aggregate (VMA). These values and calculations are more fully described in previous chapter.

D. INTERPRETATION OF TEST DATA

2.11 PREPARATION OF TEST DATA

Prepare the stability and flow values and void data:
(a) Measured stability values for specimens that depart from the standard 63.5 mm (2 $^{1}/_{2}$ in.) thickness shall be converted to an equivalent 63.5 mm (2 $^{1}/_{2}$ in.) value by means of a conversion factor. Applicable correlation ratios to convert the measured stability values are set forth in Table 17.3. Note that the conversion may be made on the basis of either measured thickness or measured volume.

Table 17.3: Stability correlation ratios

Volume of specimen, cm^3	Approximate thickness of specimen		Correlation ratio
	mm	in.	
200 to 213	25.4	1	5.56
214 to 225	27.0	1 1/16	5.00
226 to 237	28.6	1 1/8	4.55
238 to 250	30.2	1 3/16	4.17
251 to 264	31.8	1 1/4	3.85
265 to 276	33.3	1 5/16	3.57
277 to 289	34.9	1 3/8	3.33
290 to 301	36.5	1 7/16	3.03
302 to 316	38.1	1 1/2	2.78
317 to 328	39.7	1 9/16	2.50
329 to 340	41.3	1 5/8	2.27
341 to 353	42.9	1 11/16	2.08
354 to 367	44.4	1 3/4	1.92
368 to 379	46.0	1 13/16	1.79
380 to 392	47.6	1 7/8	1.67
393 to 405	49.2	1 15/16	1.56
406 to 420	50.8	2	1.47
421 to 431	52.4	2 1/16	1.39
432 to 443	54.0	2 1/8	1.32
444 to 456	55.6	2 3/16	1.25
457 to 470	57.2	2 1/4	1.19
471 to 482	58.7	2 5/16	1.14
483 to 495	60.3	2 3/8	1.09
496 to 508	61.9	2 7/16	1.04
509 to 522	63.5	2 1/2	1.00
523 to 535	64.0	2 9/16	0.96
536 to 546	65.1	2 5/8	0.93
547 to 559	66.7	2 11/16	0.89
560 to 573	68.3	2 3/4	0.86
574 to 585	71.4	2 13/16	0.83
586 to 598	73.0	2 7/8	0.81
599 to 610	74.6	2 15/16	0.78
611 to 625	76.2	3	0.76

NOTES:
1. The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5 mm (2 $^{1}/_{2}$ in.) specimen.
2. Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.).

(b) Average the flow values and the final converted stability values for all specimens of a given asphalt content. Values that are obviously in error shall not be included in the average.

(c) Prepare a separate graphical plot for these values and connects plotted points with a smooth curve that obtains the "best fit" for all values, as illustrated in Figure 2.4:

- Stability vs. Asphalt Content
- Flow vs. Asphalt Content
- Unit Weight of Total Mix vs. Asphalt Content
- Percent Air Voids (V_a) vs. Asphalt Content
- Percent Voids Filled with Asphalt (VFA) vs. Asphalt Content
- Percent Voids in Mineral Aggregate (VMA) vs. Asphalt Content

These graphs are used to determine the design asphalt content of the mix.

