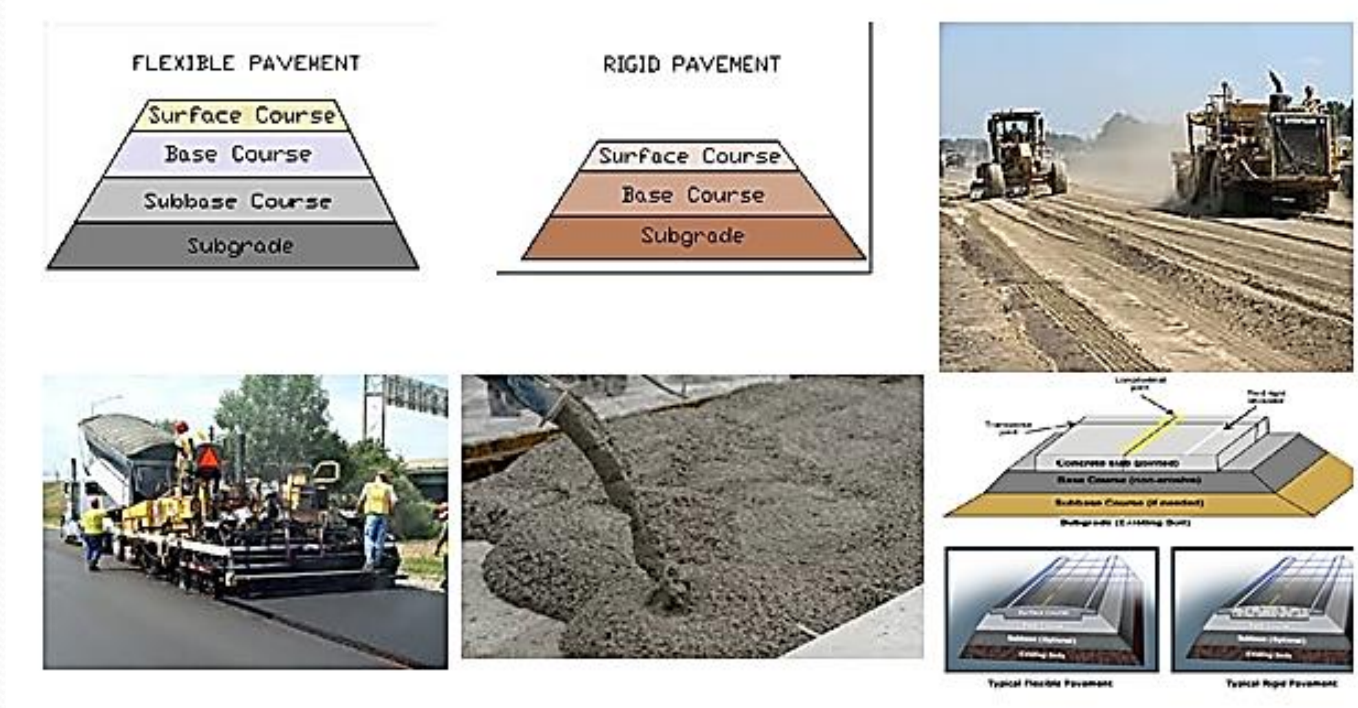
University of Anbar – College of Engineering
Departement of Civil Engineering
Highway Materials
Course No:*CE 4345*



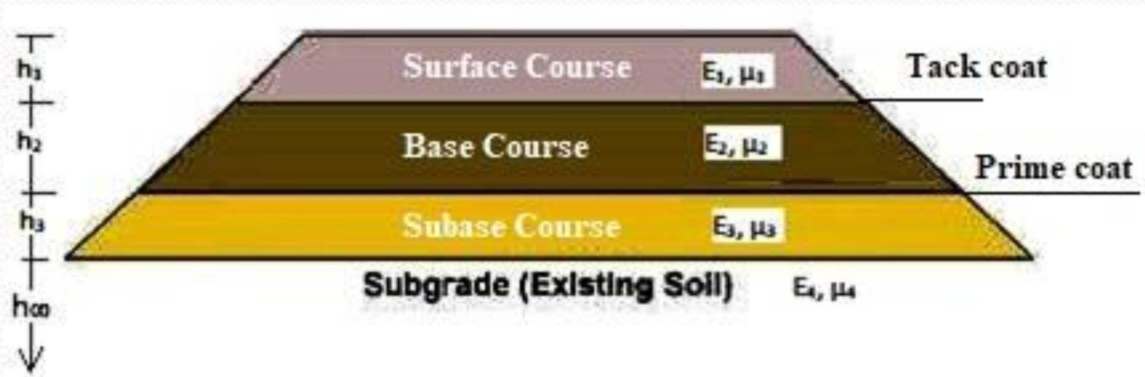
Prepared By:
Dr Talal H. Fadhil
Dr Taher M. Ahmed

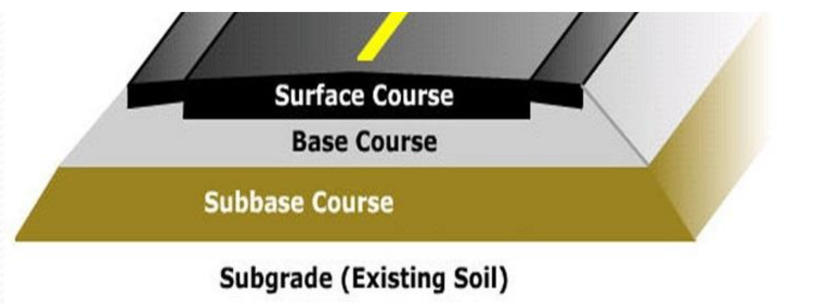
Flexible Pavement Layers:

General

- A pavement is a set of superimposed layers of imported materials (unbound and bound materials) that are placed on the natural soil for the construction of a road.

