4- High-Type Bituminous Pavements
High-Type Bituminous Pavements

- HMA Widely used in urban & rural areas.
- If properly designed & constructed, HMA pavements can carry very high volumes.
- Majority have economic life of 20 years.
- Prepared in hot mix plants.
- Thickness vary.
Fundamental Properties of Design

1. Stability: Property of compacted mixture that enables it to withstand the stresses imposed on it by moving wheel loads with sustaining substantial permanent deformation.

2. Durability: Property of compacted mixture to withstand the detrimental effects of air, water, & temperature changes.
Density of HMA

- Both stability & durability are related to the density of the mix.
- Density is expressed in terms of voids in the mixture.
- Voids: Amount of space in the compacted mixture that is not filled with aggregates or bituminous materials (i.e. filled with air).
- Dense mixture.......low voids
- Loose mixture.......high voids
- Extent of voids is determined by % of AC in the mix.
Goal of Mix Design

Determine the best or optimum asphalt content that will provide the required stability & durability as well as additional desirable properties such as impermeability, workability, & resistance to bleeding.
Density & stability increase as AC% increase up to a point where they will start to decrease because aggregates will be forced apart by excess of bituminous materials.

It is not practical to say that the best AC would be the one that would just fill the voids in the compacted mixture.

Raise in Temperature……AC expand…..AC overfill the voids……Bleeding…… loss in stability.

Traffic……Raise density……Reduce voids……Excess AC…….. Bleeding……..Loss in stability.

Compromise is needed when selecting optimum AC%.
Requirements of HMA

- Sufficient asphalt to ensure a durable pavement
- Sufficient stability under traffic loads
- Sufficient air voids in the compacted mix
  - Upper limit to prevent excessive environmental damage (permeation of harmful air & moisture).
  - Lower limit to allow room for initial densification due to traffic, and slight amount of asphalt expansion due to temperature increase.
- Sufficient workability to permit efficient placement of the mix without segregation & without sacrificing stability & performance.
- For surface mixes, proper aggregate texture & hardness to provide sufficient skid resistance in unfavorable weather conditions.
Classification of Hot-Mix Paving

- According to Asphalt Institute: Asphalt paving mixtures are designed & produced using wide range of aggregate types & sizes.
- Asphalt concrete = HMA= Intimate mixture of coarse & fine aggregates, mineral filler, and asphalt cement.
- Mixes are classified based on aggregate gradation used in the mix (i.e. Uniform graded, Open graded, Gap graded, Coarse graded, fine graded.)
Other grades
- Sheet asphalt: AC + Fine Agg. + Mineral filler (Surface mixtures)
- Sand asphalt: AC + Sand (with/without mineral filler)

Mixes are designated also according to use in layered system:
- Surface mixes: Upper layer
- Base mixes: Layer above subbase or subgrade
- Leveling mixes: Intermediate (to eliminate irregularities in existing surfaces prior to new layer).
Materials for Asphalt Concrete Paving Mixes

- **Coarse Aggregates**
  - Retain #8 (Asphalt Institute), or #10 (HMA), or #4 ASTM.
  - Function in stability by interlocking & frictional resistance.
  - Crushed stone, crushed gravel, crushed slag.
  - Should be hard, durable, and clean.

- **Fine Aggregates**
  - Pass #8 or #10 or #4 retained # 200
  - Function in stability by interlocking & frictional resistance.
  - Crushed materials and sand.
  - Void filling of coarse aggregates.
Materials for Asphalt Concrete Paving Mixes

● Mineral Filler
  ● Pass # 200
  ● Function in voids filling
  ● Limestone dust, Portland cement, Slag, Dolomite dust.
  ● Required to be dry & free from lumps.
  ● Hydrophobic in nature

● Bituminous Materials
  ● Semi solid asphalt cement (AC)
  ● More viscous grade (AC-20, AC-40) recommended for high traffic & hot climates.
  ● AC-2.5, AC-5 used in medium or low traffic in cold regions.

