# CE 451: TRANSPORTATION ENGINEERING II: PAVEMENT DESIGN AND RAILWAY ENGINEERING
## 4.00 CREDITS, 4 HRS/WEEK

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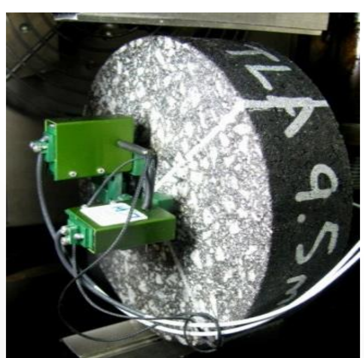
# Hot-Mix Asphalt Mix Design



# Desired Properties of HMA

Current mix design procedures are empirical, is a combination of art and science, the existing mix design has a long history of acceptable value

- The desirable mix properties are:
  - Stability
  - Durability
  - Flexibility
  - Fatigue resistance
  - Skid resistance
  - Impermeability
  - workability

# Desired Properties of HMA

- Stability
  - Is the ability of the asphalt paving mixture to resist deformation from imposed loads
  - Unstable pavements are marked by channeling (rut), and corrugation(washboarding).

Corrugations on a street

Shoving on street

# Desired Properties of HMA

- **Stability**
  - Stability is dependent on both internal friction and cohesion
  - Internal friction is dependent on surface texture, gradation of aggregate, particle shape, density of mix, and quantity and type of asphalt
  - Frictional resistance increases with the surface roughness and angularity of the aggregate particles
  - frictional resistance also increase with the area of the particle contact

# Desired Properties of HMA

- **Stability**
  - Excessive asphalt in the mix tends to act as a lubricant and lower the internal friction of the stone framework thus reduce the stability of the mixture
  - Cohesion is the internal binding force that is inherent in the asphalt mixture
  - Cohesion increases with increasing asphalt content upto optimum point and then decreases

# Desired Properties of HMA

- **Durability**
  - Is the property that describes its ability to resist the detrimental effects of air, water, temperature and traffic
  - Durability generally increases with high asphalt contents, dense gradation and well-compacted , impervious mixture
  - Thicker asphalt film are more resistant to age-hardening, i.e., a longer period of time is required to reduce a thicker film of asphalt to the same degree of brittleness as a thin film

# Desired Properties of HMA

- **Durability**
  - A mixture having a high asphalt content, with voids completely filled with asphalt, may provide the maximum in durability, however would undesirable from the standpoint of stability
  - When placed in roadway the pavement would channel and move under traffic
  - Bleeding/flushing of asphalt to the surface would also take place
  - Maximum stability are attained at some critical value of asphalt content, if more increase in asphalt, stability will decrease (lubrication of aggregates)
  - Compromise is necessary

# Desired Properties of HMA

- **Flexibility**
  - It is the ability of the paving mixture to bend slightly, without cracking, and to conform to gradual settlements and movement of base and subgrade
  - Differential settlements in the pavement occasionally occur, since it is not possible to maintain the density of subgrade uniform at all sections, so different support value
  - So asphalt layer must have the ability to conform the minor localized and differential settlements without cracking
  - Generally flexibility enhances with open-graded aggregates, but other criteria must be checked

# Desired Properties of HMA

- **Fatigue resistance**
  - Is the ability of the asphalt layer to withstand repeated flexing caused by the passage of wheel loads
  - Quantity of asphalt is of great importance for fatigue resistance, higher the asphalt content, greater the fatigue resistance
  - Dense graded asphalt mix has more fatigue resistance than the open graded mix
  - Well graded mix with higher asphalt contents without causing bleeding/flushing in a compacted pavement will give better result against fatigue failure

# Desired Properties of HMA

- **Permeability**
  - Is the resistance of paving mixture against passage of water and air
  - Void contents, interconnected voids and their accessibility to the surface are indications of susceptibility of pavement to the passage of air and water

# Desired Properties of HMA

- **Workability**
  - Is the ease with which paving mixture may be placed and compacted
  - Aggregate with high stability, sometimes lead to less workability
  - Workability are associated with quickness of the mixture to lay and compact, it should be ensured
  - However , with machine spreading workability is a not a big problem

# Objectives of HMA Mix Design

- Sufficient asphalt to ensure a durable pavement
- Sufficient mix stability to satisfy the traffic demands without distortions or displacement
- Sufficient air voids in the total compacted mix to allow for thermal expansion of the asphalt and aggregate under summer temperature without flushing, bleeding and loss of stability, yet low enough to keep away air and moisture
- Sufficient workability to permit efficient placement of the mix without segregation

# Marshall Mix Design Method

- Bruce Marshall, while serving as Bituminous Engineer with the Mississippi State Highway Department put together the concepts behind the Marshall mix design procedure.
- The U.S. Corps of Engineers conducted extensive research based on Marshall's concepts and eventually established the mix design method named after Marshall.
- AASHTO adopted this mix design procedure as AASHTO R-12 "Standard Recommended Practice for Bituminous Mixture Design Using the Marshall and Hveem Procedures" (AASHTO, 2003).
- Prior to the development of the Superpave mix design procedure, the Marshall mix design was the most commonly used mix design procedure in the US.

# Marshall Mix Design Method

- Even now, it is still the most commonly used procedure in many parts of the world.
- This procedure, contained in the Asphalt Institute's publication entitled "Mix Design Methods for Asphalt Concrete and Other Hot Mix Type" (Asphalt Institute, 1997), can be broken into seven major steps.
- Details on these steps can be found in the Asphalt Institute's "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types" (MS-2) (Asphalt Institute, 1997)

# Marshall Mix Design Method

## Step 1. Aggregate Evaluation

- The original Marshall Mix design method is only applicable for HMA containing aggregates with maximum particle size of 25 mm or less
- The aggregates proposed for use in the mix design should be evaluated against the aggregate requirements set forth by the specifying agency.
- If the aggregates meet the applicable requirements by the agency, the aggregate specific gravity, absorption, and gradation are determined.
- These will be used for determining the volumetric properties of the mix.

Table 3.10-1

| Mix Classification | 1 | 2 | 3 |
|---|---|---|---|
| Course | **Base** | **Base/ Wearing Course** | **Wearing Course** |
| Thickness (mm) | **60 - 75** | **40 - 60** | **40 - 50** |
| Sieve Size (mm) | Total % by weight passing (including filler) | | |
| 25 | 100 | -- | -- |
| 20 | 90 - 100 | 100 | 100 |
| 14 | - | 85 - 100 | 85 - 100 |
| 10 | 55 - 82 | 65 - 90 | 70 - 90 |
| 5 | 35 - 57 | 45 - 65 | 52 - 72 |
| 2.4 | 20 - 40 | 25 - 45 | 40 - 58 |
| 1.2 | 15 - 33 | 15 - 35 | 30 - 48 |
| 0.600 | 10 - 26 | 12 - 30 | 20 - 38 |
| 0.300 | 6 - 20 | 9 - 20 | 14 - 28 |
| 0.150 | 5 - 13 | 5 - 15 | 8 - 20 |
| 0.075 | 3 - 7 | 3 - 7 | 6 - 10 |
| | Bitumen Content by total weight of mixture. Percentage by weight found by analysis | | |
| | 4.0 – 6.0 | 4.5 – 6.5 | 5.0 – 7.0 |

# Marshall Mix Design Method

## Step 1. Aggregate Evaluation

- Individual aggregate gradations are combined in varying proportions to develop trial blends.
- The gradations of these trial blends should be evaluated based on past agency experience and other general principles
- With the theoretical calculations completed, batching sheets should be completed showing the batch weights for the relevant sieve sizes for each individual aggregate source used

# Marshall Mix Design Method

## Step 2. Asphalt Cement Evaluation

- The asphalt cement used in the mix design should be suitable for the geographical location where the mix will be placed.
- Run the required tests to ensure that the asphalt cement meets all the agency specifications.
- Finally, determine the mixing and compaction temperatures based on viscosities of 170 (+ - )20 and 280 (+ - ) 30 centistokes (cSt), respectively.

