Pavement Materials & Design (110401466)
Bituminous Materials

Source:

Chapter 19: Traffic & Highway Engineering by Nicholas Garber and Lester Hoel, Third Edition, Brooks/Cole.

Chapter 15-9: Highway Engineering, by Paul Wright & Karen Dixon, 7th Edition, Wiley & sons

Instructor:

Dr. TALEB M. AL-ROUSAN

Highway Materials/ Bituminous Materials

- Bituminous Materials are used for highway construction because:

1. Excellent binding & cementing power.
2. Water-proofing properties.
3. Relatively low cost.

- Bitumen: Black or dark colored solid or viscous cementious substances composed of high molecular weight hydrocarbons.
- Bitumen is soluble in carbon disulfide (CS_2).

Sources of Asphaltic Materials

- Natural Deposits:
  - Native asphalt
    - Existed in Iraq, Trinidad, Bermuda, LA California.
    - Softened by petroleum fluxes
  - Rock asphalt:
    - Deposits of sandstone or limestone rocks filled with asphalt
    - Found in California, Texas, Oklahoma
    - Not widely used

Sources of Asphaltic Materials

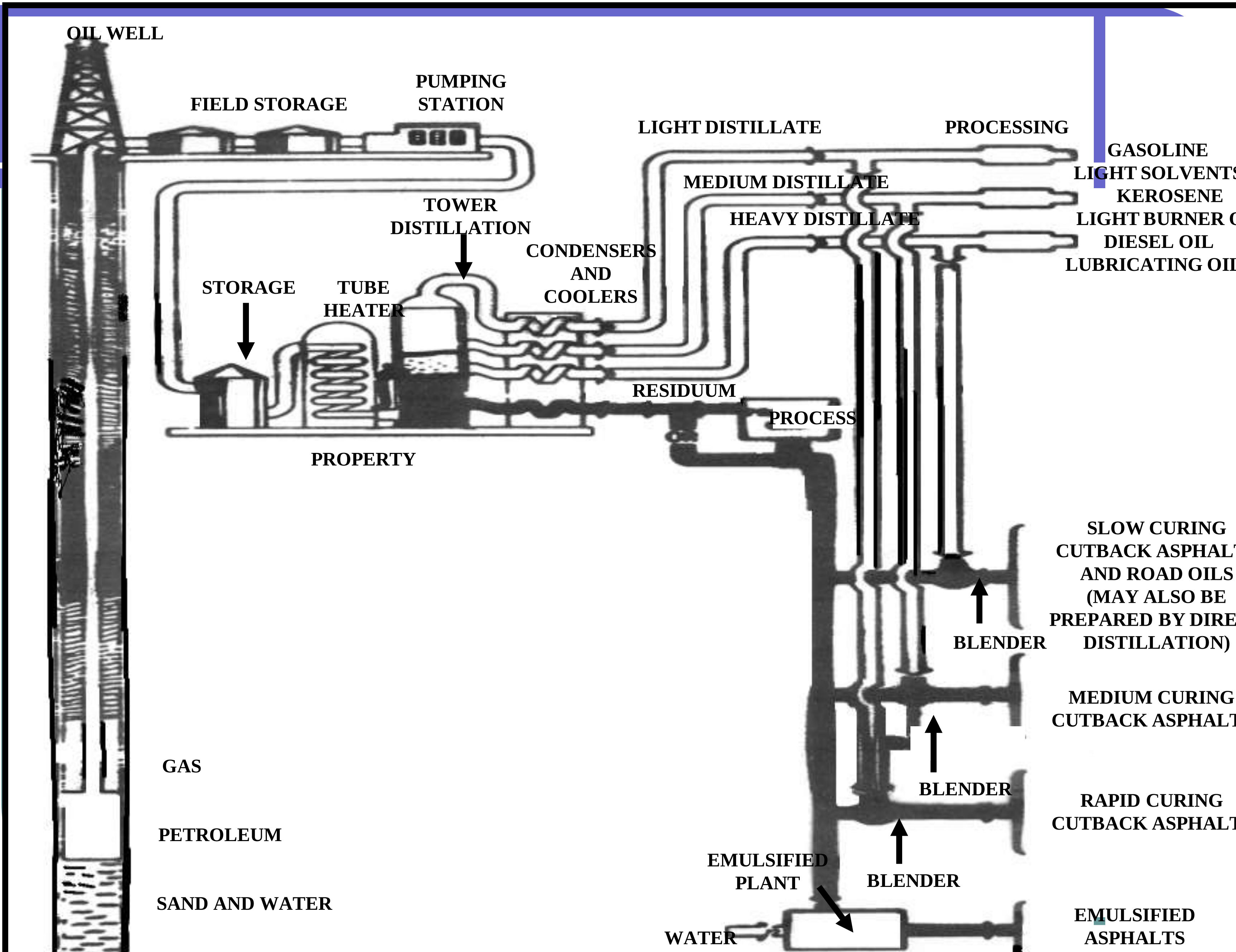
- Petroleum Asphaltic Materials:
  - The asphaltic materials obtained from the distillation of petroleum are:
    - Asphalt Cement (AC).
    - Slow-Curing liquid asphalt.
    - Medium-Curing liquid asphalt.
    - Rapid-Curing liquid asphalt.
    - Asphalt Emulsions.