● Various Specifications are available for aggregate gradations and composition for base, binder, and surface course
Job Mix Formula

- Composition of the mix must be established
- Job Mix Formula (JMF) = Design of the mixture.
- JMF is determined in two steps:
  1. Selection & combination of aggregates to meet limits of specifications.
  2. Determination of optimum asphalt content.
- JMF tolerance for each sieve size should be indicated.
Selection & Combination of Aggregates

- In normal procedure.....coarse & fine aggregates in the vicinity of the project site are sampled & examined.....If suitable can be used...... Economical alternative..... If not.......Suitable aggregate source should be found.
- Combine aggregates (Determine proportions of the separate aggregates to give a combination that meet spec.)
- Proportions must be far from extreme to provide room for JMF tolerance.
- Process: Trial & Error with critical sieve selection for start with values.
- Spread sheet (Excel)
Determination of Optimum Asphalt Content

- Lab procedure: Prepare trial mixtures using selected aggregate proportions with various percentages of AC within limits of mix spec.
- Each trial mix is prepared to secure high density.
- Density, stability, and other properties are then determined.
- Three mix design methods:
  1. Marshall
  2. Hveem
  3. SuperPave
- Methods differ in: compaction procedure and strength tests.
MARSHALL MIX DESIGN
Marshall Mix Design

- Developed by Bruce Marshall for the Mississippi Highway Department in the late 30’s
- US Army Corps of Engineers (WES) began to study it in 1943 for WWII (airfields)
  - Evaluated compaction effort
    - No. of blows, foot design, etc.
    - Decided on 10 lb. Hammer, 50 blows/side, 18” drop
    - 4% voids after traffic
- Initial criteria were established and upgraded for increased tire pressures and loads
- Procedure is valid for max aggregate size of 1.0 inch when using a 4.0 inch diameter mold. Sizes bigger than 1.0 inch require the use of modified Marshall procedure.
Step 1: Aggregate Evaluation

- Determine acceptability of aggregate for use in HMA (L.A. Abrasion, Soundness, Sand Equivalent, Flat & Elongated, % Crushed faces, ...).
- If aggregate accepted, perform the following aggregate tests: Gradation, S.G., & absorption.
- Perform blending calculations (deviate from max. density line to increase VMA).
- Prepare specimen weigh-out table by multiplying % aggregate retained between sieves times aggregate weight (1150g), then determine cumulative weights.
Marshall Mix Design Procedure
Cont.

Step 2: Asphalt cement evaluation
- Determine appropriate asphalt cement grade for type & geographic location.
- Verify that spec. properties are acceptable.
- Determine AC viscosity & S.G.
- Plot viscosity data on Temperature - Viscosity plot.
- Determine mixing & compaction temperature ranges from plot.
  - Mixing viscosity range (170 ± 20 CSt)
  - Compaction viscosity range (280 ± 30 Cst).
Mixing/Compaction Temps

Viscosity, Pa s

Compaction Range

Mixing Range

Temperature, C
Step 3: Preparation of Marshall Specimen

- Dry, then sieve aggregates into sizes (individual sizes), at least 18 samples (1150 g), total of 25 kg & 4 liters of AC.
- Prepare trial mix to check specimen height (2.5 inch ± 0.2), adjust quantity of aggregate by $Q = \left(\frac{2.5}{h1}\right) \times 1150$.
- Weigh out 18 specimens in separate containers and heat to mixing temperature.
- Heat sufficient AC to prepare a total of 18 specimens.
Marshall Mix Design Procedure Cont.

- Prepare (3) specimens @ (5) different AC contents.
- AC should be selected @ (0.5%) increments (2 above optimum AC & 2 below optimum AC).
- Optimum is decided based on experience.
- Prepare three loose mixture specimens near optimum AC to measure Rice or Maximum theoretical S.G. (TMD = Theoretical Max density).
- Note: Some agencies require that Rice S.G. conducted at all asphalt contents.
- Precision is better when mixture is close to optimum.
- Marshall mold is (4 inch diameter X 2.5 inch height).
Marshall Mix Design Procedure
Cont.

- Determine appropriate number of blows/side according to spec.
- Remove hot aggregate….place on scale….Add proper wt. of AC to obtain desired AC content.
- Mix AC & aggregates until all aggregates are uniformly coated.
- Check temperature before compaction, if higher, allow to cool……..if lower, discard & make other mix.
- Place paper disc into preheated Marshall mold and poor in loose HMA. Fill the mold and attach the mold and base plate to pedestal.
- Place the preheated hammer into the mold and apply appropriate number of blows to both sides.
Mixing

Place bowl on mixer and mix until aggregate is well-coated
Automatic Marshall Hammer
## Marshall Design Criteria

