THE UNIVERISTY OF ZAMBIA

School of Engineering

Department of Civil and Environmental Engineering

CEE 3111 - CIVIL ENGINEERING MATERIALS AND CONSTRUCTION PRACTICES

2023 ACADEMIC YEAR
SEMESTER 1

TOPIC 6

Bituminous Materials
Part 2

Asphalt Concrete

Asphalt concrete, or hot-mix asphalt (HMA), is produced by mixing asphalt binder and aggregates at high temperatures and compacting them on the road.

The objective of the asphalt concrete mix design process is to provide resistance of the pavement to:

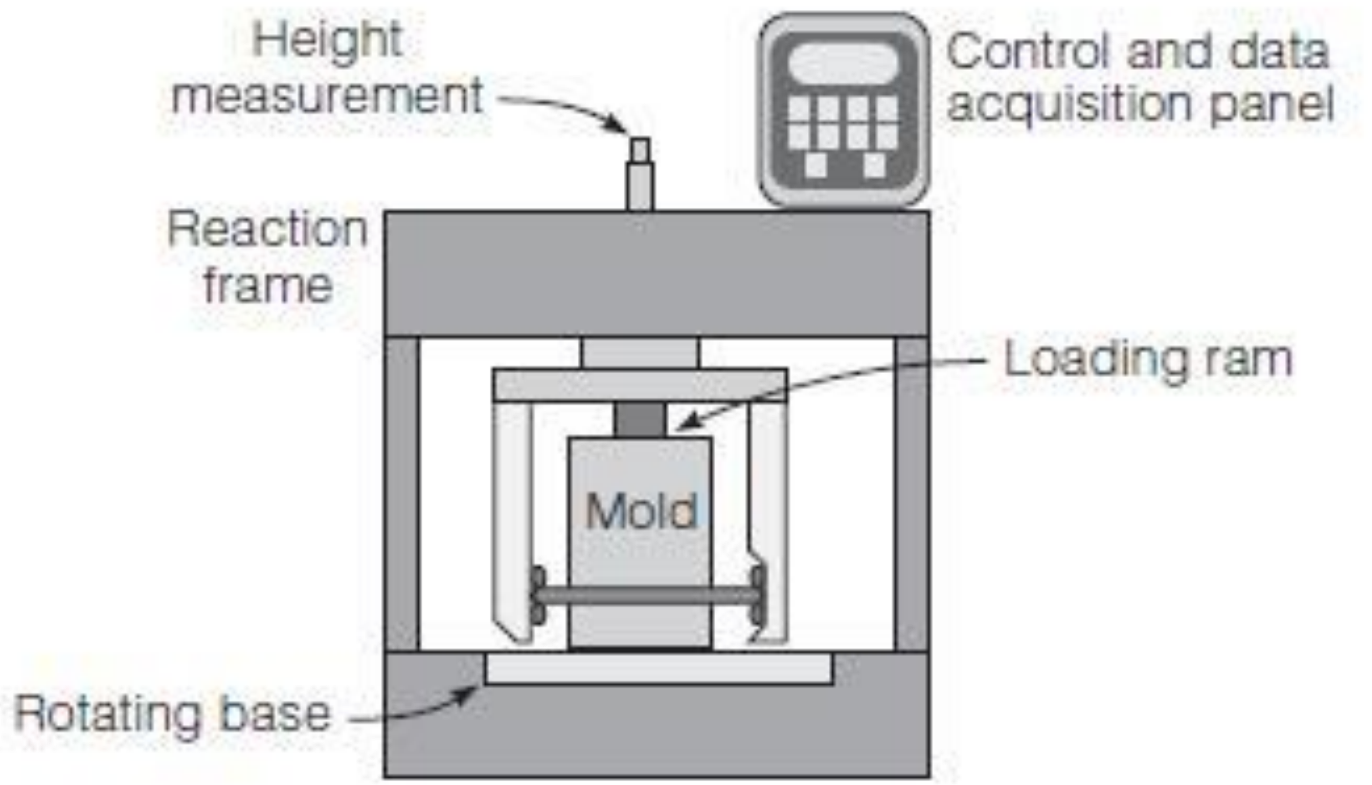
- Permanent deformation under traffic stresses, especially at high temperatures
- Fatigue cracking under repeated loadings
- Low-temperature contraction-induced thermal cracking
- Hardening or aging during production in the mixing plant and in service
- moisture-induced damage & skid resistance
- Workability, to reduce the effort needed during mixing, placing and compaction

Typical design asphalt contents range from 4% to 7% by weight of total mix

Asphalt Concrete Mix Design

- Asphalt concrete design methods:
  - ✓ Superpave Mix design – Superior Performing Asphalt Pavements (Uses Superpave gyratory compactor)
  - ✓ Marshall (ASTM D1559) – was commonly used (before superpave mix design method was developed) for its simplicity and ability to use field control (Uses Marshall hammer)
  - ✓ Hveem (ASTM D1560)
- Both Marshall and Hveem approaches are empirical, based on past observations.
- The main difference between Marshall and Hveem techniques is how they determine the optimal asphalt content.
- Their empirical character makes them unsuitable for modified binders, big aggregates, and greater traffic loads.
- The Superpave design system is performance based and is more realistic than the Marshall and Hveem methods.

Asphalt Concrete Mix Design



Superpave gyratory compactor

Asphalt Concrete Mix Design

Marshall Compactor

Marshall Mix Design

- The basic steps required for performing Marshall mix design can be summarized into two:
    i. Selection of Aggregates and
    ii. Determination of Optimum Asphalt Content
- Asphalt Institute breaks down these steps into 6:
    1. Aggregate evaluation
    2. Asphalt cement evaluation
    3. Specimen preparation
    4. Marshall stability and flow measurement
    5. Density and voids analysis
    6. Design asphalt content determination

1. Aggregate Evaluation

✓ Durability & gradation ranges.
✓ soundness,
✓ presence of harmful elements,
✓ polishing, shape, & texture

Marshall Mix Design

2. Asphalt cement evaluation

- Selection of asphalt cement grade depends on projected temperature range and traffic conditions.

