Lecture on Highway Materials

Designed and presented

By

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BASIC ENGINEERING PROPERTIES OF SOILS

Phase Relations:

Soils are considered as three-phase systems that consist of air, water, and solids

Porosity (n) *The relative amount of voids in any soil*

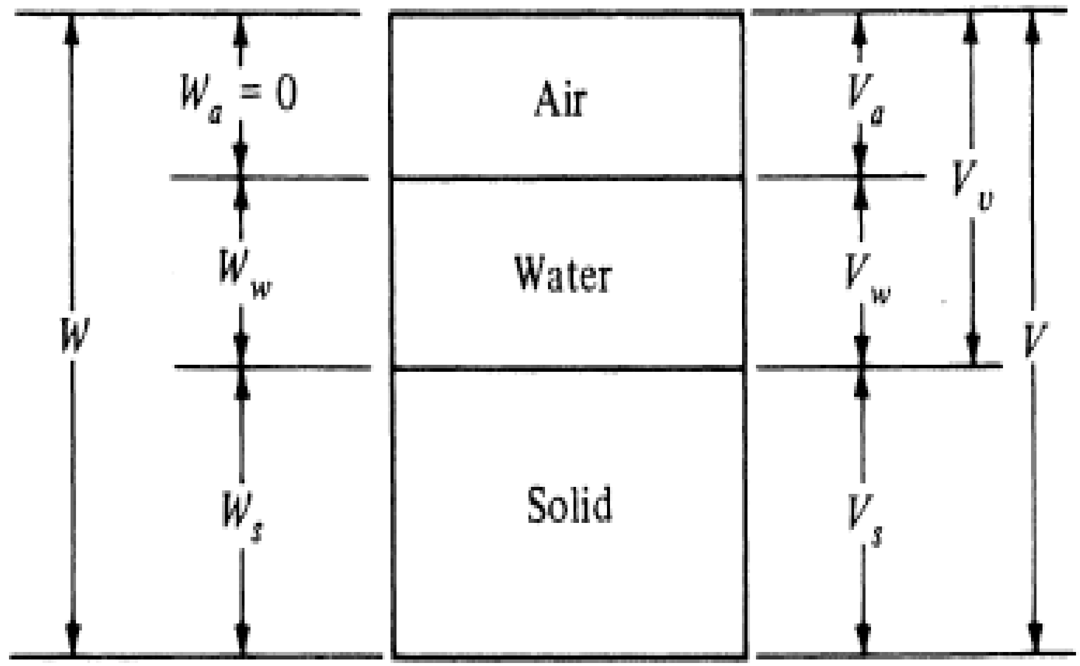
The ratio of the volume of voids to the total volume of the soil

$$n = \frac{V_v}{V}$$

Void Ratio (e)

the ratio of the volume of voids to the volume of solids

$$e = \frac{V_v}{V_s}$$



Schematic of the Three Phases of a Soil Mass

$$e = \frac{nV}{V_s} = \frac{n}{V_s}(V_s + V_v) = n(1 + e)$$

$$\Rightarrow \quad n = \frac{e}{1+e} \quad \Rightarrow \quad e = \frac{n}{1-n}$$

Moisture Content (*w*)

the ratio of the weight of water Ww in the soil mass to the oven dried weight of solids Ws

$$w = \frac{W_w}{W_s} 100$$

Degree of Saturation (*S*)

the percentage of void space occupied by water

$$S = \frac{V_w}{V_v} 100$$

Density of Soil

The ratio that relates the mass side of the phase diagram to the volumetric side

Total or bulk density γ

Dry density γ_d

Submerged or buoyant density γ'

Total Density γ

The ratio of the weight of a sample of soil to the volume

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a}$$

The total density for saturated soils

$$\gamma_{\text{sat}} = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w}$$

Dry Density γ_d

The density of the soil with the water removed

$$\gamma_d = \frac{W_s}{V} = \frac{W_s}{V_s + V_w + V_a} = \frac{\gamma}{1 + w}$$

often used to evaluate how well earth embankments have been compacted

Submerged Density (γ')

the density of the soil when submerged in water

$$\gamma' = \gamma_{sat} - \gamma_w$$

Specific Gravity of Soil Particles

The specific gravity of soil particles is the ratio of density of the soil particles to the density of distilled water

bulk density can be given as:

$$\gamma = \frac{G_s + Se}{1 + e}\gamma_w$$

γ = total or bulk density
S = degree of saturation
γ_w = density of water
G_s = specific gravity of the soil particles
e = void ratio

Example 1

Determining Soil Characteristics Using the Three-Phase Principle

The wet weight of a specimen of soil is 340 g and the dried weight is 230 g. The volume of the soil before drying is 210 cc. If the specific gravity of the soil particles is 2.75, determine the void ratio, porosity, degree of saturation, and dry density.

Solution:

weight of the water

$$W_w = 340 - 230 = 110 \text{ g}$$

For the volume of the water

$$V_w = (110/1.00) = 110 \text{ cc}$$

For the volume of the solids

$$V_s = \frac{W_s}{\gamma_s} = \frac{230}{2.75} = 83.64 \text{ cc}$$

$$(\gamma_s = \text{specific gravity} \times \text{density of water} = 2.75 \times 1)$$

For the volume of the air

$$V_a = 210 - 110 - 83.64 = 16.36 \text{ cc}$$

For the void ratio

$$e = \frac{V_w + V_a}{V_s} = \frac{110 + 16.36}{83.64} = 1.51$$

For the porosity

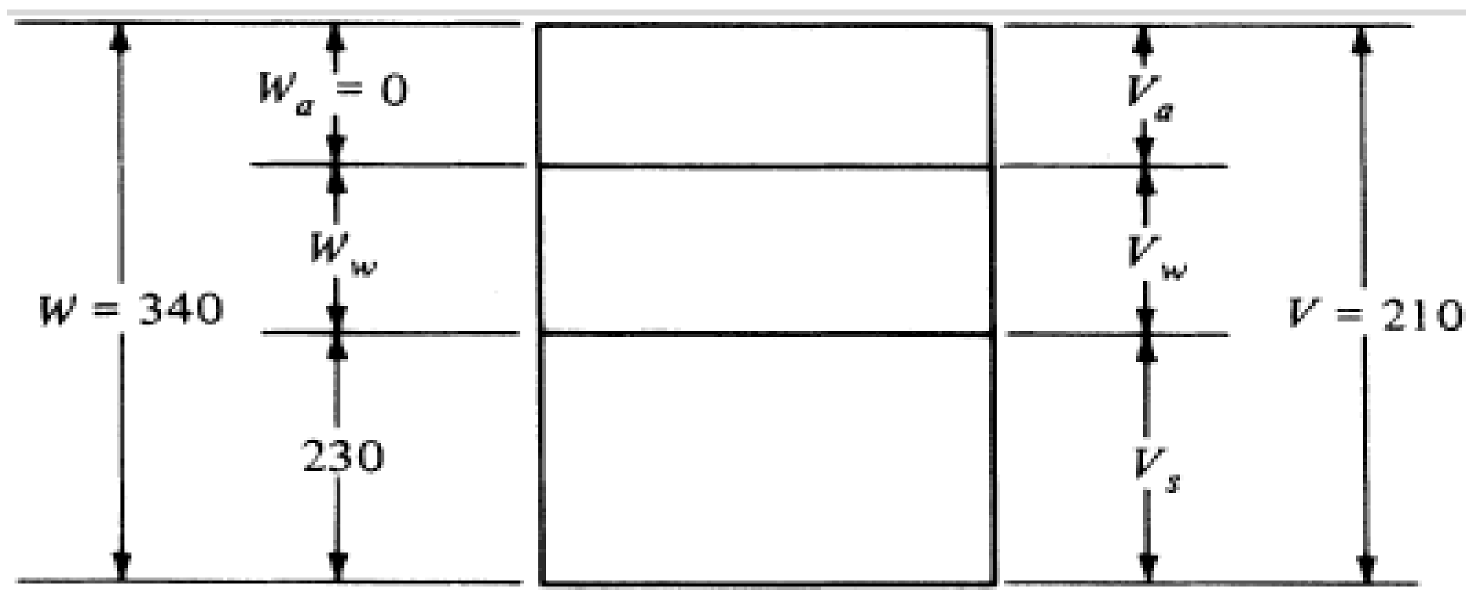
$$n = \frac{V_v}{V} = \frac{110 + 16.36}{210} = 0.60$$

For the degree of saturation

$$S = \frac{V_w}{V_v} = \frac{110}{110 + 16.36} = 0.87 \text{ or } 87\%$$

For the dry density

$$\gamma_d = \frac{W_s}{V} = \frac{230}{210} = 1.095 \text{ g/cc}$$



Example 2

Determining Soil Characteristics Using the Three-Phase Principle

The moisture content of a specimen of soil is 26 percent, and the bulk density is 116 lb/ft3. If the specific gravity of the soil particles is 2.76, determine the void ratio and the degree of saturation.

Solution:

The weight of 1 ft3 of the soil is 116 lb—that is

$$W = 116 \text{ lb} = W_s + W_w = W_s + wW_s = W_s(1 + 0.26)$$

$$\Rightarrow \quad W_s = \frac{116}{1.26} = 92.1 \text{ lb} \quad \Rightarrow \quad W_w = 0.26 \times 92.1 = 23.95 \text{ lb}$$

$$V_s = \frac{W_s}{\gamma_s} \qquad (\gamma_s = \text{specific gravity} \times \text{density of water} = 2.76 \times 62.4)$$

$$= \frac{92.1}{2.76 \times 62.4} = 0.53 \text{ ft}^3 \quad \Rightarrow \quad V_w = \frac{W_w}{\gamma_w} = \frac{23.95}{62.4} = 0.38 \text{ ft}^3$$

$$V_a = V - V_s - V_w = 1 - 0.53 - 0.38 = 0.09 \text{ ft}^3$$

$$e = \frac{V_w + V_a}{V_s} = \frac{0.38 + 0.09}{0.53} = 0.89$$

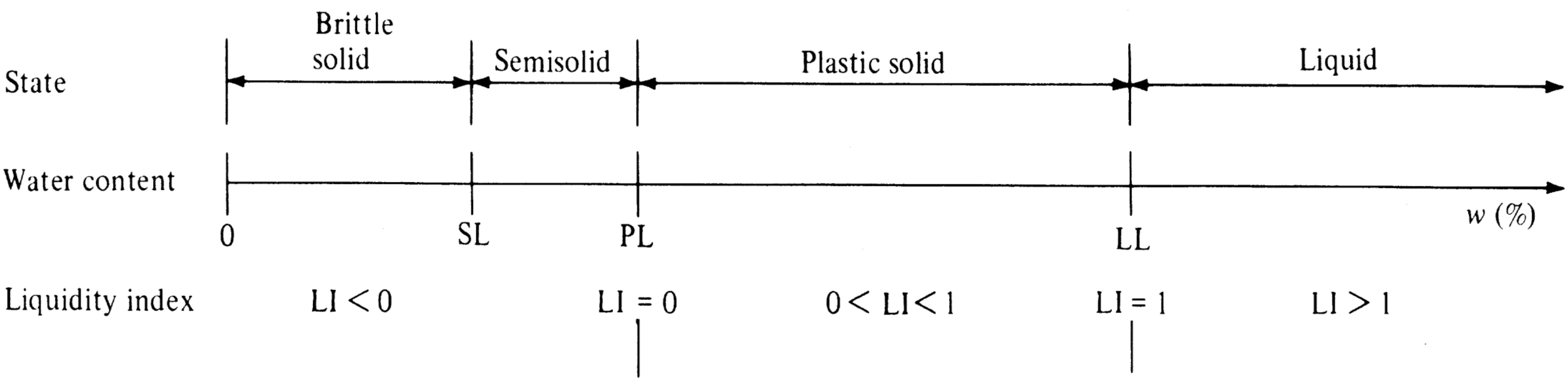
$$S = \frac{V_w}{V_v} 100 = \frac{0.38}{0.38 + 0.09} 100 = 80.9\%$$

Atterberg Limits

The stiffness or consistency of the soil at any time depends on the state at which the soil is, which in turn depends on the <u>amount of water</u> present in the soil

Atterberg limits: *The water content levels at which the soil changes from one state to the other.*

shrinkage limit (SL) **plastic limit (PL)** **liquid limit (LL)**



$$\text{LI} = \text{liquidity index} = \frac{w - \text{plastic limit (PL)}}{\text{plasticity index (PI)}}$$

shrinkage limit (SL)

