Transportation Engineering

Course Code –CE-422

Contact Hours -3+3

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Marshall Method of Mix Design

- Marshall Method of mix design is intended both for laboratory design and field control of bituminous hot-mix dense graded paving mixtures.
- Originally developed by Bruce Marshall of the Mississippi State Highway Department, the US Army Corps of Engineers refined and added certain features to Marshall's approach and it was then subsequently formalized as ASTM D 1559 and AASHTO T245.

Marshall Method of Mix Design (outline)

- It uses standard cylindrical test specimens (64 mm high and 102 mm in diameter). Two principal features of Marshall Method of mix design are Density Void Analysis and Stability Flow Test of compacted test specimen.
- Stability of test specimens is the maximum load resistance developed by standard test specimen at 60°C
- Flow value is the total movement or displacement occurring in the specimen between no load and the point of maximum load during stability test in units of 0.25mm (0.01 in).

Requirements for Marshall Method

- Marshall method of mix design require
  - Grain size distribution of the mix
  - Bitumen content
- Generally, trials are carried out to find out the optimum bitumen content for the specific gradation.

Selection and combination of Aggregates

- Selection of the aggregates to be used in a given paving mixture is a very important part of the design phase.
- In normal procedure, both coarse and fine aggregates available in the near vicinity of the proposed work are sampled and carefully examined for compliance with the individual specifications for these materials.
- In case no suitable single aggregate is available then aggregates from several different sources may have to be blended to get the required specified specimen.

Selection and combination of Aggregates

- The proportions selected must be within the specification and far enough from its extremes to provide room for the job mix tolerance so that when it is added or subtracted the mixture will not be outside the original specification range.
- Sieve Analysis of the aggregates can most economically be used in this case as determined by AASHTO methods of T27 and T37

Mineral Aggregate and Mix Composition

It is obvious that the fine aggregate and coarse aggregate only, in any combination, cannot meet the requirements of the specifications for total mineral aggregate. So, mineral fillers must be used in the mixture.

Passing Sieve Designation	Retained on Sieve Designation	Percent by weight
¾ in. (19.0 mm)	½ in. (12.5 mm)	0-6
½ in. (12.5 mm)	3/8 in. (9.5 mm)	9-40
3/8 in. (9.5 mm)	No.4 (4.75 mm)	9-45
No.4 (4.75 mm)	No. 10 (2.00 mm)	8-27
Total Coarse Aggregate	**No. 10 (2.00 mm)**	**50-65**
No. 10 (2.00 mm)	No. 40 (0.475 mm)	6-22
No. 40 (0.475 mm)	No. 80 (0.177 mm)	8-27
No. 80 (0.177 mm)	No. 200 (0.75 mm)	5-17
No. 200 (0.75 mm)	------	5-8
Total fine aggregate & filler	**Passing No. 10**	**35-50**
[illegible]		
Total mineral aggregate	------	100
Total Mix		
Total mineral aggregate		**92-95**
Asphalt cement		**5-8**
Total mix		100

Trial Mixes for Lab

- For first Trial Mixes
  - Total coarse aggregate 52 percent (50 ~ 65 percent)

Fine aggregate + Mineral Filler = (35~50)

  - Fine Aggregates is 40 percent.
  - Amount of mineral filler is 8 percent.
- Calculations made using the indicated proportions in determining the sieve analysis of the combined aggregates are as follows.

Sieve Analysis of Aggregates (percentage used for Experiment)

Passing Sieve Designation (Percent by weight)	Retained on Sieve Designation (Percent by weight)	AGGREGATE TYPE		
		COARSE AGGREGATES	FINE AGGREGATES	MINERAL FILLER
¾in.(19.0 mm)	½in.(12.5 mm)	5	----	----
½in.(12.5 mm)	3/8in.(9.5mm)	32	----	----
3/8in.(9.5mm)	No.4(4.75mm)	37	----	----
No.4(4.75mm)	No.10(2.00mm)	22	7	----
No.10(2.00mm)	No.40(0.475mm)	4	28	----
No.40(0.475mm)	No.80(0.177mm)	----	39	5
No.80(0.177mm)	No.200(0.75mm)	----	24	30
No.200(0.75mm)	-----	----	2	65
Total		100	100	100