# Marshall Mix Design Method

## Step 3. Preparation of Marshall Specimens

- Prepare the Marshall specimens in accordance to the requirements set in AASHTO R-12.
- Compact minimum three replicate specimens at each combination of aggregate and asphalt contents.
- The asphalt contents should be selected at 0.5% asphalt increments with two asphalt contents falling above and below the "optimum" asphalt content.
- These specimens are compacted using the Marshall compactor.
- Three loose specimens should also be prepared for determining the maximum theoretical specific gravity near the "optimum" asphalt content.

# Marshall Mix Design Method

## Step 3. Preparation of Marshall Specimens

**Selection of Trial Binder Content**

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

Where, P = approx. Binder content (% by wt. of mix)

a = % of aggregate retained on 2.36mm sieve

b = % of aggregate passing 2.36mm and retained on 0.075mm sieve

c = % of aggregate passing 0.075mm sieve

K = 0.15 for 11-15 % passing 0.075mm sieve

= 0.18 for 6-10 % passing 0.075mm sieve

= 0.20 for <= 5% passing 0.075mm sieve

F = 0 to 2 % (based on absorption of aggregates)

# Marshall Mix Design Method

## Step 3. Preparation of Marshall Specimens

- Preparation of aggregates:
  - aggregates are dried to $105^0$-$110^0$ C for each specimen (1200gm) separately
- Mixing and Compaction Temperature:
  - Mixing and compaction temperatures based on viscosities of 170 (+ - )20 and 280 (+ - ) 30 centistokes (cSt), respectively (around $250^0$F)
- Preparation of Mold and Hammer:
  - Mold assembly and the face of the compaction hammer should be heated to $95^0$C to $150^0$C
  - A wax paper is to be placed in the bottom of the mold before the mix is placed

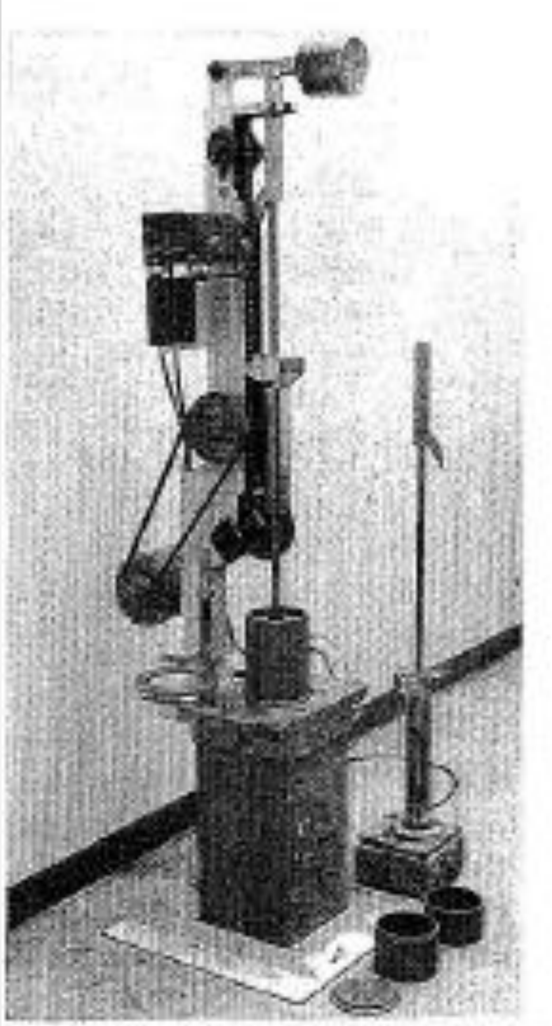


Figure 5.1 – Pedestal, hammer (mechanical) and mold used in preparing Marshall test specimens

# Determine Mixing and Compaction Temperatures

- Based on experience
  - $T_{mix}$ : 170 +/- 20 cSt
  - $T_{compact:}$ 28 0+/- 30 cSt
- Process
  - Plot dynamic and kinematic viscosities on semi-log plot
  - Be sure to convert units to cSt
  - $G_b$ = specific gravity of binder (~1.0)
  - Determine intersection with above viscosities

$$\frac{cSt \times G_b}{100} = Poise$$

$$1\ \mathrm{Pa} \cdot \mathrm{s} = 1\ \mathrm{kg} \cdot \mathrm{m}^{-1} \cdot \mathrm{s}^{-1} = 10\ \mathrm{P}$$

In 2009, AASHTO balloted a revision for T 312 to include viscosity criteria for mixing and compaction as 0.17 ± 0.02 Pa s and 0.28 ± 0.03 Pa s.