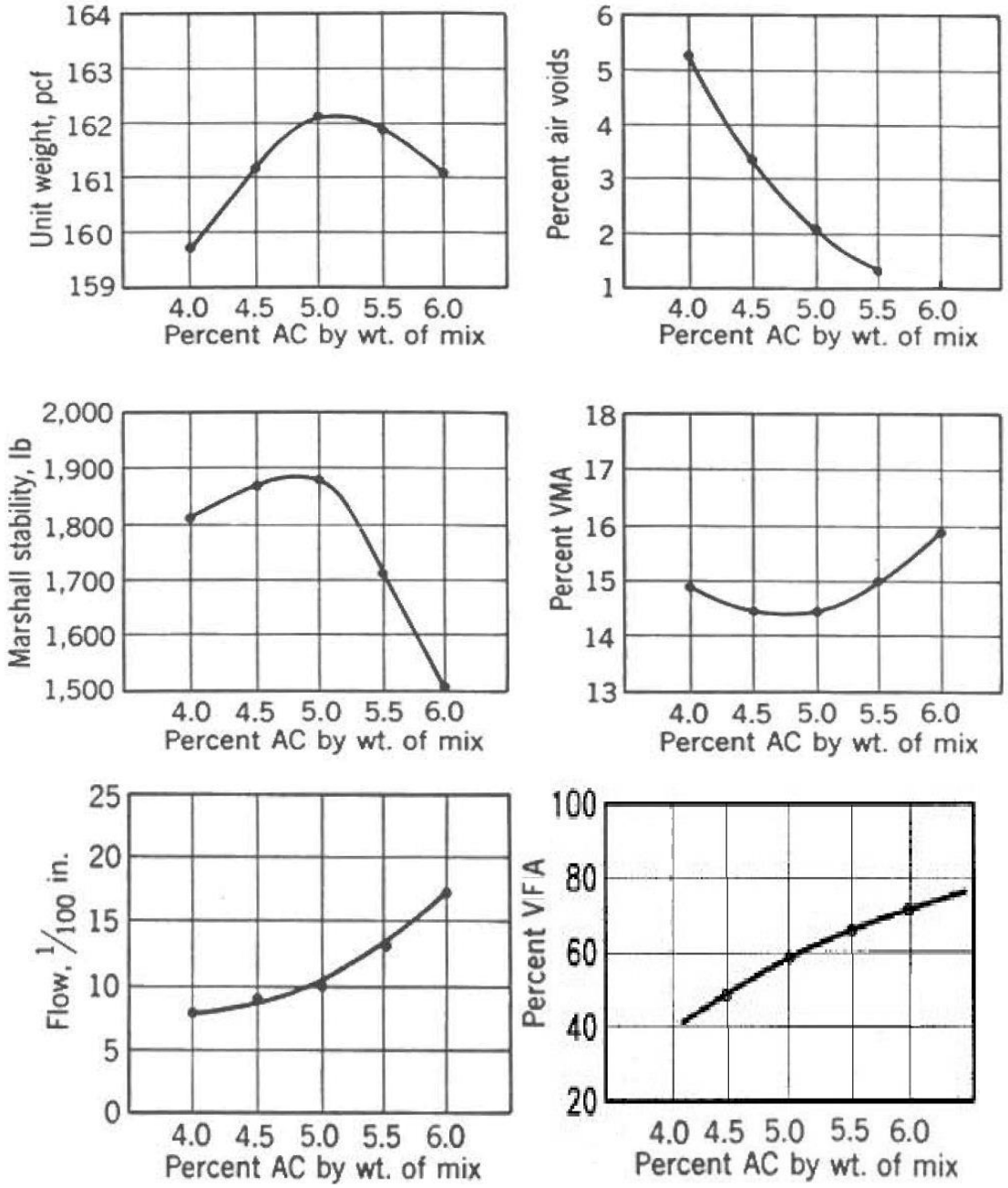


Figure 17.6 Test property curves for hot-mix design data by the Marshall method
(Reference book: "Highway Materials" by Robert D. Kerbs& Richard D. Walker. Figure 12.3, Page-398)

2.12 TRENDS AND RELATIONS OF TEST DATA

By examining the test property curves plotted for Article 2.11, information can be learned about the sensitivity of the mixture to asphalt content. The test property curves have been found to follow a reasonably consistent pattern for dense-graded asphalt paving mixes, but variations will and do occur. Trends generally noted are:

(a) The stability value increases with increasing asphalt content up to a maximum after which the stability decreases.
(b) The flow value consistently increases with increasing asphalt content.
(c) The curve for unit weight of total mix follows the trend similar to the stability curve, except that the maximum unit weight normally (but not always) occurs at slightly higher asphalt content than the maximum stability.
(d) The percent of air voids, V_a, steadily decreases with increasing asphalt content, ultimately approaching a minimum void content.
(e) The percent voids in the mineral aggregate, VMA, generally decreases, to a minimum value then increases with increasing asphalt content.
(f) The percent voids filled with asphalt, VFA, steadily increases with increasing asphalt content, because the VMA is being filled with asphalt.

2.13 CRITERIA FOR SATISFACTORY PAVING MIX

Deciding whether the asphalt paving mix will be satisfactory at the selected design asphalt content is guided by applying certain limiting criteria to the mixture test data. The Marshall method mix design criteria in Table 2.2 are recommended by the Asphalt Institute.

Table 17.4: Marshall mix design criteria

Marshall Method Mix Criteria	Light Traffic Surface & Base		Medium Traffic Surface & Base		Heavy Traffic Surface & Base	
Compaction, Number of blows on each end of specimen	35		50		75	
Stability, N (lb)	3336 (750)	–	5338 (1200)	–	8006 (1800)	–
Flow, 0.25 mm (0.01 in)	8	18	8	16	8	14
Percent Air Voids	3	5	3	5	3	5
Percent Voids in Mineral (VMA)	See Table 2.3					
Percent Voids Filled with Asphalt (VFA)	70	80	65	78	65	75