Bituminous Materials Categories

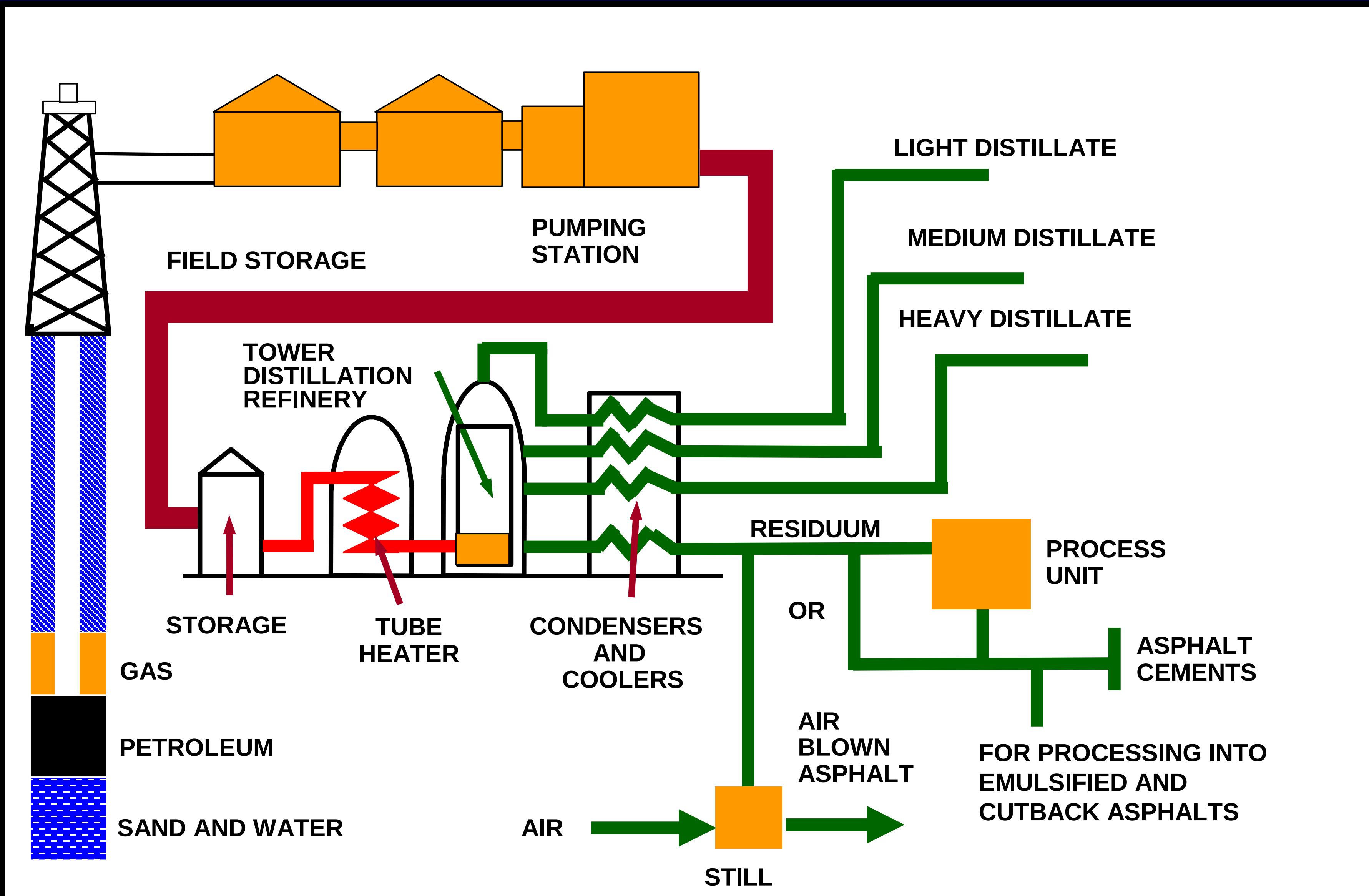
ASPHALT	TARS
● Residue of petroleum (Separated by fractional distillation) or as native asphalt ● Used extensively as binders for highways ● Dissolve in petroleum oils ● Black color ● More resistance to weathering ● Less susceptible to temp. ● Has no odor ● Used in highways & airports	● Residues from the destructive distillation (chemical change) of organic substances such as coal, wood, or petroleum ● Crude tars must undergo further refinement to become road tars ● Do not dissolve in petroleum oils, therefore it is used to seat asphalt concrete surfaces to improve oil resistance of asphalt surfaces ● Brown or Black color ● Used in airport, auto parking, fueling areas. ● More expensive