Calculations for Sieve Analysis

1200 gm of dry material is required to make one specimen for Marshall Test

Passing Sieve Size	Retained on Sieve Size	Percent by weight				Agg. Wt. (gm)
		COARSE AGGREGATE	FINE AGGREGATE	MINERAL FILLER	TOTAL AGG.	
¾in. (19.0 mm)	½in. (12.5 mm)	0.52 x 5 = **2.6**	----	----	**2.6**	**31.2**
½in. 12.5mm)	3/8in. (9.5mm)	0.52 x 32 = **16.6**	----	----	**16.6**	**199.2**
3/8in. (9.5mm)	No.4 (4.75mm)	0.52 x 37 = **19.2**	----	----	**19.2**	**230.4**
No.4 (4.75mm	No.10 (2.00mm)	0.52 x 22 = **11.4**	0.40 x 7 = **2.8**	----	**14.2**	**170.4**
No.10 (2.00mm	No.40 (0.475m	0.52 x 4 = **2.2**	0.40 x 28 = **11.2**	----	**13.4**	**160.8**
No.40 (0.475mm)	No.80 (0.177mm)	----	0.40 x 39 = **15.6**	0.08 x 5 **0.4**	**16.0**	**192.0**
No.80 (0.177mm	No.200 (0.75mm)	----	0.40 x 24 = **9.6**	0.08 x 30 **2.4**	**12.0**	**144.0**
No.200 (0.75mm	-----	----	0.40 x 2 = **0.8**	0.08 x 65 **5.2**	**6.0**	**72.0**
Total		**52.0**	**40.0**	**8.0**	**100.0**	**1200**

Estimation of Bitumen Content

- Experience
- Using filler-to-bitumen ratio guideline (ranges 0.6 to 1.2)
- Computational Formula

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

- P = Approximate mix bitumen content, percentage by weight of total mix
- a = Percentage of mineral aggregate retained on sieve No.10 in whole no.

Estimation of Bitumen Content

- b = Percentage of mineral aggregate passing sieve No.10 and retained on sieve No.200
- c = Percentage of mineral aggregate passing sieve No.200
- k = 0.15, 11-15% passing sieve No.200.

  k= 0.18, 6-10% passing sieve No.200

  k=0.20, 5% passing sieve No.200
- F = 0 to 2%, based on the absorption of light and heavy aggregates.

  F = 0.7, incase no data is available.

Preparation of Test Specimen

- Separate the aggregate in desired fractions by dry sieving.
- The aggregates are first dried to a constant weight at 105 to 110°C.
- Amount of each size fraction required to produce a batch that will give 63.5+1.27 mm high compacted specimen is weighed in a separate pan for each test specimen. It is about 1.2kg of dry aggregates.
- Prepare at least three specimens for each combination of aggregates and bitumen.

Preparation of Test Specimen

- Dry the aggregates to the required mixing temperature.
- Add heated aggregates in a mixing bowl and the required quantity of bitumen is added. Mixing is carried out until all aggregate particles are fully coated with bitumen.
- Optimal viscosity of bitumen for compaction is between 2 Pa.s and 20 Pa.s.
- If viscosity is too low, the mix will be excessively mobile resulting in pushing of the material in front of the roller, high viscosities will significantly reduce the workability of the mix and little compaction will be achieved.

Preparation of Test Specimen

- Depending upon design traffic category (light, medium and heavy), the compacted mix is expected to withstand 35, 50 and 75 blows respectively applied with compaction hammer to each end of the specimen.
- After compaction, specimens are allowed to cool in air at room temperature until no deformation results on removal from the mould.

Apparatus for Marshall Test

- Sieves conforming to ASTM Standards
- Moulds
- Compaction Hammer
- Flow meter
- The Marshall Testing Machine, a compression testing machine