NOTES

1. All criteria, not just stability value alone, must be considered in designing an asphalt pavement mix. Hot mix asphalt bases that do not meet the criteria when tested at 60^0 C (140^0 F) are satisfactory if they meet the criteria when tested at 38^0C (100^0F) and are placed 100 mm (4 inches) or more below the surface. This recommendation applies only to regions having range of climate conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climate conditions.
2. Traffic classification: Light Traffic condition resulting in a Design EAL < 10^4
   Medium Traffic condition resulting in a Design EAL between 10^4 and 10^6
   Heavy Traffic condition resulting in a Design EAL > 10^6
3. Laboratory compaction efforts should closely approach the maximum density obtained in the pavement under traffic.
4. The flow value refers to the point where the load begins to decrease.
5. The portion of asphalt cement lost by absorption into the aggregate particles must be allowed for when calculating percent of air voids.
6. Percent voids in the mineral aggregate is to be calculated on the basis of the ASTM bulk specific gravity for the aggregates.

Table 17.5: Minimum percent voids in mineral aggregate (VMA)

Nominal Maximum Particle Size 1,2		Minimum VMA, Percent		
		Design Air Voids, Percent 3		
mm	in	3.0	4.0	5.0
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19	20	21
4.75	No. 4	16	17	18
9.5	3/8	14	15	16
12.5	½	13	14	15
19	¾	12	13	14
25	1	11	12	13
37.5	1.5	10	11	12
50	2	9.5	10.5	11.5
63	2.5	9	10	11

1. Standard specification for Wire Cloth Sieves for testing purposes. ASTM E11 (AASHTO M92)
2. The nominal maximum particle size larger than the first sieve to return more than 10 percent.
3. Interpolate minimum voids in the mineral aggregate (VMA) for design air voids between those listed.

2.14 DETERMINATION OF PRELIMINARY DESIGN ASPHALT CONTENT

The design asphalt content of the asphalt paving mix is selected by considering all of the data discussed previously. As an initial starting point, the Asphalt Institute recommends choosing the asphalt content at the median of the percent air voids limits, which is four percent. All of the calculated and measured mix properties at this asphalt content should then be evaluated by comparing them to the mix design criteria in Table 17.4. If all of the criteria are met, then this is the preliminary design asphalt content. If all of the design criteria are not met, then some adjustment or compromise is necessary or the mix may need to be redesigned. A number of considerations are discussed in the next article that should be weighed even if all the design criteria are met.

2.15 SELECTION OF FINAL MIX DESIGN

The final selected mix design is usually the most economical one that will satisfactorily meet all of the established criteria. However, the mix should not be designed to optimize one particular property. Mixes with abnormally high values of stability are often less desirable because pavements with such mixes tend to be less durable and may crack prematurely under heavy volumes of traffic. This situation is especially critical where the base and subgrade materials beneath the pavement are weak and permit moderate to relatively high deflections under the actual traffic.

The design asphalt content should be a compromise selected to balance all of the mix properties. Normally the mix design criteria will produce a narrow range of acceptable asphalt contents that

pass all of the guidelines as shown by the example in Figure 2.5. The asphalt content selection can be adjusted within this narrow range to achieve a mix property that will satisfy a requirement of a specific project.