Production of Asphalt

- Asphalts are the residue, byproducts of the refinery of petroleum oils.
- Depending on the sources & characteristics of the crude oils & on properties of asphalt required more than one processing method may be employed.
- Consistency can be controlled by the mount of heavy gas oil removed.
- Consistency can be further modified by air blowing.
- Air blowing is used to increase viscosity of asphalt residue.
- Air blowing = Oxidation (i.e. air and high temp.)


OIL WELL
FIELD STORAGE
PUMPING STATION
LIGHT DISTILLATE
PROCESSING
GASOLINE
LIGHT SOLVENTS
KEROSENE
LIGHT BURNER OIL
DIESEL OIL
LUBRICATING OILS
MEDIUM DISTILLATE
HEAVY DISTILLATE
TOWER DISTILLATION
CONDENSERS AND COOLERS
STORAGE
TUBE HEATER
RESIDUUM
PROCESS
PROPERTY
SLOW CURING CUTBACK ASPHALTS AND ROAD OILS (MAY ALSO BE PREPARED BY DIRECT DISTILLATION)
BLENDER
MEDIUM CURING CUTBACK ASPHALTS
BLENDER
RAPID CURING CUTBACK ASPHALTS
BLENDER
GAS
PETROLEUM
SAND AND WATER
EMULSIFIED PLANT
WATER
EMULSIFIED ASPHALTS

Refinery Operation



Uses of Bituminous Binders

- See **Table 19.1** in Text for typical uses of asphalt.
- Asphalt Cement (AC): HMA in pavement base and surface in highways, air ports. Parking, … etc.
- Slow-Curing (SC): cold laid and mix in place.
- Medium-Curing (MC): Mixed in place and surface treatment.
- Rapid-Curing (RC): Mixed in place and surface treatment.
- Blown Asphalt: Relatively stiff and not used as paving materials. Suitable as roofing material, automobile undercoating, and as joint filler for concrete pavements.
- Asphalt Emulsions: Mixed in place and surface treatment.