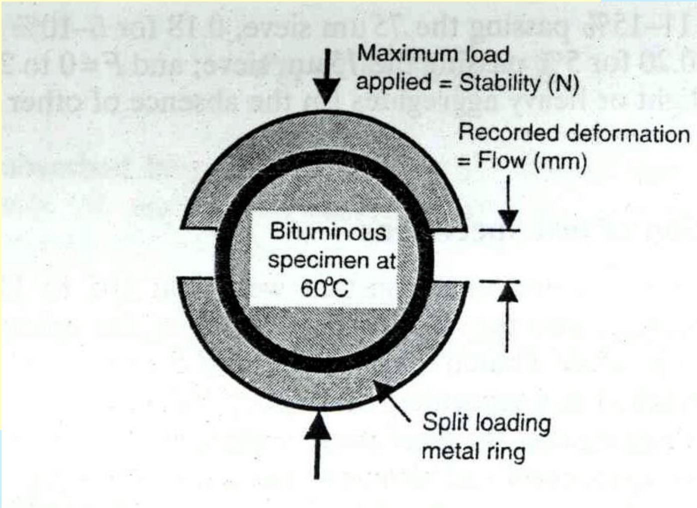
Casting of the Sample

- All fractions of aggregates are heated to a temperature of 250°F. Bitumen of specified grade is heated to a temperature of 350°F. Bitumen should not be heated for more than an hour.
- The required quantity of aggregates and bitumen is mixed manually or electrically at a temperature of 200 to 300°F.
- After mixing place it in mould and is compacted (using hammer 4.5 kg in weight and height of fall 45.7 cm) with 75 blows to the sample on each side. The specimen is then immersed in water bath at a testing temperature of 60°C for 30 to 40 minutes.

Test and Analysis for Marshall Test

- Then remove the specimen from water bath and place it on a base plate of Marshall Loading Machine. The proving ring and flow gauge are adjusted to zero reading.
- The Testing Machine will apply loads to test specimens through cylindrical segment testing heads at a constant rate.

The base plate of machine moves upward at a rate of 2 inches per minute (51 mm/min).

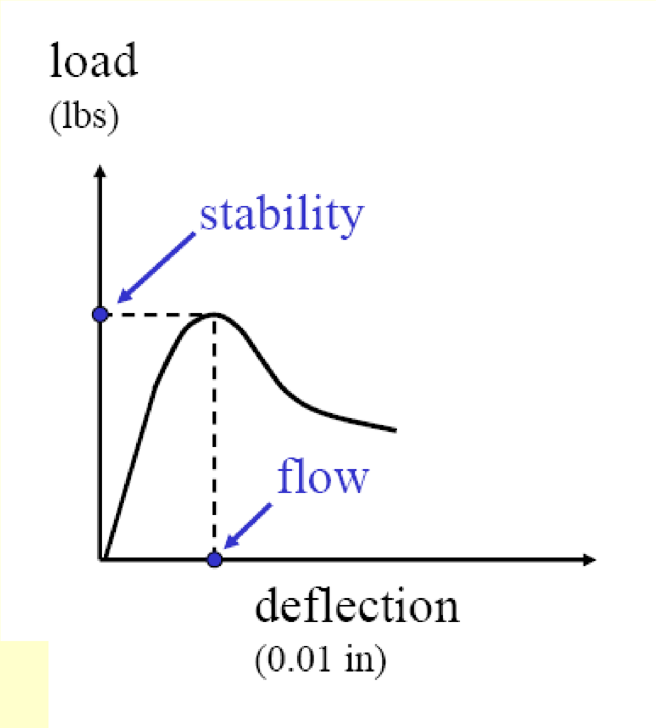


Stability and Flow Value

- The value of maximum load and dial gauges are recorded.
- Loading is applied until the specimen failure occurs.
- The elapsed time for the test after the removal of specimen is noted.

Marshall Specimen

Marshall Apparatus



Test and Analysis for Marshall Test

- In Marshall Method, each compacted test specimen is subjected to following tests and analysis in the order listed.
  - Bulk Specific Gravity Test
  - Stability and Flow Test
  - Density and Void Analysis
- Bulk Specific Gravity Test is performed on freshly compacted specimens after they have cooled to room temperature.
- It is performed by weighing the compacted specimen in air and then in water.

Test and Analysis for Marshall Test

- Stability is the force in Newton required producing failure of the test specimen. The applied testing load is determined from calibrated proving ring.
- Flow value is the magnitude of deformation of the specimen at the point of failure. The point of failure is defined by the maximum load reading obtained.

Computations

- Percentage Air Voids, Va

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

Where

- V_a = air voids in compacted mixture as a percentage of total volume.
- G_{mm} = maximum specific gravity of a paving mixture
- G_{mb} = Bulk specific gravity of a compacted mixture.