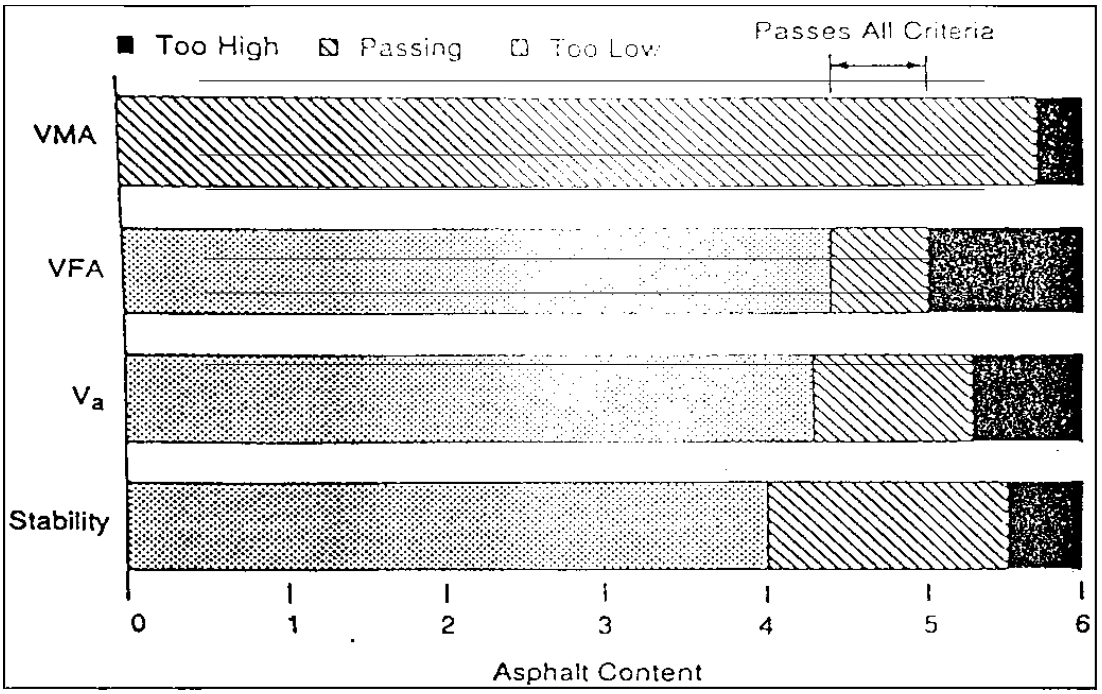


Figure 17.7 An example of the narrow range of acceptable asphalt contents

Different properties are more critical for different circumstances, depending on traffic, structure, climate, construction equipment and other factors. Therefore, the balancing process is not the same for every pavement and every mix design. These are some considerations for adjustment that should be evaluated prior to establishing the final design asphalt content:

Evaluation of VMA Curve

In many cases the most difficult mix design property to achieve is a minimum amount of voids in the mineral aggregate. The goal is to furnish enough space for the asphalt cement so it can provide adequate adhesion to bind the aggregate particles, but without bleeding when temperatures rise and the asphalt expands. Normally the curve exhibits a flattened U-shape, decreasing to a minimum value and then increasing with increasing asphalt content, shown in Figure 17.8 (a).

This dependency of VMA on asphalt content appears to be a contradiction to the definition. One might expect the VMA to remain constant with varying asphalt content, thinking that the air voids would simply be displaced by asphalt cement. In reality the total volume changes across the range

of asphalt contents; the assumption of a constant unit volume is not accurate. With the increase in asphalt the mix actually becomes more workable and compacts more easily, meaning more weight can be compressed into less volume. Therefore, up to a point, the bulk density of the mix increases and the VMA decreases.

At some point as the asphalt content increases (the bottom of the U-shaped curve) the VMA begins to increase because relatively more dense material (aggregate) is displaced and pushed apart by the less dense material (asphalt cement). It is recommended that asphalt contents on the "wet" or right-hand increasing side of this VMA curve be avoided, even if the minimum air void and VMA criteria is met. Design asphalt contents in this range have a tendency to bleed and/or exhibit plastic flow when placed in the field. Any amount of additional compaction from traffic leads to inadequate room for asphalt expansion, loss of aggregate to aggregate contact, and eventually rutting and shoving in high traffic areas. Ideally, the design asphalt content should be selected slightly to the left of the low point of the VMA curve, provided none of the other mixture criteria are violated.

In some mixes, the bottom of the U-shaped VMA curve is very flat, meaning that the compacted mixture is not as sensitive to asphalt content in this range as some other factors. In the normal range of asphalt contents, compact ability is influenced more by aggregate properties. However, at some point the quantity of asphalt will become critical to the behavior of the mix and the effect of asphalt will dominate as the VMA increases drastically.

When the bottom of the U-shaped VMA curve falls below the minimum criteria level required for the nominal maximum aggregate size of the mix [Figure 17.8 (b)], this is an indication that changes to the job mix formula are necessary. Specifically, the aggregate grading should be modified to provide additional VMA.

