Pavement Design

- Design parameters:
  - The characteristics of the subgrade.
  - The applied loads. Expressed as equivalent single axel load, ESAL.
  - The environment. Thermal conditions, moisture damage, oxidization… etc.

$$ESAL = \frac{total\ weight\ on\ the\ road}{18\ kips}$$

Structural Design

- The goal of structural design is to determine:
  - The number of layers beneath pavement.
  - The material composition of layers.
  - The thickness of the different layers.
- Calculations are chiefly concerned with traffic loading stresses.
- Other environmentally related stresses (such as temperature) are accounted for in mix design.

HMA Design

- Hot mix vs. Cold mix:
  - Hot: asphalt cement is used, widely used.
  - Cold: cutback or emulsified asphalt is used, maintenance purpose and in small application.

- HMA mix design is the process of determining what aggregate to use, what asphalt binder to use, and what optimum combination of these two ingredients.

- Objective of mix design:
  - To determine economical blend and gradation of aggregate and asphalt content that produce asphalt mix of a given desired mix properties.

- Mix design methods:
  - Marshal Method
  - Superpave Method
  - Hveem Method

- Desired Mix Properties:
  Any mix should have:

  1. Enough stability to resist loading without distortion or displacement, i.e. resist rutting and shoving.
  2. Enough durability to resist adverse effect of water damage and oxidization.
  3. Enough surface friction to resist skid.
  4. Enough workability to enable proper mixing, placing and compaction with no segregation.
  5. Enough crack resistance
     - Flexible and soft enough to resist fatigue cracking.
     - Enough stiffness and tensile strength to resist thermal cracking.
  6. Enough VMA.

- VMA should be high enough to:
  - Allow proper asphalt film thickness. Upper limit prevents excessive environmental damage
  - Allow slight compaction under traffic without bleeding. Lower limit to allow room for initial densification due to traffic.
- VMA depends on:
  - Aggregate gradation. If you have problems in satisfying VMA, use courser or finer aggregate blend.
  - Nominal maximum size.

- Variables:
  In order to meet the desired mix properties, the designer can manipulate these variables:

  1. Aggregate. Source, gradation, abrasion resistance, soundness, shape and texture.
  2. Asphalt binder. Type, durability, rheology, purity, additional modifying agents.
  3. The ratio of asphalt binder to aggregate.

- Design Process Steps:
  1. Selecting suitable material:
     Satisfying aggregate and asphalt.
  2. Selecting proper gradation
     Design of aggregate structure, DAS.
  3. Selecting optimum asphalt binder content.
     Low enough to resist rutting and high enough to resist cracking.
  4. Water resist evaluation.

Marshal Mix Design

- Optimum asphalt binder content determination.
    1. Prepare a series of initial samples, each at a different asphalt binder content.
        - For instance, two to three samples each might be made at 4.5, 5.0, 5.5, 6.0 and 6.5 percent asphalt by dry weight for 10 to 15 samples.
        - There should be at least two samples above and two below the estimated optimum asphalt content.
    2. Compact these trial mixes using the Marshall drop hammer.
        - This hammer is specific to the Marshall Mix design method.
    3. Test the samples in the Marshall testing machine for stability and flow.
        - This testing machine is specific to the Marshall Mix design method.
        - Passing values of stability and flow depend upon the mix class being evaluated.
    4. Determine the density and other volumetric properties of the samples.
    5. Select the optimum asphalt binder content.
        - The asphalt binder content corresponding to 4 percent air voids is selected as long as this binder content passes stability and flow requirements.

Superpave Mix Design

- Optimum asphalt binder content determination.
    1. Prepare several initial samples.
        - Usually two at the proposed design asphalt content, two at 0.5 percent below the design asphalt content and two at 0.5 percent above the design asphalt content.
    2. Compact these trial mixes in the Superpave Gyratory Compactor.
        - This compactor is specific to the Superpave mix design method.
    3. Determine the density and other volumetric properties of the samples.
    4. Select the optimum asphalt binder content.
        - The asphalt binder content corresponding to 4 percent air voids.

