Chapter 11

MARSHALL METHOD OF ASPHALT-CONCRETE MIX DESIGN

11.1 INTRODUCTION

Bituminous mixes (some times called asphalt mixes) are used in the surface layer of road and airfield pavements. The mix is composed usually of aggregate and asphalt cements. Some types of bituminous mixes are also used in base coarse. The design of asphalt paving mix, as with the design of other engineering materials is largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structure.

The desirable properties of Asphalt mixes are:

1. Resistance to permanent deformation: The mix should not distort or be displaced when subjected to traffic loads. The resistance to permanent deformation is more important at high temperatures.

2. Fatigue resistance: the mix should not crack when subjected to repeated loads over a period of time.

3. Resistance to low temperature cracking. This mix property is important in cold regions.

4. Durability: the mix should contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles. The compacted mix should not have very high air voids, which accelerates the aging process.

5. Resistance to moisture-induced damage.

6. Skid resistance.

7. Workability: the mix must be capable of being placed and compacted with reasonable effort.

8. Low noise and good drainage properties: If the mix is to be used for the surface (wearing) layer of the pavement structure.

Marshall stability and Hveem stabilometer tests are largely used for the routine testing. Criteria for the suitable mix design have been specified by the Asphalt Institute.

11.2 OBJECTIVE

To design the Asphalt concrete mix using Marshall method.

11.3 MARSHALL METHOD OF MIX DESIGN

In this method, the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute. There are two major features of the Marshall method of mix design. (i) density-voids analysis and (ii) stability-flow tests. The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. The flow value is the deformation that the test specimen undergoes during loading upto the maximum load. Flow is measured in 0.25 mm units. In this test, an attempt is made to obtain optimum binder content for the type of aggregate mix used and the expected traffic intensity.

11.4 STEPS OF DESIGN

1. Select aggregate grading to be used (Table 11.2)
2. Determine the proportion of each aggregate size required to produce the design grading.
3. Determine the specific gravity of the aggregate combination and asphalt cement.
4. Prepare the trial specimens with varying asphalt contents.
5. Determine the specific gravity of each compacted specimen.
6. Perform stability tests on the specimens.
7. Calculate the percentage of voids, and percent voids filled with Bitumen in each specimen.
8. Select the optimum binder content from the data obtained.
9. Evaluate the design with the design requirements.

11.5 APPARATUS

1. Mold Assembly: cylindrical moulds of 10 cm diameter and 7.5 cm height consisting of a base plate and collar extension (Figure 11.3)
2. Sample Extractor: for extruding the compacted specimen from the mould (Figure 11.2)
3. Compaction pedestal and hammer.
4. Breaking head.
5. Loading machine (Figure 11.1)
6. Flow meter , water bath, thermometers