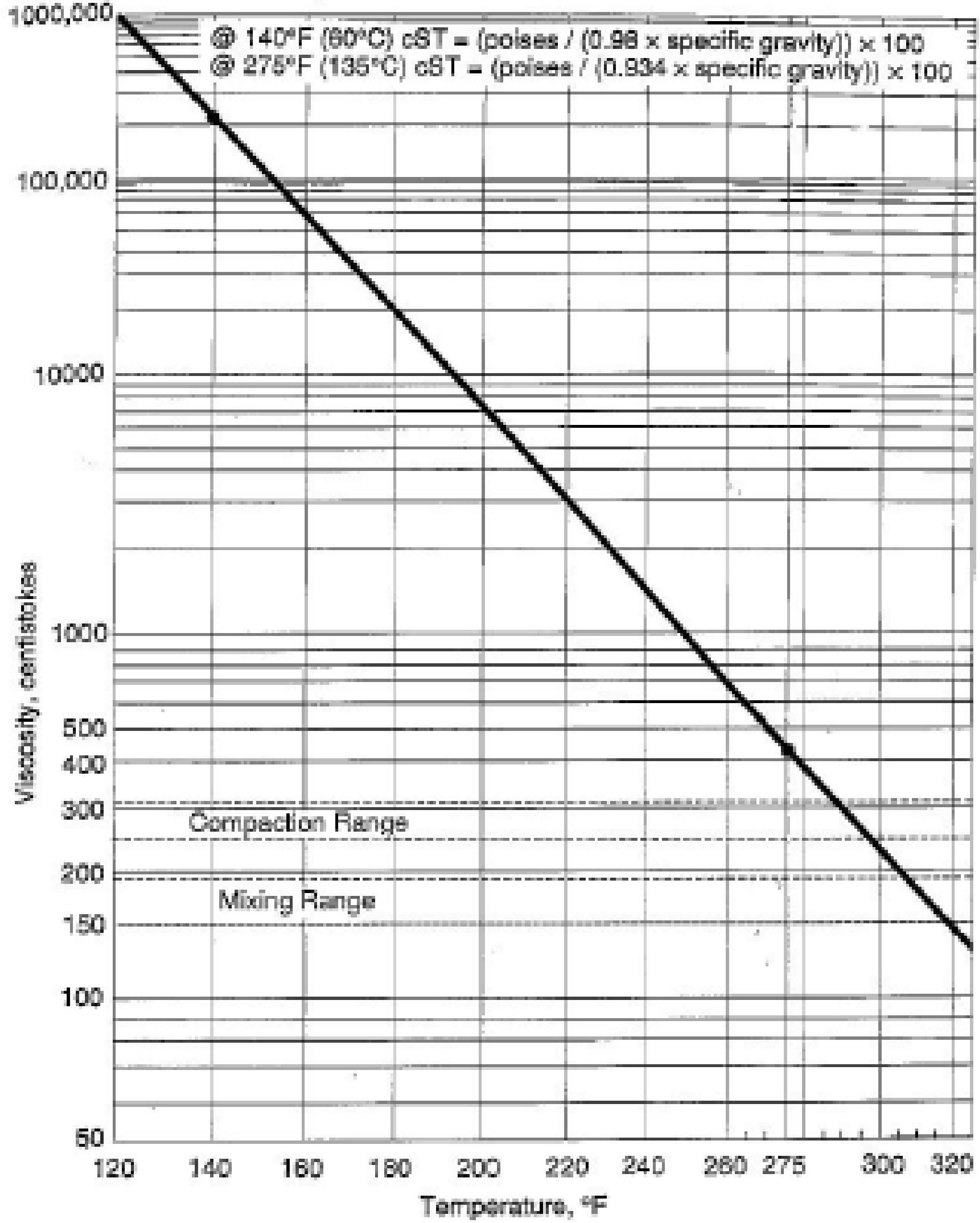



Figure 5.2 – **Determination of Mixing and Compaction Temperatures**

# Marshall Mix Design Method

Step 3. Preparation of Marshall Specimens

- Preparation of the Mixture
  - Approx 1.2 kg mix is reqd for 63.5+-1.27mm (2.5+- 0.05) inch high and 102mm (4 inch) dia specimen
  - Weight is to be adjusted after compaction of the trial specimen
  - Hot aggrs are mixed, hot asphalt is mixed thoroughly as quickly as possible, make a mix of uniform distribution of asphalt throughout
- **Compaction of specimen:**
  - Mixture is placed in the mold at the compaction temp.
  - A compactive effort of 35, 50 or 75 blows is applied to each side of the specimen (no of blows depend on traffic volume) with a compaction hammer keeping perpendicular to the base of mold. The height of free fall is 18 inch and weight of hammer is 4.5 kg.
  - Remove the specimen from the mold and cool overnight

# Marshall Mix Design Method

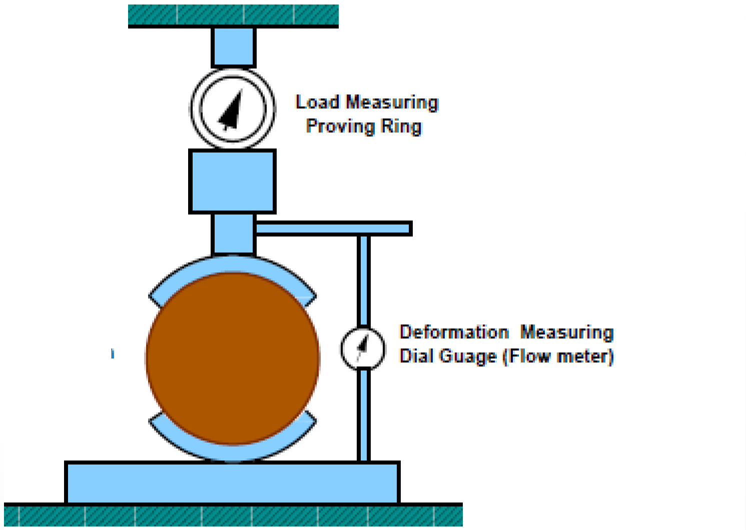
## Step 3. Preparation of Marshall Specimens

- Determine the bulk specific gravity of the compacted specimens before the Marshall stability test and maximum theoretical specific gravity of the loose mix using AASHTO T166 (ASTM D2726) "Standard Method of Test for Bulk Specific Gravity of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens" and AASHTO T209 "Standard Method of Test for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures," respectively.
- ASTM D6752 "Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Automatic Vacuum Sealing Method" is a more recently approved method for determining bulk specific gravity of compacted bituminous mixtures.

# Marshall Mix Design Method

## Step 4. Marshall Stability and Flow

- Specimens are immersed for 30-40 min in water bath at $60^0$C before test
- Load is applied to 4 inch dia and 2-1/2 inch height cylindrical specimens through semi-circular testing heads
- Rate of loading is const strain of 51mm /minute
- Total test duration after removing from the water bath is 30 seconds



# Marshall Mix Design Method

Step 4. Marshall Stability and Flow

- Stability is defined as the maximum load carried by a compacted specimen tested at $60^0C$ at a loading rate of 2 in./min.
- The two primary factors in determining the stability are the angle of internal friction of the aggregate and the viscosity of the asphalt cement.
- Therefore mixes with angular aggregates will have a higher stability than mixes with rounded aggregates.
- Similarly, mixes with more viscous asphalt cements will have a higher stability than mixes with less viscous asphalt cements.

# Marshall Mix Design Method

## Step 4. Marshall Stability and Flow

- The primary use of the Marshall stability is to evaluate the effect of asphalt cement in the Marshall mix design procedure.
- It is not specifically correlated to the stability of mixes in the field.
- Increasing the Marshall stability in the laboratory does not automatically translate to increased stability of mixes in the field.
- Flow is the vertical deformation of the sample at failure. Measured in unit of 0.01inch (0.25mm). High flow values typically indicate a plastic mix that could be susceptible to permanent deformation.