When a saturated soil is slowly dried, the volume shrinks

The moisture content at which further drying will not result in additional shrinkage is the Shrinkage Limit

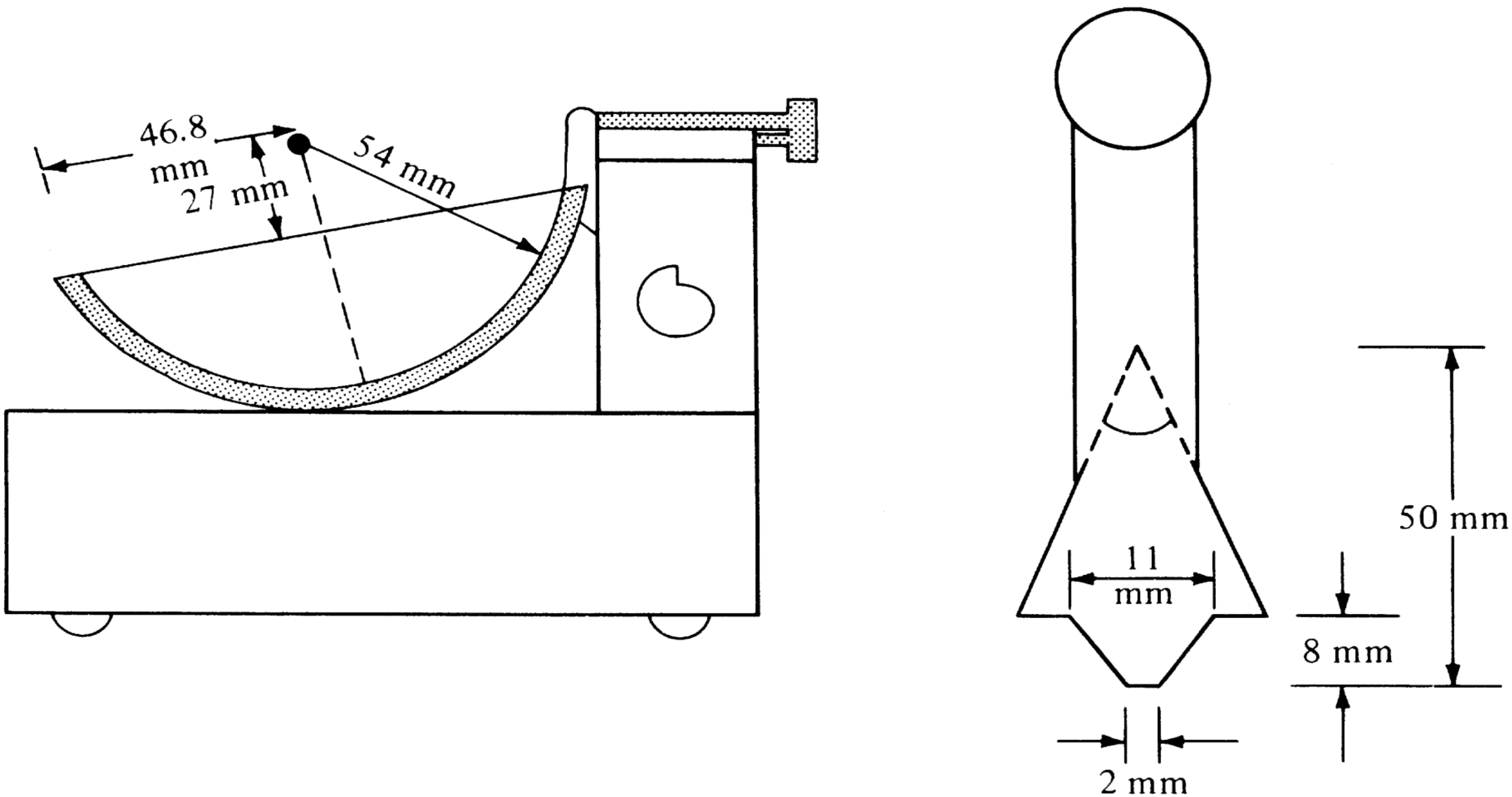
plastic limit (PL)

The moisture content at which the soil crumbles when it is rolled down to a diameter of one-eighth of an inch

The moisture content is higher than the PL if the soil can be rolled down to diameters less than one-eighth of an inch

liquid limit (LL)

The moisture content at which the soil will flow and close a groove of one-half inch within it after the standard LL equipment has been dropped 25 times



Schematic of the Casagrande Liquid Limit Apparatus

plasticity index (PI)

The range of moisture content over which the soil is in the plastic state is the difference between the LL and the PL is known as the plasticity index (PI)

$$PI = LL - PL$$

PI : *plastic limit*
LL : *liquid limit*
PL: *plasticity index*

Liquidity Index (LI)

PL and LL can be determined <u>only</u> on remolded soils

These limits may not apply to the undisturbed soil

The structure of the soil particles in the undisturbed state may be different from that in the disturbed state

The liquidity index is used to reflect the properties of the natural soil

$$\mathrm{LI} = \frac{w_n - \mathrm{PL}}{\mathrm{PI}}$$

w_n:natural moisture content of the soil
LI: liquidity index

Permeability

The property that describes how water flows through the soil

the <u>coefficient of permeability (K)</u>, is the constant of proportionality of the relationship between the flow velocity and the hydraulic gradient between two points in the soil

$$K = \frac{u}{i} \Rightarrow u = Ki$$

u : velocity of water in the soil

i : hydraulic gradient $i = \frac{h}{l}$ (head loss h per unit length l)

K : coefficient of permeability

CLASSIFICATION OF SOILS FOR HIGHWAY USE

Soil classification is a method by which soils are systematically categorized according to their probable engineering characteristics

The classification of a given soil is determined by conducting relatively simple tests on disturbed samples of the soil

However, the engineering properties of a given soil can be predicted reliably from its classification, this should not be regarded as a substitute for the detailed investigation of the soil properties

The most commonly used classification systems

AASHTO Classification System

Unified Soil Classification System (USCS)

AASHTO Classification System

This system has been described by AASHTO as a means for determining the relative quality of soils for use in:

Embankments

Subgrades

Subbases

Bases

soils are classified into seven groups, A-1 through A-7, with several subgroups

The classification is based on its particle size distribution and the Atterberg limits, (LL, and PI).

Soils are evaluated within each group by using an empirical formula to determine the group index (GI) of the soils, given as

$$GI = (F - 35)[0.2 + 0.005(LL - 40)] + 0.01(F - 15)(PI - 10) \qquad (17.18)$$

where

GI = group index

F = percent of soil particles passing 0.075 mm (No. 200) sieve in whole number based on material passing 75 mm (3 in.) sieve

LL = liquid limit expressed in whole number

PI = plasticity index expressed in whole number

The GI is determined to the nearest whole number

Granular soils fall into classes A-1 to A-3 are:

A-1 soils consist of well-graded granular materials

A-2 soils contain significant amounts of silts and clays

A-3 soils are clean but poorly graded sands.

When soils are properly drained and compacted, their value as subgrade material decreases as the GI increases

A soil with a GI of zero (*an indication of a good subgrade material*) will be better as a subgrade material than one with a GI of 20 (*an indication of a poor subgrade material*).

Table 17.1 AASHTO Classification of Soils and Soil Aggregate Mixtures

General Classification	*Granular Materials (35% or Less Passing No. 200)*							*Silt-Clay Materials (More than 35% Passing No. 200)*			
	A-1			*A-2*							*A-7*
Group Classification	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*	*A-4*	*A-5*	*A-6*	*A-7-5, A-7-6*
Sieve analysis											
Percent passing											
No. 10	−50 max.	—	—	—	—	—	—	—	—	—	
No. 40	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit	—		—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

*Plasticity index of A-7-5 subgroup ≤ LL − 30. Plasticity index of A-7-6 subgroup > LL − 30.

SOURCE: Adapted from *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 27th ed., Washington, D.C., The American Association of State Highway and Transportation Officials, copyright 2007. Used with permission.

Unified Soil Classification System (USCS)

classifies coarse-grained soils on the basis of grain size characteristics and fine-grained soils according to plasticity characteristics.

i.e.

the engineering properties of any coarse-grained soil depend on its ***particle size distribution***

properties for a fine-grained soil depend on its ***plasticity*** four major groups of materials, consisting of *coarse-grained* soils, *fine-grained* soils, *organic* soils, and *peat*.

only the materials that pass the 75 mm (3in) is used for the classification of the sample.

coarse-grained
- Gravels (G): more than 50% larger than 4.75 mm, i.e. retained on No. 4
- Sands (S): more than 50 % smaller than 4.75mm i.e. passed through the No. 4 sieve

Soils with more than 50 percent of their particles being retained on the No. 200 sieve

fine-grained
- Clays (C)
  - CL
  - CH
- Silt (M)
  - ML
  - MH

Soils with less than 50 percent of their particles retained on the No. 200 sieve

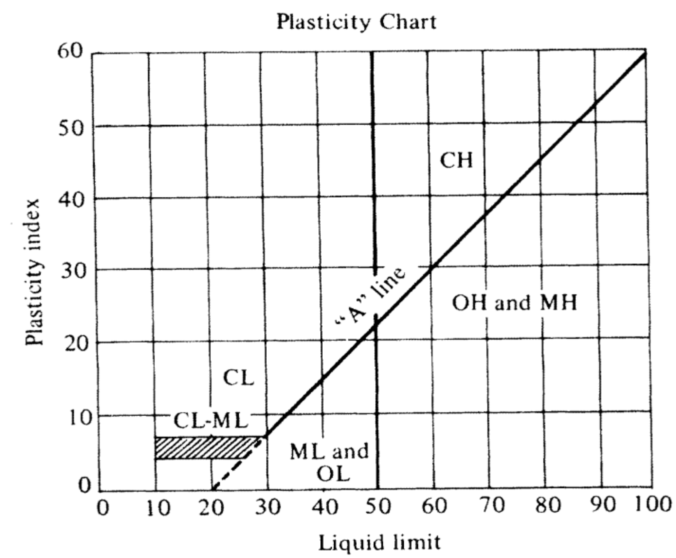


Table 17.2 USCS Definition of Particle Sizes

Soil Fraction or Component	*Symbol*	*Size Range*
1. Coarse-grained soils		
Gravel	G	75 mm to No. 4 sieve (4.75 mm)
Coarse		75 mm to 19 mm
Fine		19 mm to No. 4 sieve (4.75 mm)
Sand	S	No. 4 (4.75 mm) to No. 200 (0.075 mm)
Coarse		No. 4 (4.75 mm) to No. 10 (2.0 mm)
Medium		No. 10 (2.0 mm) to No. 40 (0.425 mm)
Fine		No. 40 (0.425 mm) to No. 200 (0.075 mm)
2. Fine-grained soils		
Fine		Less than No. 200 sieve (0.075 mm)
Silt	M	(No specific grain size—use Atterberg limits)
Clay	C	(No specific grain size—use Atterberg limits)
3. Organic soils	O	(No specific grain size)
4. Peat	Pt	(No specific grain size)

Gradation Symbols	*Liquid Limit Symbols*
Well graded, W	High LL, H
Poorly graded, P	Low LL, L

SOURCE: Adapted from *The Unified Soil Classification System,* Annual Book of ASTM Standards, Vol. 4.08, American Society for Testing and Materials, West Conshohocken, PA, 2002.

A gravel or sandy soil is described as *well graded* or *poorly graded*, depending on the values of two shape parameters known as:

coefficient of uniformity, Cu

$$C_u = \frac{D_{60}}{D_{10}}$$

coefficient of curvature, Cc

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

$$D_{60} = \text{grain diameter at } 60\% \text{ passing}$$
$$D_{30} = \text{grain diameter at } 30\% \text{ passing}$$
$$D_{10} = \text{grain diameter at } 10\% \text{ passing}$$

Gravels are described as well graded if Cu > 4 and 1 < Cc > 3

Sands are described as well graded if Cu > 6 and 1< Cc > 3

Example 3 Classifying a Soil Sample Using the AASHTO Method

Using the AASHTO method for classifying soils, determine the classification of the soil and state whether this material is suitable in its natural state for use as a subbase material.