Computations

- Maximum Specific Gravity, G_{mm}

$$G_{mm} = \frac{100}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4}}$$

- Where, W 1 = %age weight of coarse aggregates , W 2 =%age weight of fine aggregates , W 3 = %age weight of mineral aggregates , W 4 = %age weight of bitumen , G 1 = Specific Gravity of coarse aggregates , G 2 = Specific Gravity of fine aggregates , G 3 = Specific Gravity of mineral aggregates , G 4 = Density of bitumen (g/cm^3)

Computation

Percentage of Voids in mineral Aggregates, VMA

- **VMA** = **V**b + **V**a

Where, Va = %age of voids in aggregates , Vb = %age of voids in bitumen

- **Vb = Gmb X (W 4 / G 4)**

<u>Percentage of voids filled with bitumen, VFB</u>

- **VFB = (Vb / VMA) X 100**

Calculation Tables

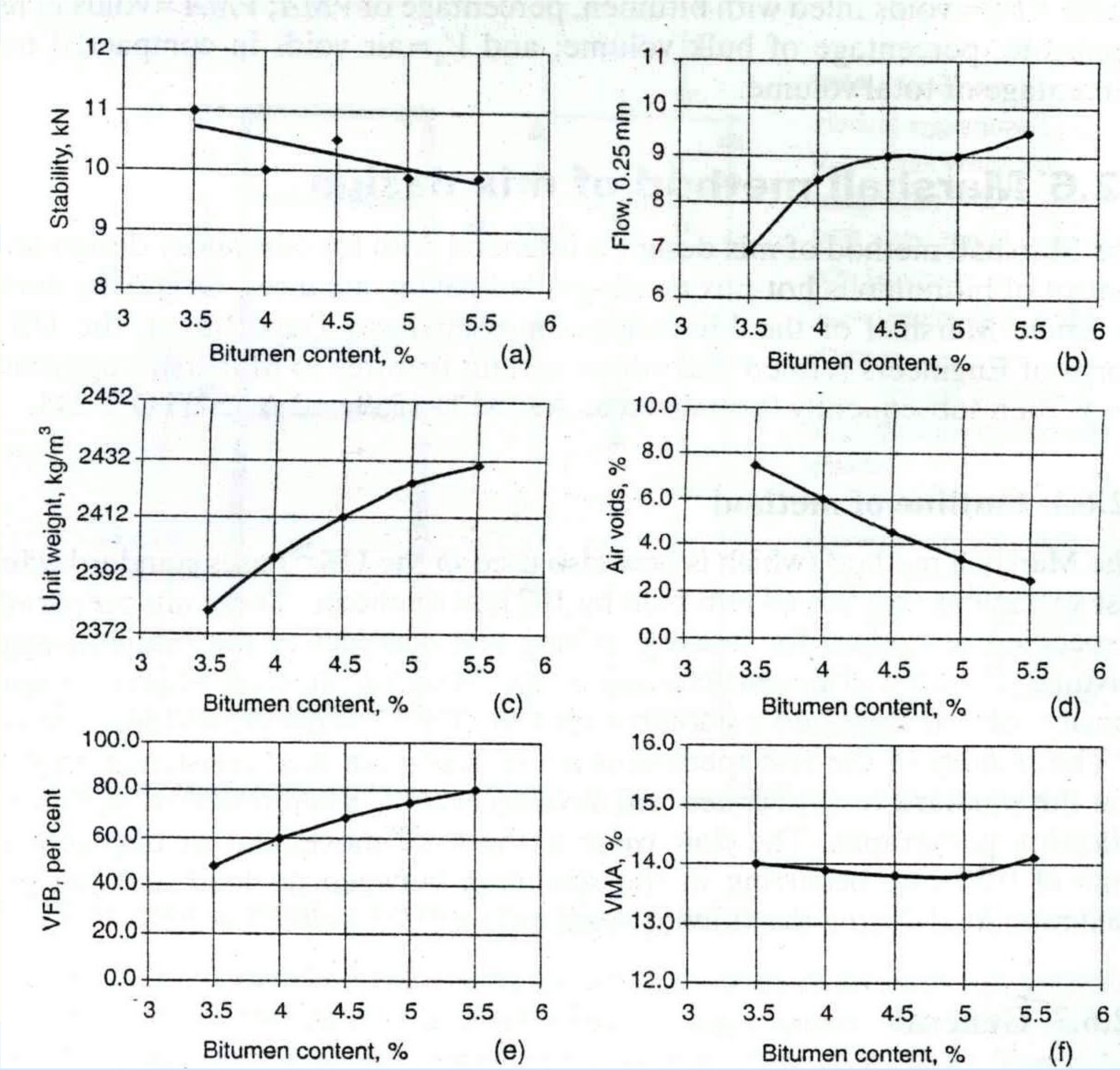
%age of Bitumen Content	Height of sample (mm)	Weight of agg. in air (gms)	Weight of agg. in water (gms)	Bulk Specific Gravity (Gmb)	Specific Gravity (Gmm)	%age of air voids in agg. (Va)	%age of voids in bitumen (Vb)	Voids in mineral agg. (VMA)	Voids filled with btmn (VFB)