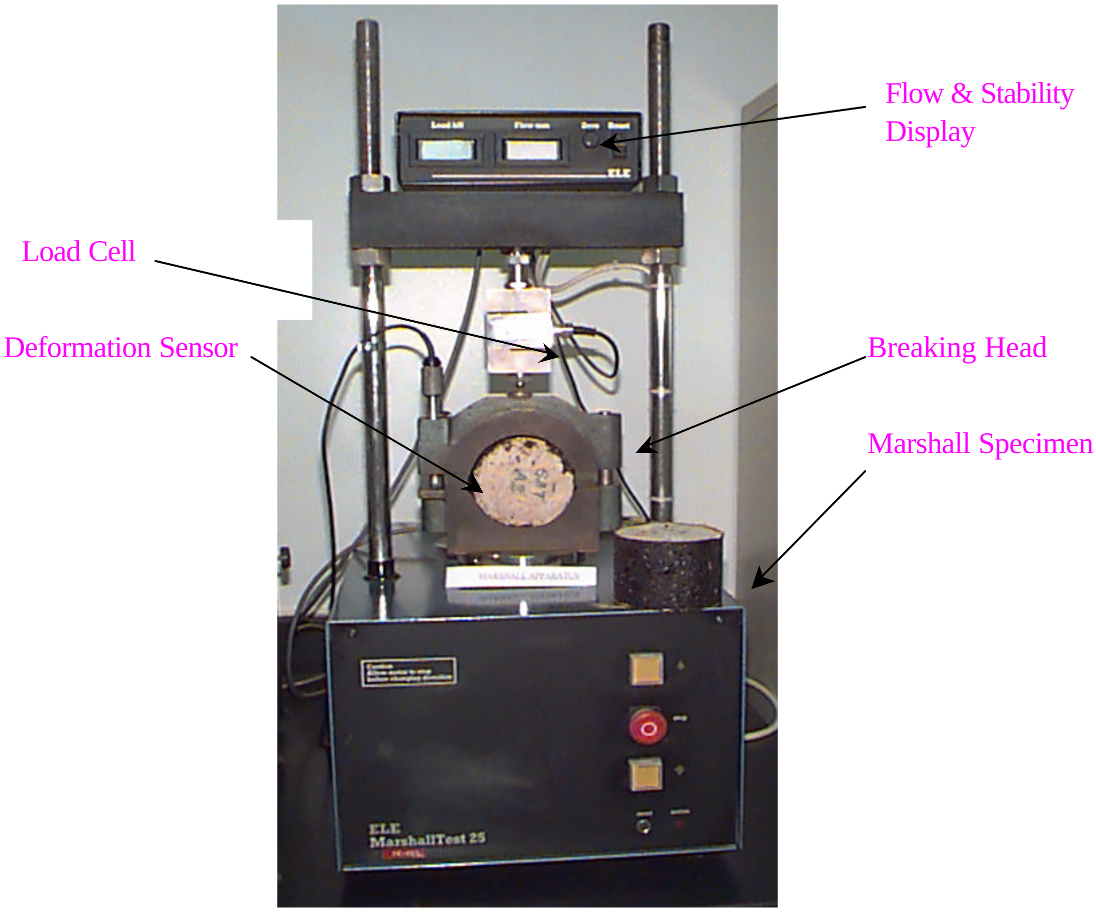

Figure 11.1 Marshall Stability & Flow Test Setup

Figure 11.2 Marshall Specimen Extractor

11.6 PROCEDURE

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

- Bulk density determination.
- Stability and flow test.
- Density and voids analysis.

11.6.1 Preparation of test specimens

The coarse aggregate, fine aggregate, and the filler material should be proportioned so as to fulfill the requirements of the relevant standards. The required quantity of the mix is taken so as to produce compacted bituminous mix specimens of thickness 63.5 mm approximately. 1200 gm of aggregates and filler are required to produce the desired thickness. The aggregates are heated to a temperature of 175° to 190°C the compaction mould assembly and rammer are cleaned and kept pre-heated to a temperature of 100°C to 145°C. The bitumen is heated to a temperature of 121°C to 138°C and the required amount of first trial of bitumen is added to the heated aggregate and thoroughly mixed. The mix is placed in a mould and compacted with number of blows specified. The sample is taken out of the mould after few minutes using sample extractor.

Figure 11.3 Test Specimen Preparation

11.6.2 Bulk density of the compacted specimen

The bulk density of the sample is usually determined by weighting the sample in air and in water. It may be necessary to coat samples with paraffin before determining density. The specific gravity G_{bcm} of the specimen is given by

$$G_{bcm} = \frac{W_a}{W_a - W_w}$$

where,

W_a = weight of sample in air (g)

W_w = weight of sample in water (g)

11.6.3 Stability test

In conducting the stability test, the specimen is immersed in a bath of water at a temperature of 60° ± 1°C for a period of 30 minutes. It is then placed in the Marshall stability testing machine (Fig. 7.1) and loaded at a constant rate of deformation of 5 mm per minute until failure. The total maximum in kN (that causes failure of the specimen) is taken as Marshall Stability. The stability value so obtained is corrected for volume (Table 11.1). The total amount of deformation is units of 0.25 mm that occurs at maximum load is recorded as Flow Value. The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds.

11.7 RESULTS AND CALCULATIONS

Following results and analysis is performed on the data obtained from the experiments.

11.7.1 Bulk specific gravity of aggregate (G_{bam})

Since the aggregate mixture consists of different fractions of coarse aggregate, fine aggregate, and mineral filler with different specific gravities, the bulk specific gravity of the total aggregate in the paving mixture is given as

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

where,

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

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

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

11.7.2 Maximu specific gravity of aggregate mixture (G_{bam})

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

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

where,

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

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

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

11.7.3Percent voids in compacted mineral aggregate (VMA)

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

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

where,

VMA = percent voids in mineral aggregates.

G_{bcm} = bulk specific gravity of compacted specimen

G_{bam} = bulk specific gravity of aggregate.

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

11.7.4 Percent air voids in compacted mixture (P_{av})

Percent air voids is the ratio (expressed as a percentage) between the volume of the air voids between the coated particles and the total volume of the mixture.