Liquid Asphalt

- Asphalt cement is semisolid at room or normal temperature (stiff).
- To make asphalt workable (soften) it should be heated.
- Softening by heating is not feasible in all cases.
- In order to attain workable asphalt cement at ambient temp. they must be liquefied.
- Asphalt is liquefied by two methods:

1. Dissolve (Cut) the asphalt in solvent.
2. Emulsify asphalt in water.

Cutback Asphalt

- Asphalts are mixed with volatile solvents.
- Cutback asphalt = AC + Petroleum solvent
- After cutback asphalt is exposed to air, the volatile solvent evaporates, and asphalt regains its original characteristics.
- Rate of curing can vary depending on the volatility of the solvent used (few minutes to several days):

1. Rapid-curing (RC): gasoline or naphtha.
2. Medium-curing (MC): Kerosene
3. Slow-curing (SC): Road oil

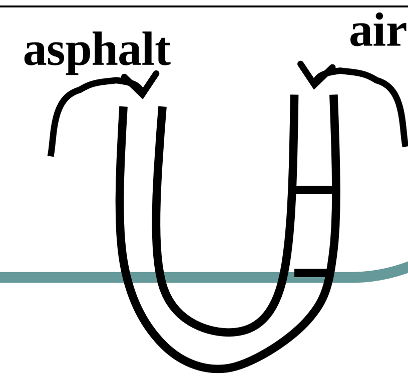
Cutback Asphalts

RAPID CURING (RC)	MEDIUM CURING (MC)	SLOW CURING (SC) (Road Oil)
85-100pen+gasoline	120-150pen	200-300pen+diesel
ASPHALT + NAPHTHA	ASPHALT + KEROSENE	ASPHALT + OIL
SURFACE TREATMENT	STOCKPILE PATCH	Prime Coat
ROAD MIX (FB-1, FB-2)	Road Mixing	Dust Control
30% solvent RC - 30	MC - 30	SC - 70
RC - 70	MC - 70	SC - 250
RC - 250	MC - 250	SC - 800
10% solvent RC - 800	MC - 800	SC - 3000
	MC-3000	
AASHTO M81	AASHTO M82	ASTM D2026

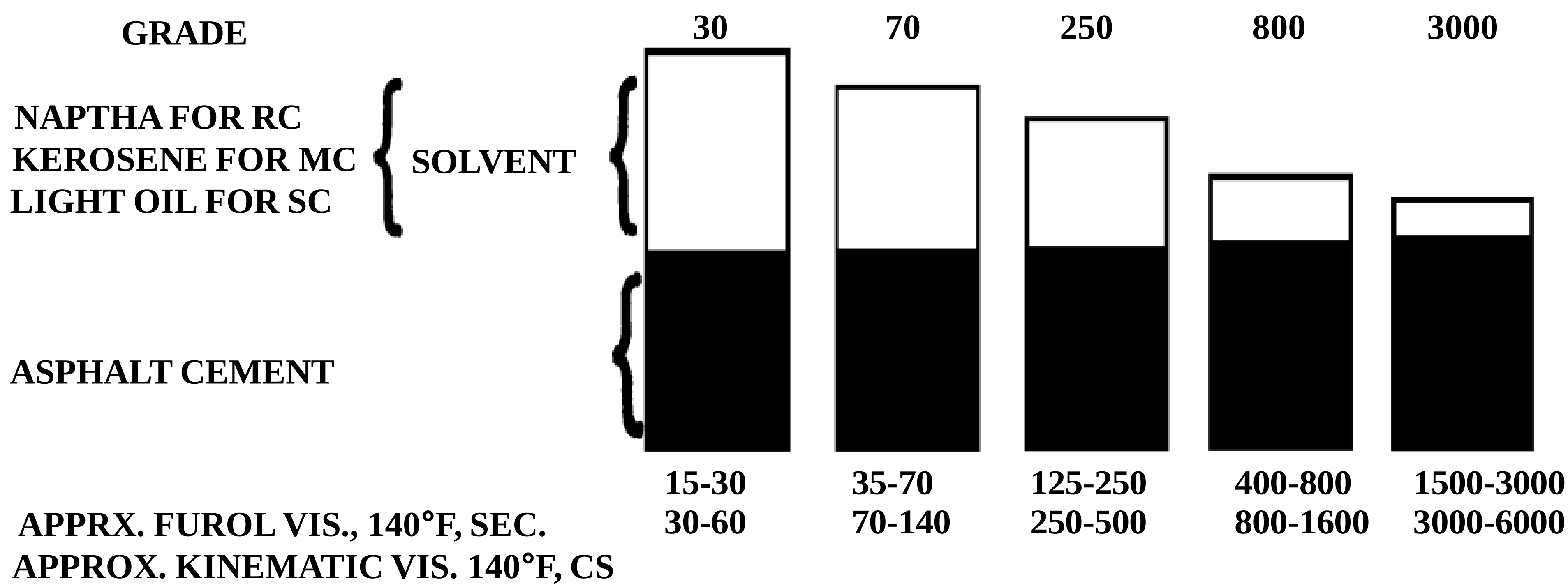
Grades based on min. Kinematic Viscosity @ 60C (cSt)