Calculation Tables

ple	%age of Bitumen Content	Max. Proving Ring Reading (mm)	Stability Value (KN)		Flow Dial Gauge Reading (mm)	Flow Value
			Measured	Corrected		

Graphs

- Percentage of Bitumen Vs Percentage of Air voids in Aggregates (Va)
- Percentage of Bitumen Vs Voids in Mineral Aggregates (VMA)
- Percentage of Bitumen Vs Voids Filled with Bitumen (VFB)
- Percentage of Bitumen Vs Bulk Specific Gravity
- Percentage of Bitumen Vs Marshall Stability Value
- Percentage of Bitumen Vs Flow Value



Stability, kN
Bitumen content, %
(a)
Flow, 0.25 mm
Bitumen content, %
(b)
Unit weight, kg/m3
Bitumen content, %
(c)
Air voids, %
Bitumen content, %
(d)
VFB, per cent
Bitumen content, %
(e)
VMA, %
Bitumen content, %
(f)

Stability Correlation Ratios

Table 12.1 Stability correlation ratios

Specimen volume (cm³)	Approx. specimen thickness (mm)	Correlation ratio	Specimen volume (cm³)	Approx. specimen thickness (mm)	Correlation ratio
277–289	34.9	3.33	457–470	57.2	1.19
290–301	36.5	3.03	471–482	58.7	1.14
302–316	38.1	2.78	483–495	60.3	1.09
317–328	39.7	2.50	496–508	61.9	1.04
329–340	41.3	2.27	509–522	63.5	1.00
341–353	42.9	2.08	523–535	65.1	0.96
354–367	44.4	1.92	536–546	66.7	0.93
368–379	46.0	1.79	547–559	68.3	0.89
380–392	47.6	1.67	560–573	69.8	0.86
393–405	49.2	1.56	574–585	71.4	0.83
406–420	50.8	1.47	586–598	73.0	0.81
421–431	52.4	1.39	599–610	74.6	0.78
432–443	54.0	1.32	611–625	76.2	0.76
444–456	55.6	1.25			

Stability Correlation Ratios

Table 12.2 Marshall Mix design criteria

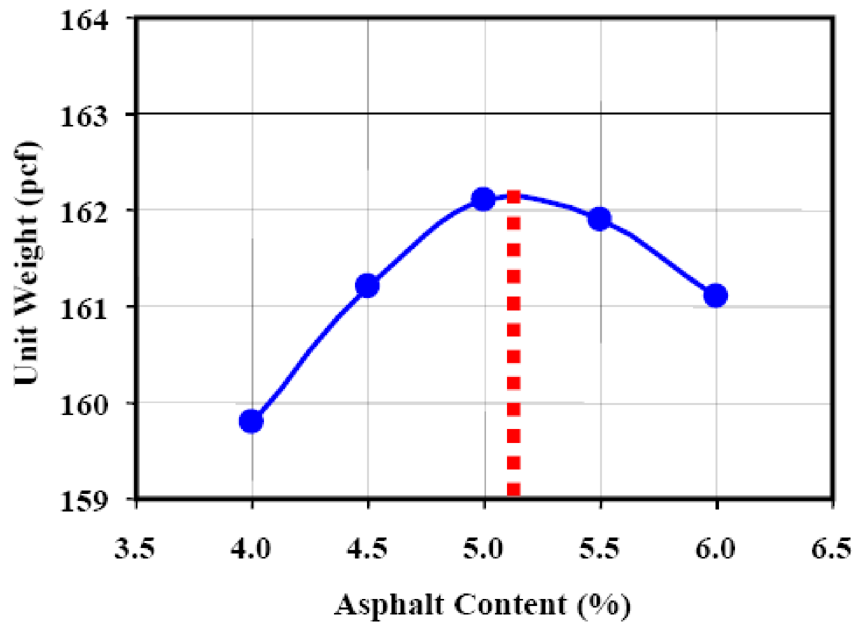
Marshall method Mix criteria	Light traffic: Surface and base Min	Light traffic: Surface and base Max	Medium traffic: Surface and base Min	Medium traffic: Surface and base Max	Heavy traffic: Surface and base Min	Heavy traffic: Surface and base Max
Compaction: No. of blows to each end of specimen	35		50		75	
Stability, N	3336		5338		8006	
Flow, 0.25 mm	8	18	8	16	8	14
% air voids	3	5	3	5	3	5
% voids in mineral aggregate (*VMA*)			See Table12.3			
% voids filled with bitumen (*VFB*)	70	80	65	78	65	75

