

**Chapter: Two**  
**Pavement Design**

**2.1 Introduction**

Pavement are among the costliest items associated with highway construction and maintenance, and are largely responsible for making highway system the most expensive public works project undertaken by any society. Because the pavement and associated shoulder structures are the most expensive items to construct and maintain, it is important for highway engineers to have a basic understanding of pavement design principles.

Highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favourable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the subgrade.

**2.2 Requirements of Pavement**

An ideal pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
- Structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed,
- Produce least noise from moving vehicles,
- Dust proof surface so that traffic safety is not impaired by reducing visibility.

- Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost.

## **2.3 Factors affecting pavement design**

### **2.3.1 Traffic and loading**

Traffic is the most important factor in the pavement design. The key factors include contact pressure, wheel load, axle configuration, moving loads, load, and load repetitions.

- **Contact pressure:** The tyre pressure is an important factor, as it determines the contact area and the contact pressure between the wheel and the pavement surface. Even though the shape of the contact area is elliptical, for sake of simplicity in analysis, a circular area is often considered.
- **Wheel load:** The next important factor is the wheel load, which determines the depth of the pavement required to ensure that the subgrade soil is not failed. Wheel configuration affects the stress distribution and deflection within a pavement. Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits. The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler.
- **Axle configuration:** The load carrying capacity of the commercial vehicle is further enhanced by the introduction of multiple axles.
- **Moving loads:** The damage to the pavement is much higher if the vehicle is moving at creep speed. Many studies show that when the speed is increased from 2 km/hr to 24 km/hr, the stresses and deflection reduced by 40%.
- **Repetition of Loads:** The influence of traffic on pavement not only depends on the magnitude of the wheel load, but also on the frequency of

the load applications. Each load application causes some deformation and the total deformation is the summation of all these. Although the pavement deformation due to single axle load is very small, the cumulative effect of number of load repetition is significant. Therefore, modern design is based on total number of standard axle load (usually 80 KN single axle).

### **2.3.2 Structural models**

The structural models are various analysis approaches to determine the pavement responses (stresses, strains, and deflections) at various locations in a pavement due to the application of wheel load. The most common structural models are layered elastic model and visco-elastic models.

### **2.3.3 Material characterization**

The following material properties are important for both flexible and rigid pavements.

- When pavements are considered as linear elastic, the elastic moduli and Poisson ratio of subgrade and each component layer must be specified.
- If the elastic modulus of a material varies with the time of loading, then the resilient modulus, which is elastic modulus under repeated loads, must be selected in accordance with a load duration corresponding to the vehicle speed.
- When a material is considered non-linear elastic, the constitutive equation relating the resilient modulus to the state of the stress must be provided. However, many of these material properties are used in visco-elastic models which are very complex and in the development stage.

### **2.3.4 Environmental factors**

Environmental factors affect the performance of the pavement materials and cause various damages. Environmental factors that affect pavement are of two types, temperature and precipitation:

- **Temperature.** The effect of temperature on asphalt pavements is different from that of concrete pavements. Temperature affects the resilient modulus of asphalt layers, while it induces curling of concrete slab. In rigid pavements, due to difference in temperatures of top and bottom of slab, temperature stresses or frictional stresses are developed. While in flexible pavement, dynamic modulus of asphaltic mixture varies with temperature. Frost causes differential settlements and pavement roughness. Most detrimental effect of frost penetration occurs during the spring break up period when the ice melts and subgrade is in a saturated condition.
- **Precipitation.** The precipitation from rain and snow affects the quantity of surface water infiltrating into the subgrade and the depth of ground water table. Poor drainage may bring lack of shear strength, pumping, loss of support, etc.

## **2.4 Pavement materials**

### **2.4.1 Soil**

Soil is an accumulation or deposit of earth material, derived naturally from the disintegration of rocks or decay of vegetation that can be excavated readily with power equipment in the field or disintegrated by gentle mechanical means in the laboratory. The supporting soil beneath pavement and its special under courses is called sub grade. Undisturbed soil beneath the pavement is called natural sub grade. Compacted sub grade is the soil compacted by controlled movement of heavy compactors. In general, the desirable properties of sub grade soil as a highway material are:

- Stability
- Incompressibility
- Permanency of strength

- Minimum changes in volume and stability under adverse conditions of weather and ground water
- Good drainage, and
- Ease of compaction

#### **2.4.2 Aggregate**

Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete). By volume, aggregate generally accounts for 92% to 96% of bituminous concrete and about 70% to 80% of Portland cement concrete. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a by-product of other manufacturing industries. Figure 2.1 illustrates some types of aggregate . Aggregate used in asphaltic mixtures are either:

1. **Crushed aggregate** (such as limestone, granite),
2. **Natural aggregate** (such as gravel and sand) or
3. **Secondary aggregate** (such as RAP, demolition aggregate, ...etc.)