# Marshall Mix Design Method

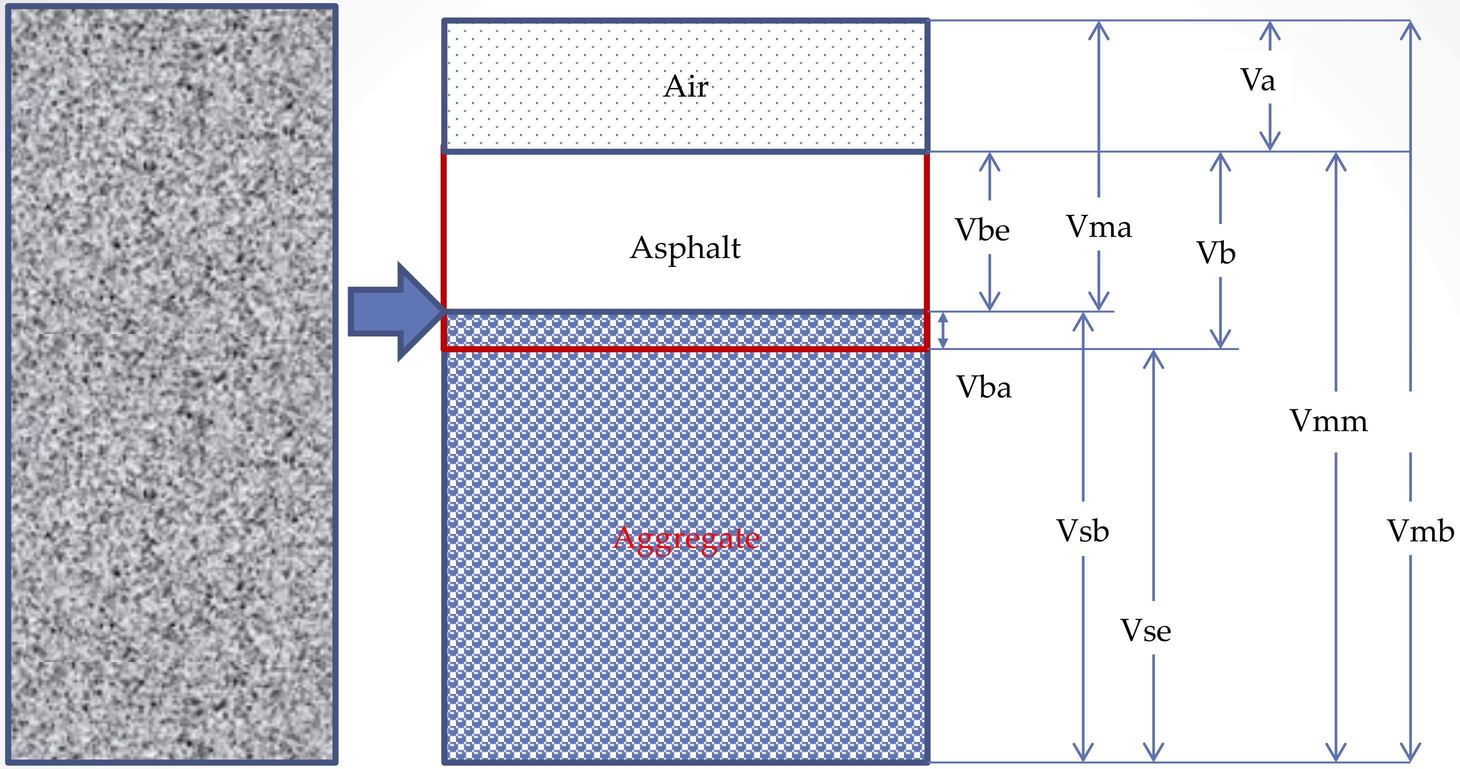
## Step 5. Density and Void Analysis

- Using the bulk specific gravity and maximum theoretical specific gravity test results, the volumetric properties of the mix can be determined

# Bulk Specific Gravity (Gmb)

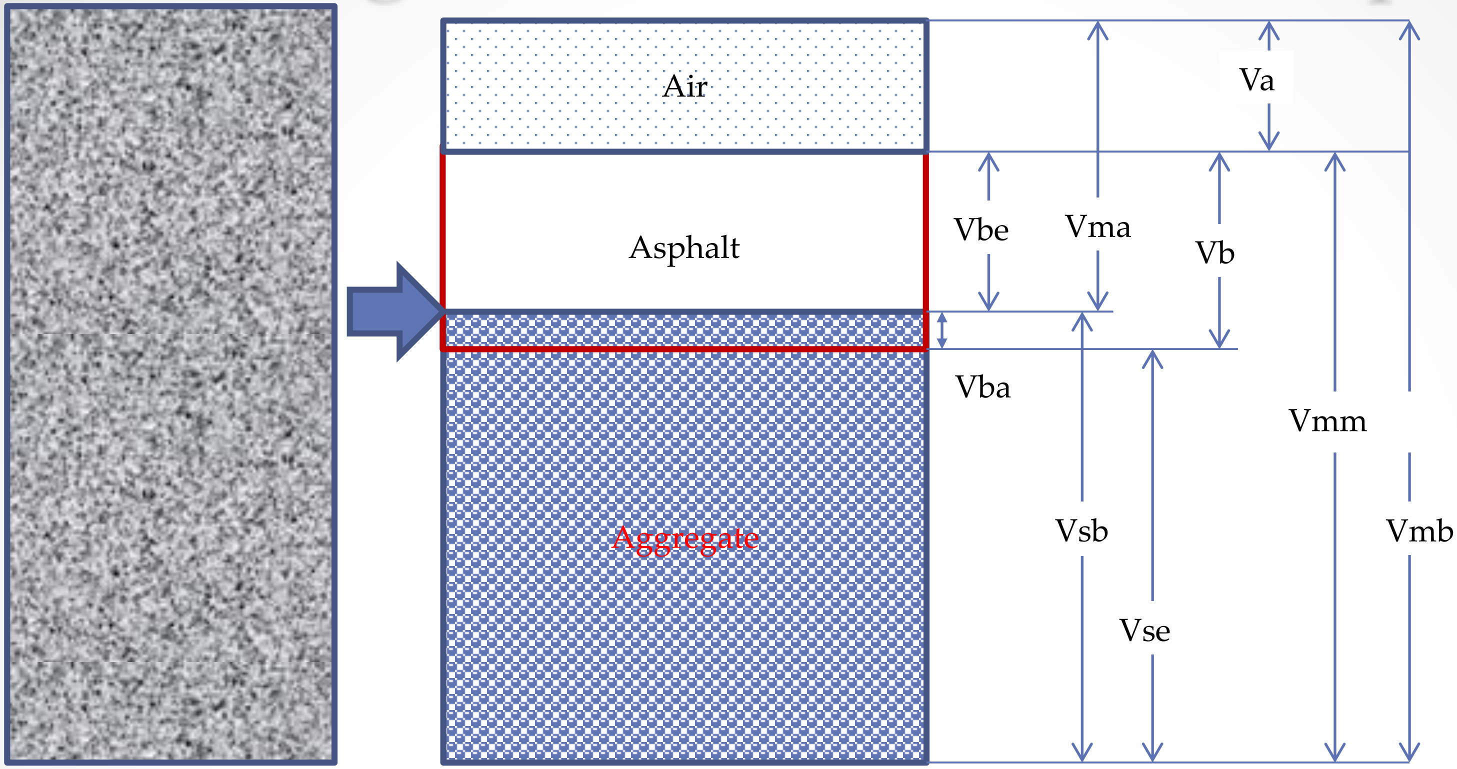
$$G_{mb} = \frac{W_{dry}}{W_{SSD} - W_{Submerged}}$$

# Weight-Volume Relationships




Vma = volume of voids in mineral aggregate
Vmb = volume of compacted specimen
Vmm = voidless volume of paving mix
Va =volume of air voids
Vb =volume of asphalts
Vba =volume of absorbed asphalts
Vbe =volume of effective asphalt
Vsb =volume of aggregate (by bulk specific gravity)
Vse= volume of aggrgate (by effective specific gravity)