- Asphalt roadways (also called *asphalt concrete pavements*) are specifically engineered and consist of multiple layers or courses of asphalt mix and other materials .The structural layers are usually referred to as (i) surface course, (ii) intermediate course (binder course), (iii) base course, (iv) subbase course, and (v) subgrade.





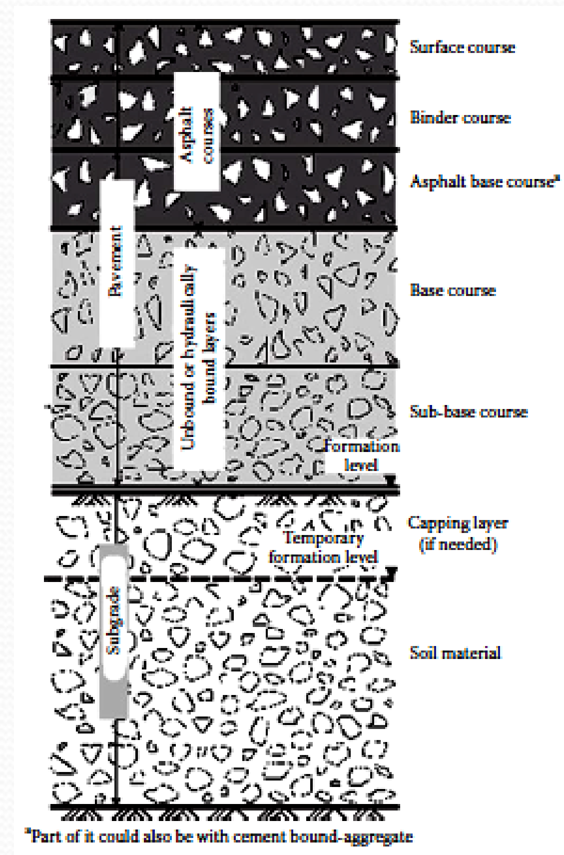


Figure (3-1)

- The main structural function of a pavement is to sustain traffic loads and distribute them to the subgrade. The stresses transferred to the surface of the subgrade should be such as to cause minimal deformation of the subgrade soil layer.

- Additionally, part of the upper layers of the pavement structure should be almost impervious to water such as asphalt concrete layer, so that the subgrade, as well as the unbound layers, is protected from the detrimental effect of surface water (rainfall).

- Finally, the pavement surface should be skid resistant, resistant to the polishing action of tyres. In general, the flexible pavement structure consists of two characteristic sets of layers with different mechanical properties and performance: the unbound or hydraulically bound aggregate layers such as base course (if untreated with asphalt such as macadam) and subbase course which is seated on the subgrade, and the bound asphalt (surface, binder, and base course) layers, seated on the previous set of layers as shown in the Figure (3-1).

- All the other layers are characterized as pavement upper layers or upper structure.

Subgrade

- Subgrade is commonly compacted before the construction of a road, pavement and are sometimes stabilized by the addition of asphalt, lime, Portland cement or other modifiers. The subgrade is the foundation of the pavement structure, on which the subbase course is laid. **The final longitudinal and cross sectional slopes must be completed during subgrade compaction reaching to the formation level. Formation level is the level of the last layer of the embankment directly on which the subbase course is constructed.**
- In the case of needing to fill the embankment reaching to the desired level of the road embankment. Multi-layers of suitable soil are constructed reaching to the formation level. Embankments shall be constructed of material spread in successive layers (not more than 20 cm height) for compaction, each layer extending over the full width of the embankment at the height of the layer.
- According to ISSRB the properties of the suitable soils for embankment construction are:
  - The Unit Dry Weight of natural ground shall comply with minimum 88% of that determined by AASHTO TI 80-74 (Modified AASHTO Compaction Test) up to the depth 25cm.
  - Sub grade soil compaction (the active soil layer) 30cm below the formation level in all parts of the embankment and cut areas throughout the whole length and width of section shall be not less than 95%.
  - The minimum CRB shall be 5% at 95% of the maximum density.
  - Liquid limit and plasticity index should be less than 55% & 30% respectively.
  - Dry unit weight in modified compaction is greater than1.70 g/cm^3

Subbase Course

The sub-base is the first layer constructed over the subgrade (formation level). Materials of subbase layer must consists of: sand, gravel or sand-gravel mixture. The sub-base performs the following basic functions:

1. It reduces the loads, transfers and distributes them to the subgrade.
2. It eases the traffic of the worksite vehicles during construction.
3. It protects the base course materials from contamination from soil material (clay, silt, organic materials, etc.).
4. It acts as an anti-frost protective layer (prevent the capillary action) in cases where soil material is frost susceptible.
5. It reduces intrusion of fines (typically micron-size mineral mater) from the subgrade in rigid pavement.

Requirements According to ISSRB.

- **Coarse Aggregate** (that retained on 2mm (No.10) sieve)). Coarse aggregate shall consist of hard, durable particles or fragments of gravel free from dirt and other objectionable matter. It shall have a percentage of wear not exceeding 45.
- **Fine aggregate** (passing the 2mm sieve), it shall consist of sharp natural sand or a well graded mixture of sharp natural sand , silt , clay and stone dust . It shall not contain more than 2% of organic matter. **The material passing the 0.425 mm (No.40) sieve has a L.L & P.I as 25% , 6% respectively**

- **Soluble salts** shall not be more 10 % with maximum dilution of 1:50 . The sulphate content in terms of SO_3 shall **not be more** than 5 % by weight (i.e. gypsum content equals to 10.75 %).
- The granular sub-base gradations follows the limitations of Table (1)

Table(1): Selected Granular Material – Grade Requirements

US Sieve Size Mm	Alternative	Type A	Type B	Type C	Type D
75	3 in	100			
50 .0	2 in	95-100	100		
25,0	1 in		75-95	100	100
9.5	3/8 in	30-65	40-75	50-85	60-100
4.75	No.4	25-55	30-60	35-65	50-85
2.36	No.8	16-42	21-47	26-52	42-72
0.30	No.50	7-18	14-28	14-28	23-42
0.075	No.200	2-8	5-15	5-15	5-20

The California Bearing Ratio (CBR) for the type B ,C,& D when tested in accordance with (ASTM D 1883) using modified compaction shall not be less than 35% for type B , 30% for type C , and 20% for type D , at 95 % of the maximum density established according to AASHTO T 180 0r ASTM D 1557.