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<td>75</td>
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<tr>
<td><strong>Stability N (lb.)</strong></td>
<td>3336 (750)</td>
<td>5338 (1200)</td>
<td>8006 (1800)</td>
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<td><strong>Flow, 0.25 mm (0.1 in)</strong></td>
<td>8 to 18</td>
<td>8 to 16</td>
<td>8 to 14</td>
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<tr>
<td><strong>Air Voids, %</strong></td>
<td>3 to 5</td>
<td>3 to 5</td>
<td>3 to 5</td>
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<tr>
<td><strong>Voids in Mineral Agg. (VMA)</strong></td>
<td>Varies with aggregate size</td>
<td>Varies with aggregate size</td>
<td>Varies with aggregate size</td>
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<tr>
<td><strong>Voids Filled w/Asph (VFA) [some agencies]</strong></td>
<td>70 to 80</td>
<td>65 to 78</td>
<td>65 to 75</td>
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</table>
Minimum VMA Requirements

Nominal Maximum Aggregate Size - Millimetres

Nominal Maximum Aggregate Size - Inches

Minimum V.M.A. - Percent

Normally Acceptable VMA

Basis of Diagram
ASTM Bulk Specific Gravity of Aggregate

Deficient in Either Asphalt or Air Voids

1.2
Remove paper filter from top & bottom of specimen and allow to cool then extrude from mold using hydraulic jack.

Mark and allow to sit @ room temp. overnight before further testing.

Determine Bulk S.G. of each compacted specimen.

Measure Rice S.G. for the loose mix specimen.
Bulk S.G. of Compacted Mix

- Determine the weight of the compacted specimen in air \((A)\).
- Immerse specimen in water (25c) for 3 – 5 minutes and record its weight \((C)\).
- Surface dry the specimen and determine SSD weight \((B)\).
- Bulk S.G. = \(G_{mb} = [A / (B-C)]\)

\[
G_{mb} = \frac{W_{dry}}{W_{ssd} - W_{sub}}
\]
Bulk S.G. of Compacted Mix Cont.
Rice S.G. of Loose Mix

- Required for void analysis.
- If the mix contain absorptive aggregates, place loose mix in oven for (4hrs) at mixing temp. so that AC is completely absorbed by aggregate prior to testing.
- Separate particles.....Cool to room temp......place in container....determine dry weight (A).
- Fill pycnometer with water & take wt. (D).
- Put the asphalt mix sample in the pycnometer & add water to fill it @25c.
- Removed entrapped air by vacuuming until residual pressure manometer reads 30 mmHg or less. Maintain this pressure for 5 to 15 minutes. Agitate container while vacuuming.
Rice S.G. of Loose Mix

- Fill pycnometer with water….dry outside…..take wt. \( E \) = Wt of Pycnometer + Asphalt mix sample + water.
- \( G_{mm} = TMD = \left[ \frac{A}{A + D - E} \right] \)

\[
G_{mm} = \frac{Wt_{mix-loose}}{Wt_{pyc+w1} + Wt_{loose} - Wt_{pyc+w2+mix}}
\]

- If test is conducted on 3 specimens mixed at or near optimum….Average 3 results….then calculate effective S.G. (Gse) of aggregate….. Then calculate Gmm for the remaining mixes with different AC contents.
- If Rice S.G. is found for each mix with different AC….. Then calculate Gse of aggregates in each case…. Then calculate Average Gse…… then calculate Gmm values using the average for all five mixes.
Rice S. G. of Loose Mix
% Weights of Total Mix

\[ W_{t_{mix}} = W_{t_{asp}} + W_{t_{agg}} \]

\[ P'_{W_{t_{asp}}} = \frac{W_{t_{asp}}}{W_{t_{mix}}} \times 100 = P_b \]

\[ P'_{W_{t_{agg}}} = \frac{W_{t_{agg}}}{W_{t_{mix}}} \times 100 = P_s = 100 - P_b \]
S.G. of Aggregates

Bulk S.G. of combined aggregates

\[ G_{sb,comb} = \frac{\sum_{i=1}^{n} P_{Wti}}{\sum_{i=1}^{n} \frac{P_{Wti}}{G_{sb,i}}} \]

\[ P_{Wti} = \% \text{ by wt of material } i \]

\[ G_{sb} = \frac{(P1 + P2 + P3)}{((P1/G1) + (P2/G2) + (P3/G3))} \]

\[ P1,2,3 = \% \text{ by wt of aggregates 1, 2, and 3} \]

\[ G1,2,3 = \text{Bulk S.G. of aggregates 1, 2, and 3} \]