# Weight-Volume Relationships




Wb = weight of asphalt
Ws = weight of aggregate

$\gamma_w$ = unit wt of water
Gmb= bulk specific gravity of compacted paving mixture
Density of compacted specimen= (Wb + Ws)/Vmb
Percent voids in mineral aggregate = (Vbe + Va)/Vmb x 100
Percent air voids in compacted specimen = (Va/Vmb) x 100
Voids filled with asphalt VFA= Vbe/Vma x 100

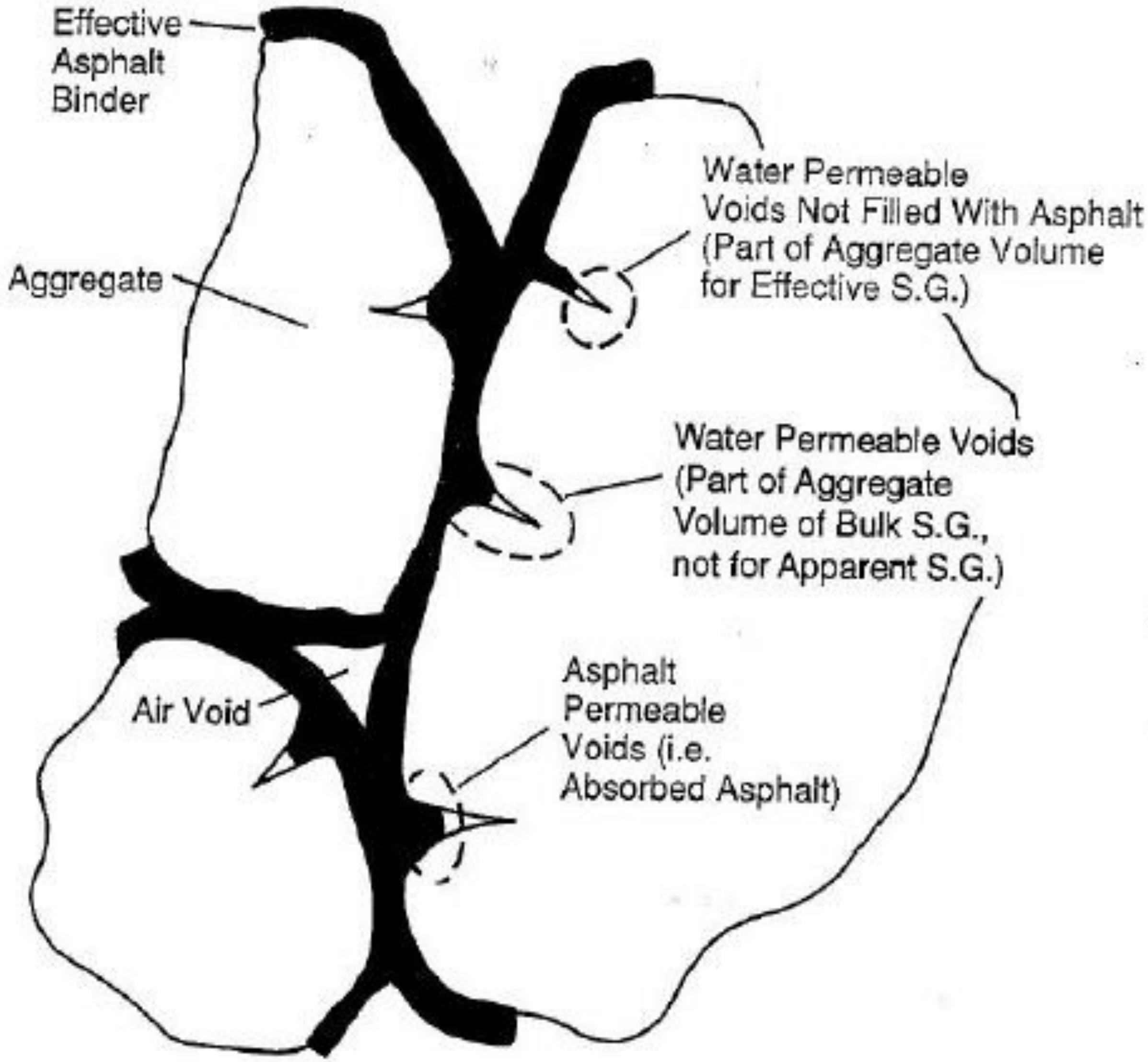



Figure 4.1 – **Illustrating bulk, effective, and apparent specific gravities; air voids; and effective asphalt content in compacted asphalt paving mixture**

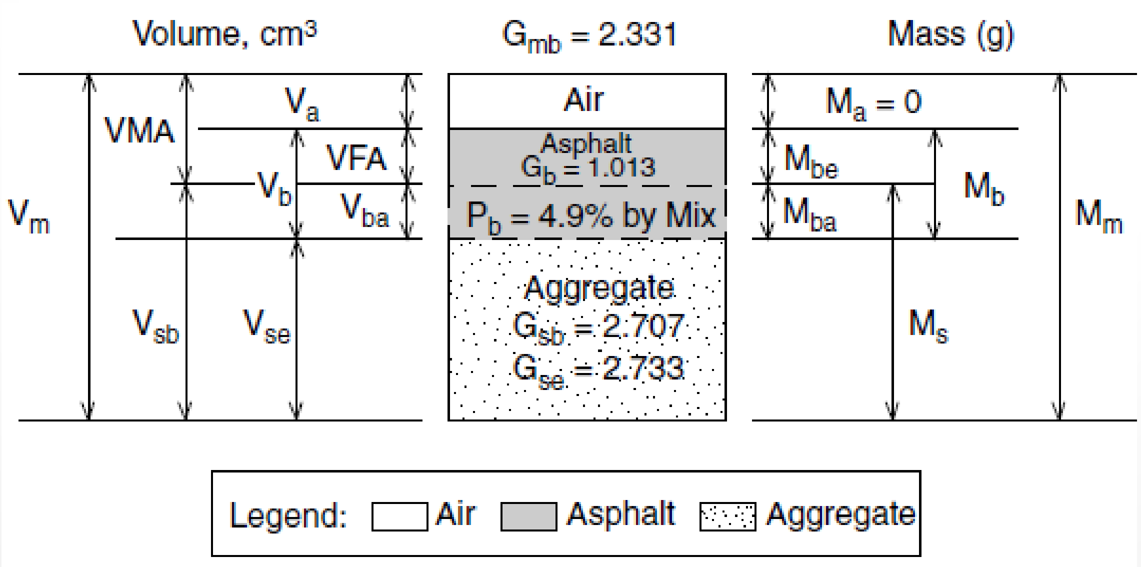
# Marshall Mix Design Method

## Step 5. Density and Void Analysis

This example involves the computation of (a) percent air voids, (b) VMA, (c) voids filled with ashphalt (VFA), (d) effective asphalt content, (e) absorbed asphalt content, and (f) maximum theoretical specific gravity based on the following information:

Mixture Bulk Specific Gravity, $G_{mb} = 2.331$
Asphalt Binder Specific Gravity, $G_b = 1.013$
percent binder, $P_b = 5.0\%$ by mix
Aggregate Bulk Specific Gravity, $G_{sb} = 2.707$
Aggregate Effective Specific Gravity, $G_{se} = 2.733$

Figure 7.8 shows the phase diagram for Example 7.1 with the assumption that calculations are based on a unit volume (i.e. 1 cm$^3$). As air has no mass, we can determine that the mass of air is 0 g. Based on the mass–volume relationships, the following calculations can be made.