Base Course

❑ The base course layer is located between the sub-base course and the asphalt concrete layers. Base course constructed either from bituminous materials (Hot Mix Asphalt HMA) as a stabilized layer or unbound granular materials such as crushed gravel, crushed stone, and vibratory-compacted Macadam stone.

❑ Base courses may be approximately 100–300 mm thick with a higher thickness being necessary to withstand heavier traffic loads and reduce the strain within the pavement and make it less prone to fatigue cracking. **The prime coat is used to bond the base and subbase course.**

VIBRATORY-COMPACTED MACADAM STONE BASE MATERIAL

U.S. Sieve Size		Percent Passing by Weight	
mm	Imperial	Coarse Aggregate	Fine Aggregate
63.0	2½ in	100	—
50.0	2 in	90-100	-
37.5	1½ in	35-70	-
25.0	1 in	0-15	-
12. 5	½ in	0-5	-
9.5	⅜ in	-	100
4.75	No. 4	-	85-100
0.15	No. 100	-	10-30

❑ Purposes(Functions):

i- It works as foundation to pavement.

ii- It distributes load over larger area of sub base.

iii- Prevents excessive (large) deformation.

Surface Course

- The surface (wearing or dressing) course is the upper structural layer in an asphalt pavement, it is typically between approximately (40 and 75 mm) thick. This course is directly exposed to traffic and environmental forces and it must be produced with the highest-quality materials to achieve the following purposes:

1. adequate wet weather friction for safety.
2. high resistance to load-induced rutting, shoving, and surface cracking.
3. high resistance to thermally induced cracking.
4. low permeability to minimize surface-water infiltration.
5. high durability to resist disintegration due to the combined effects of aging, traffic loading, and freeze–thaw effects.
6. appropriate surface texture for noise control, safety.
7. Smoothness or comfortable of riding.

- Surface courses contain highly angular aggregates and an appropriate performance-graded binder to resist traffic and environmental forces. If the surface course is also the top layer in the pavement, then the aggregates must be resistant to polishing under traffic loading to provide appropriate skid resistance over the service life of the pavement. **The tack coat is used to bond surface and base course.**

❑ Aggregate gradation limits according to ISSRB

ASPHALT MIXTURE GRADINGS

Sieve size	mm	Type I	Type II	Type IIIA	Type IIIB
		Base Course	Binder or Leveling Course	Surface or Wearing Course	
		% Passing by Weight of Total aggregate + Filler			
1½ in	37.5	100			
1	25.0	90-100	100		
¾	19.0	76-90	90-100	100	
½	12.5	56-80	70-90	90-100	100
3/8	9.5	48-74	56-80	76-90	90-100
No. 4	4.75	29-59	35-65	44-74	55-85
No. 8	2.36	19-45	23-49	28-58	32-67
No. 50	300 µm	5-17	5-19	5-21	7-23
No. 200	75 µm	2-8	3-9	4-10	4-10
Asphalt Cement (% weight of total mix)		3-5.5	4-6	4-6	4-6

E. Asphalt concrete (AC)

- Various types of hot mix asphalt (HMA) consist of mineral aggregate (coarse, fine, and filler) and asphalt cement are used in the construction of flexible pavements depending on the project requirements, to ensure optimal use of the asphalt. Types and specifications of asphalt mixture depend on the traffic loading, climatic conditions and the layer type and thickness within the flexible pavement .

Properties considered in mix design

- A good performance of asphalt mixture pavements can be achieved from a **correct design, high quality for materials and production, and controlled methods in construction**. There are several properties that contribute to the quality of asphalt mixture pavements. They include **stability, durability, impermeability, workability, flexibility, and fatigue resistance.**

1- Stability : Stability of an asphalt mixture pavement is the ability of the mixture to resist shoving and rutting under loads (traffic). A stable pavement maintains the shape and smoothness required under repeated loading

LOW STABILITY	
Causes	**Effects**
Excess binder in asphalt mixture	Washboarding, rutting, and flushing or bleeding
Excess medium size sand in asphalt mixture	Tenderness during rolling and for a period after construction, and difficulty in compacting
Rounded aggregate, little or no crushed surfaces	Rutting and channeling

2. **Durability:** Durability is the ability of the asphalt mixture pavement to resist changes in the consistency of binder due to volatilization and oxidation of asphalt components and disintegration of the aggregate. These factors may be the result of weather, traffic, or a combination of the two. Generally, durability of an asphalt mixture may be enhanced by three methods. They are: using maximum binder content, using a sound aggregate, and designing and compacting the asphalt mixture for maximum impermeability.

POOR DURABILITY	
Causes	**Effects**
Low binder content	Dryness or raveling
High void content through design or lack of compaction	Early hardening of binder followed by cracking or disintegration
Water susceptible (hydrophilic) aggregate in asphalt mixtures	Films of binder strip from aggregate leaving an abraded, raveled, or mushy pavement

3. Impermeability: Impermeability is the resistance of an asphalt mixture pavement to the passage of air and water into or through the mixture. This characteristic is related to the void content of the compacted asphalt mixture. Impermeability is important for the durability of a compacted paving asphalt mixture, virtually all asphalt mixture used in highway construction is permeable to some degree.

MIX TOO PERMEABLE	
Causes	**Effects**
Low binder content	Thin binder films that causes early aging and raveling
High void content in design asphalt mixture	Water and air may easily enter pavement causing oxidation and disintegration
Inadequate compaction	Results in high voids in pavement leading to water infiltration and low strength

4. Workability: describes the ease with which a paving asphalt mixture may be placed and compacted. Workability may be improved by changing mix design parameters, aggregate sources, and/or gradation.