3. Specimen preparation

- The full Marshall mix-design procedure requires 18 specimens 101.6 mm in diameter and 63.5 mm high.

- The stability and flow are measured for 15 specimens.

- In addition, 3 specimens are used to determine the theoretical maximum specific gravity G_{mm}

Marshall Mix Design

4. Marshall Stability and Flow Measurement

- **Marshall stability** - maximum load asphalt concrete can carry when tested in the Marshall Apparatus
- **Marshall flow** - deformation of the specimen when the load starts to decrease
- Stability is reported in newtons and flow is reported in units of 0.25 mm of deformation

5. Density and Voids Analysis

- Involves determination of VTM, VMA, and VFA

6. Design Asphalt Content Determination

- Traditionally, test results and calculations are tabulated and graphed to determine optimum asphalt content

Marshall Mix Design

Asphalt Institute Criteria for Marshall Mix Design (The Asphalt Institute, 2001)

	Traffic Level					
	Light		Medium		Heavy	
Compaction (Blows)	35		50		75	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Stability, kN (lb)	3.34 (750)	—	5.34 (1,200)	—	8.01 (1,800)	—
Flow, 0.25 mm (0.01 in.)	8	18	8	16	8	14
Air Voids, %	3	5	3	5	3	5
VMA, %	Use Criteria in Table for minimum percent of VMA					
VFA, %	70	80	65	78	65	75

Marshall Mix Design

Minimum Percent Voids in Mineral Aggregate (VMA) (The Asphalt Institute, 2001)

Nominal Maximum Particle Size[1]	Minimum VMA, Percent — Design Air Voids 3.0	4.0	5.0
2.36 mm (No. 8)	19.0	20.0	21.0
4.75 mm (No. 4)	16.0	17.0	18.0
9.5 mm (3/8 in.)	14.0	15.0	16.0
12.5 mm (1/2 in.)	13.0	14.0	15.0
19.0 mm (3/4 in.)	12.0	13.0	14.0
25.0 mm (1.0 in.)	11.0	12.0	13.0

Marshall Mix Design

Density and Void Analysis

- Mix design and construction control require density and voids study of compacted asphalt mixtures, regardless of mix design method.

- Weights are utilized instead of volumes because volumes are difficult to measure; specific gravity is used to convert weight to volume.

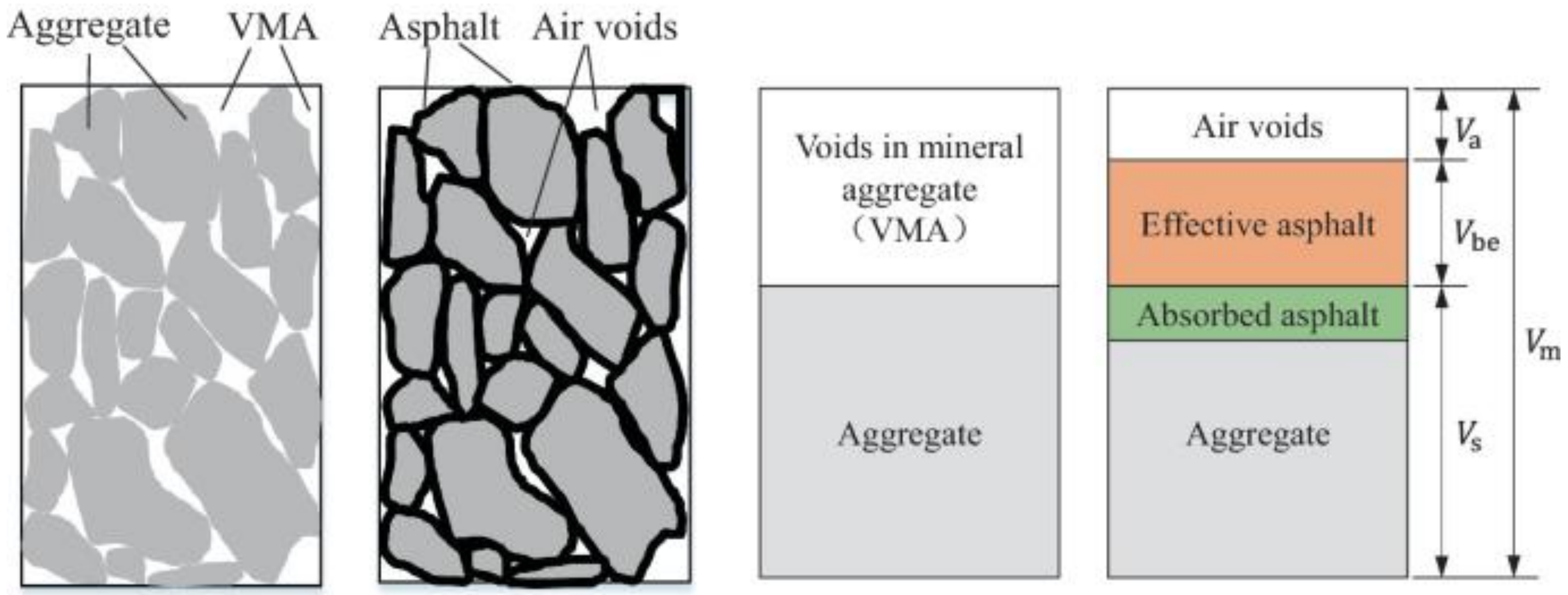
- Three important parameters commonly used are:
  - ✓ **Voids in Total Mix) (VTM)** - % of air voids between the coated aggregates after compaction. Usually between 2-4%. Affects durability of asphalt pavement
    1. The lower the air voids, the less permeable.
    2. Water and air can enter the mix through too many air gaps.
    3. Low air voids can cause flashing or bleeding, as excess binder squeezes to the surface.