Mechanical Analysis

Sieve No.	*Percent Finer*	*Plasticity Tests:*
4	97	LL = 48%
10	93	PL = 26%
40	88	
100	78	
200	70	

Solution

- Determining the plasticity index $PI = LL - PL$ = 48% - 26% = 22%
- Determining the group index
  $GI = (F\text{-}35)\ [0.2 + 0.005(LL - 40)] + 0.01(F - 15)\ (PI - 10)$
  $GI = (70 - 35)\ [0.2 + 0.005(48 - 40)] + 0.01(70 - 15)\ (22 - 10) = 15$
- Since the materials passing No.200 sieve = 70% > 35% then the class is either A-4, A-5, A-6, A-7
- Since the LL= 48% > 40% then eliminate class A-4, A-6
- Since the PI= 22% > 10% then eliminate class A-5
- Since (LL – 30) = (48 – 30) = 18% < 30% then the soil class is A-7-6 (15) and therefore it is unsuitable as subbase material in its natural state

Example 4

Classifying a Soil Sample Using the Unified Soil Classification System

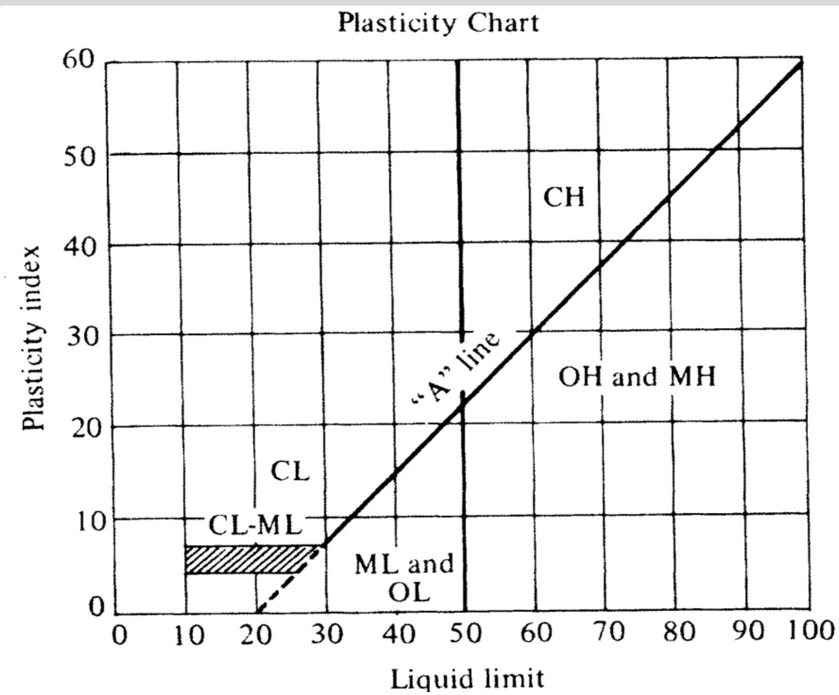
Classify the soil using the USCS and state whether or not it can be used in the natural state as a subbase material.

Mechanical Analysis

Sieve No.	*Percent Passing (by weight)*	*Plasticity Tests:*
4	98	LL = 40%
10	93	PL = 30%
40	85	
100	73	
200	62	

Solution

- Since more than 50% (62%) of the soil passes the No. 200 sieve, the soil is fine grained.
- Since PI = 40 -30 = 10; therefore, it is either silt or organic clay
- Since the LL is less than 50% (40%); therefore, it is low LL
- This soil can be classified as ML or OL
- It therefore is not useful as a subbase material



Example 5

Classify the soil using the USCS and state whether or not it can be used as a subbase material.

Mechanical Analysis		
Sieve No.	*Percent Passing (by weight)*	*Plasticity Tests:*
4	95	LL = nonplastic
10	30	PL = nonplastic
40	15	
100	8	
200	3	

Solution

- Since the pass through the No. 200 = only 3% < 50% then soil is coarse grained
- Since the pass through the No. 4 = 95% > 50% the soil is classified as sand
- Because the soil is non-plastic, it is necessary to determine its coefficient of uniformity Cu and coefficient of curvature Cc.

From semi log chart

*D*60 = 3.8 mm

*D*30 = 2 mm

*D*10 = 0.25 mm

$$C_u = \frac{D_{60}}{D_{10}} = \frac{3.8}{0.25} = 15.2 > 6$$

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} = \frac{2^2}{0.25 \times 3.8} = 4.2$$

- This sand is not well graded, is classified as SP, and therefore can be used as a subbase material if properly drained and compacted

California Bearing Ratio (CBR) Test

originally developed by the California Division of Highways prior to World War II and was used in the design of some highway pavements

The objective of the test is to determine the relative strength of a soil with respect to crushed rock, which is considered an excellent coarse base material

The test is conducted on samples of soil compacted to required standards and immersed in water for *four days*, during which time the samples are loaded with a surcharge that simulate the estimated weight of pavement material to be supported by the soil

This test is done by conducting a penetration test on the samples that still carrying the simulated load and using a standard CBR equipment

The CBR is defined as

$$BR = \frac{(unite\ load\ for\ 0.1\ piston\ penetration\ in\ test\ specimen)({}^{lb}/_{in^2})}{(unite\ load\ for\ 0.1\ piston\ penetration\ in\ standard\ crushed\ rock)({}^{lb}/_{in^2})}$$

The unit load for 0.1 piston in standard crushed rock is usually taken as 1000 lb/in2,

$$CBR = \frac{(unite\ load\ for\ 0.1\ piston\ penetration\ in\ test\ specimen)({}^{lb}/_{in^2})}{1000}$$

BITUMINOUS MATERIALS

There are different types of paving binders

Binder: is the material that is used to bind other components of the mix

The binder in flexible pavement is usually the bitumen

The binder in rigid pavement is usually the Portland cement

The binder in stabilized layers under pavement can be lime, cement or any other type

Bitumen refers to the viscous liquid, soled or semi solid material consisting essentially of hydrocarbons and their derivatives, soluble in CS_2 and CCL_4, substantially non volatile, soften when heated, have strong adhesive properties with colors ranging from dark brown to black.

**Note: some consider that asphalt is the bituminous mixture with aggregate (bituminous concrete), while other consider asphalt as the American term of bitumen.*

***Note: bitumen should be distinguished from tar, that is bitumen is either naturally found or produced by the fractional distillation of crude oil, while tar is produced by the fractional distillation of coal.*

BITUMEN SOURCES

1- Natural Deposits

Natural deposits of asphalt occur as either native asphalt or rock asphalt.

The largest deposit of native asphalt is known to have existed in Iraq several thousand years ago. It was used in ship building industry in Sumeria about 6000 BC.

The properties of native asphalt vary from one deposit to another, particularly with respect to the *amount of insoluble material*

Rock asphalt is a natural deposit of *sandstone* or *limestone* rocks filled with asphalt

2- Petroleum Asphalt

The asphalt materials obtained from the distillation of petroleum are in the form of different types of asphalts, which include asphalt cements

slow-curing liquid asphalts

rapid-curing liquid asphalts

medium-curing liquid asphalts

asphalt emulsions

Refining Processes

fractional distillation

destructive distillation (cracking)

The refining processes used to obtain petroleum asphalts can be divided into two main groups: and

The ***fractional distillation process*** removes the different volatile materials in the crude oil at successively higher temperatures until the petroleum asphalt is obtained as residue. *Steam or a vacuum* is used to gradually increase the temperature.

Steam distillation is a continuous flow process in which the crude petroleum is pumped through tube stills or stored in batches, and the temperature is increased gradually to facilitate the evaporation of different materials at different temperatures

Destructive Distillation. Cracking processes are used when larger amounts of the light fractions of materials (such as motor fuels) are required.

Intense heat and high pressures are applied to produce chemical changes in the material. *temperatures as high as 1100F and pressure higher than 735 lb/in2*

The asphalt obtained from cracking is not used widely in paving, because it is more susceptible to weather changes than that produced from fractional distillation.

DESCRIPTION AND USES OF BITUMINOUS BINDERS

Asphalt Cements

They are semisolid hydrocarbons with certain physiochemical characteristics that make them good cementing agents.

They are also very viscous, and when used as a binder for aggregates in pavement construction, it is necessary to heat both the aggregates and the asphalt cement prior to mixing the two materials

the particular grade of asphalt cement is designated by its *penetration* and *viscosity* as an indication of the consistency at a given temperature,

Asphalt cements are used mainly in the manufacture of hot-mix, hot-laid asphalt concrete

The softest grade used for highway pavement construction has a penetration value of 200 to 300, and the hardest has a penetration value of 60 to 70.

Asphalt Cutbacks

used mainly in cold-laid plant mixes, road mixes (mixed-in-place), and as surface treatments

Slow-Curing Asphalts

can be obtained directly as *slow-curing straight run asphalts* through the distillation of crude petroleum Or:

as slow-curing cutback asphalts by "cutting back" asphalt cement with a heavy distillate such as diesel oil

They have lower viscosities than asphalt cement and are very slow to harden

Slow-curing asphalts are designated as SC-70, SC-250, SC-800, or SC-3000, where the numbers relate to the approximate kinematic viscosity in centistokes at 60C (140F).

Medium-Curing Cutback Asphalts

Medium-curing (MC) asphalts are produced by fluxing, or cutting back residual asphalt (usually 120 to 150 penetration) with light fuel oil or kerosene

The term medium refers to the medium volatility of the kerosene-type diluter used. Medium-curing cutback asphalts harden faster than slow-curing liquid asphalts

The fluidity of medium-curing asphalts depends on the amount of solvent in the material

These medium-curing asphalts can be used for the construction of pavement bases, surfaces, and surface treatments

Rapid-Curing Cutback Asphalts

(RC) cutback asphalts are produced by blending asphalt cement with a petroleum distillate that will evaporate easily

Gasoline or naphtha generally is used as the solvent

The grade of rapid-curing asphalt required dictates the amount of solvent to be added to the residual asphalt cement.
RC-3000 requires about 15 percent of distillate
RC-70 requires about 40 percent.

(RC) is used for jobs similar to those for which the MC series is used

Emulsified Asphalts

produced by breaking asphalt cement, usually of 100 to 250 penetration range, into minute particles and dispersing them in water with an emulsifier.

The minute particles remain in suspension in the liquid phase as long as the water does not evaporate or the emulsifier does not break.

Asphalt emulsions therefore consist of asphalt (55 to 70 percent by weight), water, and an emulsifying agent, which in some cases also may contain a stabilizer.

Asphalt emulsions generally are classified as *anionic*, cationic, or *nonionic*

The anionic, cationic types have electrical charges surrounding the particles, whereas the nonionic type is neutral

Anionic	Emulsions containing negatively charged particles of asphalt
Cationic	Emulsions having positively charged particles of asphalt

anionic and cationic asphalts generally are used in highway maintenance and construction

Blown Asphalts

It is obtained by blowing air through the semisolid residue obtained during the latter stages of the distillation process

The process involves stopping the regular distillation while the residue is in the liquid form

The material is maintained at a high temperature while air is blown through it

Blown asphalts are relatively stiff compared to other types of asphalts and can maintain a firm consistency at the maximum temperature when exposed to the environment.

Blown asphalt generally is not used as a paving material. However, it is very useful as a roofing material, for automobile undercoating, and as a joint filler for concrete pavements

Road Tars

Tar properties are significantly different from petroleum asphalts

Tars are obtained from the destructive distillation of such organic materials as coal

In general, tars are more susceptible to weather conditions than similar grades of asphalts, and they set more quickly when exposed to the atmosphere

PROPERTIES OF ASPHALT MATERIALS

Consistency

Aging and temperature sustainability

Resistance to water action

Rate of curing

The consistency usually considered under two conditions:

(1) variation of consistency with temperature and
(2) consistency at a specified temperature.

Variation of Consistency with Temperature

The consistency of any asphalt material changes as the temperature varies

The change in consistency of different asphalt materials may differ considerably even for the same amount of temperature change

If blown semisolid asphalt and a sample of semisolid regular paving-grade asphalt with the same consistency at a given temperature

But at the high temperatures the regular paving-grade asphalt is much softer than the blown asphalt

This property of asphalt materials is known as *temperature susceptibility*

Consistency at a Specified Temperature

It is essential that when the consistency of an asphalt material is given, the associated temperature also should be given.

Aging and Temperature Sustainability

Weathering : is the natural deterioration gradually takes place to asphalt materials caused by chemical and physical reaction as a result of the exposure of the asphalt materials to environmental elements, due to which the materials lose their plasticity and become brittle.

weathering must be minimized to make asphalt act successfully for paving.