POOR WORKABILITY	
Causes	**Effects**
Large maximum size particle	Rough surface, difficult to place
Excessive coarse aggregate	May be hard to compact
Too low an asphalt mixture temperature	Uncoated aggregate, not durable, rough surface, hard to compact
High fines content	Asphalt mixture may be dry or gummy, hard to handle, not durable

Flexibility: is the ability of an asphalt mixture pavement to adjust to gradual settlements and movements in the subgrade without cracking. Since virtually all subgrade either settle (under loading) or rise (from soil expansion), flexibility is a desirable characteristic for all asphalt mixtures pavement.

Fatigue resistance: is the pavement's resistance to repeated bending under wheel loads (traffic). Air voids (related to binder content) and binder viscosity have a significant effect on fatigue resistance. As the percentage of air voids in the pavement increases, either by design or lack of compaction, pavement fatigue life (the length of time during which an in-service pavement is adequately fatigue-resistant) is drastically shortened. Likewise, a pavement containing binder that has aged and hardened significantly has reduced resistance to fatigue. The thickness and strength characteristics of the pavement and the supporting strength of the subgrade also have an effect on the pavement life and prevention of load associated cracking. Thick, well supported pavements do not bend as much under loading as thin or poorly supported pavements. Therefore, thick well supported pavements have longer fatigue lives.

POOR FATIGUE RESISTANCE	
Causes	**Effects**
Low asphalt binder content	Fatigue cracking
High design voids	Early aging of binder followed by fatigue cracking
Lack of compaction	Early aging of binder followed by fatigue cracking
Inadequate pavement thickness	Excessive bending followed by fatigue cracking

Asphalt concrete (AC)

General

- ➢ The main objectives of mix design is developing an economical blend of aggregates and asphalt that meet design requirements and covers all performance requirements of Hot Mix Asphalt (HMA) which includes **mix design in the lab, preparation of the mixtures in the plant, construction in the suite and monitoring the performance during the service life**.
- ➢ There are **several methods** that are used in designing the HMA:
  - **Marshall Mix Design** Method (Resistance to Plastic Deformation)
  - **Superpave Method**.

Marshall Mix Design Method

✓ The basic of the Marshall mix design method were originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the U.S. Army. The Marshall method seeks to select the asphalt binder content at a desired density that satisfies minimum stability and range of flow values. **Marshal test is limited to be used for maximum aggregate size of 25.4 mm (1 in), furthermore it is used for design and evaluating asphalt concrete mixture**. Because it is a simple and inexpensive (apparatus and test procedure) therefore it is widely used in world.

✓ There are two major features of the Marshall method of mix design. **(i) density-voids analysis** and **(ii) stability-flow tests**. **The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C**. **The flow value is the deformation that the test specimen undergoes during loading up to the maximum load.** Flow is measured in 0.25 mm units. In this test, an attempt is made to obtain optimum binder content for the type of aggregate mix used and the expected traffic intensity.

Steps of Design

1. Select the set of sieves for aggregate grading of the specified course (base, binder and surface courses).

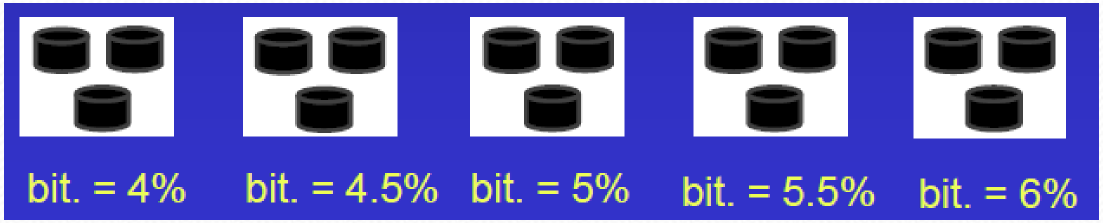
2. Determine the proportion of each aggregate type (blending Agg.A, Agg.B, Agg.C) required to produce the design grading which finally gives gradation within specification requirements .

3. Determine the specific gravity (Bulk & Apparent) of the aggregate combination and asphalt cement.

$$G_{sb} = \frac{P_1 + P_2 + P_3 + \cdots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \cdots + \frac{P_n}{G_n}}$$

G_{sb} = bulk specific gravity of combined aggregate
P_i = percent of contribution aggregate i.
G_i = bulk specific gravity of aggregate i.

4. Prepare the trial specimens (three specimens as one set) with varying asphalt contents (4%,4.5%, 5%, 5.5%, and 6%). The asphalt content is from the total weight of the mix (0.5% increment). The specimen is cylindrical shape of 101.6 mm (4 inches) in diameter and 63.5 mm height (2.5 inches).



5. Determine the mixing and compaction temperatures using Rotational viscometer.

6. Mix the specimens at mixing temperature and then compact the trial specimen sets by Marshall hammer 75 blows for each face at compaction temperature.

7. After one night cooling, determine the specific gravity of each compacted specimen.

8. Perform Marshall test (stability and flow) on each specimen.

9. Calculate the volumetric properties on each specimen.

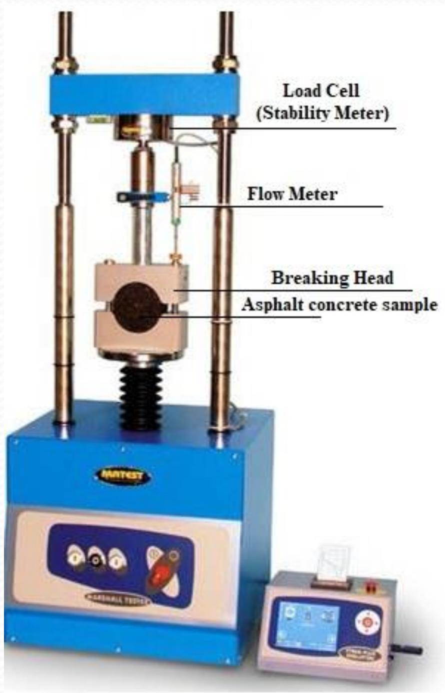
10. Select the optimum binder content from the data obtained.