# Marshall Mix Design Method

Mass of Mix:

$$M_m = V_m G_m \rho_w = 1 \text{ cm}^3 \times 2.331 \times 1.0 \text{ g/cm}^3 = 2.331 \text{ g}$$

Mass of Asphalt:

$$M_b = P_b M_m = 5/100 \times 2.331 \text{ g} = 0.117 \text{ g}$$

Mass of Aggregate:

$$M_a = M_m - M_b = 2.331 \text{ g} - 0.117 \text{ g} = 2.214 \text{ g}$$

Bulk Vol. Agg.:

$$V_{sb} = \frac{M_s}{G_{sb}\rho_w} = \frac{2.214 \text{ g}}{2.707 \times 1.0 \text{ g/cm}^3} = 0.817 \text{ cm}^3$$

Effective Vol. of Agg.:

$$V_{se} = \frac{M_s}{G_{se}\rho_w} = \frac{2.214 \text{ g}}{2.733 \times 1.0 \text{ g/cm}^3} = 0.810 \text{ cm}^3$$

Vol. of Total Asphalt:

$$V_b = \frac{M_b}{G_b\rho_w} = \frac{0.117 \text{ g}}{1.013 \times 1.0 \text{ g/cm}^3} = 0.115 \text{ cm}^3$$

Vol. of Absorbed Asphalt:

$$V_{ba} = V_{sb} - V_{se} = 0.817 \text{ cm}^3 - 0.810 \text{ cm}^3 = 0.007 \text{ cm}^3$$

# Marshall Mix Design Method

Vol. Effective Asphalt:

$$V_{be} = V_b - V_{ba} = 0.115\ \text{cm}^3 - 0.007\ \text{cm}^3 = 0.108\ \text{cm}^3$$

Vol. Air Voids:

$$V_a = V_m - V_{se} - V_b = 1\text{-}0.810\text{-}0.115 = 0.075$$

Mass of Absorbed Asphalt:

$$M_{ba} = V_{ba} G_b \rho_w = 0.007\ \text{cm}^3 \times 1.013 \times 1.0\ \text{g/cm}^3 = 0.007\ \text{g}$$

Mass of Effective Asphalt:

$$M_{be} = V_{be} G_b \rho_w = 0.108\ \text{cm}^3 \times 1.013 \times 1.0\ \text{g/cm}^3 = 0.109\ \text{g}$$

% of Voids:

$$P_a = \frac{V_a}{V_m} 100\% = \frac{0.075\ \text{cm}^3}{1.0\ \text{cm}^3} \times 100\% = 7.5\%$$

Voids in Mineral Aggregate:

$$\text{VMA} = \frac{V_a + V_{be}}{V_m} 100\% = \frac{0.075\ \text{cm}^3 + 0.108\ \text{cm}^3}{1.0\ \text{cm}^3} \times 100\% = 18.3\%$$

# Marshall Mix Design Method

Voids Filled With Asphalt:

$$VFA = \frac{V_{be}}{VMA}100\% = \frac{0.108\ cm^3}{0.183\ cm^3} \times 100\% = 59.0\%$$

Effective Asphalt Content (% Mass of Mix):

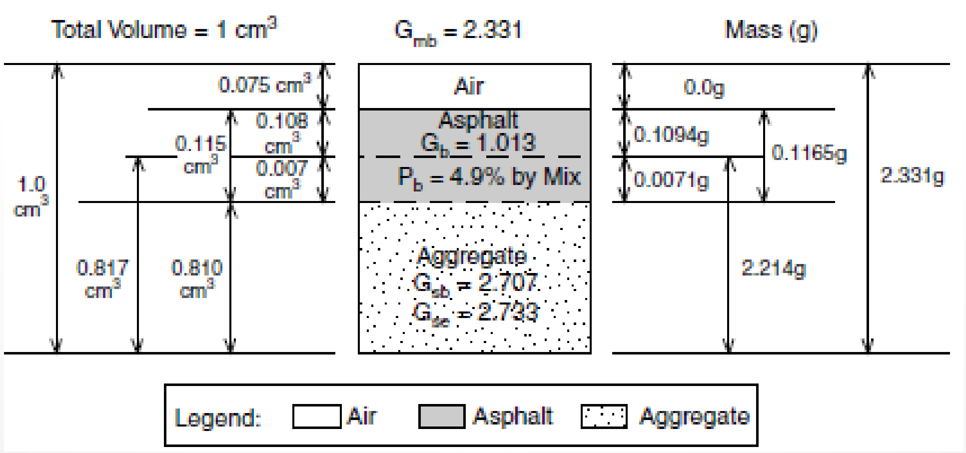
$$P_{be} = \frac{M_{be}}{M_m}100\% = \frac{0.109\ g}{2.331\ g} \times 100\% = 4.7\%$$

Absorbed Asphalt Content (percent Mass of Aggregate):

$$P_{ba} = \frac{M_{ba}}{M_s}100\% = \frac{0.007\ g}{2.314\ g} \times 100\% = 0.3\%$$

Maximum Theoretical Specific Gravity:

$$G_{mm} = \frac{G_{mb}}{(V_m - V_a)/V_m} = \frac{2.331}{(1.0\ cm^3 - 0.075\ cm^3)/1.0\ cm^3} = 2.520$$



# Marshall Mix Design Method

## Step 6. Tabulating and Plotting Test Results

- With the completion of Steps 4 and 5, the average (from three replicates) results can be tabulated and plotted. The following plots can then be made to evaluate the mix:
  - Density (or Unit Weight) vs. Asphalt Content
  - Marshall Stability vs. Asphalt Content
  - Flow vs. Asphalt Content
  - Air Voids vs. Asphalt Content
  - VMA vs. Asphalt Content
  - VFA vs. Asphalt Content