$$\nu = k * t \text{ (sec)}$$

$$\text{stoke} = \text{St} = \text{cm}^2/\text{sec}$$



Composition of Cutback Asphalts



30% solvent

10% solvent

Use of Cutback Asphalts

Cutback Asphalts used less frequently now

use of emulsions becoming more common.

1. **Env. Concerns (especially with RC's) Hydrocarbons evaporate into air.**

2. **Economic - costly to buy 2 petroleum products.**

3. **Safety - low flash pts - danger of fire.**

4. **Higher application temp, dry conditions required**

Emulsified Asphalts

- It’s a mixture of asphalt cement, water, and emulsifying agent (1-2% by volume).
- Emulsifying agents place electrical charge around each droplet of asphalt.
- Negative (Anionic).
- Positive (Cationic).
- Since like electrical charges repel, asphalt droplets stay suspended in water.
- The emulsion stay in this stable situation until disturbed by:

1. Mixing with aggregates.
2. Evaporation of water.

Emulsions

- When used (i.e. exposed to air), it sets or breaks.
- Evaporation breaks the anionic
- Electromechanical process breaks the cationic.
- Emulsions are graded based on the rate of setting:

1. Rapid Setting (RS)
2. Medium Setting (MS)
3. Slow setting (SS)

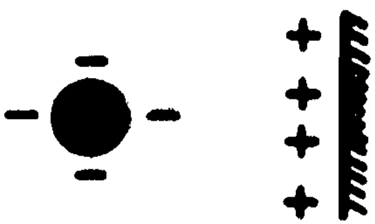
- Anionic emulsions use RS, MS, SS
- Cationic emulsions use CRS, CMS, CSS

EMULSIONS

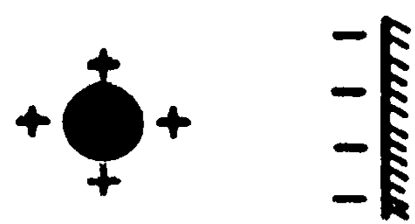
ASPHALT
+
WATER
+
EMULSIFIER

ANIONIC
(-)
ALKALINE

CATIONIC
(+)
ACID



LIMESTONE



SILICA
(Sil. Gravel)

Emulsions

RAPID SETTING (RS)
Tack Coat
Surface Treatment
(spray applications)

MEDIUM SETTING (MS)
Road Mix (open-graded)

SLOW SETTING (SS)
Road Mix (dense)
Slurry Seals
Tack Coat
Fog Seal

weaker surface charge

Emulsion Grades

ANIONIC	AASHTO M140 ASTM D977	CATIONIC AASHTO M208 ASTM D2397	
RS	RS-1	CRS - 1	more asph than
	RS-2 (more viscous, more asph.)	CRS - 2	anionic
MS	MS-1	CMS-2	
	MS-2	CMS-2h	
	MS-2h		
	HFMS-1, 2, 2h *		
SS	SS-1	CSS-1	
	SS-1h	CSS-1h	

"h" = harder AC (40-90 pen)
[usually 100-200 pen]

*high float emulsions - test to measure property of emulsion residue

Advantages of Emulsions

- Pollution free (i.e. no solvents required).
- Used with no additional heat.
- Less cost than cutback.
- More energy efficient than cutback.