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

where,

P_{av} = percent air voids in compacted mixture

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

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

11.8 DETERMINATION OF OPTIMUM BINDER CONTENT

Five separate smooth curves are drawn (Figure 11.4) with percent of asphalt on x-axis and the following on y-axis

- unit weight
- Marshall stability
- Flow
- VMA
- Voids in total mix (P_{av})

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

$$B_0 = \frac{B_1 + B_2 + B_3}{3}$$

where,

B_0 = optimum Bitumen content.

B_1 = % asphalt content at maximum unit weight.

B_2 = % asphalt content at maximum stability.

B_3 = % asphalt content at specified percent air voids in the total mix.

11.9 EVALUATION AND ADJUSTMENT OF MIX DESIGN

The overall objective of the mix design is to determine an optimum blend of different components that will satisfy the requirements of the given specifications (Table 11.3). This mixture should have:

1. Adequate amount of asphalt to ensure a durable pavement.

2. Adequate mix stability to prevent unacceptable distortion and displacement when traffic load is applied.

3. Adequate voids in the total compacted mixture to permit a small amount of compaction when traffic load is applied without bleeding and loss of stability.

4. Adequate workability to facilitate placement of the mix without segregation.

If the mix design for the optimum binder content does not satisfy all the requirements of specifications (table 11.3) It is necessary to adjust the original blend of aggregates. The trial mixes can be adjusted by using the following guidelines.

1. If low voids : The voids can be increased by adding more coarse aggregates.

2. If high voids : Increase the amount of mineral filler in the mix.

3. If low stability: This condition suggests low quality of aggregates. The quality of aggregates should be improved. (use different aggregate or use cement coated aggregate)

Table 11.1 **Stability Correlation Ratios**

Volume of specimen, cm^3	Approximate thickness of specimen mm	in.	Correlation ratio
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

Table 11.2 Aggregate Specifications (MPW)

Sieve Size	Percent by Passing Weight		
	Type I Base course	Type II Binder or leveling course	Type III Wearing course
1 - ½ inch	100	--	--
1 inch	72 – 100	100	--
¾ inch	60 – 89	82 – 100	100
½ inch	46 – 76	60 – 84	66 – 95
3/8 inch	40 – 67	49 – 74	54 – 88
No. 4	30 – 54	32 – 58	37 – 70
No. 8	22 – 43	23 – 45	26 – 52
No. 16	15 – 36	16 – 34	18 – 40
No. 30	10 – 28	12 – 25	13 – 30
No. 50	6 – 22	8 – 20	8 – 23
No. 100	4 – 14	5 – 13	6 – 16
No. 200	2 – 8	4 – 7	4 - 10
Asphalt cement (% by weight of total aggregate)	3.5 – 5.0	4.0 – 6.5	4.5 – 6.5

Table11.3 MPW Specifications

Description	Type I Base course		Type II Binder or leveling course		Type III Wearing course	
	Min.	Max.	Min.	Max.	Min.	Max.
Marshall specimens (ASTM D 1559) No. of comp. Blows, each end of specimen	75		75		75	
Stability, kg.	350	--	500	--	600	--
Flow, 0.25 mm	8	16	8	16	8	16
VMA	13	--	14	--	15	--
Air voids, %	3	8	3	8	4	6
Aggregate voids filled with bitumen, %	60	80	65	85	70	85
Immersion compression specimen (AASHTO T 165) index of retained strength, %	70	--	70	--	70	--