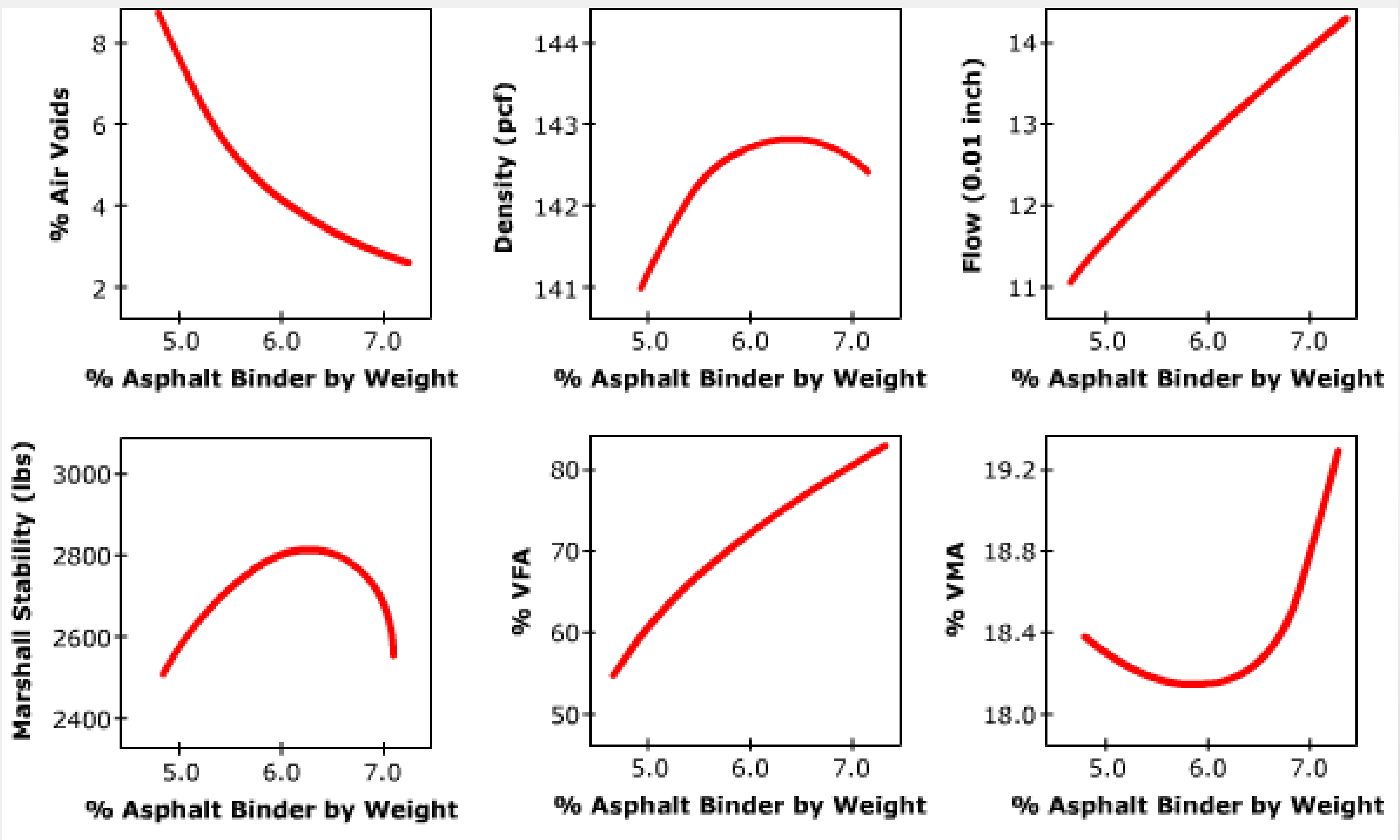
# Marshall Mix Design Method

Step 6. Tabulating and Plotting Test Results

- The density plot typically shows a trend of increasing density until the peak is reached. After this peak, the density begins to decrease.
- The Marshall stability has a similar trend but its peak is typically at a lower asphalt content than density.
- Flow typically increases with increasing asphalt content.
- The percent air voids should decrease and the VFA increase with increasing asphalt content.
- VMA is another property that increases with asphalt content until it reaches its peak and then decreases with additional increase in asphalt content

# Marshall Mix Design Method

## Step 7. Optimum Asphalt Content Determination



# Marshall Mix Design Method

## Step 7. Optimum Asphalt Content Determination

**Table 5.2 – Marshall mix design criteria**

| Marshall Method Mix Criteria [1] | Light Traffic Surface & Base | | Medium Traffic Surface & Base | | Heavy Traffic Surface & Base | |
|---|---|---|---|---|---|---|
| | Min | Max | Min | Max | Min | Max |
| Compaction, number of blows 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 Aggregate (VMA) | *See Table 5.3* | | | | | |
| 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 paving mix. Hot mix asphalt bases that do not meet these criteria when tested at 60°C (140°F) are satisfactory if they meet the criteria when tested at 38°C (100°F) and are placed 100 mm (4 inches) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climatic conditions.
2. Traffic classifications
   - Light — Traffic conditions resulting in a Design EAL $<10^4$
   - Medium — Traffic conditions resulting in a Design EAL between $10^4$ and $10^6$
   - Heavy — Traffic conditions 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 air voids.
6. Percent voids in the mineral aggregate is to be calculated on the basis of the ASTM bulk specific gravity for the aggregate.

# Marshall Mix Design Method

## Step 7. Optimum Asphalt Content Determination

Table 5.3 – **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 | 19.0 | 20.0 | 21.0 |
| 4.75 | No. 4 | 16.0 | 17.0 | 18.0 |
| 9.5 | 3/8 | 14.0 | 15.0 | 16.0 |
| 12.5 | 1/2 | 13.0 | 14.0 | 15.0 |
| 19.0 | 3/4 | 12.0 | 13.0 | 14.0 |
| 25.0 | 1.0 | 11.0 | 12.0 | 13.0 |
| 37.5 | 1.5 | 10.0 | 11.0 | 12.0 |
| 50 | 2.0 | 9.5 | 10.5 | 11.5 |
| 63 | 2.5 | 9.0 | 10.0 | 11.0 |

1 - Standard Specification for Wire Cloth Sieves for Testing Purposes, ASTM E11 (AASHTO M92)
2 - The nominal maximum particle size is one size larger than the first sieve to retain more than 10 percent.
3 - Interpolate minimum voids in the mineral aggregate (VMA) for design air void values between those listed.

# Marshall Mix Design Method

**Step 7. Optimum Asphalt Content Determination**

- Determination of Preliminary Design Asphalt content
  - Choose asphalt content at the median of the percent air voids; 4%
  - All the calculated and measured mix properties at this asphalt content should be evaluated against the mix design criteria
  - If all the criteria are met, then this is the preliminary design content
  - If all of the design criteria are not met, then some adjustment or compromise is necessary or the mix may need to be redesign
  - A number of consideration should be weighed even if all the design criteria are met

# Marshall Mix Design Method

Step 7. Selection of Final Mix design

- The final selected mix design is usually the most economical one that will satisfactorily meet all the established criteria
- The asphalt content selection can be adjusted within the narrow range (asphalt contents passing the criteria) to achieve a mix property that will satisfy requirement of a specific project
- Different properties are more critical for different circumstances, depending on traffic, structure, climate, constructions equipment and other
- Balancing process is not the same for every project