Durability: the ability of an asphalt material to resist weathering

factors that influence weathering

- ***oxidation***
- ***volatilization***
- ***temperature***
- ***exposed surface area***

oxidation

Is the chemical reaction that takes place when the asphalt material is attacked by oxygen in the air causes gradual hardening (loss of the plasticity)

volatilization

Is the evaporation of the lighter hydrocarbons from the asphalt material. causes the loss of the plastic characteristics of the asphalt material.

temperature

temperature has a significant effect on the rate of oxidation and volatilization

The relationship between temperature increase and increases in rates of oxidation and volatilization is not linear. The rate of organic and physical reactions in the asphalt material approximately doubles for each 10C (50F) increase in temperature.

exposed surface area

The exposed surface of the material also influences its rate of oxidation and volatilization

direct relationship between surface area and rate of oxygen absorption and loss due to evaporation in grams/cm3/minute

inverse relationship exists between volume and rate of oxidation and volatilization.

the rate of hardening is directly proportional to the ratio of the surface area to the volume.

This fact is taken into consideration when asphalt concrete mixes are designed for pavement construction in that the air voids are kept to the practicable minimum required for stability to reduce the area exposed to oxidation.

Rate of curing

Curing is defined as the process through which an asphalt material increases its consistency as it loses solvent by evaporation.

Rate of Curing of Cutbacks

the rate of curing of any cutback asphalt material depends on the distillate used

the rate of curing indicates the time that should elapse before a cutback will attain a consistency that is thick enough for the binder to perform satisfactorily.

The rate of curing is affected by both *inherent* and *external* factors.

The important inherent factors

- Volatility of the solvent
- Quantity of solvent in the cutback
- Consistency of the base material

The important external factors

- Temperature
- Ratio of surface area to volume
- Wind velocity across exposed surface

Rate of Curing for Emulsified Asphalts

depend on the rate at which the water evaporates from the mixture.

When weather conditions are favorable, the water is displaced relatively rapidly, and so curing progresses rapidly

When weather conditions include high humidity, low temperature, or rainfall immediately following the application of the emulsion, its ability to properly cure is affected adversely.

The effect of surface and weather conditions on is more critical for anionic emulsions,

A major advantage of *cationic emulsions* is that they release their water more readily.

Resistance to water action

The asphalt must sustain its ability to adhere to the aggregates even in the presence of water

In hot-mix, hot-laid asphalt concrete, where the aggregates are thoroughly dried before mixing, stripping does not normally occur and so no preventive action is usually taken.

When water is added to a hot-mix, cold-laid asphalt concrete, commercial antistrip additives usually are added to improve the asphalt's ability to adhere to the aggregates.

ASPHALT MIXTURES

Asphalt mixtures are a uniformly mixed combination of asphalt cement, coarse aggregate, fine aggregate, and other materials, depending on the type of asphalt mixture.

Asphalt mixtures are the most popular paving material

When Asphalt mixtures used in constructing highway pavements, it must:
- resist deformation from imposed traffic loads,
- be skid resistant even when wet, and
- not be affected easily by weathering forces

Note:

- Batch plant: percentage depend on weight. Continuous plant: percentage depend on volume.
- Hot mix: after heating aggregate & asphalt. Cold mix: mixing at normal temperature (emulsified asphalt).
- Dense mix: % air voids $\leq$ 10%. Open mix: % air voids > 10%.

Hot-Mix, Hot-Laid Asphalt Mixture

Hot-mix, hot-laid asphalt mixture is produced by properly blending asphalt cement, coarse aggregate, fine aggregate, and filler (dust) at temperatures ranging from about 175 to 325F, depending on the type of asphalt cement used.

Suitable types of asphalt materials include AC-20, AC-10, and AR-8000 with penetration grades of 60 to 70, 85 to 100, 120 to 150, and 200 to 300.

hot-laid asphalt mixture normally is used for high-type pavement construction, and the mixture can be described as

	High-Type Surfacing	Base
open-graded	M.S. 3⁄8 to 3⁄4 in	M.S. 3⁄4 to 11⁄2 in
coarse-graded	M.S. 1⁄2 to 3⁄4 in	M.S. 3⁄4 to 11⁄2 in
dense-graded	M.S. 1⁄2 to 1 in	M.S. 1 to 11⁄2 in
fine-graded	M.S. 1⁄2 to 3⁄4 in	M.S. 3⁄4 in

The overall objective of the mix design is to determine an optimum blend of the different components that will satisfy the requirements of the given specifications.

Main desirable properties of aggregate:

1) *Inter particle friction*

The primary mechanism of load transfer:

a. Surface texture: particles rough surface provides the resistance to displacement

b. Particle shape: the more angular the particles the more the interlock between them, many shapes for particles, round, fractured, & cubical

Angularity No. = voids percentage in round particles - voids percentage in any shape

0% < Angularity No. > 10%

c. Gradation Aggregate is either dense graded or open graded, it is not recommended to have any gabs in its gradations

The ultimate dense gradation can be obtained according to Fuller equation:

$$\frac{P}{100} = \left(\frac{d}{D}\right)^{0.5}$$

D = diameter of max. size particle, (passing 100%); inch
d = size of opening for any sieve, inch
P = percent passing of that sieve.

2) Durability:

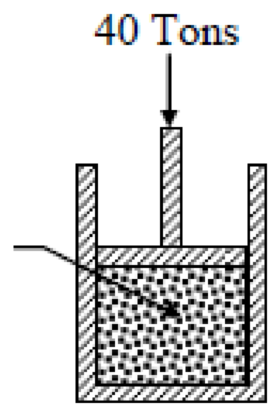
Durability represents the resistance to crashing, degradation, and disintegration.

a. Crashing

Aggregates used in pavement construction should be strong enough to resist crushing under traffic wheel loads

It is usually indicated by the Crashing Value

Aggregates passing 12.5 mm sieve and retained on 10 mm subjected to a pressure of 40 tons



$$Crushing\ Value = \frac{Weight\ of\ materials\ passing\ sieve\ No.7}{Original\ Weight}$$

$$\boldsymbol{Crashing\ Value\ should\ be\ \leq 12\%}$$

b. Degradation

damaging or ruining caused mainly due to mechanical effect

The Los Angeles test is a measure of degradation of mineral aggregates of standard grading resulting from abrasion or attrition, impact, and grinding in a rotating steel drum containing steel spheres.

The (L.A.) abrasion test is used to indicate aggregate toughness and abrasion characteristics

Aggregate abrasion characteristics are important because aggregate in HMA must resist crushing, degradation and disintegration in order to produce a high quality HMA.

GRADING OF TEST SAMPLE

Sieve Size		Mass of Indicated Sizes, g			
Passing	Retained	A (12 balls)	B(11 balls)	C(8 balls)	D(6 balls)
1 ½"	1"	1250 ±25	-	-	-
1"	3/4'	1250 ±25	-	—	-
3/4"	1/2"	1250 ±10	2500 ±10	-	-
½"	3/8"	1250 ±10	2500 ±10	—	—
3/8"	1/4"	-	-	2500 ±10	-
1/4"	#4	-	-	2500 ±10	-
#4	#8	-	-	-	5000 ±10
TOTAL		5000 ±10	5000±10	5000 ±10	5000±10

NOTE: A, B, C, and D, in the above table, represent grading of aggregate and in parenthesis the number of steel balls to be used for the particular grading.

$$Abrasion\ Value = \frac{weight\ of\ materials\ passing\ sieve\ No.12}{Original\ sample\ weight}$$

Should be $\leq 30\%$

c. Disintegration

Fragmentation in mineral aggregate due to chemical effect

Chemical Stability: refers to specific problems due to chemical composition

The soundness test determines an aggregate’s resistance to disintegration by weathering and, in particular, freeze-thaw cycles.

The soundness test repeatedly submerges an aggregate sample in a sodium sulfate or magnesium sulfate solution. This process causes salt crystals to form in the aggregate’s water permeable pores.

The formation of these crystals creates internal forces that apply pressure on aggregate pores and tend to break the aggregate.

After a specified number of submerging and drying repetitions, the aggregate is sieved to determine the percent loss of material.

3) Wet ability:

Means the aggregate adhesion with asphalt, or resistance to stripping of asphalt film from aggregate in the presence of water

It is affected by:

a. Mechanical interlock:

Developed by:

- Rough surface texture.
- Porous aggregate
- No surface coating

b. Chemical reactivity:

Basic minerals (of aggregate) + Acidic portion (of asphalt) = Compound not soluble in water

c. Interfacial tension:

- Hydrophobic aggregate (water-hating) *preferable*
- Hydrophilic aggregate (water-loving) *non-preferable (local)*

Aggregate Gradation

The first phase in any mix design is the selection and combination of aggregates to obtain a gradation within the limits prescribed. This sometimes is referred to as mechanical stabilization.

Aggregates usually are categorized as course, fine, and filler. The coarse aggregate retained in a No. 8 sieve, sand is predominantly fine aggregate passing the No. 8 sieve, and filler is predominantly mineral dust that passes the No. 200 sieve

The procedure used to select and combine aggregates is as follows:

1. Discarding the over size.

2. Separating into two or more portions on selected proper sieve.

3. Recombining using proper percentage for recombination with specification requirement (mid-specification limits).

4. Addition of fine materials (& Filler) if necessary.

Example 6

Rectify the gradation of the aggregate according to the listed specification.

Sieve size	(% passing) Natural grading	Specifications
1"	100	100
3/4"	90	100
1/2"	80	95 – 65
3/8"	60	60 – 40
No.4	40	40 – 24
No.10	30	30 – 20
No.40	20	20 – 10
No.80	10	10 – 5
No.200	5	5 – 3

Solution

First: the oversize in sieve ¾” should be discarded to comply with the spec., by discarding retained materials on 1” and ¾” the remaining sample will be 100% passing both of these sieves but this may lead to another violation in other sieves.

Second: the violation is seen all over the rest of the sieves starting from 3/8" on. Accordingly the rectifying process requires the separation in this sieve and calculating the remaining on the higher sieves then to compute the passing proportions in order to consider each part as different sample on which several trials of blending proportions to be conducted until the specification is reached.

In this case 50% of each part will make the sample compatible with the required specification

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sieve size	(% passing) Natural grading	Specifications	Step (1) Portion passing 3/4"	(A) Step (2) Portion Passing 3/8"	Percent retained (5)-(4)	(B) Portion passing 3/8"	(C) 50% A + 50% B
1"	100	100	100	-	0 – 0	100	100
3/4"	90	100	100	-	0 – 0	100	100
1/2"	80	95 – 65	(100/90)*80=89	-	11 – 33	67	83
3/8"	60	60 – 40	(100/90)*60=67	100	33 – 100	0	50
No.4	40	40 – 24	(100/90)*40=45	(100/67)*45=67		0	33
No.10	30	30 – 20	(100/90)*30=34	(100/67)*34=51		0	26
No.40	20	20 – 10	(100/90)*20=22	(100/67)*22=33		0	16
No.80	10	10 – 5	(100/90)*10=11	(100/67)*11=16		0	8
No.200	5	5 – 3	(100/90)*5=6	(100/67)*6=9		0	4.5

Example 7

Rectify the gradation of the aggregate according to the listed specification.