Asphalt Concrete Mix Design

- ✓ **Voids Filled with Asphalt (VFA)**
- ✓ **Voids in the Mineral Aggregate (VMA)**

- Regardless of the compaction method, the samples are first used to determine the bulk specific gravity of the mix

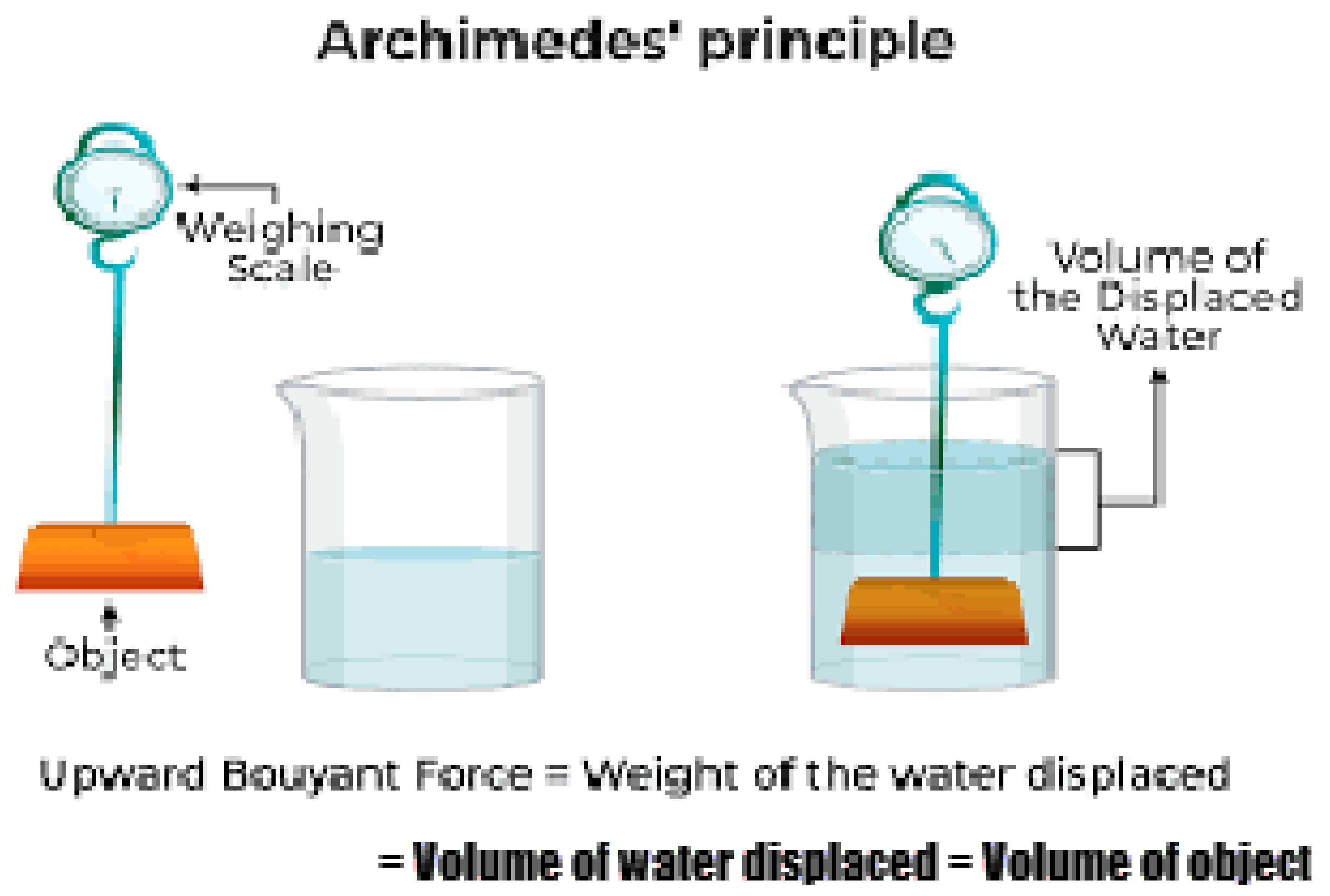
$$G_{mb} = \frac{A}{B - C}$$

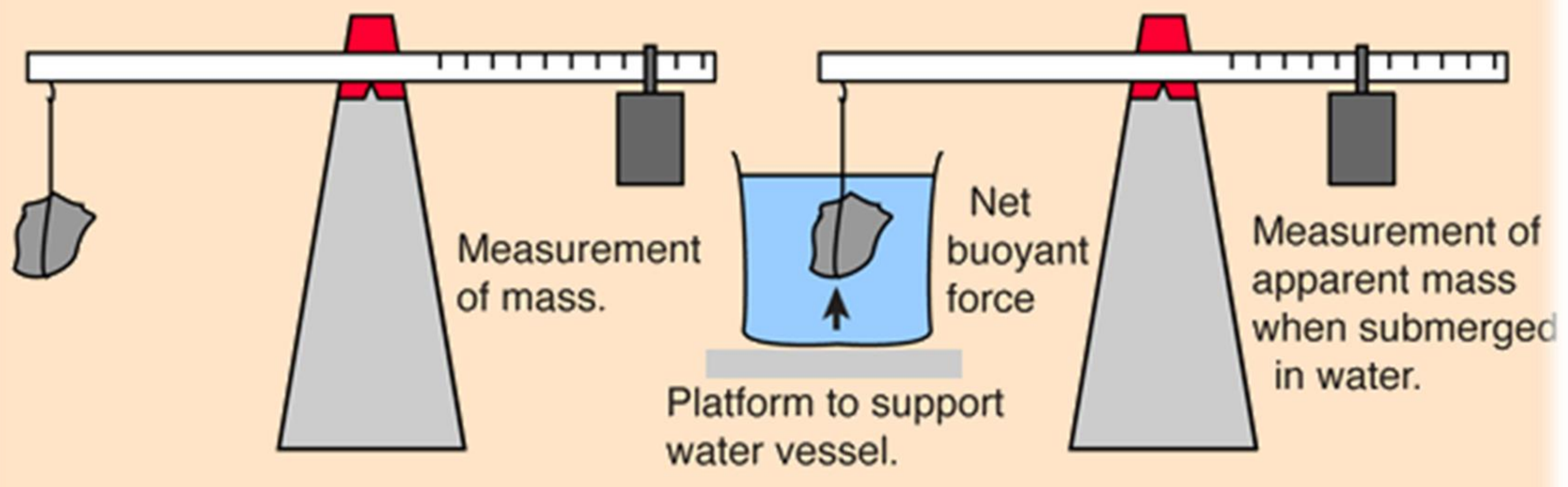


Where:

- G_{mb} = Bulk Specific Gravity of the Mix
- A = Dry Weight of Sample
- B = Saturated Surface Dry Weight of Sample
- C = Submerged Weight

Asphalt Concrete Mix Design





Archimedes' principle aids in the experimental determination of density by providing a convenient and accurate method for determining the volume of an irregularly shaped object, like a rock.

If an object is massed in air and found to have mass **m** = 200 grams

and is then submerged in water and found to have apparent mass **m'** = 80 grams

then it has displaced **m - m'** = 120 grams of water. Since water has a density of 1 gram/cm^3, this implies

Volume of object = **V** = 120 cm^3.

The density of the object is then $\rho = m/V$ = 1.66666666 gm/cm^3.

Asphalt Concrete Mix Design

- The theoretical maximum specific gravity – Sp. Gr. excluding air voids

$$G_{mm} = \frac{A}{A + D - E}$$

Where:

- G_{mm} = Theoretical maximum specific gravity of the asphalt concrete
- A = dry weight of loose material