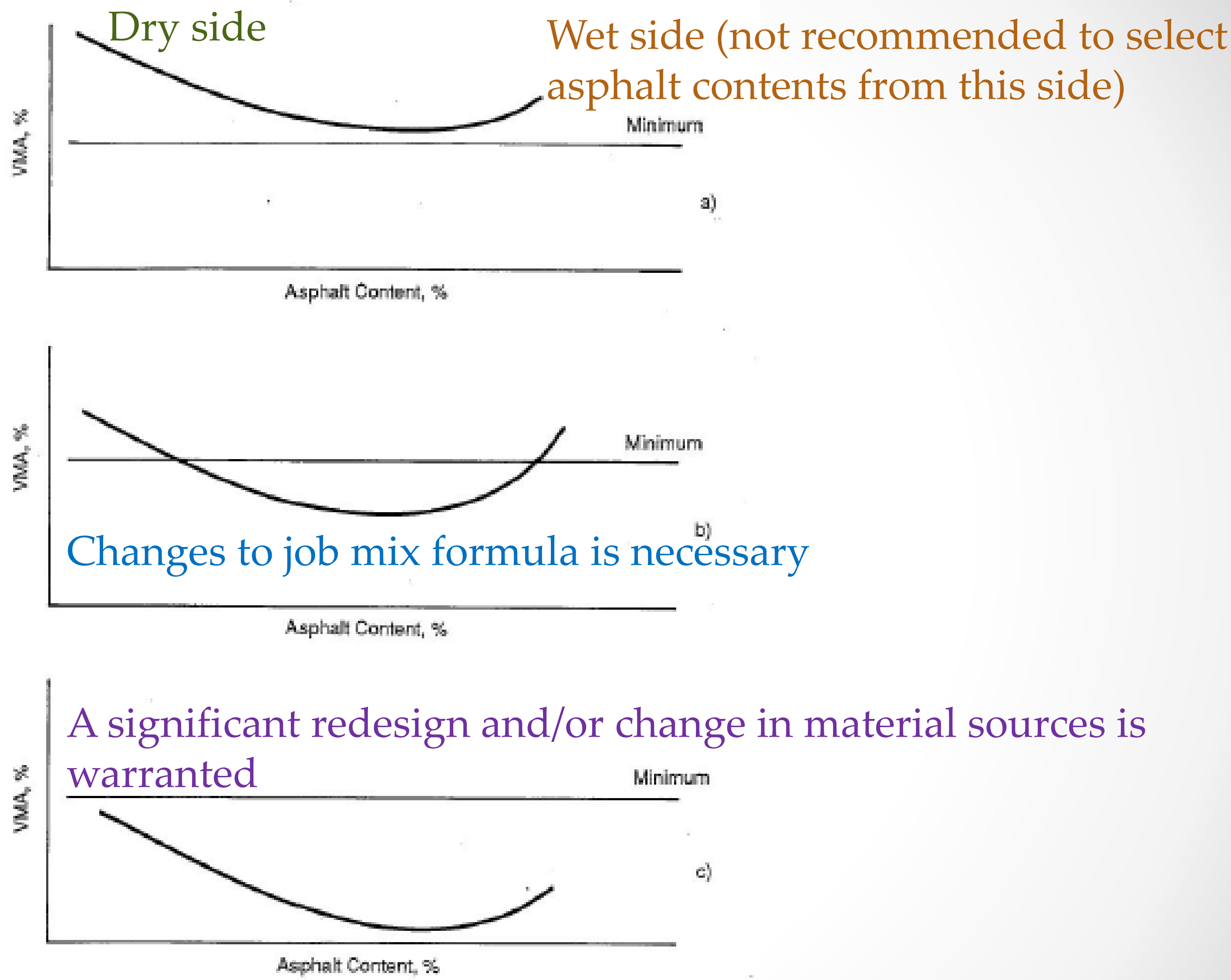



Figure 5.7 – **Relationship between VMA and specification limit**

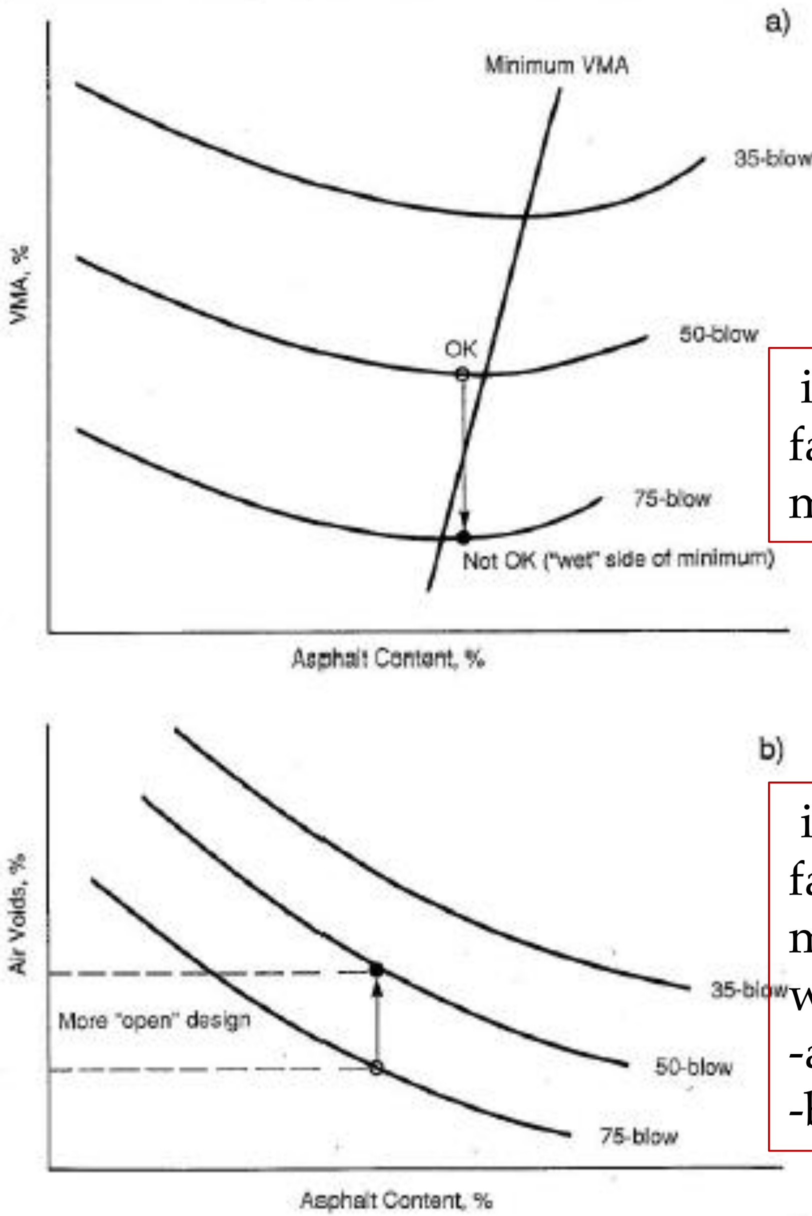



Figure 5.8 – **Effect of Marshall compactive effort on VMA and air voids.**

## Effect of Compaction level

- It is important that the compactive effort used to simulate the design traffic expected in the pavement be selected accordingly in the laboratory

if a mix is designed with 50 blows actually faces a heavier traffic (close to 75 blows)a mix susceptible to rutting is the result

if a mix is designed with 75 blows actually faces a lighter traffic (close to 50 blows)a more open, permeable mix will allow air and water.
-aging, stripping
-brittle, crack at early stage, ravalling

# Effect of Air voids

- Design air voids (3 to 5 percent of mix ) will achieve if the mix is designed at correct compactive effort, & presence of air voids after construction is 8%
- Mix ultimate consolidate less than 3% expected to rut or shove (heavy traffic situation)
- If more than 5%, brittleness, premature cracking, ,ravelling, stripping