1	2	3	4
Sieve	Specifications	Target	Passing Natural Grading
3/4"	100	100	90
1/2"	90 – 100	95	82
3/8"	77 – 93	85	72
No. 4	44 – 74	59	40
No. 8	24 – 58	41	26
No. 50	5 – 21	13	4
No. 200	4 – 10	7	0.5

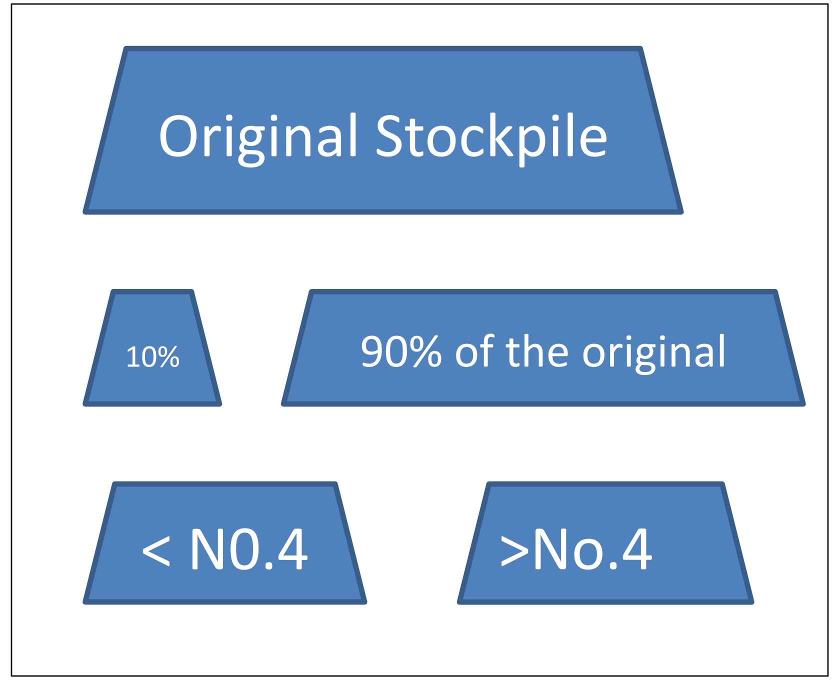
Solution

1- Step (1): discarding the oversize. i.e. discarding the retained on 3/4" sieve which equals 10% of the whole original stock pile.

Since the 90% is going to be 100% of the new stockpile after discarding the oversize material, then all other proportions are to be computed as follows:

$$new\ proportion\ \% = \frac{100}{90} \times old\ proportion\%$$

The resulting proportions as listed in column 5 are drifted away from the target towards the course Boundaries with violation in sieves No 50 and 200.



Step (2): separating the resulting stock by the sieve No.4 (4.75 mm){ * the smallest recommended sieve to separate by is No. 8 for practicality reasons. Accordingly; two stocks are resulting, the first (A) is passing No.4 (smaller than 4.75 mm) represents 44%, and the Other (B) is retained by No.4 (larger than 4.75 mm) represents 56%. It should be noted that the proportions of this stock are computed in light of the retained proportions

Since stock (A) is 100% passing No.4 sieve, any percentage to be used from this stock will give its own proportions without any effect of stock (B) on it. i.e. the blended stock will have lower proportions of these fine particles. This may imply the utilization of a filler material to fill the gap in the sieve No. 200 and No. 50, for no matter how big the portion of stock (A) to be used the required specification will not be met.

Since the target is 7% in sieve No. 200, and the available gradation is less than 1.25, then the filler is required about 6%. Taking under consideration that this percentage will be added to all proportions of the passed materials.

Depending on the sieve No.4 specification target which is 59% and in order to have it verified, in addition to the 6% of the filler plus 0% from stock (B), a 53% of stock (A) is required to complete the 59%. This may by the lead to the first iteration or trial. This trial states the blending of the following:

$$6\% \text{ filler} + 53\% \text{ stock (A)} + x\% \text{ stock (B)} = 100$$
$$X \text{ stock (B)} = 100 - 6 - 53 = 41\%$$

According to the final blended stock proportions the coarse, fine and filler proportions are computed as follows:

Coarse aggregate = 100 – Passing No.4 = 100 – 59 = 41%
Fine Aggregate = Passing No.4 – Filler = 59 – 6.7 = 52.3%
Filler = = 6.7 %
Total = 41 + 52.3 + 6.7 = 100%

5	6	7	8	9
Step (1) discarding 3/4"	Step (2)			
	(A) Passing No.4	(B) Retained No.4	(B) Retained No.4	(B) Passing No.4
100	100	100 – 100 = 0	0	100
(100/90)*82= 90	100	100 – 90 = 10	(100/56)*10= 18	100 – 18 = 82
(100/90)*72= 79	100	100 – 79= 21	(100/56)*21=37.5	100 – 37.5= 62.5
(100/90)*40= 44	100	100 – 44 = 56	100	100-100 =0
(100/90)*26= 29	(100/44)*29=66		100	0
(100/90)*4= 4.4	(100/44)*4.4=10		100	0
(100/90)*0.5= 0.55	(100/44)*0.55=1.25		100	0

10			11
Step (3)			
53%(A)	41% (B)	6% Filler	
0.53X100	0.41X100	0.06X100	53+41+6=100
0.53X100	0.41X82	0.06X100	53+33.6+6=92.6
0.53X100	0.41X62.5	0.06X100	53+25.6+6=84.6
0.53X100	0.41X0	0.06X100	53+0+6= 59
0.53X66	0.41X0	0.06X100	35+0+6= 41
0.53X10	0.41X0	0.06X100	5.3+0+6= 11.3
0.53X1.25	0.41X0	0.06X100	0.66+0+6= 6.7

H.W.

Three aggregates are to be blended to meet specification. The aggregates, gradations, and specifications are as in Table below. Determine the most suitable proportion of each stock using the trial and error method.

sieve		Agg. A	Agg. B	Agg. C	Spec.
1/2"	12.5	100	100	100	100
3/8"	9.5	62	100	100	72 - 88
No. 4	4.75	8	100	78	45 - 65
No. 8	2.36	2	91	52	30 - 60
No. 16	1.18	0	73	36	25 - 55
No. 30	600		51	29	16 - 40
No. 50	300		24	24	8 25
No. 100	150		4	20	4--8
No. 200	75		1	18	3--6

sieve		Agg. A	Agg. B	Agg. C	Spec.	Blend 1	Blend 2
1/2"	12.5	100	100	100	100	100	100
3/8"	9.5	62	100	100	72 - 88	87.46	84.8
No. 4	4.75	8	100	78	45 - 65	62.16	56.6
No. 8	2.36	2	91	52	30 - 60	48.37	43.7
No. 16	1.18	0	73	36	25 - 55	36.33	32.7
No. 30	600		51	29	16 - 40	26.69	24
No. 50	300		24	24	8 25	16.08	14.4
No. 100	150		4	20	4--8	8.12	7.2
No. 200	75		1	18	3--6	6.45	5.7

DESIRABLE PROPERTIES ASPHALT MIXTURES

1) *Stability* : resistance to permanent deformation due to the applied loading (plastic deformation).

Stability is affected by:

- Frictional resistance
  - Rough aggregate surface texture
  - Optimum asphalt content
  - Dense gradation
  - Compaction
- Cohesion (tensile strength)
  - Rheology of asphalt
  - Adhesion with aggregate
  - Surface area of aggregate

Inertia of pavement

- Speed of vehicles
- Concentration of load
- Axle load

2) *Durability*: Resistance to weathering (air, water, & oil) & abrasive action of traffic.

Durability is affected by:

- Asphalt content (asphalt film)
- Gradation (dense or open)
- Degree of compaction

3) *Flexibility*: The ability to bend repeatedly without fracture. (fatigue resistance)

4) *Skid resistance*: The ability to provide safe coefficient of friction.

Skid resistance is affected by:

- Asphalt content
- Gradation (dense or open)
- Fractured aggregate

5) *Imperviousness:* Lack of permeability

6) *Workability*: The ability to provide smooth shaping of the finished pavement.

Workability is affected by:

- Balanced portions of materials
- Efficient equipment's

JOB MIX FORMULA

The process in which the proportions of all types of ingredient materials are decided to provide the asphalt mixture desirable properties.

1- the selection of aggregate quality

(hard, rough, hydrophobic, . . . Etc.)

Well graded to ensure (contact surface, workable, flexible, impermeable)

2- the selection of asphalt grade

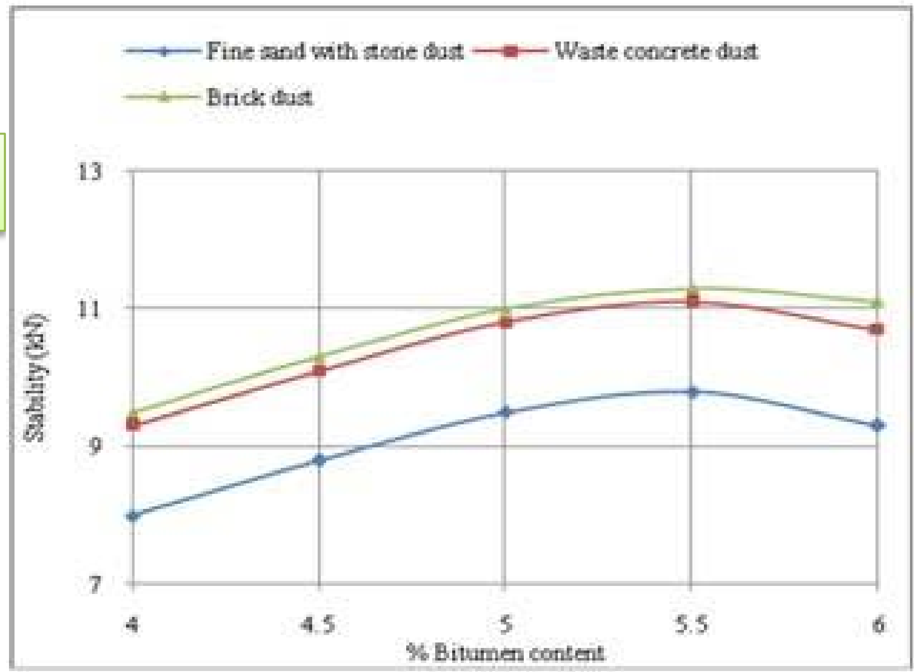
hard enough: to provide sufficient tensile strength at elevated temperature.

Soft enough: for durability, flexibility, workability.

3- the selection of optimum asphalt content

Using as much as possible: for durability, flexibility, workability.

Using not so much that stability may reduce below some minimum value.



ANALYSIS OF MIXTURE

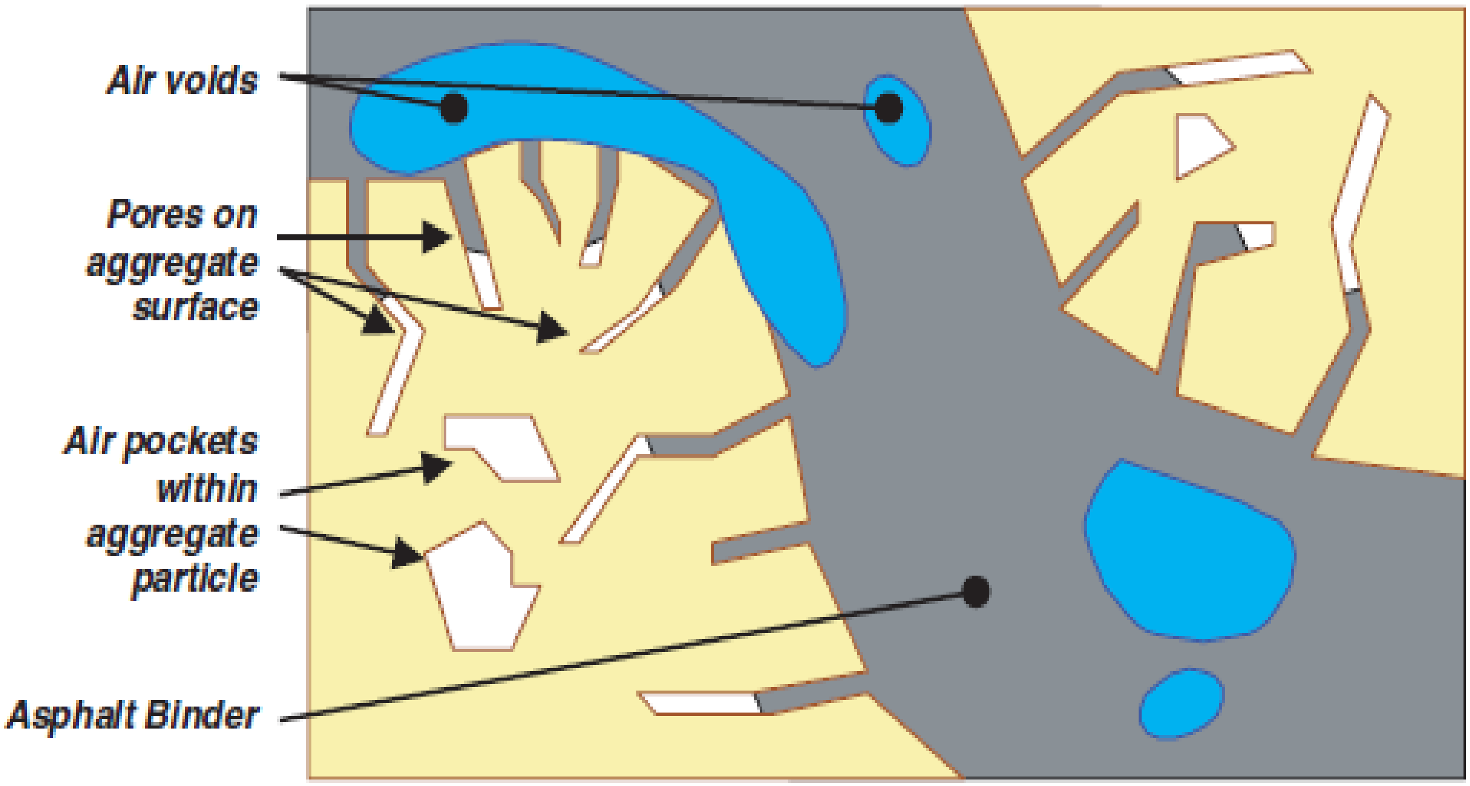
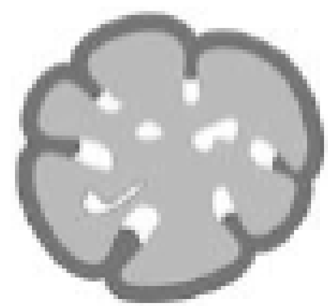


Figure 5-2. Air in asphalt concrete. Air can exist in pores on the aggregate surface, pockets within aggregate particles, or voids within the asphalt binder or between the binder and aggregate particles. Only the last type of air is included in the air void content of asphalt concrete mixtures.