11. Evaluate the design with the design requirements

Marshall Apparatus

1.Mold Assembly: cylindrical moulds of 101.6 mm (4 in) diameter and 76.2 mm (3 in) height consisting of a base plate and collar extension.

2. Marshall Compactor.
3. Sample Extractor: for extruding the compacted specimen from the mould.
4.Water bath ($60^{o}C$, 30-40 min)
5. Loading machine (Marshall Apparatus)
6. Breaking head.
7. Flow meter , water bath, thermometers



Test Procedure

In the Marshall test method of mix design, three compacted samples are prepared for each binder content. At least four binder contents are to be tested to get the optimum binder content. All the compacted specimens are subject to the following tests:

- **Bulk density determination.**
- **Stability and flow test.**
- **Density and voids analysis**.

Preparation of test specimens

The coarse aggregate, fine aggregate, and the filler material should be proportioned so as to fulfill the requirements of the relevant standards. The required quantity of the mix is taken so as to produce compacted bituminous mix specimens of thickness 63.5 mm approximately. 1200 gm of aggregates and filler (together) are required to produce the desired thickness. The aggregates are heated to a temperature of 155° to 175°C; furthermore, the compaction mould assembly and rammer are cleaned and kept pre-heated to a temperature of 100°C to 145°C.

The bitumen is heated to a temperature of 125°C to 145°C and the required amount of first trial of bitumen is added to the heated aggregate and thoroughly mixed. The mix is placed in a mold and compacted with number of blows specified (75 blows) for each face. The sample is taken out of the mold after few minutes using sample extractor.

Bulk density of the compacted specimen

The bulk density of the sample is usually determined by weighting the sample in air (W_1), immersed in water (W_2) , and surface saturated dry (SSD) (W_3). The specific gravity G_{mb} can be calculated for each samples for all sets using the following formula:

Traffic volume	Light ESAL < 10^4	Medium 10^4< ESAL< 10^6	Heavy 10^6< ESAL
No. of Blows/face	35	50	75

$$G_{mb} = \frac{W_1}{W_3 - W_2}$$

Stability Test

Before putting the samples in a worm bath (60° ± 1°C) **the height of each samples must be recorded**. Then the stability test is conducted where the specimens are immersed in a bath of water at a temperature of 60° ± 1°C for a period of 30 - 40 minutes. It is then placed in the Marshall stability testing machine and loaded at a constant rate of deformation of 50.8 mm per minute until failure. The total maximum in kN (that causes failure of the specimen) is taken as Marshall Stability. The stability value so obtained is corrected for volume. The total amount of deformation is units of 0.25 mm that occurs at maximum load is recorded as Flow Value. **The above procedure is repeated for each sample for all sets. The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds.**

Theoretical Maximum Specific Gravity ((G_{mm})

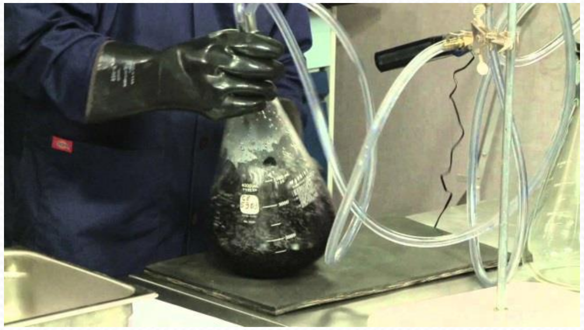
The theoretical maximum specific gravity (G_{mm}) of a HMA mixture is the specific gravity excluding air voids. Thus, theoretically, if all the air voids were eliminated from an HMA sample, the combined specific gravity of the remaining aggregate and asphalt binder would be the theoretical maximum specific gravity. Theoretical maximum specific gravity is used to calculate percent air voids in compacted HMA.

Test Procedure

1. Separate the particles of the sample which is taken from HMA **for each set** to be a loose, taking care not to fracture the mineral particles, so that the particles of the fine aggregate portion are not larger than 6.3 mm (1/4 in). Than take and weigh a amount from the sample in dry condition as (**W_1**) to the nearest 0.1 g.

2. Determine and record the mass of the empty bowl immersed completely in water as (**W_2**) to the nearest 0.1 g.
3. Put the sample taken in Step 1 inside the bowl and then it is covered with distillated water more than 1 inch over the surface of the sample (25^{o}C temperature of water).
4. Place the lid on the bowl and attach the vacuum line. To ensure a proper seal between the flask and the lid, wet the O-ring or use a petroleum gel. Remove entrapped air by subjecting the contents to a vacuum of 3.7 ±0.3 kPa (27.5 ±2.5 mm Hg) for 15 ±2 minutes.

5. Turn off the vacuum pump, slowly open the release valve, and remove the lid.
6. Suspend and immerse the bowl and contents in water at 25 ±1°C for 5 ±1 minutes and then record the weight as (**W_3**) to the nearest 0.1 g.
7. Then G_{mm} can be calculated as follow:



$$G_{mm} = \frac{W_1}{W_1-(W_3-W_2)}$$

Calculation of Air Voids

Air voids can be calculated for each sample for all sets using the following formula

$$V_a = \left[\frac{G_{mm}-G_{mb}}{G_{mm}}\right] \times 100$$

Selection the Optimum Asphalt Content (OAC)

In order to find the OAC of the mixture, six graphs must be sketched asphalt content **vs** (density, stability, flow, air voids (V_a), Voids in Mineral Aggregate (VAM), Voids Filled with Asphalt (VFA).