Properties of Asphaltic Materials

- Consistency
- Durability
- Rate of curing
- Resistance to water action

Consistency

- Considered under two conditions:
  - Variation of consistency with temperature (temperature susceptibility)
    - Consistency of any asphaltic material changes as temperature changes.
    - The change in consistency of different asphaltic materials may differ considerably even for the same amount of temperature change.
  - Consistency at specified temperature
    - Consistency of asphalt material will vary from solid to liquid depending on the temperature.
    - It is essential that when consistency is given the associated temperature should be given too.

Durability

- When asphalt is exposed to environment, natural deterioration (***weathering***) gradually takes place, and the materials lose their plasticity and become brittle.
- For better performance weathering must be minimized.
- **Durability** :The ability of asphalt to resist weathering.
- Factors influencing weathering:
  - Oxidation.
  - Volatilization.
  - Temperature.
  - Exposed surface area.
  - Age hardening.

Durability/ Factors Influencing Weathering

- Oxidation:
  - oxygen attack asphalt… cause hardening and loss of plastic characteristics.
- Volatilization:
  - evaporation of lighter hydrocarbons from asphalt…. Cause loss of plastic characteristics.
- Temperature:
  - higher temperature cause higher oxidation and volatilization… non linear.
- Exposed surface area:
  - as area increases rate of oxidation and volatilization increases.
- Age hardening:
  - if sample is heated and then allowed to cool, its molecules will be rearranged to form a gel-like structure, which will cause continuous hardening of the asphalt over time even if its protected from oxidation or volatilization. Rate of age hardening is high in the first few hours but gradually decrease (negligible after 1 year).

Rate of Curing

- Curing: the process through which an asphalt material increases its consistency as it loses solvent by evaporation.
- Rate of curing of cutback:
  - Inherent factors
    - Volatility of the solvent.
    - Quantity of solvent in the cutback.
    - Consistency of the base material.
  - External factors:
    - Temperature.
    - Ratio of surface area to volume.
    - Wind velocity across exposed surface.
- Rate of curing of Asphalt Emulsions
  - Depend on the rate of water evaporates from the mixture.
  - Lower curing with high humidity, low temperature, and rain.
  - Cationic release their water more rapidly.

Resistance to Water Action

- Its important that asphalt continue to adhere to the aggregate even with the presence of water.
- Asphalt will strip from the aggregate if the bond is lost which will result in deterioration of the pavement.
- In HMA stripping does not normally occur.
- Commercial anti stripping additives are usually added to improve asphalt ability to adhere to asphalt.

Bitumen Laboratory Tests

- **Purity Tests:**
  - Solubility test.
  - Presence of water.
- Consistency Tests:
  - Kinematic and Absolute viscosity.
  - Saybolt Furol viscosity
  - Penetration.
  - Softening Point.
  - Ductility.
- Durability (Volatility & Aging) Tests:
  - Distillation.
  - Loss on heating
  - Thin film oven test
  - Flash point

Purity Tests/ Solubility

- Measures the purity of asphalt
- 2 g of AC dissolved in 100 ml of trichloroethylene and filtered through a fiberglass filter pad.
- Amount of material retained on the filter is weighed and expressed as % of original sample.
- Spec. + 99% pure.

Solubility Test

Purity Tests/ Presence of Water

- Water present in asphalt cause asphalt to foam when heated above 100 C.