*Figure 2.1: Some types of aggregates*

The main desirable properties of aggregate are:

- **Strength.** The aggregates used in top layers are subjected to (i) Stress action due to traffic wheel load, (ii) Wear and tear, (iii) crushing. For a high quality pavement, the aggregates should possess high resistance to crushing, and to withstand the stresses due to traffic wheel load.
- **Hardness.** The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. The aggregates should be hard enough to resist the abrasive action caused by the movements of traffic. The abrasive action is severe when steel tyre vehicles moves over the aggregates exposed at the top surface.
- **Toughness.** Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tyre wheels from one particle to another at different levels which causes severe impact on the aggregates.
- **Shape of aggregates.** Aggregates, which happen to fall in a particular size range, may have rounded, cubical, angular, flaky or elongated particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded

particles of the same aggregate. Hence, too flaky and too much elongated aggregates should be avoided as far as possible.

- **Adhesion with bitumen.** The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials; otherwise, the coated aggregate by bitumen will be stripped off in the presence of water.
- **Durability.** The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action.
- **Freedom from deleterious particles.** Specifications for aggregates used in bituminous mixes usually require the aggregates to be clean, tough, durable in nature, and free from excess amount of elongated pieces, dust, clay balls and other objectionable material. Similarly, aggregates used in Portland cement concrete mixes must be clean and free from deleterious substances such as clay lumps, silt and other organic impurities.

#### **2.4.3 Bitumen**

Bituminous materials are widely used all over the world in highway construction. These hydrocarbons are found in natural deposits or are obtained as a product of the distillation of crude petroleum. The bituminous materials used in highway construction are either asphalts or tars. All bituminous materials consist primarily of bitumen and have strong adhesive properties with colours ranging from dark brown to black. They vary in consistency from liquid to solid; thus, they are divided into liquids, semisolids, and solids. The solid form is usually hard and brittle at normal temperatures but will flow when subjected to long, continuous loading. The liquid form is obtained from the semisolid or solid forms by heating, dissolving in solvents, or breaking the



material into minute particles and dispersing them in water with an emulsifier to form an asphalt emulsion. Figure 2.2 illustrates bitumen

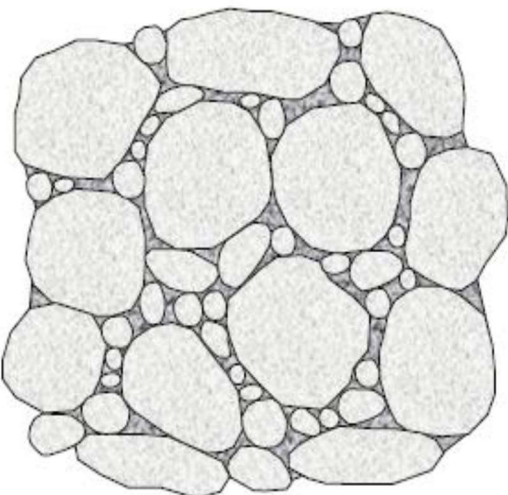


*Figure 2.2: Bitumen*

## 2.5 Asphalt Mixtures

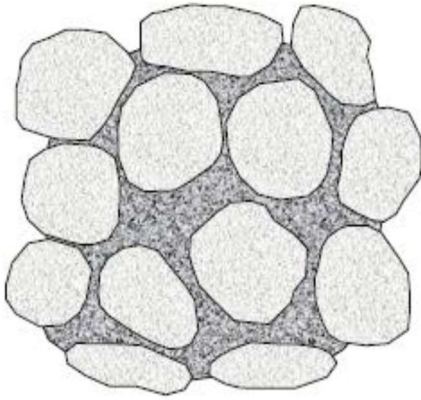
### 2.5.1 Mixtures gradation types

- ***Dense Graded Aggregate or Well Graded Aggregate***

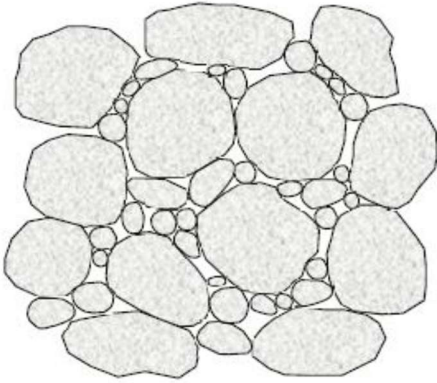
<i>Illustration</i>	<i>Characteristics</i>
	<ul style="list-style-type: none"><li>• Wide range of sizes</li><li>• Grain to grain contact</li><li>• Low void content</li><li>• Low permeability</li><li>• High stability</li><li>• Difficult to compact</li></ul>