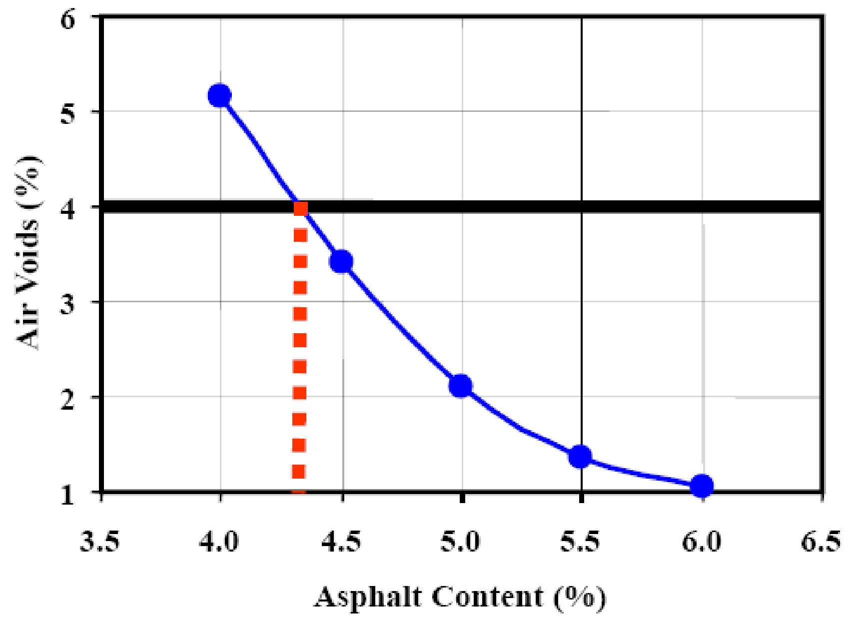
Table 12.3 Minimum values for voids in mineral aggregate (*VMA*)

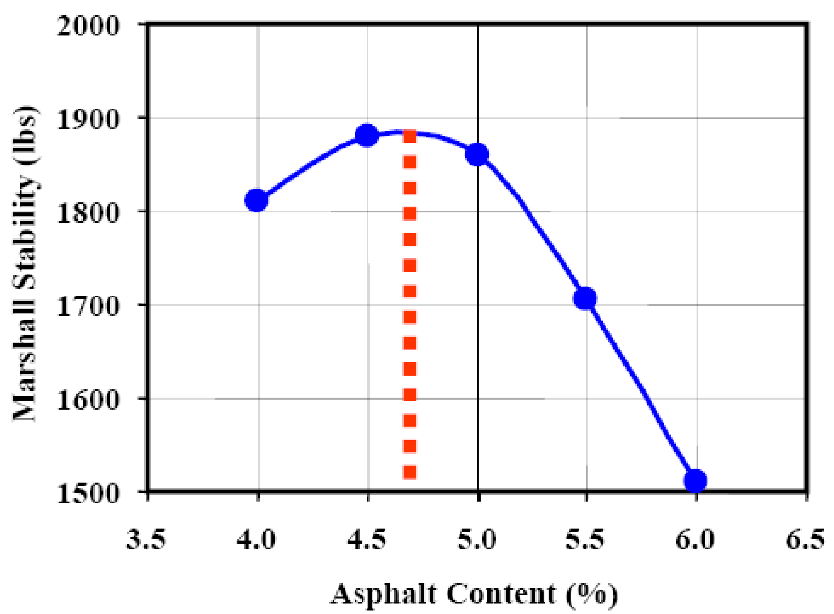
Nominal maximum particle size* (mm)	Design air voids, % 3.0	4.0	5.0
1.18	21.5	22.5	23.5
2.36	19.0	20.0	21.0
4.75	16.0	17.0	18.0
9.5	14.0	15.0	16.0
12.5	13.0	14.0	15.0
19.0	12.0	13.0	14.0
25.0	11.0	12.0	13.0
37.5	10.0	11.0	12.0

Optimum Bitumen Content

- Maximum Stability Value
- Maximum Unit Weight
- 4% Air Voids







Optimum Bitumen Content