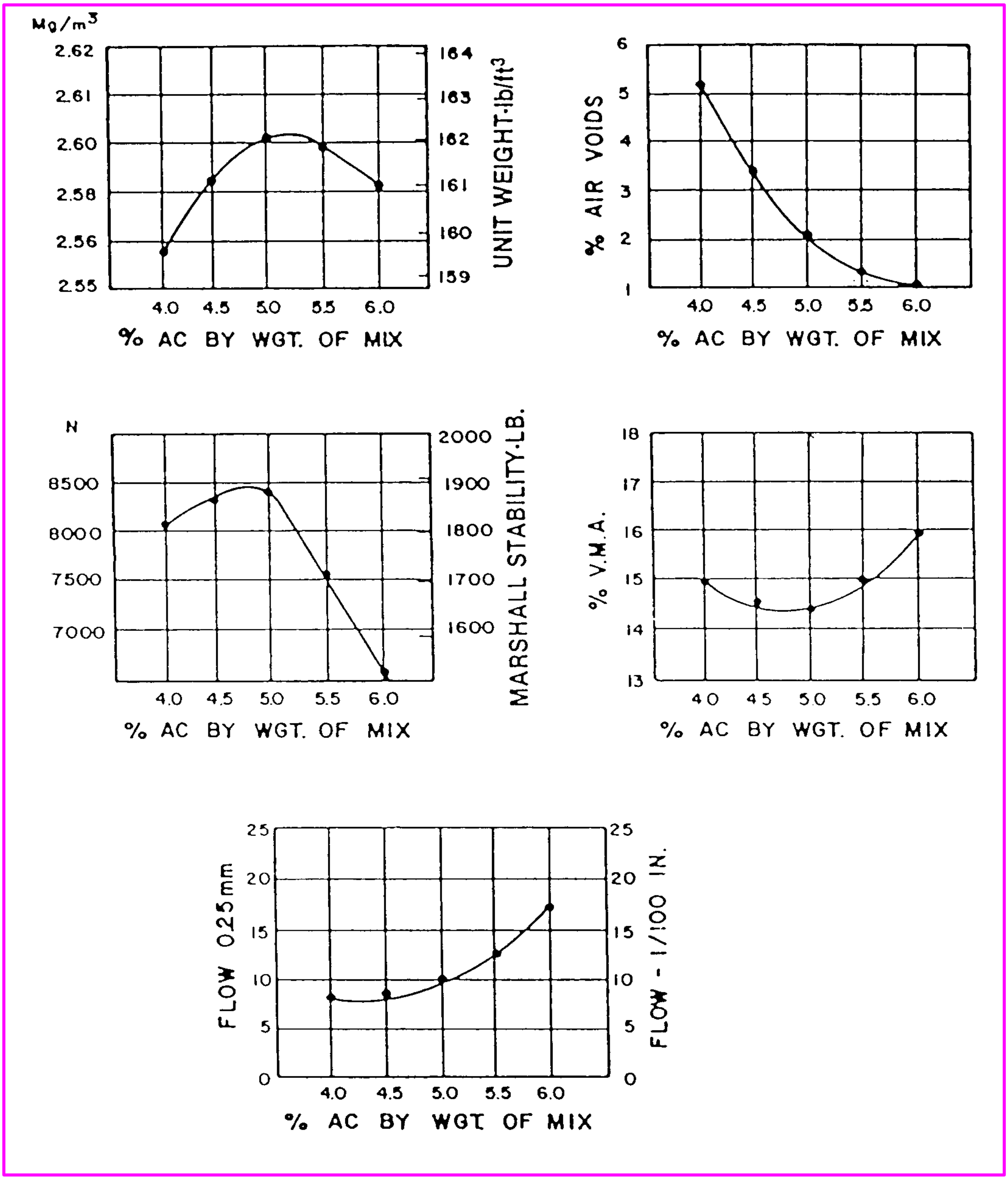

Figure. 11.4 Marshall Test – Typical Plots

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Marshall Test

DATA SHEET 2

Specification for Aggregate Selection

(From Kuwait Motorway Specifications for Wearing Course Type III)

S/L No.	Sieve size (Passing)	Specification Range(%) Pass	Our Selection	% Retained	Sample Wt. (gm)
0	25.0 mm to 19.0 mm (3/4")	100			
1	19.0 mm to 12.5 mm (1/2")	66-95			
2	12.5 mm to 9.5 mm (3/8")	54-88			
3	9.5 mm to 4.75 mm (no.4)	37-70			
4	4.75 mm to 2.36 mm (no.8)	26-52			
5	2.36 mm to 1.18 mm (no.16)	18-40			
6	1.18 mm to 600 um (no.30)	13-30			
7	600 um to 300 um (no.50)	8-23			
8	300 um to 150 um (no.100)	6-16			
9	150 um to 75 um (no.200)	4-10			
10	< 75 um (filler) Pan	0			

Total wt.=1200 gm

	% of Total Aggregate
Coarse Aggregate =	
Fine Aggregate =	
Filler (Agg. dust) =	

% Bitumen	Wt.of bitumen

Specific Gravity

Coarse Aggregate	
Fine Aggregate	
Filler	
Bitumen	

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DATA SHEET 2

Marshall Stability Test

Type of grading aggregate:

Mixing temperature °C :

Number of blows :

Grade of Bitumen :

Compaction temperature:

% Asphalt by Weight of Total Aggregate Mix	Weight of specimen (g)						G_{bcm}			Stability			Flow		
	In Air			In water											
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3

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DATA SHEET 3

Asphalt % by weight of Total Aggregate Mix	G_{bcm}	Volume	G_{bam}	G_{mp}	VMA	Pav	Stability		Flow
							Obs.	Corr.	