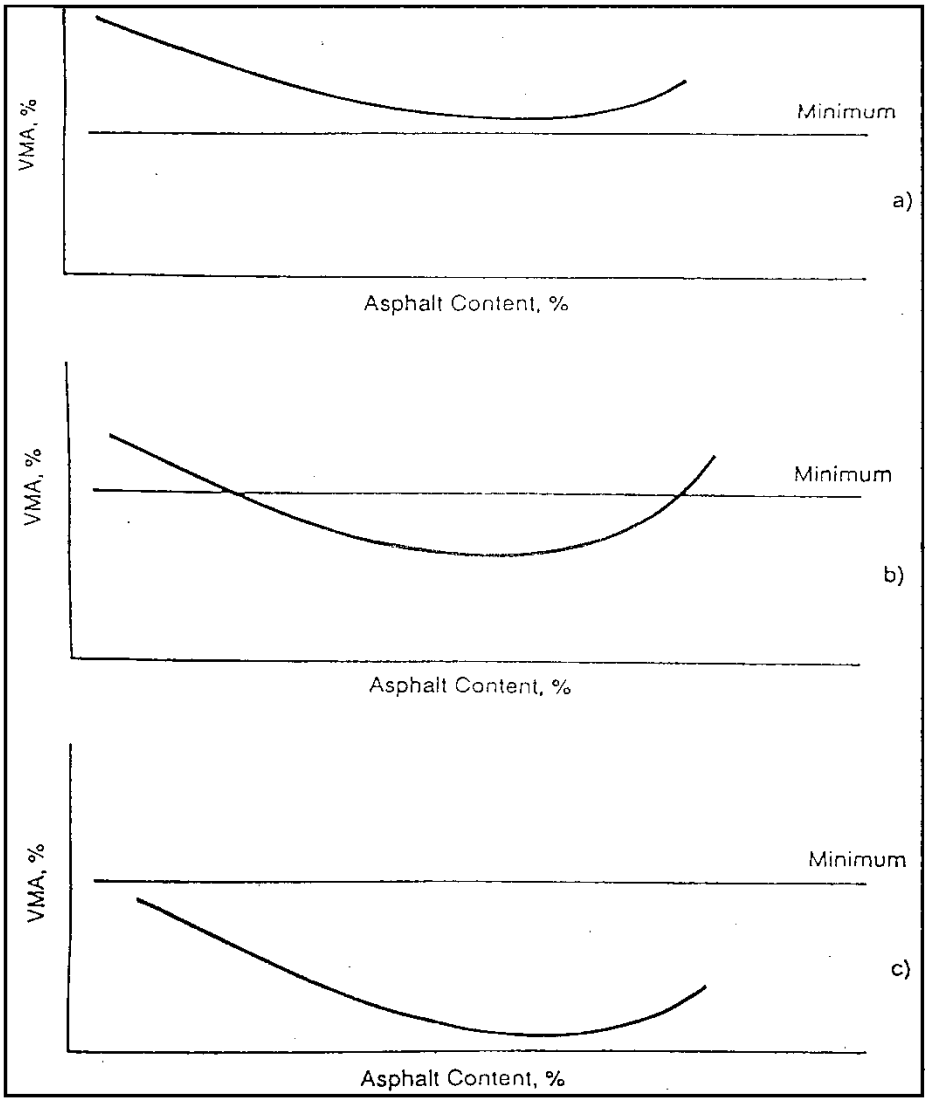


Figure 17.8 Relationship between VMA and specification limit

The design asphalt content should not be selected at the extremes of the acceptable range even though the minimum criteria are met. On the left-hand side, the mix would be too dry, prone to segregation and would probably be too high in air voids. On the right-hand side, the mix would be expected to rut.

If the minimum VMA criteria are completely violated over the entire asphalt content range [curve is completely below minimum, Figure 2.6(c)], a significant redesign and/or change in material sources is warranted.

Effect of Compaction Level

At the same asphalt content, both air voids (V_a) and voids in the mineral aggregate (VMA) decrease with higher compactive effort. The three levels of compaction of the Marshall mix procedure can

be used to illustrate the consequences of this fact. As shown in Figure 17.9(a), not only do the magnitudes of the values change but the asphalt content value at the minimum VMA shifts.

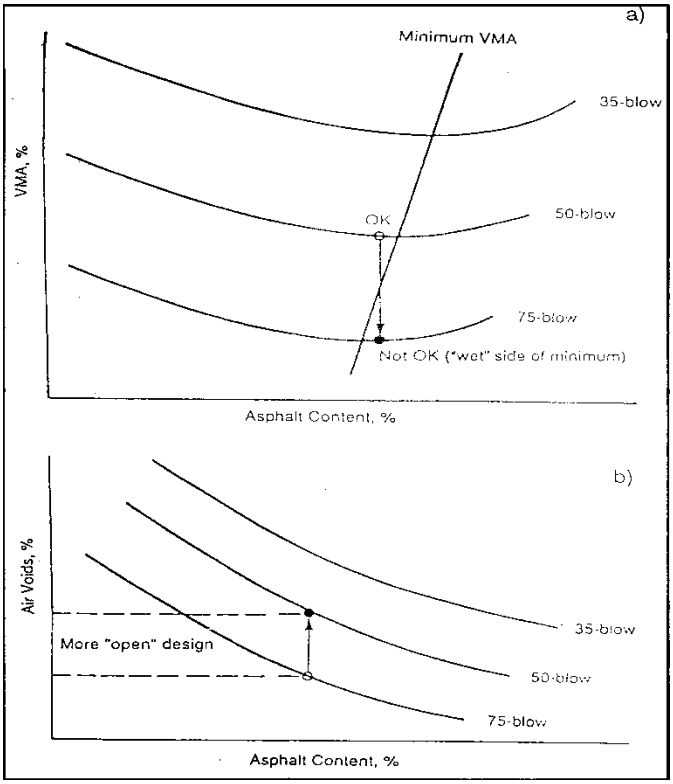


Figure 17.9 Effect of Marshall compactive effort on VMA and air voids

If a mix is designed slightly to the left of minimum VMA at a compaction level of 50 blows and the pavement actually endures heavier traffic than expected (closer to 75 blow design level); then, the same asphalts content now plots on the right hand or "wet" side of the minimum VMA point for a mix designed using 75 blow compactions. Ultimately, a mix susceptible to rutting is the result.