Aggregate coated with asphalt, showing air voids



Aggregate particle coated with asphalt, showing absorbed asphalt, permeable and impermeable porous

V_o : volume of air voids in total mix

V_{S1} : volume of effective asphalt

V_{S2} : volume of absorbed asphalt

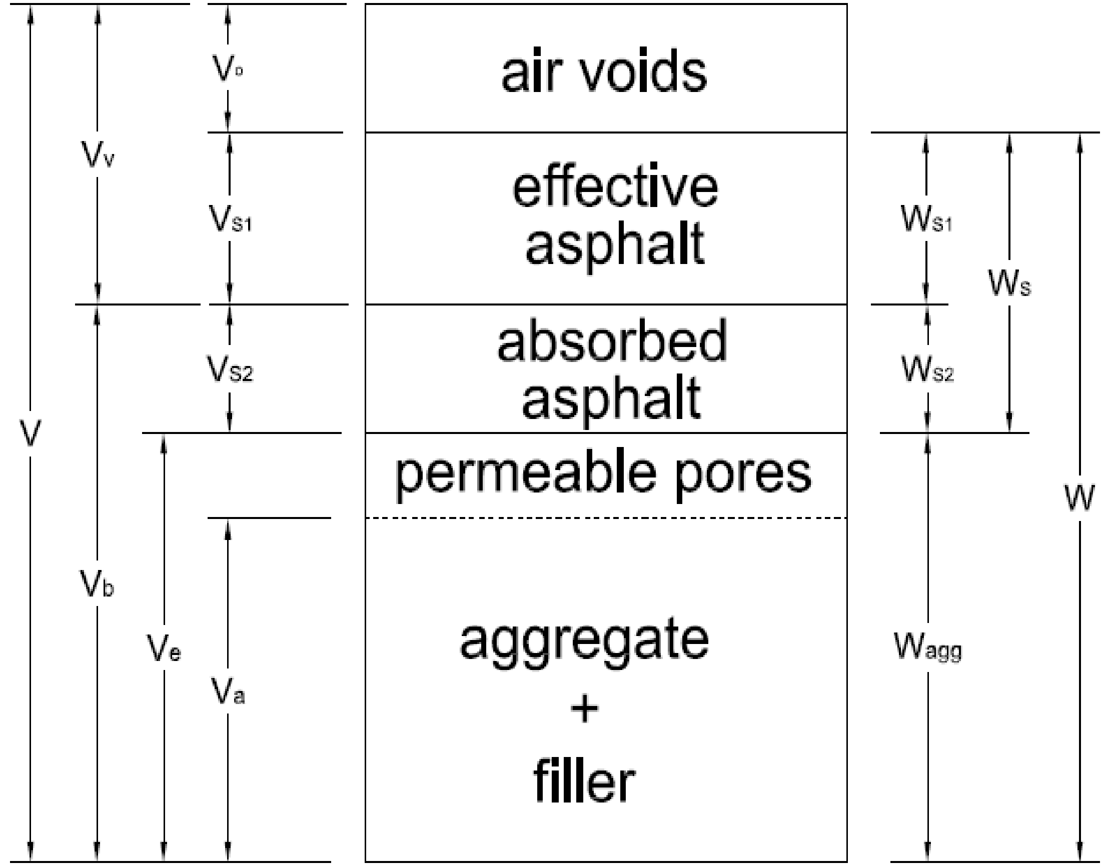
V_a : apparent volume of aggregate

V_e : effective volume of aggregate

V_b : bulk volume of aggregate

V_v : voids in mineral aggregate

V : total volume of mixture



% AV : percentage of air voids in total mix

$$\%AV = \frac{V_o}{V_m} \times 100$$

% VMA : percentage of voids in mineral aggregate

$$\%VMA = \frac{V_o + V_{S1}}{V_m} \times 100$$

% VFA : percentage of voids filled with asphalt

$$\%VFA = \frac{V_{S1}}{V_o + V_{S1}} \times 100$$

Bulk GA = bulk specific gravity of combined aggregate $= \frac{W_{Agg}}{V_b}$

$$= \frac{100}{\frac{\%\ cource}{G_{s(cource)}} + \frac{\%\ fine}{G_{s(fine)}} + \frac{\%\ filler}{G_{s(filler)}}}$$

Ex.:

50% (1"-No.4) Gs=2.6, 45%,

45% (No.4-No.200) Gs=2.65,

5% (No.200) Gs=3.15

$$\text{Bulk } G_{Agg.} = \frac{100}{\frac{50}{2.6} + \frac{45}{2.65} + \frac{5}{3.15}} = 2.64$$

P_S = total percentage of asphalt (by weight of the total mix)

P_A = percentage of aggregate (by weight of the total mix)

$P_S + P_A = 100\% \longrightarrow P_A = 100 - P_S$

Theoretically in void-less mix

the maximum specific gravity of the mixture (max G_m)

the (max Gm) by testing in the lab. According to (ASTM, D2041)

$$\boxed{\max G_m = \frac{W}{V - V_o}} \qquad \boxed{\text{effective } G_A = \frac{W_A}{V_e}}$$

the bulk or actual specific gravity of the mixture (Bulk G_m)

$$\boxed{Bulk\ G_m = \frac{W}{V} = \frac{W_{in\ air}}{W_{in\ air} - W_{in\ water}}}$$

This bulk specific gravity (Bulk Gm) is either taken from a core specimen of an existing pavement or a sample compacted in lab

For loos uncompact mixture at ***nearly optimum*** asphalt content

$$\text{effective } G_A = \frac{100 - P_s}{\dfrac{100}{max G_m} - \dfrac{P_s}{G_s}}$$

Since effective G_A is a constant property (independent of asphalt content) by conducting a lab test to determine the theoretical max Gm for a certain Ps, the effective GA could be found and then this equation could be used to determine the max Gm for any other Ps other than optimum without lab test.

For any other asphalt content

$$\max G_m = \frac{100}{\dfrac{P_A}{eff\, G_A} + \dfrac{P_s}{G_s}}$$

or

$$\max G_m = \frac{100}{\dfrac{100 - P_s}{eff\, G_A} + \dfrac{P_s}{G_s}}$$

Note: $\frac{P_s}{G_s}$ may represent the asphalt volume in the mix and $\frac{P_A}{eff\ G_A}$ is the effective volume of aggregate

$$\%AV = \frac{V_o}{V_m} \times 100 \qquad \%AV = \frac{\max G_m - Bulk\ G_m}{\max G_m} \times 100$$

$$\%AV = \left(1 - \frac{Bulk\ G_m}{\max G_m}\right) \times 100$$

Or it can be derived as:

$$\%AV = \frac{V_o}{V_m} = \frac{V_o + V_m - V_m}{V_m} = \frac{V_m - (V_m - V_o)}{V_m} = 1 - \frac{V_m - V_o}{V_m} = 0$$

$$= 1 - \frac{(V_m - V_o).\, w_m}{V_m.\, w_m} = 1 - \frac{\frac{w_m}{V_m}}{\frac{w_m}{V_m - V_o}} = 1 - \frac{Bulk\ G_m}{\max G_m}$$

Air voids should range between (3 – 5)

$$\%VMA = \frac{V_V}{V_m} \times 100 \quad = 100 - \frac{Bulk\ G_m \times P_A}{\text{Bulk}\ G_A}$$

can be derived as follows:

$$\%VMA = \frac{V_V}{V_m} = \frac{V_m - V_b}{V_m} = 1 - \frac{V_b}{V_m} = 1 - \frac{V_b . w_m}{V_m . w_m} = 1 - \frac{Bulk\ G_m . V_b}{w_m} . \frac{w_A}{w_A}$$

$$= 1 - \frac{Bulk\ G_m . \frac{P_A}{100}}{Bulk\ G_A} = 100 - \frac{Bulk\ G_m . P_A}{Bulk\ G_A}$$

Minimum V.M.A = 15

$$\%VFA = \frac{V_{S1}}{V_V} \times 100 \qquad \%VFA = \frac{VMA - AV}{VMA} \times 100$$

can be derived as follows:

$$\%VFA = \frac{V_{S1}}{V_V} = \frac{V_V - V_o}{V_V} = \frac{(V_V - V_o)/V_m}{V_V/V_m} = \frac{VMA - AV}{VMA}$$

$$\%VFA = \frac{Bulk\ G_m \times P_{S1}}{\text{Bulk } G_m \times P_{S1} + G_S \times \%AV} \times 100$$

Voids filled asphalt should range between (70 – 85)

The absorbed asphalt (***by weight of aggregate***)

$$absorbed\ asphalt\ P''_{S2} = \frac{V_{S2}.G_S}{w_A} = \left[\frac{1}{Bulk\ G_A} - \frac{1}{eff\ G_A}\right].G_s \times 100$$

can be derived as follows:

$$P''_{S2} = \frac{w_{s2}}{w_A} = \frac{V_{S2}.G_S}{w_A} = \frac{(V_b - V_e).G_s}{w_A} = \left[\frac{V_b}{w_A} - \frac{V_e}{w_A}\right].G_s = \left[\frac{1}{Bulk\ G_A} - \frac{1}{eff\ G_A}\right].G_s$$

The effective asphalt (***by weight of total mix***)

$$effective\ asphalt\ P_{S1} = \frac{V_{S1}.G_S}{w_m} \times 100 = P_S - \frac{P''_{S2}.P_A}{100}$$

can be derived as follows:

$$P_{S1} = \frac{w_{s1}}{w_m} = \frac{w_{S1} + w_{S2} - w_{S2}}{w_m} = \frac{w_{S1} + w_{S2}}{w_m} - \frac{w_{S2}}{w_m} = P_S - \frac{\frac{w_{S2}}{w_A}}{\frac{w_m}{w_A}} = P_S - \frac{P''_{S2} - P_A}{100}$$

Effective asphalt should range between (4.5 – 6.5)

Example 8

Determine the percentages of air voids, voids in mineral aggregate, and voids filled with asphalt for an asphalt mix having the same material but the asphalt content is 5.7% and the core from the pavement layer has

$$W_{in\ air} = 1200 \text{ gm} \ \& \ W_{in\ water} = 692\text{gm}$$

An asphalt mixture has the following aggregate and asphalt properties.