- D= calibration weight of the submerged vacuum bowl
- E= submerged weight of the vacuum bowl with the sample
- Once G_{mm} for sample at one asphalt content is determined, it can be used to estimate G_{mm} at other asphalt contents by first computing the effective specific gravity

$$Air\ Voids\ (percent) = \left(\frac{G_{mm} - G_{mb}}{G_{mm}}\right) \times 100$$

Asphalt Concrete Mix Design

- Maximum theoretical specific gravity of uncompacted Samples:

$$G_{mm} = \frac{100}{\left(\frac{P_s}{G_{se}} + \frac{P_b}{G_b}\right)} \qquad G_{se} = \frac{P_s}{\left(\frac{100}{G_{mm}} - \frac{P_b}{G_b}\right)}$$

- Where:
- G_{mm} = Theoretical maximum specific gravity of the asphalt concrete
- P_s = % weight of aggregate
- P_b = % weight of the asphalt cement
- G_{se} = effective specific gravity of the aggregate coated with asphalt (determined for only one asphalt content, it is constant for all asphalt contents)
- The Marshal method uses this method for determining G_{mm} at each of the asphalt contents.
- The Superpave method requires directly measuring G_{mm} at each asphalt content evaluated during the mix design process

Asphalt Concrete Mix Design

Density and Void Analysis

1. $\textbf{\textit{Voids in Total Mix}}$

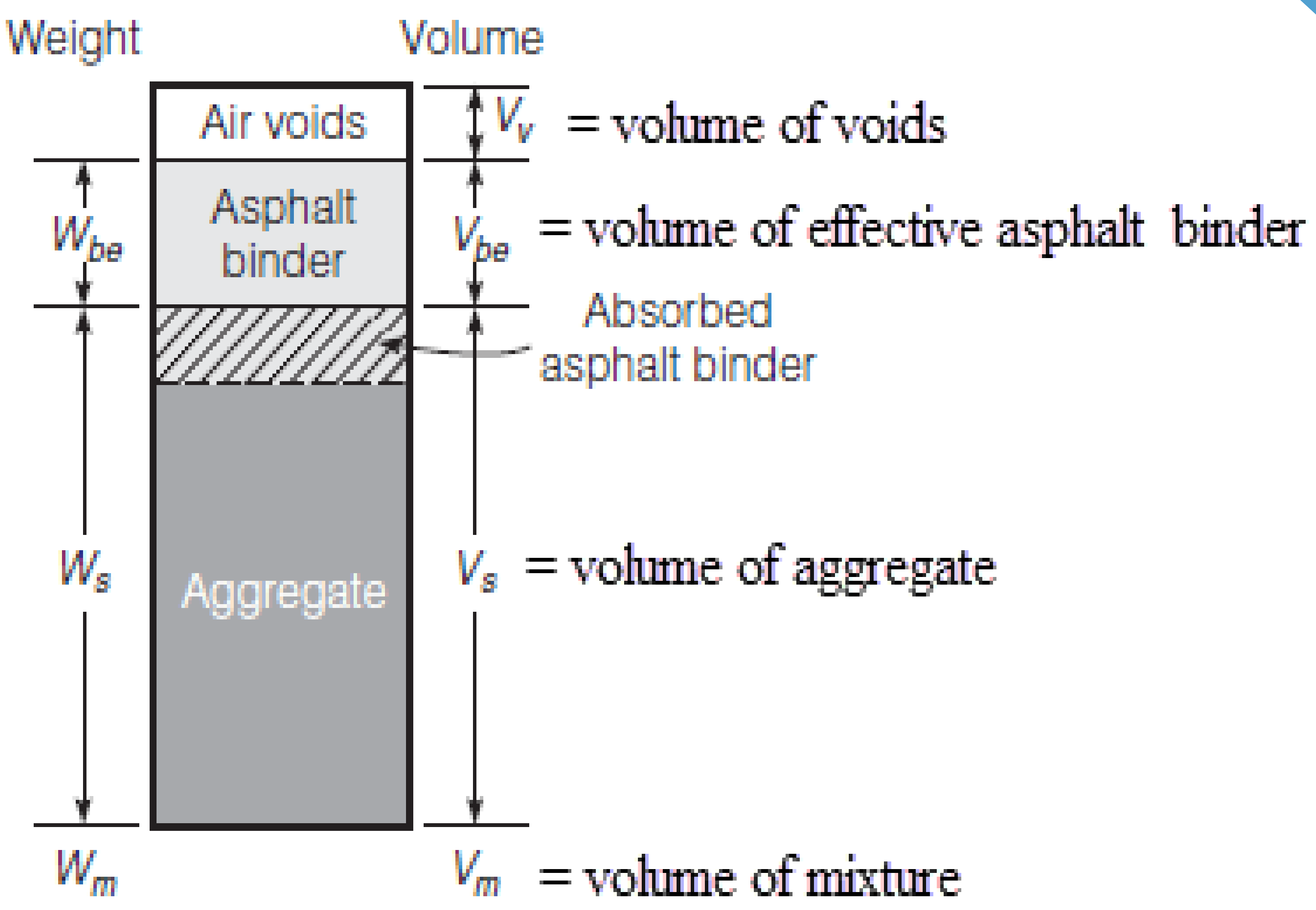
$$\mathrm{VTM} = \frac{V_v}{V_m} \times 100 = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right)$$