This scenario can also work in the opposite direction. If a mix, designed at a compaction level of 75 blows as shown in Figure 2.7(b), is placed in a pavement with much lower volumes of traffic, then the final percentage of air voids (V_a) will be considerably higher than planned. This condition could lead to a more open, permeable mix allowing air and water to pass through easily. The consequence of this situation is a mix that hardens prematurely, becomes brittle and cracks at an early age or the aggregate ravels out of the mix because of the loss of asphalt adhesion. This condition may also lead to stripping.

For this reason, it is important that the compactive effort used to simulate the design traffic expected in the pavement be selected accordingly in the laboratory. Also, the mixture must be constructed with appropriate compaction equipment in the field to produce adequate initial density regardless of climatic conditions.

It is also important to note that the VMA criteria do not change based on the level of compaction. The reasoning for having sufficient VMA (providing space for the asphalt and air voids) is consistent regardless of the traffic level for which the mixture is being designed.

Effect of Air Voids

It should be emphasized that the design range of air voids (3 to 5 percent) is the level desired after several years of traffic. This goal does not vary with traffic as seen in Table 2.2; the laboratory compactive effort is supposed to be selected for the expected traffic. This design air void range will normally be achieved if the mix is designed at the correct compactive effort and the percent air voids after construction is about 8 percent. Some consolidation with traffic is expected and desired.

The consequence of a change in any factor orany detour in the procedure that offsets the total process will be a loss of performance or service life. It has been shown that mixtures that ultimately consolidate to less than three percent air voids can be expected to rut and shove if placed in heavy traffic locations. Several factors may contribute to this occurrence, such as an arbitrary or accidental increase in asphalt content at the mixing facility or an increased amount of ultra-fine particles passing the 75 µm (No. 200) sieve beyond that used in the laboratory, which will act as an asphalt extender. Similarly, problems can occur if the final air void content is above five percent or if the pavement is constructed with over eight percent air voids initially. Brittleness, premature cracking, raveling and stripping are all possible under these conditions. The overall objective is to limit adjustments of the design asphalt content to less than 0.5 percent air voids from the median of the design criteria (four percent), especially on the low side of the range and to verify that the plant mix closely resembles the laboratory mix.

Effect of Voids Filled with Asphalt

Although VFA, VMA and V_a are all interrelated and only two of the values are necessary to solve for the other, including the VFA criteria helps prevent the design of mixes with marginally acceptable VMA. The main effect of the VFA criteria is to limit maximum levels of VMA and subsequently maximum levels of asphalt content. VFA also restricts the allowable air void content for mixes that are near the minimum VMA criteria. Mixes designed for lower traffic volumes will not pass the VFA criteria with a relatively high percent air voids (five percent) even though the air void criteria range is met. The purpose is to avoid less durable mixes in light traffic situations.

Mixes designed for heavy traffic will not pass the VFA criteria with relatively low percent air voids (less than 3.5 percent) even though that amount of air void is within the acceptable range. Because low air void contents can be very critical in terms of permanent deformation (as discussed previously), the VFA criteria helps to avoid those mixes that would be susceptible to rutting in heavy traffic situations.

The VFA criteria provide an additional factor of safety in the design and construction process in terms of performance. Since changes can occur between the design stage and actual construction, an increased margin for error is desirable.

Influence of Structure and Climate

Mix design is a compromise of many factors. The asphalt content that provides the best overall performance in addition to passing the previously discussed conventional criteria would be considered the design value. The CAMAS computer program contained in the Asphalt Institute *Computer Assisted Asphalt Mix Analysis System package*, provides an additional tool for evaluating the predicted performance of a specific mix placed in a particular situation. The various mathematical models contained in the program have not been fully verified and the program is currently considered only a research tool. However, models are included for examining fatigue life, subgrade deformation and asphalt concrete deformation of the pavement and mix for the actual climatic and traffic conditions. If any of these levels of performance are not acceptable, then either the mix or the structure could be modified and a subsequent evaluation performed.