Absorption of combined agg = \[ [(P1 A1/100) + (P2 A2/100) + (P3 A3/100)] \]

\[ \text{Where } A1,2,3 = \text{Absorption of aggregates 1, 2, and 3} \]
Effective S.G. of Aggregates

Gse = Ratio of the oven dry wt. in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temp. to the wt. of an equal volume of gas-free distilled water.

\[ G_{se,comb} = \frac{P_s}{100} - \frac{P_b}{G_{mm} - G_{asp}} \]

Ps = % of aggregates by total wt. of mixture = (Pmm = 100) – Pb

Pb = % of asphalt by total wt. of mixture

Gmm = Max. theoretical S.G

Gasp = Gb = S.G. of asphalt
Max. Theoretical S.G

Gmm = Ratio of the wt. in air of a unit volume of an uncompacted bituminous paving mixture at a stated temp. to the wt. of an equal volume of water.

\[ G_{mm} = \frac{P_{mm}}{P_s} + \frac{P_b}{G_{se}} + \frac{G_{mm}}{G_b} \]

Ps = % of aggregates by total wt. of mixture = (Pmm =100) – Pb

Pb = % of asphalt by total wt. of mixture

Gse = Effective S.G. of aggregates

Gb = S.G. of asphalt
Density Void Analysis

WEIGHT-VOLUME RELATIONSHIPS FOR ASPHALT CONCRETE

WEIGHTS

\[ \begin{align*}
W_{t_{\text{air}}} &= 0 \\
W_{t_{\text{asp}}} \\
W_{t_{\text{agg}}} \\
W_{\text{mvb}} &= \gamma_{\text{mix}}
\end{align*} \]

AGGREGATE

\[ \begin{align*}
\text{Aggregate Voids Filled w/ Asphalt}
\end{align*} \]

AIR

\[ \begin{align*}
V_{\text{air}} \\
V_{b} = V_{\text{asp}} \\
V_{\text{ba}} \\
V_{\text{mm}} \\
V_{\text{agg-sc}} \\
V_{\text{agg-vb}} \\
V_{\text{be}} \\
V_{\text{VMA}} \\
1 = V_{\text{mvb}}
\end{align*} \]

given \( \gamma_{\text{mix}} \), % a.c. \rightarrow \text{weights}

\[ \begin{align*}
\text{to convert to volumes} \rightarrow G_{\text{sb-od}}, G_{\text{se}}, G_{\text{mm}}, G_{\text{asp}}
\end{align*} \]
% Air Voids

• Voids in Total Mix = Air Voids: The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as % of the bulk volume of the compacted paving mixture

• Low VTM …. Minimize aging, permeability, and stripping.

\[
\%V_{\text{air}} = P_a = VTM = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100
\]

\[
\%V_{\text{air}} = 100 \times (1 - V_b - V_{\text{agg-se}})
\]

\[3 \leq \%V_{\text{air}} \leq 8\]
Density of Compacted Mix

\[
\gamma_{mix} = \gamma_{mb} = G_{mb} \gamma_w = \frac{Wt_{asp} + Wt_{agg}}{V_{asp} + V_{agg-se} + V_{air}}
\]

\[
\gamma_{mm} = G_{mm} \gamma_w = \frac{Wt_{asp} + Wt_{agg}}{V_{asp} + V_{agg-se}}
\]

Density of water = 1000 kg/ m^3 (62.4 lb/ft^3)
Voids In Mineral Aggregates (VMA)

- The volume of intergranular space between the aggregate particles of a compacted paving mixture that includes the air voids and volume of the asphalt not absorbed into the aggregate.
- \( VMA = V_{\text{effective asphalt}} + V_{\text{air}} \)
- Doesn’t include volume of absorbed asphalt.
- Low VMA affects durability….lower effective asphalt oxidize faster….. Thin film coatings are easily penetrated by water.

\[
\%VMA = 100 - \frac{G_{mb}P_s}{G_{sb\text{-}od,comb}}
\]

\[
\%VMA = 100\times (1 - V_{agg\text{-}sb})
\]
Percent Air Voids

Calculated using both specific gravities

\[
\text{Air voids} = \left( 1 - \frac{G_{mb}}{G_{mm}} \right) \times 100
\]

\[
\frac{\text{Mass agg + AC}}{\text{Vol. agg, AC, Air Voids}} = \frac{\text{Vol. agg, AC}}{\text{Vol. agg, AC, Air Voids}}
\]
Voids Filled with Asphalt (VFA)