The aggregate gradation is as follows:

Sieve size	% passing
1”	100
No.4	45
No.200	5

For course aggregate Gs = 2.64

For fine aggregate Gs = 2.67

For filler Gs = 3.10

For asphalt (40 – 50) Gs = 1.04

For the asphalt concrete that contains 5% asphalt, the maximum specific gravity max Gm = 2.49

Solution

$$Bulk\ G_A = \frac{100}{\frac{\%\ cource}{G_{s(cource)}} + \frac{\%\ fine}{G_{s(fine)}} + \frac{\%\ filler}{G_{s(filler)}}} = \frac{100}{\frac{55}{2.64} + \frac{40}{2.67} + \frac{5}{3.1}} = 2.672$$

$$\text{effective } G_A = \frac{100 - P_s}{\frac{100}{maxG_m} - \frac{P_s}{G_s}}$$

$$\text{effective } G_A = \frac{100 - 5}{\frac{100}{2.49} - \frac{5}{1.04}} = 2.687$$

This property
is constant

For the layer with asphalt content 5.7%

$$Bulk\ G_m = \frac{W_{in\ air}}{W_{in\ air} - W_{in\ water}}$$

$$= \frac{1200}{1200 - 692} = 2.362$$

$$\text{calculated max } G_m = \frac{100}{\frac{100 - P_s}{eff\,G_A} + \frac{P_s}{G_s}}$$

$$= \frac{100}{\frac{100 - 5.7}{2.687} + \frac{5.7}{1.04}} = 2.464$$

$$\%AV = \left(1 - \frac{Bulk\ G_m}{\max\ G_m}\right) \times 100 \qquad = \left(1 - \frac{2.362}{2.464}\right) \times 100 = 4.13\%$$ OK $3 < 4.1 < 5$

$$\%VMA = 100 - \frac{Bulk\ G_m \times P_A}{\text{Bulk}\ G_A} \qquad = \left(100 - \frac{2.362 \times 94.3}{2.672}\right) = 16.64$$ OK $16.6 > 15$

$$absorbed\ asphalt\ P''_{S2} = \left[\frac{1}{Bulk\ G_A} - \frac{1}{eff\ G_A}\right].G_s \times 100 = \left[\frac{1}{2.672} - \frac{1}{2.687}\right].1.04 \times 100 = 0.23\%$$

$$effective\ asphalt\ = P_S - \frac{P''_{S2}.P_A}{100} = 5.7 - \frac{0.23 * 94.3}{100} = 5.48\%$$ OK $4.5 < 5.48 > 6.5$

$$\%VFA = \frac{VMA - AV}{VMA} \times 100 \qquad = \frac{16.64 - 4.13}{16.64} \times 100 = 75.12\%$$

Or:

$$\%VFA = \frac{Bulk\ G_m \times P_{S1}}{\text{Bulk}\ G_m \times P_{S1} + G_S \times \%AV} \times 100 = \frac{2.362 * 5.48}{2.362 * 5.48 + 1.04 * 4.1} \times 100 = 75.2$$ OK $<75 < 85$

Example 9 An asphalt mixture has the following aggregate and asphalt properties.

The aggregate gradation is as follows:

Aggregate	%	Bulk G_A
course	45	2.605
fine	47	2.715
mineral filler	8	2.725

Asphalt content: 6.4% by the weight of the total mix

Tested maximum $G_m = 2.438$

For asphalt $G_s = 1.01$

Determine the various properties of the mixture if the asphalt content is 5% by the weight of the total mix and the actual (bulk) $G_m = 2.391$

Solution

$$Bulk\ G_A = \frac{100}{\frac{\%\ cource}{G_{s(cource)}} + \frac{\%\ fine}{G_{s(fine)}} + \frac{\%\ filler}{G_{s(filler)}}} = \frac{100}{\frac{45}{2.605} + \frac{47}{2.715} + \frac{8}{2.725}} = 2.665$$

$$\text{effective } G_A = \frac{100 - P_s}{\frac{100}{maxG_m} - \frac{P_s}{G_s}} \qquad \text{effective } G_A = \frac{100 - 6.4}{\frac{100}{2.438} - \frac{6.4}{1.01}} = 2.699$$

This value is not changing

For the asphalt content 5%

$$\text{calculated max } G_m = \frac{100}{\frac{100 - P_s}{eff\, G_A} + \frac{P_s}{G_s}} = \frac{100}{\frac{100-5}{2.699} + \frac{5}{1.01}} = 2.491$$

By the weight of aggregate

$$absorbed\ asphalt\ P''_{S2} = \left[\frac{1}{Bulk\ G_A} - \frac{1}{eff\ G_A}\right].G_s \times 100 = \left[\frac{1}{2.665} - \frac{1}{2.699}\right].1.01 \times 100 = 0.48\%$$

By the weight of total mix

$$effective\ asphalt\ P_{S1} = P_S - \frac{P''_{S2}.P_A}{100} = 5 - \frac{0.48 * 95}{100} = 4.54\%$$

OK 4.5 < 4.58 > 6.5

$$\%AV = \left(1 - \frac{Bulk\ G_m}{\max G_m}\right) \times 100 = \left(1 - \frac{2.391}{2.491}\right) \times 100 = 4\%$$

OK 3 < 4 < 5

$$\%VMA = 100 - \frac{Bulk\ G_m \times P_A}{\text{Bulk } G_A} = \left(100 - \frac{2.391 \times 95}{2.665}\right) = 14.78\%$$

OK 14.7 > 15

$$\%VFA = \frac{Bulk\ G_m \times P_{S1}}{\text{Bulk } G_m \times P_{S1} + G_S \times \%AV} \times 100 = \frac{2.391 * 4.54}{2.391 * 4.54 + 1.01 * 4} \times 100 = 72.9$$

OK 70<72.9 < 85

Example 10

Assume that the compacted HMA mixture with the following properties:

Bulk specific gravity of the mixture Bulk Gm = 2.421

Theoretical maximum specific gravity of the mixture max Gm = 2.521

Asphalt binder specific gravity Gs = 1.03

Asphalt binder content Ps = 0.05% by mass of the total mix

Aggregate properties:

Type	% of total aggregate	Bulk G
A	50%	2.695
B	25%	2.611
C	25%	2.655

- **Calculate the Bulk Specific Gravity of the combined aggregate**
- **Calculate the Effective Specific Gravity of the aggregate**
- **Calculate the Percent Absorbed Asphalt for the Mixture**
- **Calculate the Percent Effective Asphalt For the Mixture**
- **Calculate the Percent Voids in Total Mix for the Mixture**
- **Calculate the Percent Voids in Mineral Aggregate for the Mixture**
- **Calculate the Percent Voids Filled with Asphalt for the Mixture**

Solution

$$Bulk\ G_A = \frac{100}{\frac{\%\,A}{G_{sA}} + \frac{\%\,B}{G_{sB}} + \frac{\%\,C}{G_{sC}}} = \frac{100}{\frac{50}{2.695} + \frac{25}{2.611} + \frac{25}{2.655}} = 2.663$$

$$\text{effective } G_A = \frac{100 - P_s}{\frac{100}{maxG_m} - \frac{P_s}{G_s}} = \frac{100 - 5}{\frac{100}{2.521} - \frac{5}{1.03}} = 2.729$$

$$absorbed\ asphalt\ P''_{S2} = \left[\frac{1}{Bulk\ G_A} - \frac{1}{eff\ G_A}\right].G_s \times 100 = \left[\frac{1}{2.663} - \frac{1}{2.729}\right].1.03 \times 100 = 0.94\%$$

$$effective\ asphalt\ P_{S1} = P_S - \frac{P''_{S2}.P_A}{100} = 5 - \frac{0.94 * 95}{100} = 4.1\%$$

$$\%AV = \left(1 - \frac{Bulk\ G_m}{\max G_m}\right) \times 100 = \left(1 - \frac{2.421}{2.521}\right) \times 100 = 4\%$$

$$\%VMA = 100 - \frac{Bulk\ G_m \times P_A}{\text{Bulk } G_A} = \left(100 - \frac{2.421 \times 95}{2.663}\right) = 13.6\%$$

$$\%VFA = \frac{Bulk\ G_m \times P_{S1}}{\text{Bulk } G_m \times P_{S1} + G_S \times \%AV} \times 100 = \frac{2.421 * 4.1}{2.421 * 4.1 + 1.03 * 4} \times 100 = 70.6\ \%$$

Or:

$$\%VFA = \frac{VMA - AV}{VMA} \times 100 = \frac{13.6 - 4.0}{13.6} \times 100 = 70.6\%$$

Mix Design Methods:

1. Marshall method
2. Hveem method
3. Immersion – compression
4. Indirect tensile strength
5. Creep method

MARSHALL METHOD OF MIX DESIGN

In Marshall method:

the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute.

The two major features

(i) density-voids analysis and

(ii) stability-flow tests.

Marshall stability 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.

It is an attempt to obtain optimum binder content for the type of aggregate and the expected traffic intensity

STEPS OF DESIGN

1. Select aggregate grading to be used
2. Determine the proportion of each aggregate size required to produce the design grading.
3. Determine the specific gravity of the aggregate combination and asphalt cement.
4. Prepare the trial specimens with varying asphalt contents.
5. Determine the specific gravity of each compacted specimen.
6. Perform stability tests on the specimens.
7. Calculate the percentage of voids, and percent voids filled with Bitumen in each specimen.
8. Select the optimum binder content from the data obtained.
9. Evaluate the design with the design requirement's.

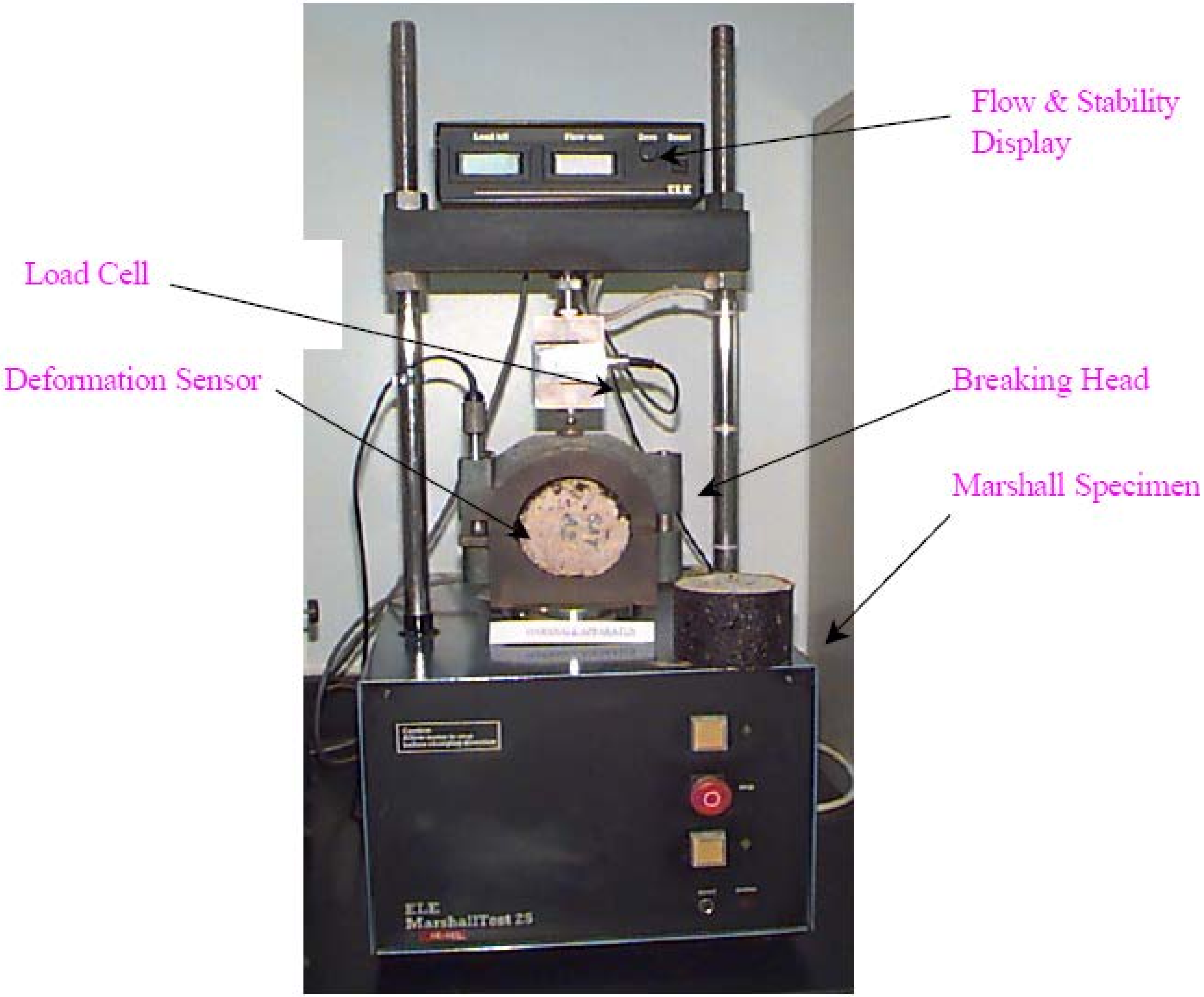


Figure 11.2 Marshall Specimen Extractor

PROCEDURE

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

Bulk density of the compacted specimen

The bulk density of the sample is usually determined by weighting the sample in air and in water. It may be necessary to coat samples with paraffin before determining density.

$$Bulk\ G_m = \frac{W_{in\ air}}{W_{in\ air} - W_{in\ water}}$$

Stability test

In stability test, the specimen is immersed in a bath of water at a temperature of 60° ± 1°C for a period of 30 minutes.

