

# Marshall Mix Design

Lecture Notes in Transportation Systems Engineering

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## 1 Overview

The mix design (wetmix) determines the optimum bitumen content. This is preceded by the dry mix design discussed in the previous chapter. There are many methods available for mix design which vary in the size of the test specimen, compaction, and other test specifications. Marshall method of mix design is the most popular one and is discussed below.

## 2 Marshall mix design

The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded. The important steps involved in Marshall mix design are summarized next.

## 3 Specimen preparation

Approximately 1200gm of aggregates and filler is heated to a temperature of  $175 - 190^{\circ}\text{C}$ . Bitumen is heated to a temperature of  $121 - 125^{\circ}\text{C}$  with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of  $154 - 160^{\circ}\text{C}$ . The mix is placed in a preheated mould and compacted by a rammer with 50 blows on either side at temperature of  $138^{\circ}\text{C}$  to  $149^{\circ}\text{C}$ . The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of  $63.5 \pm 3$  mm. Vary the bitumen content in the next trial by +0.5% and repeat the above procedure. Number of trials are predetermined. The prepared mould is loaded in the Marshall test setup as shown in the figure 1.

## 4 Properties of the mix

The properties that are of interest include the theoretical specific gravity  $G_t$ , the bulk specific gravity of the mix  $G_m$ , percent air voids  $V_v$ , percent volume of bitumen  $V_b$ , percent void in mixed aggregate VMA and percent voids filled with bitumen VFB. These calculations are discussed next. To understand these calculation a phase diagram is given in Figure 2.

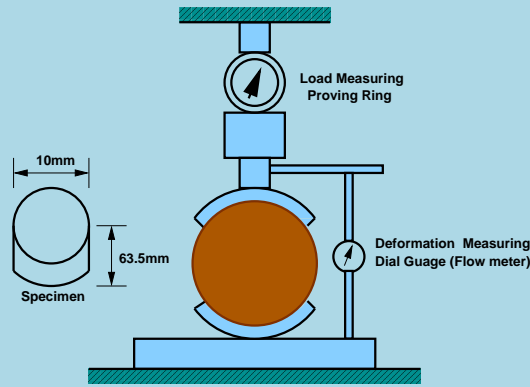


Figure 1: Marshall test setup

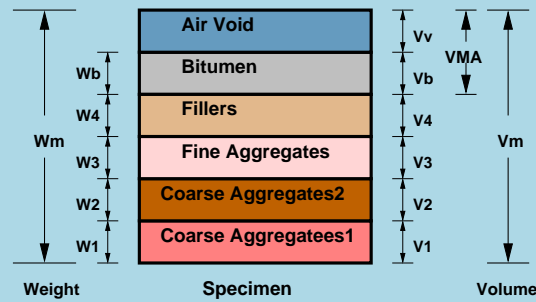


Figure 2: Phase diagram of a bituminous mix

#### 4.1 Theoretical specific gravity of the mix $G_t$

Theoretical specific gravity  $G_t$  is the specific gravity without considering air voids, and is given by:

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}} \quad (1)$$

where,  $W_1$  is the weight of coarse aggregate in the total mix,  $W_2$  is the weight of fine aggregate in the total mix,  $W_3$  is the weight of filler in the total mix,  $W_b$  is the weight of bitumen in the total mix,  $G_1$  is the apparent specific gravity of coarse aggregate,  $G_2$  is the apparent specific gravity of fine aggregate,  $G_3$  is the apparent specific gravity of filler and  $G_b$  is the apparent specific gravity of bitumen,

#### 4.2 Bulk specific gravity of mix $G_m$

The bulk specific gravity or the actual specific gravity of the mix  $G_m$  is the specific gravity considering air voids and is found out by:

$$G_m = \frac{W_m}{W_m - W_w} \quad (2)$$

where,  $W_m$  is the weight of mix in air,  $W_w$  is the weight of mix in water, Note that  $W_m - W_w$  gives the volume of the mix. Sometimes to get accurate bulk specific gravity, the specimen

is coated with thin film of paraffin wax, when weight is taken in the water. This, however requires to consider the weight and volume of wax in the calculations.

### 4.3 Air voids percent $V_v$

Air voids  $V_v$  is the percent of air voids by volume in the specimen and is given by:

$$V_v = \frac{(G_t - G_m)100}{G_t} \quad (3)$$

where  $G_t$  is the theoretical specific gravity of the mix, given by equation 26.1. and  $G_m$  is the bulk or actual specific gravity of the mix given by equation 26.2.

### 4.4 Percent volume of bitumen $V_b$

The volume of bitumen  $V_b$  is the percent of volume of bitumen to the total volume and given by:

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}} \quad (4)$$

where,  $W_1$  is the weight of coarse aggregate in the total mix,  $W_2$  is the weight of fine aggregate in the total mix,  $W_3$  is the weight of filler in the total mix,  $W_b$  is the weight of bitumen in the total mix,  $G_b$  is the apparent specific gravity of bitumen, and  $G_m$  is the bulk specific gravity of mix given by equation 26.2.

### 4.5 Voids in mineral aggregate $VMA$

Voids in mineral aggregate  $VMA$  is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen, and is calculated from

$$VMA = V_v + V_b \quad (5)$$

where,  $V_v$  is the percent air voids in the mix, given by equation 26.3. and  $V_b$  is percent bitumen content in the mix, given by equation 26.4. (4).