The decision-making process for selecting the design asphalt content in the mix varies with the circumstances involved in the specific case. Depending on the particular structure or agency policy, certain factors may be more important than others. Although it was found that it is not feasible, suitable, or practical to directly trade-off thickness for better mix compaction or a change in asphalt content, there are other advantages to integrating structural design and mix design.

The type of structure can alter the engineer's evaluation in many ways. For example, in an asphalt concrete overlay of a Portland cement concrete pavement, there would be little concern for fatigue, since the tensile strains in the bottom of the AC overlay would be minimal. This is also true for the subgrade deformation related to the compressive strain on the top of the subgrade. The main consideration would be how to limit the AC rutting as well as any supplementary treatments for minimizing reflective cracking. In this particular case, it may be worthwhile to look at the effects of altering the compactive effort in the lab and field while changing the asphalt content. Depending on the environmental conditions during construction, it may be worthwhile to use heavier rollers or a longer period of rolling to achieve more or the same density with less asphalt in the mix. Mixes with asphalt contents on the high side of the acceptable range are usually avoided in this situation.

In an asphalt pavement, all three performance indicators need to be evaluated in terms of future maintenance. Initially, it is important that the subgrade be adequately protected by the structure; the number of allowable repetitions based on subgrade deformation should exceed that expected or the pavement's performance may have little to do with proper mix design. In some cases, depending on location and traffic volume, the engineer may consider whether cracking or rutting is less of a future maintenance concern and the mix design can be selected accordingly. With all other factors being equal, mixes with asphalt contents on the high side of the range are less prone to cracking because of the additional flexibility. Similarly, mixes on the low side of the range are less susceptible to rutting.

Finally, climate can have a major impact on mix and pavement performance for a given pavement structure. Mix designs do not usually consider this factor except in selecting the category or grade of asphalt cement. Table 17.6 gives recommended asphalt grades for various temperature conditions.

Table 17.6: Selecting Asphalt Grade

Temperature Condition	Asphalt Grades	
Cold, Mean Annual Temperature $\leq 7^0$ C (45^0 F)	AC-5 AR-2000 120/150 pen.	AC-10 AR-4000 85/100 pen.
Warm, Mean Annual Temperature between 7^0 C (45^0 F) and 24^0 C (75^0 F)	AC-10 AR-4000 85/100 pen.	AC-20 AR-8000 60/70 pen.
Hot, Mean Annual Temperature between $\geq$ 24^0 C (75^0 F)	AC-20 AR-8000 60/70 pen.	AC-40 AR-16000 40/50 pen.

In hot climates, harder, more viscous asphalts are normally used to obtain more stability from asphalt adhesion as well as from aggregate interlock. If the mix is designed and constructed to maximize aggregate to aggregate contact, then the properties of the asphalt cement are less important. Regardless, asphalt contents on the low side of the acceptable range are recommended for these areas.

In colder climates, softer, less viscous asphalts are recommended to produce a mix which is less susceptible to low temperature shrinkage cracking. Rutting is less of a concern; therefore, additional stability from asphalt adhesion is not necessary. Usually asphalt contents on the high side of the acceptable range are recommended to furnish a mix which is more elastic and resilient.

Specific Project Conditions

The season of the year when the pavement is being constructed can be another factor to be considered when selecting the final design asphalt content. Summer paving would usually call for lower asphalt contents, while fall or early spring construction would dictate higher asphalt contents to assist compaction in cooler temperatures. Any shift in asphalt content is only a minor amount within the narrow range that passes all the previous criteria.

The amount and handling of traffic can also influence the final decision. If the actual traffic is at the low or high end of the broad traffic categories for selecting the laboratory compactive effort and mix design criteria, then the asphalt content could be slightly modified accordingly. Higher traffic areas would demand the lower asphalt contents within the acceptable range. Mixes to be used in overlay situations with reduced lane detours, where the pavement will undergo severe loading concentrations such as highly channelized wheel passes, very slow speeds or steep upgrades, demand additional attention in all phases of production. The design asphalt content

should be selected from the low end of the acceptable range and initial compaction requirements must be met. Traffic should be held off of the pavement as long as possible while the mix is cooling to normal temperatures. This cooling allows the asphalt to contribute more to the mix stability and less as a compaction lubricant.

2.16 MODIFIED MARSHALL METHOD FOR LARGE AGGREGATE

A modified Marshall method has been developed by Kandhal of the National Center for Asphalt Technology for mixes composed of aggregates with maximum size up to 38 mm (1.5 in.). This procedure is documented in draft form in the 1990 Proceedings of the Association of Asphalt Paving Technologists (AAPT). The procedure is basically the same as the original method except for these differences that are due to the larger specimen size that is used:

(a) The hammer weighs 10.2 kg (22.5 lb.) and has a 149.4 mm (5.88 in.) flat tamping face. Only a mechanically operated device is used for the same 457 mm (18 in.) drop height.