2. $\textbf{\textit{Voids Filled with Asphalt}}$

$$\mathrm{VFA} = \frac{V_{be}}{V_{be}+V_v} \times 100 = 100\left(\frac{VMA-VTM}{VMA}\right)$$

3. $\textbf{\textit{Voids in Mineral Aggregate}}$

$$\mathrm{VMA} = \frac{V_V+V_{be}}{V_m} \times 100 = 100\left(1 - \frac{P_s}{G_{sb}}\right)$$



- G_{sb} = Specific gravity of the aggregate
- The effective asphalt is the total asphalt minus the absorbed asphalt

Asphalt Concrete Mix Design

Density and Void Analysis – Example 1

- A compacted asphalt concrete specimen contains 5% asphalt binder (Sp. Gr. 1.023) by weight of total mix, and aggregate with a specific gravity of 2.755. The bulk density of the specimen is 2.441 Mg/ m^3. Ignoring absorption, compute VTM, VMA, and VFA.

Solution:

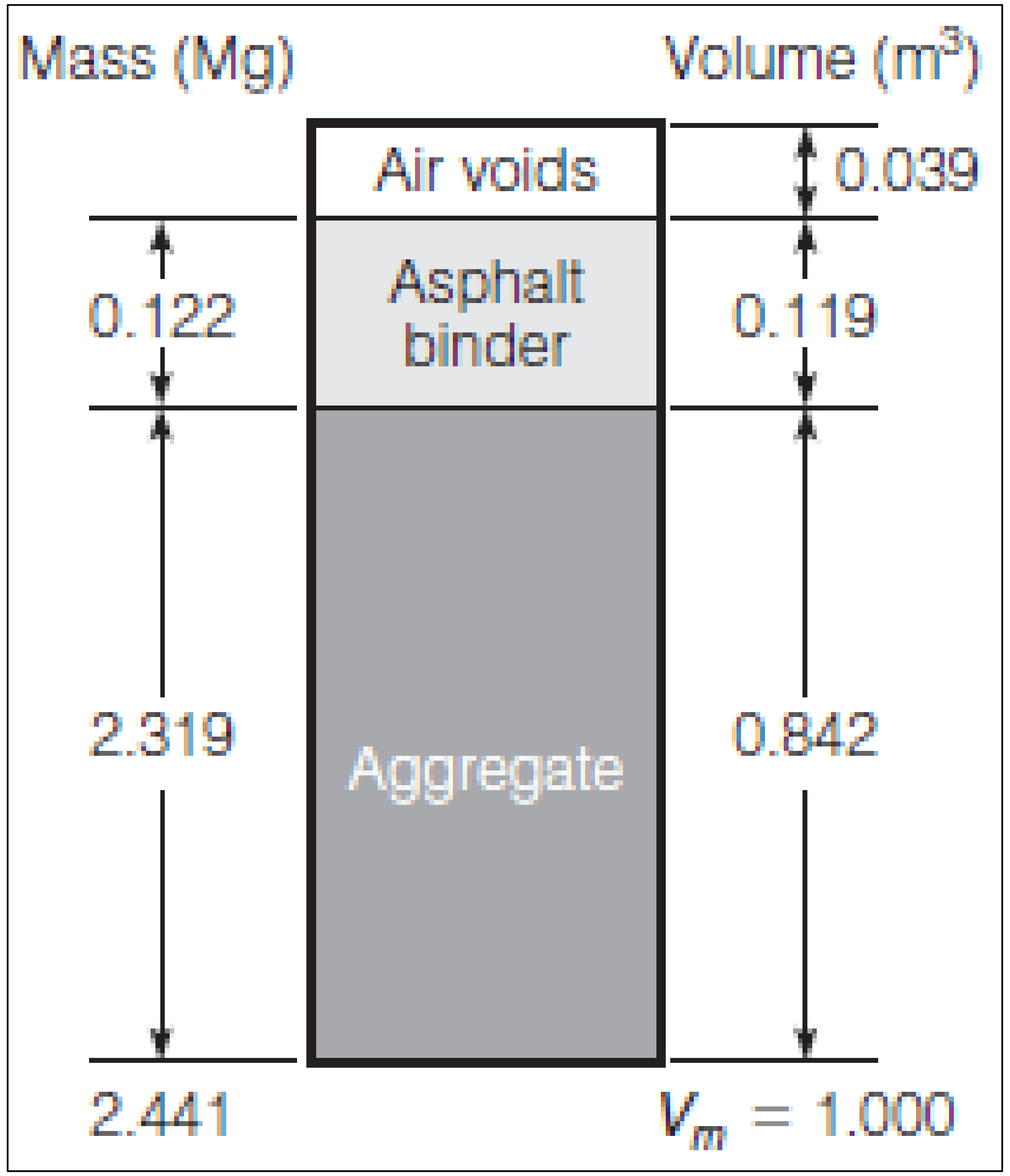
Referring to the figure:

Assume Vm=1 m^3

Determine mass of mix and components:

Total mass = 1 * 2.441 = 2.441 Mg

➢ Mass of asphalt binder = 0.05 * 2.441 = 0.122 Mg
   Mass of aggregate = 0.95 * 2.441 = 2.319 Mg



Asphalt Concrete Mix Design

Density and Void Analysis – Example 1

Determine volume of components:

$$V_b = \frac{0.122}{1.023} = 0.119m^3$$

Since the problem statement specified no absorption, $V_{be} = V_b$ Determine Vs = Volume of Stone (Aggregate)

$$V_s = \frac{2.319}{2.755} = 0.842m^3$$

Determine V_v = Volume of Voids

$$V_s = V_m - V_s - V_b$$

$$V_s = 1 - 0.842 - 0.199 = 0.039m^3$$

Asphalt Concrete Mix Design

Density and Void Analysis – Example 1

Volumetric calculations:

$$VTM = \frac{V_v}{V_m} \times 100 = \frac{0.039}{1.00} \times 100 = 3.9\%$$

$$VMA = \frac{V_v + V_{be}}{V_m} \times 100 = \frac{0.039 + 0.119}{1.00} \times 100 = 15.8\%$$

$$VFA = \frac{V_{be}}{V_{be} + V_v} \times 100 = \frac{0.119}{0.119 + 0.039} \times 100 = 75\%$$

Asphalt Concrete Mix Design

Volumetric Relationships used for asphalt mix design analysis – Example 2

An asphalt concrete specimen has the following properties:

1. Asphalt content = 5.9% by total weight of mix
2. Bulk specific gravity of the mix , Gmb = 2.457
3. Theoretical maximum specific gravity, Gmm = 2.598
4. Bulk specific gravity of aggregate, Gsb = 2.692 Calculate the percents VTM, VMA, and VFA.

Solution

$$VTM = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right) = 100\left(1 - \frac{2.457}{2.598}\right) = 5.4\%$$

$$VMA = \left(100 - G_{mb}\frac{P_s}{G_{sb}}\right) = \left(100 - 2.457\frac{100 - 5.9}{2.692}\right) = 14.1\%$$

$$VFA = 100\left(\frac{VMA - VTM}{VMA}\right) = 100\left(\frac{14.1 - 5.9}{14.1}\right) = 61.7\%$$

Marshall Mix Design – Example

- The Marshall method was used to design an asphalt concrete mixture. A PG 64-22 asphalt cement with a specific gravity G_b of 1.031 was used. The mixture contains a 9.5 mm nominal maximum particle size aggregate with a bulk specific gravity G_{sb} of 2.696. The theoretical maximum specific gravity G_{mm} of the mix at asphalt content of 5.0% is 2.470. Trial mixes were made with average results as shown in the following table:

Asphalt Content (P_b) (% by Weight of Mix)	Bulk Specific Gravity (G_{mb})	Corrected Stability (kN)	Flow (0.25 mm)
4.0	2.360	6.3	9
4.5	2.378	6.7	10
5.0	2.395	5.4	12
5.5	2.405	5.1	15
6.0	2.415	4.7	22

- Determine the design asphalt content using the Asphalt Institute design criteria for medium traffic.
- Assume a design air void content of 4%.

Marshall Mix Design – Example

- Step 1: Compute G_{se} at 5% asphalt binder content and G_{mm} = 2.470

$$G_{se} = \frac{P_s}{(\frac{100}{G_{mm}} - \frac{P_b}{G_b}} = \frac{100 - 5}{\frac{100}{2.470} - \frac{5}{1.031}} = 2.666$$

- Step 2: Use G_{se} at 5% asphalt binder to calculate G_{mm} for the other asphalt contents At 4.0 % asphalt binder:

$$G_{se} = \frac{100}{(\frac{P_s}{G_{se}} - \frac{P_b}{G_b}} = \frac{100}{\frac{100 - 4.0}{2.666} + \frac{4.0}{1.031}} = 2.51$$

- Step 3: Compute VTM At 4.0 % asphalt binder:

$$VTM = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right) = 100\left(1 - \frac{2.360}{2.51}\right) = 5.86\%$$

Marshall Mix Design – Example

Step 4: Compute VMA At 4.0 % asphalt binder:

$$VMA = \left(100 - G_{mb}\frac{P_s}{G_{sb}}\right) = \left(100 - 2.360\frac{100-4}{2.696}\right) = 16\%$$

Step 5: Compute VFA At 4.0 % asphalt binder:

$$VFA = 100\left(\frac{VMA - VTM}{VMA}\right) = 100\left(\frac{16.0 - 5.86}{16.0}\right) = 63.3\%$$