Hveem Mix Design

- Optimum asphalt binder content determination.
    1. Prepare multiple initial samples, each at a different asphalt binder content.
        - For instance, one sample each might be made at 4.5, 5.0, 5.5, 6.0, 6.5 and 7 percent asphalt by dry weight for a total of six samples.
    2. Compact these trial mixes in the California Kneading Compactor.
        - This compactor is specific to the Hveem mix design method.
    3. Test the samples for stability and cohesion using the Hveem stabilometer and cohesiometer.
        - These tests are specific to the Hveem mix design method.
        - Passing values of stability and cohesion depend upon the mix class being evaluated.
        - Typically, all samples pass the cohesion test and three or four pass the stability test.
    4. Determine the density and other volumetric properties of the samples.
    5. Select the optimum asphalt binder content.
        - The asphalt binder content corresponding to 4 percent air voids is selected as long as this binder content passes stability and cohesion requirements.

HMA Weight-Volume Terms and Relationships

- Since weight measurements are typically much easier, they are typically taken then converted to volume by using specific gravities.

V_T = Total volume of the compacted specimen
V_a = Volume of air voids
V_b = Volume of asphalt binder
V_{be} = Volume of effective asphalt binder
V_{ba} = Volume of absorbed asphalt binder
V_{agg} = Volume of aggregate
V_{eff} = Effective volume of aggregate = $(V_T - V_a)$

G_{sa} = Apparent specific gravity of the aggregate
G_b = Asphalt binder specific gravity
G_{sb} = Bulk specific gravity of the aggregate
G_{se} = Effective specific gravity of the aggregate
G_{mb} = Bulk specific gravity of the compacted mixture
G_{mm}= Maximum theoretical specific gravity of mixture

W_T = Total weight of the compacted specimen
W_D = Dry weight
W_{SSD} = Saturated surface dry (SSD) weight
W_{sub} = Weight submerged in water
W_b = Weight of the asphalt binder
W_{be} = Weight of effective asphalt binder
W_{ba} = Weight of absorbed asphalt binder
W_{agg} = Weight of aggregate

P_b = Asphalt content by weight of mix (%)
P_s = Aggregate content by weight of mix (%)
P_a = Percent air voids

γ_W = Unit weight of water

- Bulk Specific Gravity of the Compacted Asphalt Mixture (G_{mb})

  This value is used to determine weight per unit volume of the compacted mixture. It is very important to measure G_{mb} as accurately as possible. Since it is used to convert weight measurements to volumes, any small errors in G_{mb} will be reflected in significant volume errors, which may go undetected.

$$G_{mb} = \frac{W_D}{W_{SSD} - W_{sub}}$$

- Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures (G_{mm})

  The ratio of the mass of a given volume of voidless ($V_a = 0$) HMA at a stated temperature to a mass of an equal volume of gas-free distilled water at the same temperature. Multiplying G_{mm} by the unit weight of water gives Theoretical Maximum Density (TMD).

$$G_{mm} = \frac{W_{agg} + W_b}{V_{eff} + V_b}$$

$$G_{mm} = \frac{1}{\frac{1 - P_b}{G_{se}} + \frac{P_b}{G_b}}$$

- Air Voids (V_a)

  The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture. The amount of air voids in a mixture is extremely important and closely related to stability and durability. For typical dense-graded mixes with 12.5 mm, (0.5-inch) nominal maximum aggregate sizes air voids below about 3 percent result in an unstable mixture while air voids above about 8 percent result in a water-permeable mixture.

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100$$

- Voids in the Mineral Aggregate (VMA)

  The volume of void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the specimen.

$$VMA = \left(1 - \frac{G_{mb}(1 - P_b)}{G_{sb}}\right) \times 100$$

$$VMA = 100 - \left[\frac{(G_{mb} P_s)}{G_{sb}}\right]$$

- Voids Filled with Asphalt (VFA)

  The portion of the voids in the mineral aggregate that contain asphalt binder. This represents the volume of the effective asphalt content. It can also be described as the percent of the volume of the VMA that is filled with asphalt cement. VFA is inversely related to air voids: as air voids decrease, the VFA increases.

$$VFA = \left(\frac{P_{be} \times G_{mb}}{G_b + VMA}\right) \times 100$$

$$VFA = \frac{VMA - V_a}{VMA} \times 100$$

$$VFA = VMA - P_a$$

- Volume of Absorbed Asphalt (V_{ba})
  The volume of asphalt binder in the HMA that has been absorbed into the pore structure of the aggregate.

$$V_{ba} = \frac{W_{ba}}{W_{agg}} \times 100$$

$$V_{ba} = \left(\frac{G_{se} - G_{sb}}{G_{sb} G_{se}}\right) G_b \times 100$$

- Effective Asphalt Content (P_{be})
  The total asphalt binder content of the HMA less the portion of asphalt binder that is lost by absorption into the aggregate.

$$P_{be} = V_b - V_{ba}$$