(b) The specimen has a 152.4 mm (6 in.) diameter by 95.2 mm (3.75 in.) height.

(c) The batch weights are typically 4 kg.

(d) The equipment for compacting and testing (molds and breaking heads) are proportionately larger to accommodate the larger specimens.

(e) The mix is placed in the mold in two approximately equal increments, with spading performed after each increment to avoid honey combing.

(f) The number of blows needed for the larger specimen is 1.5 times (75 or 112 blows) that required of the smaller specimen (50 or 75 blows) to obtain equivalent compaction.

(g) The design criteria should be modified as well. The minimum stability should be 2.25 times and the range of flow values should be 1.5 times the same criteria listed in Table 2.2 for the normal sized specimens.

(h) Similar to the normal procedure, these values should be used to convert the measured stability values to an equivalent value fora specimen with a 95.2 mm (3.75 in.) thickness, if the actual thickness varies:

Table 17.7: Height of Marshall specimen and Correlation Ratio

Approximate Height (mm)	Approximate Height (in.)	Specimen Volume (cc)	Correlation Ratio
88.9	3 1/2	1608 to 1626	1.12
90.5	3 9/16	1637 to 1665	1.09
92.1	3 5/8	1666 to 1694	1.06
93.7	3 11/16	1695 to 1723	1.03
95.2	3 3/4	1724 to 1752	1.00
96.8	3 13/16	1753 to 1781	0.97
98.4	3 7/8	1782 to 1810	0.95
100.0	3 15/16	1811 to 1839	0.92
101.6	4	1840 to 1868	0.90

Composition of Paving Mixtures
(ASTM D3515) for Marshal Method of Mix Design

Type of Mix: Dense Mix
Mix Designation: ¾" (19 mm)
Course Aggregate: Stone Chips
Bitumen: 80/100 pen. grade Bitumen
Fine Aggregate and Mineral Filler: Fine Fraction of Course Aggregate
Traffic Category: Medium Traffic (Compaction: 50 blows per face)

Sieve Size	% Passing	% Retained (Cumulative)	% Retained (Individual)	Batch Weight (gm)
1 in (25 mm)	100	0	0	0
¾ in (19 mm)	95	5	5	57
$^3/_8$ in (9.5 mm)	68	32	27	312
# 4 (4.75 mm)	50	50	18	208
# 8 (2.36 mm)	36	64	14	162
# 50 (300 μm)	12	88	24	277
# 200 (75 μm)	5	95	7	81
M.F.	0	100	5	58
Total			**100**	**1155**

% of Bitumen (of Total Mix), P_b

4.0% = 48.13 gm, 4.5% = 54.42 gm, 5.0% = 60.79 gm
5.5% = 67.22 gm, 6.0% = 73.72 gm

Specific Gravity

C.A. (1 inch - #8) (G_1) : 2.68 (ASTM C-127)
F.A. (#8 - #200) (G_2) : 2.68 (ASTM C-128)
M.F. (Passing #200) (G_3) : 2.77 (ASTM D-854)
Bitumen (G_b) : 1.02 (ASTM D-5)

Mixing Criteria:

Temperature: 148 – $153^0 \Rightarrow 150^0$ C, Time: 2.5 min.
Compaction Temp.: 138 – $142^0 \Rightarrow 140^0$ C
Oven Temperature for Bitumen and Aggregate: 155^0 C, Time: 2 hrs.

Experiment No: 17

Determination of Optimum Asphalt Content by Marshall Method of Mix Design

Name : **Student No**:

Asphalt content (P_b)%	Specimen wt. in air (W_a) gm	Specimen wt. in water (W_w) gm	Specimen wt. in air (SSD) (W_s) gm	G_{mb}	Unit wt. (lb/cft) G_{mb}x62.4	G_{mm}	P_S	G_{sb}	$\%V_a$	%VMA	%VFA	Height of specimen (mm)	Correction factor	Stability observed (lbs.)	Corrected stability (lbs.)	Flow value (0.25 mm)

$$G_{mb} = \frac{W_a}{Ws - W_w}; \qquad G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}; \qquad P_s = 100 - P_b; \qquad P_{mm} = 100; \qquad G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}; \qquad G_{sb} = \frac{P_1 + P_2 + P_3}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3}}$$

$$\%V_a = 100\frac{G_{mm} - G_{mb}}{G_{mm}}; \qquad \%VMA = 100 - \frac{G_{mb} * P_s}{G_{sb}}; \qquad \%VFA = \frac{\%VMA - \%V_a}{\%VMA} * 100$$