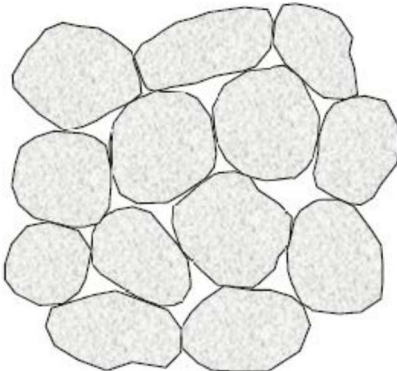
- **Gap Graded Aggregate**

<i>Illustration</i>	<i>Characteristics</i>
	<ul style="list-style-type: none"> <li>• Missing middle sizes</li> <li>• No Grain to grain contact</li> <li>• Moderate void content</li> <li>• Moderate permeability</li> <li>• Low stability</li> <li>• Easy to compact</li> </ul>

- **Open Graded Aggregate**

<i>Illustration</i>	<i>Characteristics</i>
	<ul style="list-style-type: none"> <li>• Few fine particles</li> <li>• Grain to grain contact</li> <li>• High void content</li> <li>• High permeability</li> <li>• High stability</li> <li>• Difficult to compact</li> </ul>

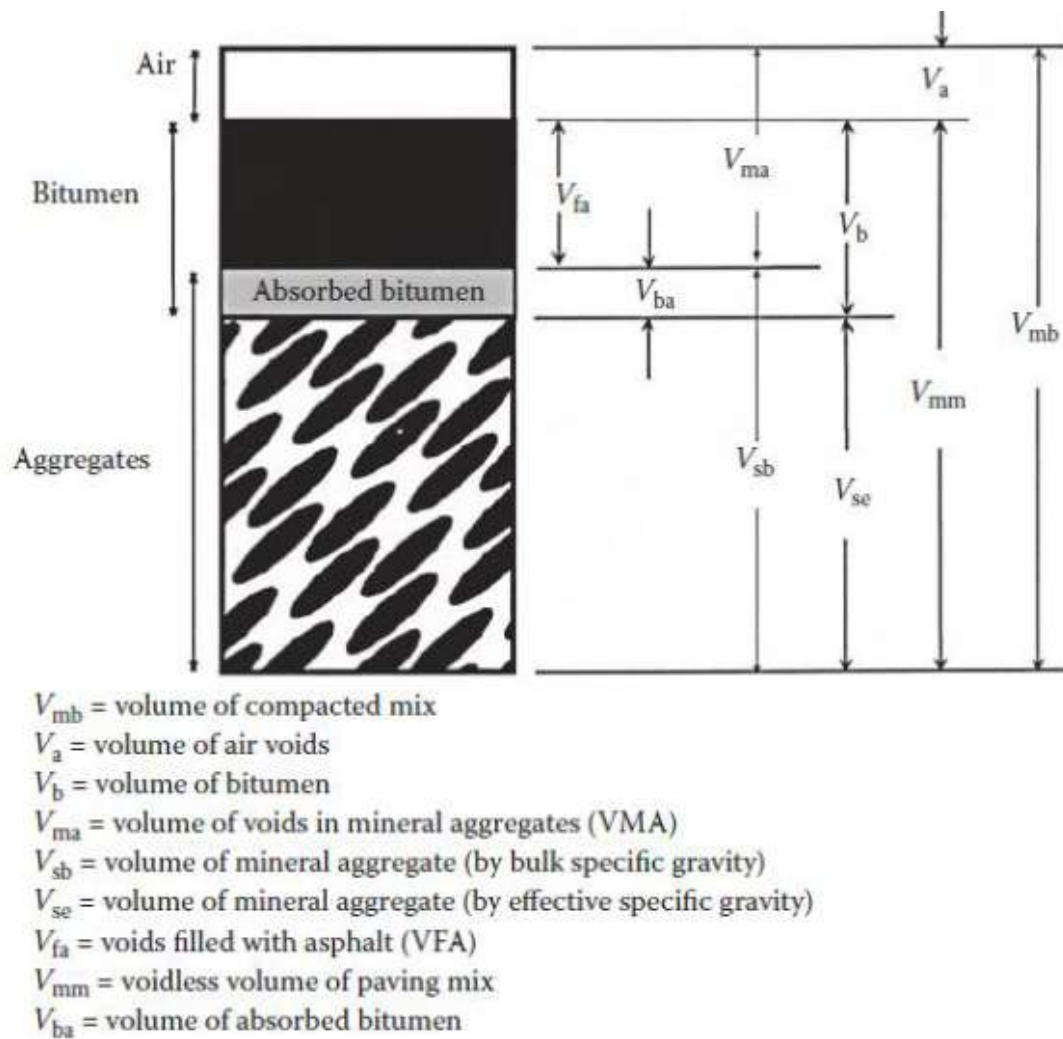
- **Uniformly Graded Aggregate**

<i>Illustration</i>	<i>Characteristics</i>
	<ul style="list-style-type: none"> <li>• Narrow range of sizes</li> <li>• Grain to grain contact</li> <li>• High void content</li> <li>• High permeability</li> <li>• Low stability</li> <li>• Difficult to compact</li> </ul>