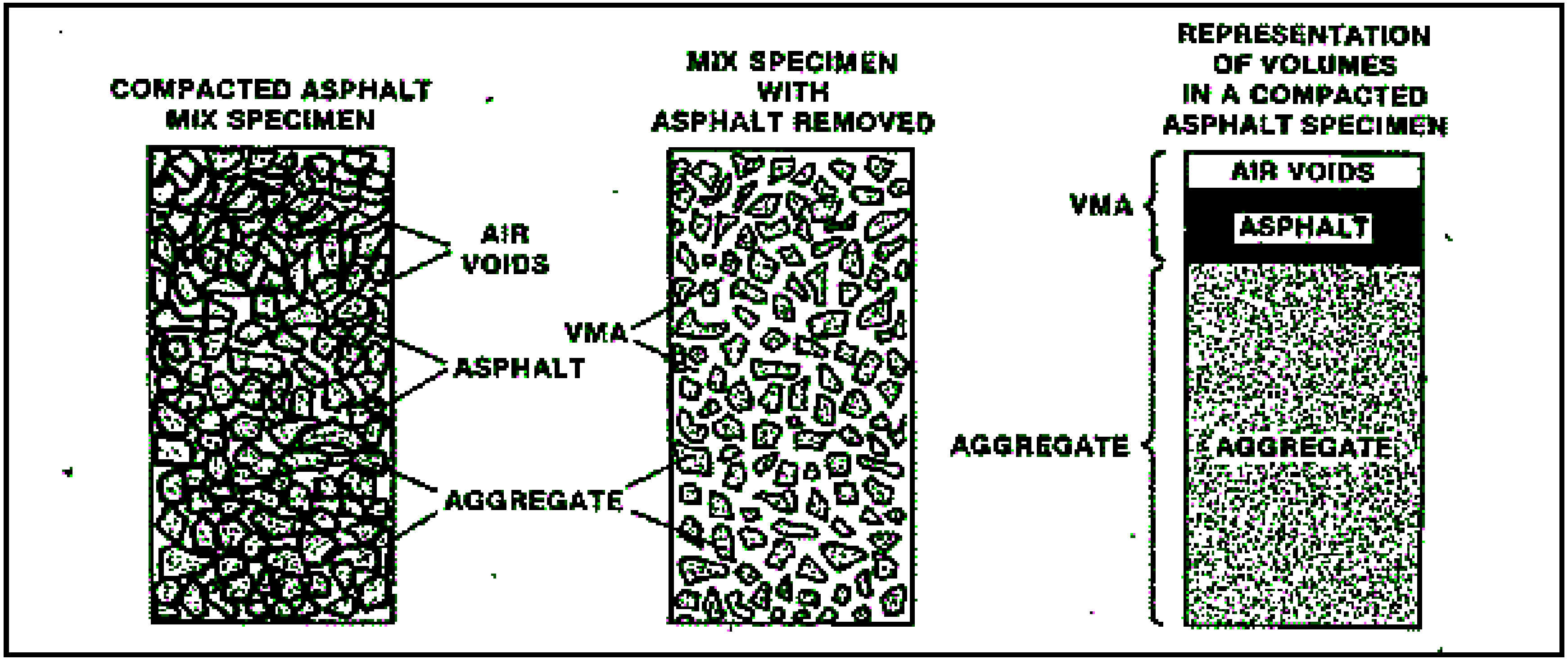
$$\text{VMA \%} = 100 - \left[\frac{(G_{mb} * P_s)}{G_{sb}}\right]$$

$$P_s = 1 - P_b$$

Where: P_s is aggregate (coarse + fine + filler) percentage in total mix.
P_b = Percentage of asphalt content.

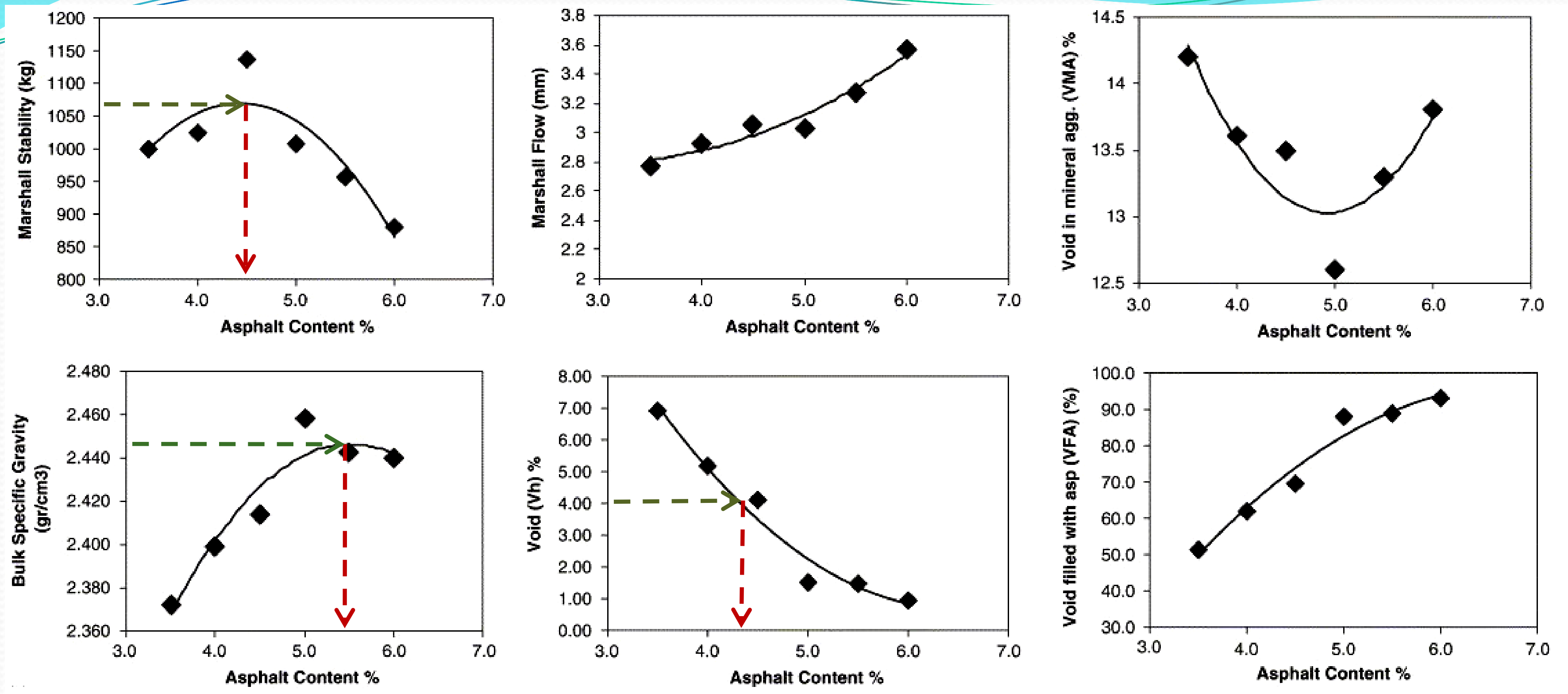
$$VFA\% = \left(\frac{VMA - V_a}{VMA}\right) 100$$