### 4.6 Voids filled with bitumen $VFB$

Voids filled with bitumen  $VFB$  is the voids in the mineral aggregate frame work filled with the bitumen, and is calculated as:

$$VFB = \frac{V_b \times 100}{VMA} \quad (6)$$

where,  $V_b$  is percent bitumen content in the mix, given by equation 26.4. and  $VMA$  is the percent voids in the mineral aggregate, given by equation 26.5.

## 5 Determine Marshall stability and flow

Marshall stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (5 cm per minute). While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall flow value of the specimen.

## 6 Apply stability correction

It is possible while making the specimen the thickness slightly vary from the standard specification of 63.5 mm. Therefore, measured stability values need to be corrected to those which would have been obtained if the specimens had been exactly 63.5 mm. This is done by multiplying each measured stability value by an appropriated correlation factors as given in Table below.

Table 1: Correction factors for Marshall stability values

Volume of specimen (cm <sup>3</sup> )	Thickness of specimen (mm)	Correction Factor
457 - 470	57.1	1.19
471 - 482	68.7	1.14
483 - 495	60.3	1.09
496 - 508	61.9	1.04
509 - 522	63.5	1.00
523 - 535	65.1	0.96
536 - 546	66.7	0.93
547 - 559	68.3	0.89
560 - 573	69.9	0.86

## 7 Prepare graphical plots

The average value of the above properties are determined for each mix with different bitumen content and the following graphical plots are prepared:

1. Binder content versus corrected Marshall stability
2. Binder content versus Marshall flow
3. Binder content versus percentage of void ( $V_v$ ) in the total mix
4. Binder content versus voids filled with bitumen ( $VFB$ )
5. Binder content versus unit weight or bulk specific gravity ( $G_m$ )

## 8 Determine optimum bitumen content

Determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found from the graphs obtained in the previous step.

1. Binder content corresponding to maximum stability
2. Binder content corresponding to maximum bulk specific gravity ( $G_m$ )
3. Binder content corresponding to the median of designed limits of percent air voids ( $V_v$ ) in the total mix (i.e. 4%)

The stability value, flow value, and  $VFB$  are checked with Marshall mix design specification chart given in Table below. Mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads.

Table 2: Marshall mix design specification

Test Property	Specified Value
Marshall stability, kg	340 (minimum)
Flow value, 0.25 mm units	8 - 17
Percent air voids in the mix $V_v\%$	3 - 5
Voids filled with bitumen $VFB\%$	75 - 85

Figure 3: Marshal graphical plots

## 9 Numerical example - 1

The specific gravities and weight proportions for aggregate and bitumen are as under for the preparation of Marshall mix design. The volume and weight of one Marshall specimen was found to be 475 cc and 1100 gm. Assuming absorption of bitumen in aggregate is zero, find  $V_v$ ,  $V_b$ ,  $VMA$  and  $VFB$ ;

Item	A_1	A_2	A_3	A_4	B
Wt (gm)	825	1200	325	150	100
Sp. Gr	2.63	2.51	2.46	2.43	1.05

### Solution

$$\begin{aligned}G_t &= \frac{825 + 1200 + 325 + 150 + 100}{\frac{825}{2.63} + \frac{1200}{2.51} + \frac{325}{2.46} + \frac{150}{2.43} + \frac{100}{1.05}} \\&= \frac{2600}{1080.86} \\&= 2.406 \\G_m &= \frac{1100}{475} \\&= 2.316 \\V_v &= \frac{2.406 - 2.316}{2.406} \times 100 \\&= 3.741 \% \\V_b &= \frac{100}{1.05} \times \frac{2.316}{1100} \\&= 20.052 \% \\VMA &= (3.741 + 20.05) \\&= 23.793 \% \\VFB &= \frac{20.052}{23.793} \times 100 \\&= 84.277 \%\end{aligned}$$

## 10 Numerical example - 2

The results of Marshall test for five specimen is given below. Find the optimum bitumen content of the mix.

Bitumen content	Stability (kg)	Flow (units)	$V_v$ (%)	$VFB$ (%)	$G_m$
3	499.4	9.0	12.5	34	2.17
4	717.3	9.6	7.2	65	2.21
5	812.7	12.0	3.9	84	2.26
6	767.3	14.8	2.4	91	2.23
7	662.8	19.5	1.9	93	2.18

**Solution** Plot the graphs and find bitumen content corresponding to

1. Max stability = 5 percent bitumen content.
2. Max  $G_m$  = 5 percent bitumen content.
3. 4% percent air void = 3 percent bitumen content.

The optimum bitumen extent is the average of above = 4.33 percent.

## 11 Summary

Marshal stability test is the performance prediction measure conducted on the bituminous mix. The procedure consists of determination of properties of mix, Marshal stability and flow analysis and finally determination of optimum bitumen content. The concept of phase diagram is used for the calculations.

## 12 Problems

1. In Marshall stability test, the sample is compacted using a rammer giving
  - (a) 50 blows
  - (b) 20 blows
  - (c) 25 blows
  - (d) 75 blows
2. The Marshall flow value is expressed in units of
  - (a) 25 mm
  - (b) 2.5mm



- (c) 5mm
- (d) 3mm

## 13 Solutions

1. In Marshall stability test, the sample is compacted using a rammer giving

- (a) 50 blows ✓
- (b) 20 blows
- (c) 25 blows
- (d) 75 blows

2. The Marshall flow value is expressed in units of

- (a) 25 mm
- (b) 2.5mm ✓
- (c) 5mm
- (d) 3mm

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