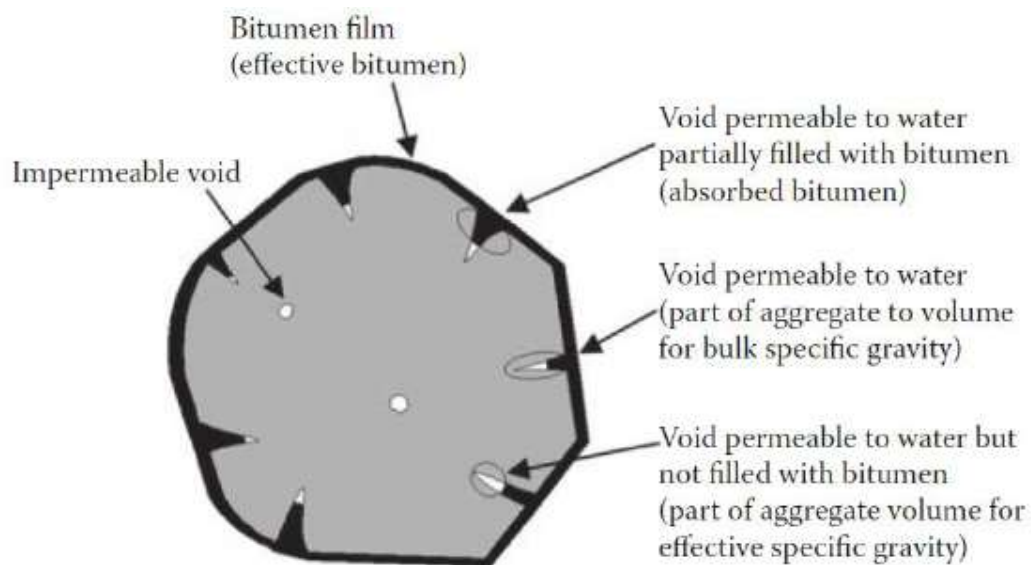
### **2.5.2 Compacted bituminous mixture**

The volume of the compacted specimen of any bituminous mixture consists of the volume occupied by aggregates, the volume occupied by bitumen and the volume of air voids. The volume, which is occupied by bitumen and air voids, is known as volume in mineral aggregates (VMA). When bituminous binder is added, part of the volume of air voids is filled with bitumen (asphalt). The volume is known as voids filled with asphalt (VFA). The above volumetric characteristic properties are presented in Figure 2.3. Aggregates (attributed to the surface pores) normally possess and absorb a certain quantity of bitumen. As a consequence, the remaining bitumen quantity is in fact the one that coats the aggregates, fills the voids and provides cohesion in the mixture. This quantity of bitumen is designated as 'effective' bitumen quantity, and it is always less than the initial quantity of bitumen added, unless the aggregate's absorption is zero (ideal case).

The surface pores, in the absence of bitumen, absorb water (surface voids permeable to water). Because of the lower viscosity of water in comparison to bitumen's viscosity, water absorption is always higher than bitumen absorption. The schematic representation of an aggregate-coated particle given in Figure 2.4 the above, as well as other concepts.



**Figure 2.3: Illustration of volumes in compacted asphaltic mixture**



**Figure 2.4: Coated aggregate particle**

Provided that the bulk specific gravity ( $G_{sb}$ ) and the effective specific gravity ( $G_{se}$ ) of the total aggregate, as well as the specific gravity of the bitumen ( $G_b$ ), are known, the volumetric properties of bituminous mixture (asphalt mixture) may be determined. The bulk density of the sample usually is determined by weighing the sample in air and in water. It may be necessary to coat samples made from open-graded mixtures with paraffin before determining the density. The bulk specific gravity  $G_{mb}$  of the sample—that is, the compacted mixture—is given as

$$G_{mb} = \frac{W_a}{W_a - W_w} \dots\dots\dots(2.1)$$

where

$W_a$  = weight of sample in air (g)

$W_w$  = weight of sample in water (g)

### **2.5.3 Determination of the design asphalt content of the mix**

#### **Analysis of Results from Marshall Test**

The first step in the analysis of the results is the determination of the average bulk specific gravity for all test specimens having the same asphalt content. **The average unit weight of each mixture is then obtained by multiplying its average specific gravity by the density of water.** A smooth curve that represents the best fit of plots of unit weight versus percentage of asphalt is determined, as shown in Figure 2.5(a). This curve is used to obtain the bulk specific gravity values that are used in further computations as in Example 1.