It is then placed in the Marshall stability testing machine and loaded at a constant rate of deformation of 5 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***.

RESULTS AND CALCULATIONS

Bulk specific gravity of aggregate ($Bulk\ G_A$)

$$Bulk\ G_A = \frac{100}{\frac{\%\ cource}{G_{s(cource)}} + \frac{\%\ fine}{G_{s(fine)}} + \frac{\%\ filler}{G_{s(filler)}}}$$

Maximum specific gravity of aggregate mixture ($max\ G_m$)

maximum specific gravity of aggregate mixture should be obtained as per ASTM D2041, however because of the difficulty in conducting this experiment an alternative procedure could be utilized

$$\max G_m = \frac{100}{\frac{100 - P_s}{eff\,G_A} + \frac{P_s}{G_s}}$$

Percent voids in compacted mineral aggregate (%VMA)

$$\%VMA = 100 - \frac{Bulk\ G_m \times P_A}{\text{Bulk}\ G_A}$$

Percent air voids in compacted mixture (%AV)

$$\%AV = \frac{\max G_m - Bulk\ G_m}{\max G_m} \times 100$$

DETERMINATION OF OPTIMUM BINDER CONTENT

Five separate smooth curves are drawn with percent of asphalt on x-axis and the following on y-axis

unit weight | Marshall stability | Flow | VMA | Voids in total mix

Optimum binder content

Bo :

is selected as the average binder content for *maximum density*, *maximum stability* and *specified percent air voids* in the total mix

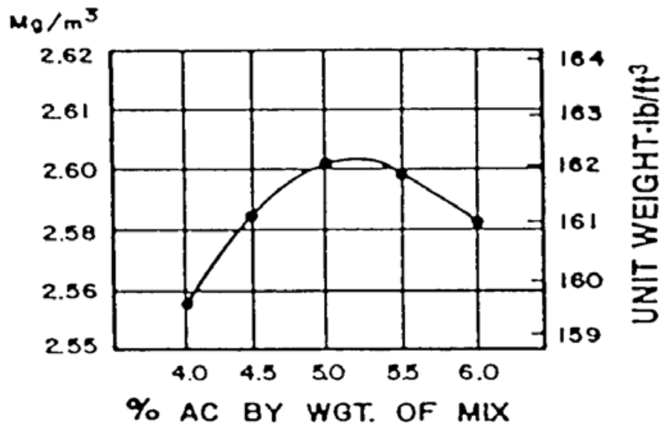
$$B_0 = \frac{B_1 + B_2 + B_3}{3}$$

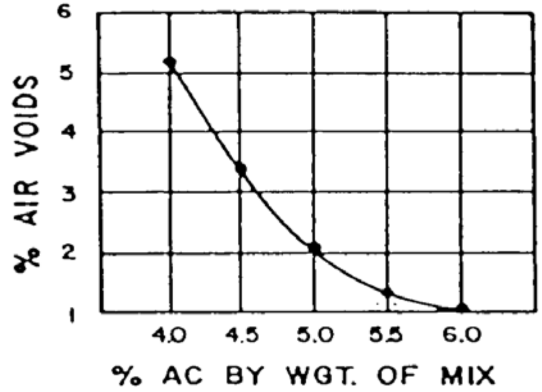
B_0 = optimum Bitumen content.

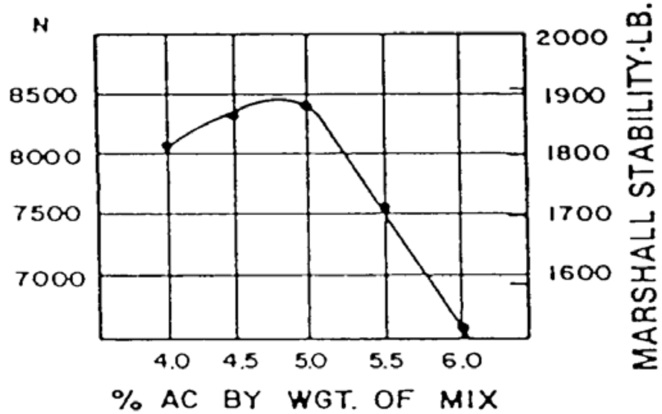
B_1 = % asphalt content at maximum unit weight.

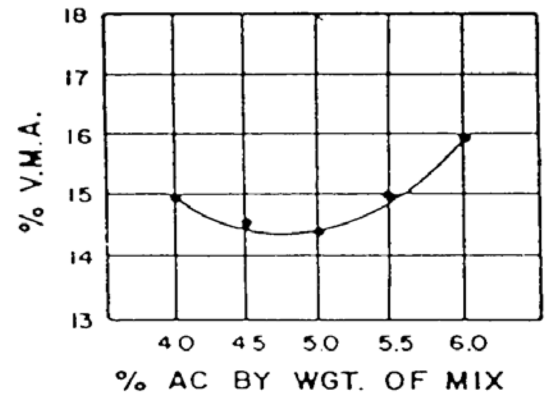
B_2 = % asphalt content at maximum stability.

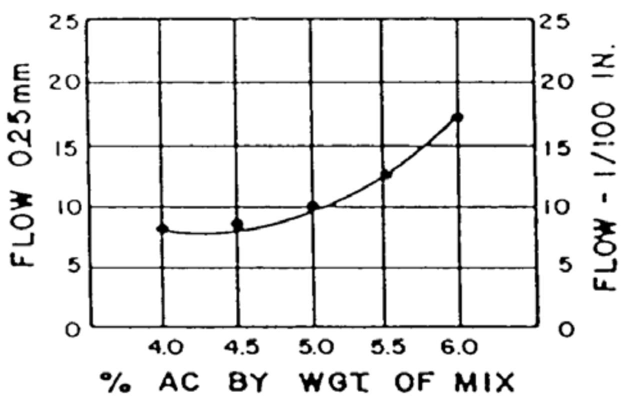
B_3 = % asphalt content at specified percent air voids in the total mix.

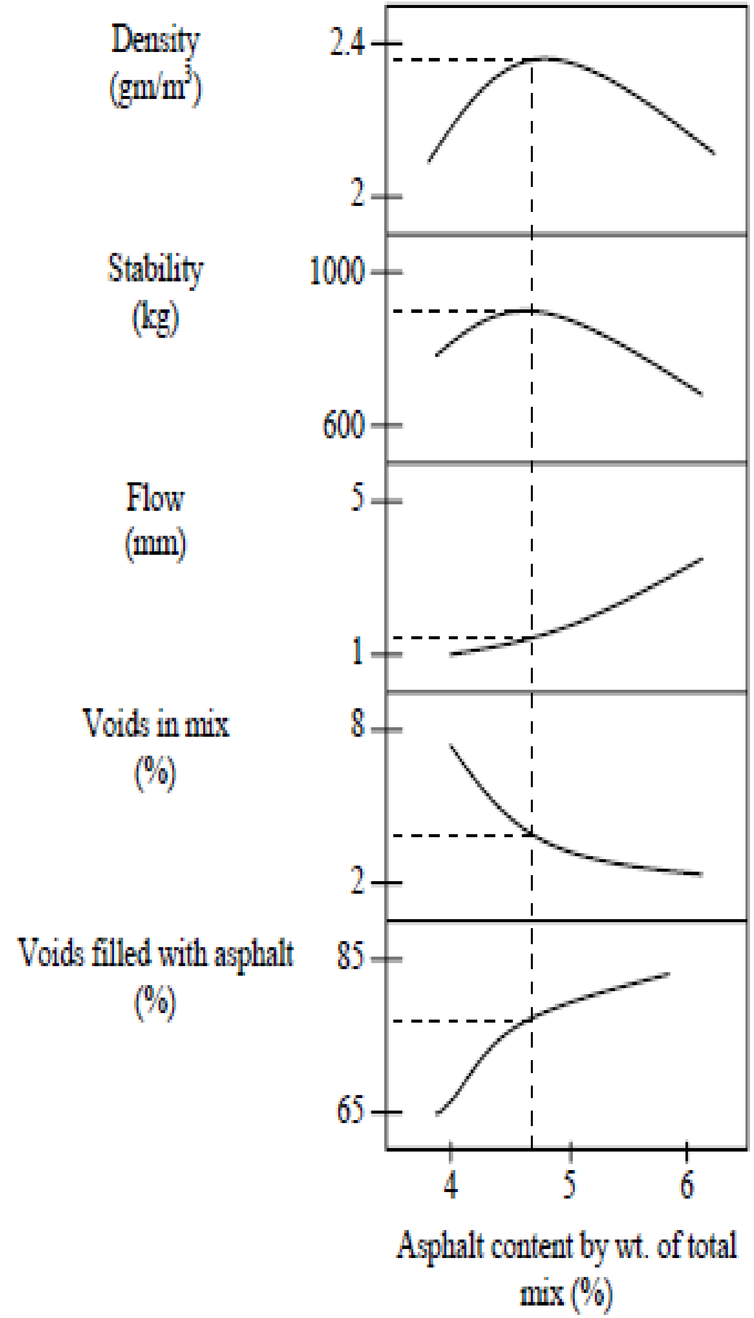

Mg/m3
2.62
2.61
2.60
2.58
2.56
2.55
164
163
162
161
160
159
UNIT WEIGHT-lb/ft3
4.0
4.5
5.0
5.5
6.0
% AC BY WGT. OF MIX


6
5
4
3
2
1
% AIR VOIDS
4.0
4.5
5.0
5.5
6.0
% AC BY WGT. OF MIX


N
8500
8000
7500
7000
2000
1900
1800
1700
1600
MARSHALL STABILITY-LB.
4.0
4.5
5.0
5.5
6.0
% AC BY WGT. OF MIX


18
17
16
15
14
13
% V.M.A.
4.0
4.5
5.0
5.5
6.0
% AC BY WGT. OF MIX


25
20
15
10
5
0
FLOW 0.25 mm
FLOW - 1/100 IN.
4.0
4.5
5.0
5.5
6.0
% AC BY WGT. OF MIX


Density
(gm/m3)
2.4
2
Stability
(kg)
1000
600
Flow
(mm)
5
1
Voids in mix
(%)
8
2
Voids filled with asphalt
(%)
85
65
4
5
6
Asphalt content by wt. of total mix (%)

EVALUATION AND ADJUSTMENT OF MIX DESIGN

The overall objective of the mix design is to determine an optimum blend of different components that will satisfy the requirements of the given specifications. This mixture should have:

1. Adequate amount of asphalt to ensure a durable pavement.

2. Adequate mix stability to prevent unacceptable distortion and displacement when traffic load is applied.

3. Adequate voids in the total compacted mixture to permit a small amount of compaction when traffic load is applied without bleeding and loss of stability.

4. Adequate workability to facilitate placement of the mix without segregation.

Description	Type I Base course		Type II Binder or leveling course		Type III Wearing course	
	Min.	Max.	Min.	Max.	Min.	Max.
Marshall specimens (ASTM D 1559) No. of comp. Blows, each end of specimen	75		75		75	
Stability, kg.	350	--	500	--	600	--
Flow, 0.25 mm	8	16	8	16	8	16
VMA	13	--	14	--	15	--
Air voids, %	3	8	3	8	4	6
Aggregate voids filled with bitumen, %	60	80	65	85	70	85
Immersion compression specimen (AASHTO T 165) index of retained strength, %	70	--	70	--	70	--

If the mix design for the optimum binder content does not satisfy all the requirements of specifications. It is necessary to adjust the original blend of aggregates.

The trial mixes can be adjusted by using the following guidelines:

1. If low voids : The voids can be increased by adding more coarse aggregates.

2. If high voids : Increase the amount of mineral filler in the mix.

3. If low stability: This condition suggests low quality of aggregates. The quality of aggregates should be improved. (use different aggregate or use cement coated aggregate)