Illustration of VMA in a Compacted Mix Specimen



(Note: For simplification the volume of absorbed asphalt is not shown.)

Marshall Test graphs



Selection of OAC:

1. Asphalt content at maximum stability = a
2. Asphalt content at maximum density = b
3. Asphalt content at 4% air voids = c

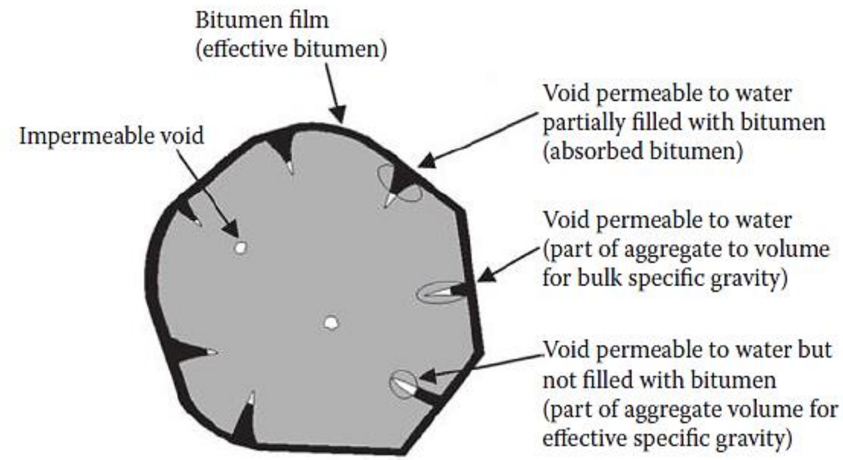
$$OAC = \frac{a+b+c}{3}$$

$$OAC = \frac{4.5+5.5+4.3}{3} = 4.77 \approx 4.8\,\%$$

(H.W) Project the OAC (4.8) on the six graphs to find the related asphalt mixture properties .

Effective specific gravity of the aggregate (G_{se})

It is determined after the aggregate is coated with asphalt or binder. The mass is the **dry mass of the aggregate without binder,** but the volume is the **volume of the dry particle plus only the surface aggregate voids not filled with binder. G_{se} is an aggregate property depending on who much surface voids it has.**



$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

or

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

G_{se} = effective specific gravity of the used aggregate ,
P_b= percent of asphalt content by total mix .
G_{mm}= Maximum specific gravity of mix, and
G_b= specific gravity of asphalt (bitumen)
$P_s = 1 - P_b$

$$G_{mm} = 100/[(P_s/G_{se}) + (P_b/G_b)],$$

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

The effective specific gravity of the total aggregate should have a value between the apparent specific gravity (G_{sa}) and the bulk specific gravity of the total aggregate(G_{sb}). **(i.e. $G_{sa} > G_{se} > G_{sb}$).** If not, the test determining the maximum specific gravity of loose bituminous mixture must be repeated.

Superpave Aggregate Structure

➢ Superpave mix design specifies aggregate gradation control points through which aggregate gradations must pass. These control points are very general and are a starting point for a job mix formula.

➢ To specify aggregate gradation, control points are added to the **0.45 power chart**. These **Control points through which gradations must pass** are:

- **Maximum size**
- **Nominal maximum size**
- **An intermediate size (2.36 mm, No. 8)**
- **Dust size (0.075 mm , No.200)**