- The % of the volume of the VMA that is filled with asphalt cement.
- \[ VFA = \left[ \frac{V_{eb}}{(V_{eb} + V_{air}) = V_{MA}} \right] \times 100 \]

\[ %VFA = \frac{VMA - VTM}{VMA} \times 100 \]

\[ %VFA = \frac{V_{be}}{1 - V_{agg-sb}} \times 100 \]
Effective Asphalt (Pbe)

- available for coating, binding, or filling voids
- NOT absorbed by aggregate

\[
\% P_{be} = P_b - \frac{P_{ba} \times P_s}{100}
\]

\[
\% P_{be} = \frac{V_{be} G_{asp} \gamma_w}{Wt_{agg} + Wt_{asp}} \times 100
\]
Density

- used to control quality during construction
  - % of max theoretical lab density
- % of optimum lab density
  - compare with field density
    - nuclear density meter (non-destructive)
    - cores

\[ D_{mm} = G_{mm} \gamma_w \]
\[ D_{mb} = G_{mb} \gamma_w \]
\[ D_{mb-field} = G_{mb-field} \gamma_w \]
Marshall Stability & Flow

- **Stability**: Maximum load carried by a compacted specimen tested (@ 60c) at a loading rate of (2 in/min).
- Stability is affected by angle of internal friction of aggregates & viscosity of asphalt.
- **Flow**: Vertical deformation of the sample in hundreds of an inch (0.01 inch) or (0.25 mm).

- **Heights**
  - Used to correct stability measurements

- **Stability and flow**
  - Specimen immersed in water bath @ 60°C for 30 to 40 minutes.
  - Remove from bath.... Pat with towel..... Then place in Marshal Testing head.
  - Apply load @ 2 inch (50 mm)/min loading rate
  - Max. load = uncorrected stability (N or Lb)
  - Corresponding vertical deformation = flow (0.01 inch or 0.25 mm)
  - When load start to decrease, remove flowmeter.
  - Note: Test should be completed in 60 sec.
Marshall Stability and Flow
Tabulating & Plotting Test Results

- Tabulate the results from testing
- Correct stability values for specimen height (ASTM D1559).
- Calculate Avg. of each set of 3 specimens.
- Prepare the following plots:
  - %AC vs. Unit wt. (Density)
  - %AC vs. Corrected Marshall stability
  - %AC vs. Flow
  - %AC vs. Air voids (VTM)
  - %AC vs. VMA
  - %AC vs. VFA
## Test Results & Mix Properties for Marshall mix

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<tr>
<th>Sample #</th>
<th>%AC</th>
<th>Wt. in Air (Dry)</th>
<th>Wt. in water (SSD)</th>
<th>Wt. in air (SSD)</th>
<th>Volume</th>
<th>Bulk Density</th>
<th>Theor. Max Density</th>
<th>Air Voids</th>
<th>VMA</th>
<th>VFA</th>
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Figure 4–24. Graphical Illustration of HMA Design Data by Marshall Method
Determination of Optimum AC Content

- National Asphalt Pavement Association (NAPA) Procedure
- Asphalt Institute Procedure
(NAPA) Procedure

**Target optimum asphalt content** = the asphalt content at 4% air voids
The target stability is checked
Use target optimum asphalt content to check if these criteria are met. If not - adjust slightly to meet all criteria if possible; else change gradation and repeat analysis.
Marshall Design Use of Data
Asphalt Institute Procedure

Target optimum asphalt content = average

Air Voids, %

Stability

Unit Wt.

Asphalt Content, %
Use target optimum asphalt content to check if ALL criteria are met
(If not - adjust slightly to meet all criteria if possible; else change gradation and repeat analysis)
Marshall Design Method

- **Advantages**
  - Attention on voids (volumetrics), strength, durability
  - Inexpensive equipment
  - Easy to use in process control/acceptance

- **Disadvantages**
  - Impact method of compaction
  - Does not directly consider shear strength
  - Load perpendicular to compaction axis
  - Developed for dense grad, ≤ 1” max size, viscosity or pen graded ac