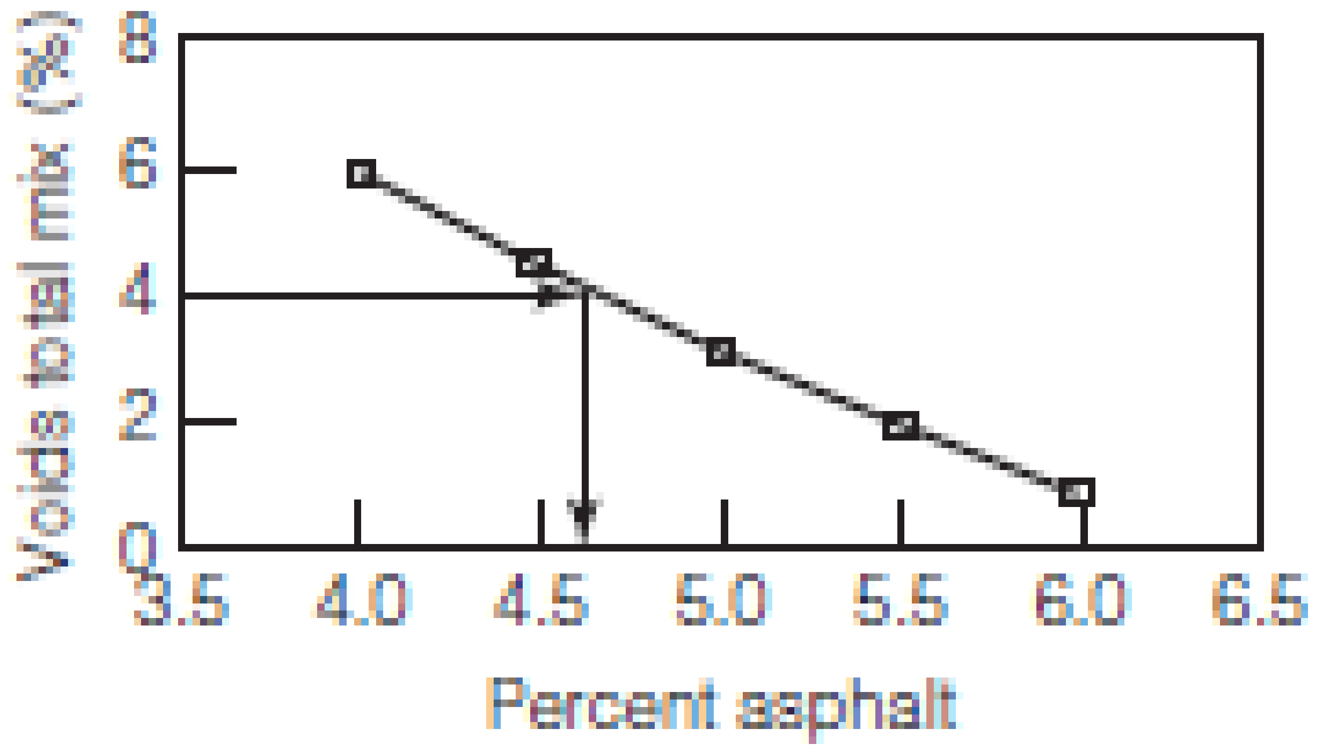
Marshall Mix Design – Example

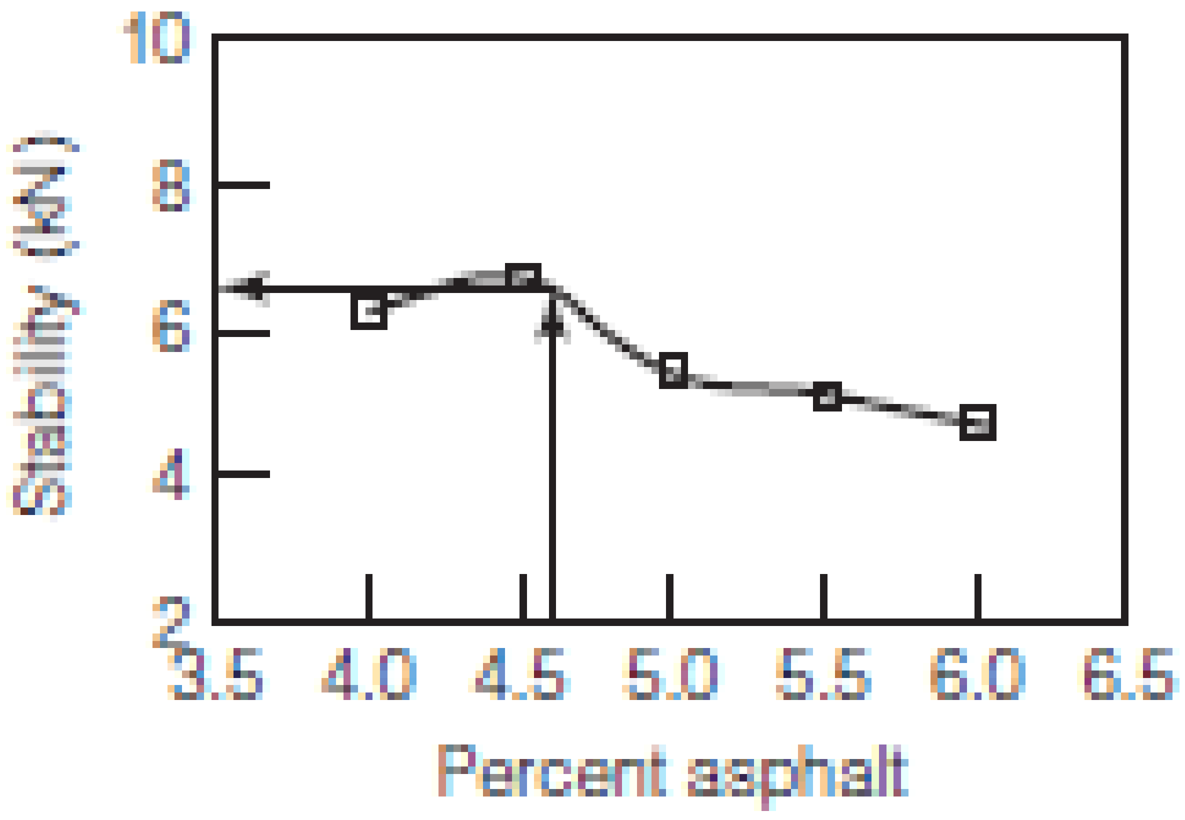
Summary of Calculations

P_b (%)	G_{mb}	Corrected Stability (kN)	Flow, (0.25 mm)	G_{mm}	G_{se}	VTM (%)	VMA (%)	VFA (%)
4.0	2.360	6.3	9	2.507		5.9	16.0	63.3
4.5	2.378	6.7	10	2.488		4.4	15.8	71.9
5.0	2.395	5.4	12	2.470	2.666	3.0	15.6	80.5
5.5	2.405	5.1	15	2.452		1.9	15.7	87.8
6.0	2.415	4.7	22	2.434		0.8	15.8	95.0