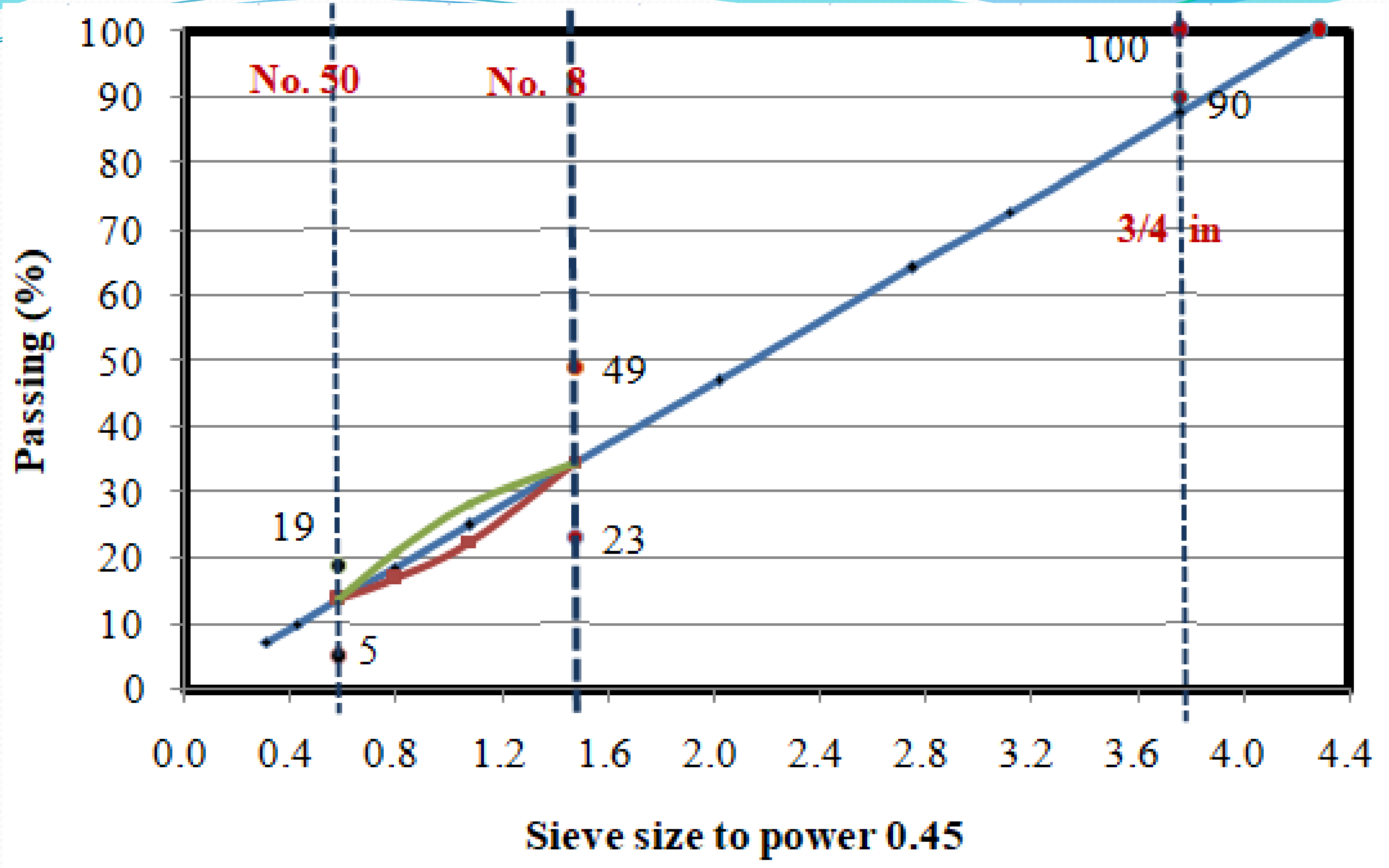
Boundaries of aggregate restricted zone

Sieve (mm)	Type of asphalt concrete				
	AC 37.5	AC 25.0	AC 19	AC 12.5	AC 9.5
4.75	34.7–34.7	39.5–39.5	—	—	—
2.36	23.3–27.3	26.8–30.8	34.6–34.6	39.1–39.1	47.2–47.2
1.18	15.5–21.5	18.1–24.1	22.3–28.3	25.6–31.6	31.6–37.6
0.6	11.7–15.7	13.6–17.6	16.7–20.7	19.1–23.1	23.5–27.5
0.3	10.0–10.0	11.4–11.4	13.7–13.7	15.5–15.5	18.7–18.7

➢ The zone determined is known as the **restricted zone**. Minimum and maximum limit values of it (boundaries) are given in Table above. The criterion of restricted zone is obligatory and it is recommended that the target mix gradation **should pass outside the restricted zone**. The restricted zone prevents a gradation from following the maximum density line in fine aggregate sieves. **Gradations that follow the maximum density line often have inadequate VMA to allow room for sufficient binder for durability**. These gradations are typically sensitive to asphalt content, which may easily become plastic with even minor variations in binder content.

➢ One of these recommendations was the implementation of the restricted zone (RZ) which lies along the maximum density line between the intermediate aggregate size (2.36- or 4.75-mm, **depending on the nominal maximum size of the aggregate blend**) and the 0.3 mm(No.50) size and form a band through which it usually was considered undesirable for a gradation to pass. The restricted zone was established in the initial Superpave guidelines to limit the amount of rounded, natural sand in the Superpave mix, which contributed to the mix instability and premature rutting

Siev (mm)	to 0.45	% Passing	lower	upper	Restricted Zone	
25.4	4.29	100.00	100	100		
19	3.76	87.75	90	100		
12.5	3.12	72.68				
9.5	2.75	64.24	56	80		
4.75	2.02	47.03	35	65		
2.36	1.47	34.33	23	49	34.6	34.6
1.18	1.08	25.13			22.3	28.3
0.6	0.79	18.54			16.7	20.7
0.3	0.58	13.57	5	19	13.7	13.7
0.15	0.43	9.93				
0.075	0.31	7.27	2	8		



Passing (%)
100
90
80
70
60
50
40
30
20
10
0
No. 50
No. 8
3/4 in
100
90
49
19
23
5
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
Sieve size to power 0.45

Table 5.4 Gradation specifications for dense asphalt concrete mixtures in accordance to American standards

	Dense-graded asphalt concrete mixtures				
	Mix designation				
	37.5 mm	*25.0 mm*	*19.0 mm*	*12.5 mm*	*9.5 mm*
Sieve (mm)	*(%) Passing, by mass*				
50	100	—	—	—	—
37.5	**90–100**[a]	100	—	—	—
25.0	—	**90–100**[a]	100	—	—
19.0	56–80	—	**90–100**[a]	100	—
12.5	—	56–80	—	**90–100**[a]	100
9.5	—	—	56–80	—	**90–100**[a]
4.75	23–53	29–59	35–65	44–74	55–85
2.36	**15–41**	**19–45**	**23–49**	**28–58**	**32–67**
1.18	—	—	—	—	—
0.600	—	—	—	—	—
0.300	4–16	5–17	5–19	5–21	7–23
0.150	—	—	—	—	—
0.075	**0–6**	**1–7**	**2–8**	**2–10**	**2–10**

[a] Figures in boldface refer to control points proposed by Superpave design methodology (Asphalt Institute SP-2 2001).