Marshall Mix Design – Example

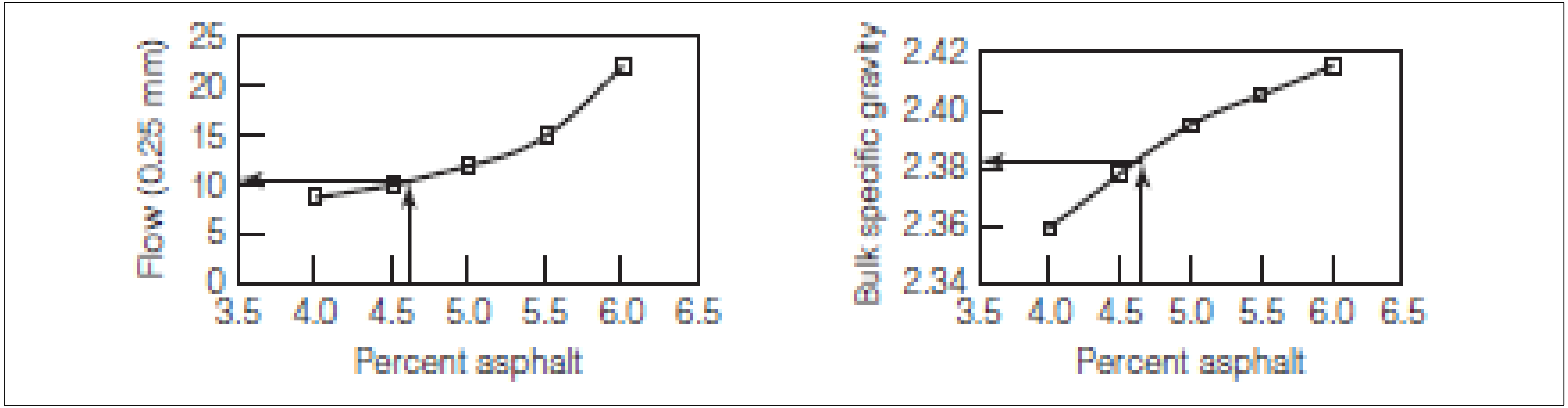
Step 6: Plot stability, flow and volumetric parameters versus asphalt content





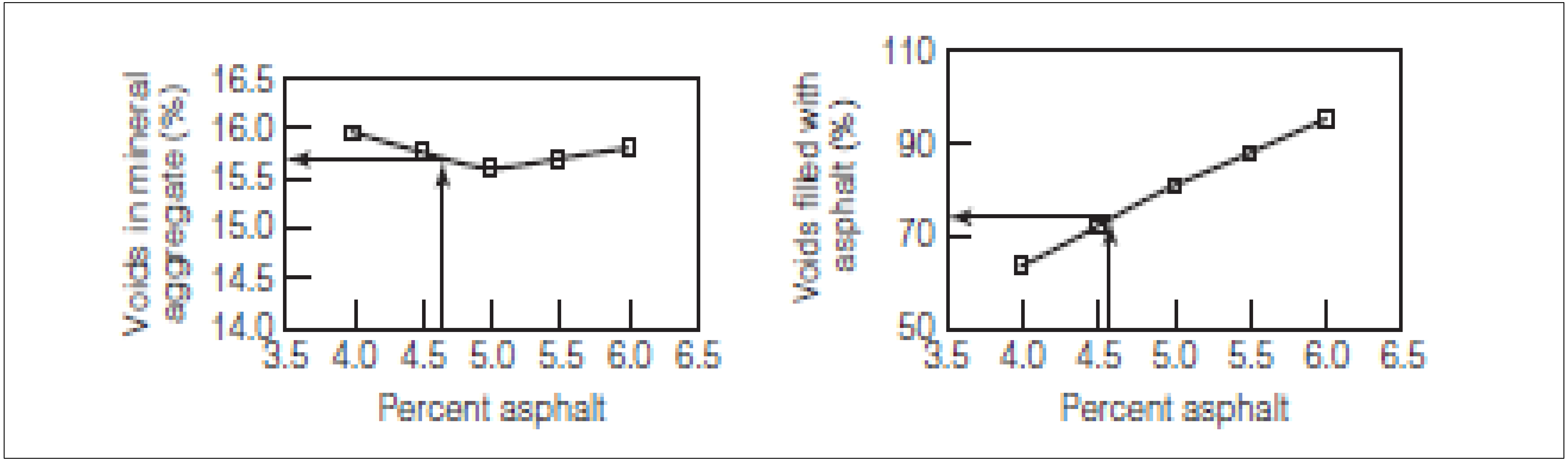
Marshall Mix Design – Example

Step 6: Plot stability, flow and volumetric parameters versus asphalt content



Marshall Mix Design – Example

Step 6: Plot stability, flow and volumetric parameters versus asphalt content



Marshall Mix Design – Example

Step 7: Determine the asphalt content at VTM=4% and the corresponding parameters. Compare with criteria:

At VTM = 4%, Find Corresponding Parameters from Graphs		
Parameter	From Graph	Criteria
% of Asphalt binder at VTM = 4%	4.6	
Stability in N at 4.6 % Binder	6600	5400 (min)
Flow (0.25 mm) at 4.6 % Binder	10.5	8 to 16
VMA (%) at % 4.6 % Binder	15.7	15.0 (min)
VFA at 4.6 % Binder	75	65 to 78

Since all parameters are within acceptance criteria, Optimum Asphalt Content = 4.6 %

Quiz 7

Thank You!!!