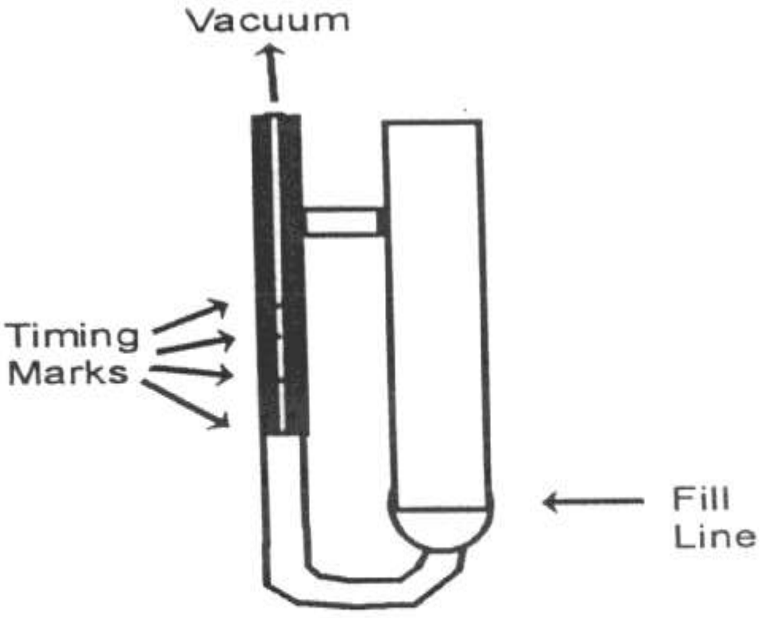
- Water content test:
  - Asphalt sample mixed with suitable distillate in a distillation flask connected with a condenser.
  - Sample gradually heated.
  - The quantity of water collected is then expressed as a percent of the total sample volume.

Consistency Tests/ Viscosity

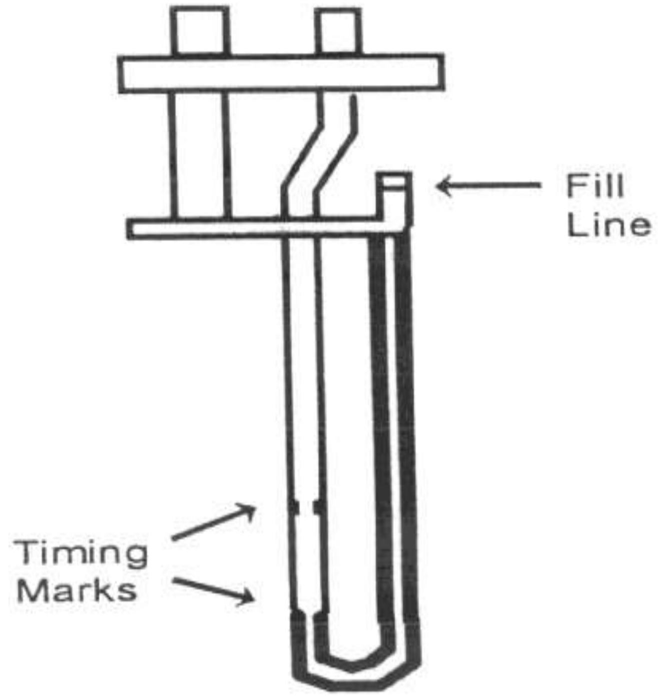
- *Viscosity*: the ratio between the applied shear stress and the rate of shear.
- Viscosity: Resistance of a fluid to flow.

Absolute	Kinematic
• U-shaped tube with timing marks & filled with asphalt • Placed in 60C bath • Vacuum used to pull asphalt through tube • Time to pass marks • Visc. in Pa s (Poise =Ps) • 1 Pa.s = 10 Ps = 1000 cPs	• Cross arm tube with timing marks & filled with asphalt • Placed in 135C bath • Once started gravity moves asphalt through tube • Time to pass marks • Visc. in mm^2 / s (centistoke) • = Absolute/ density

Viscosity Tubes



Asphalt Institute Tube



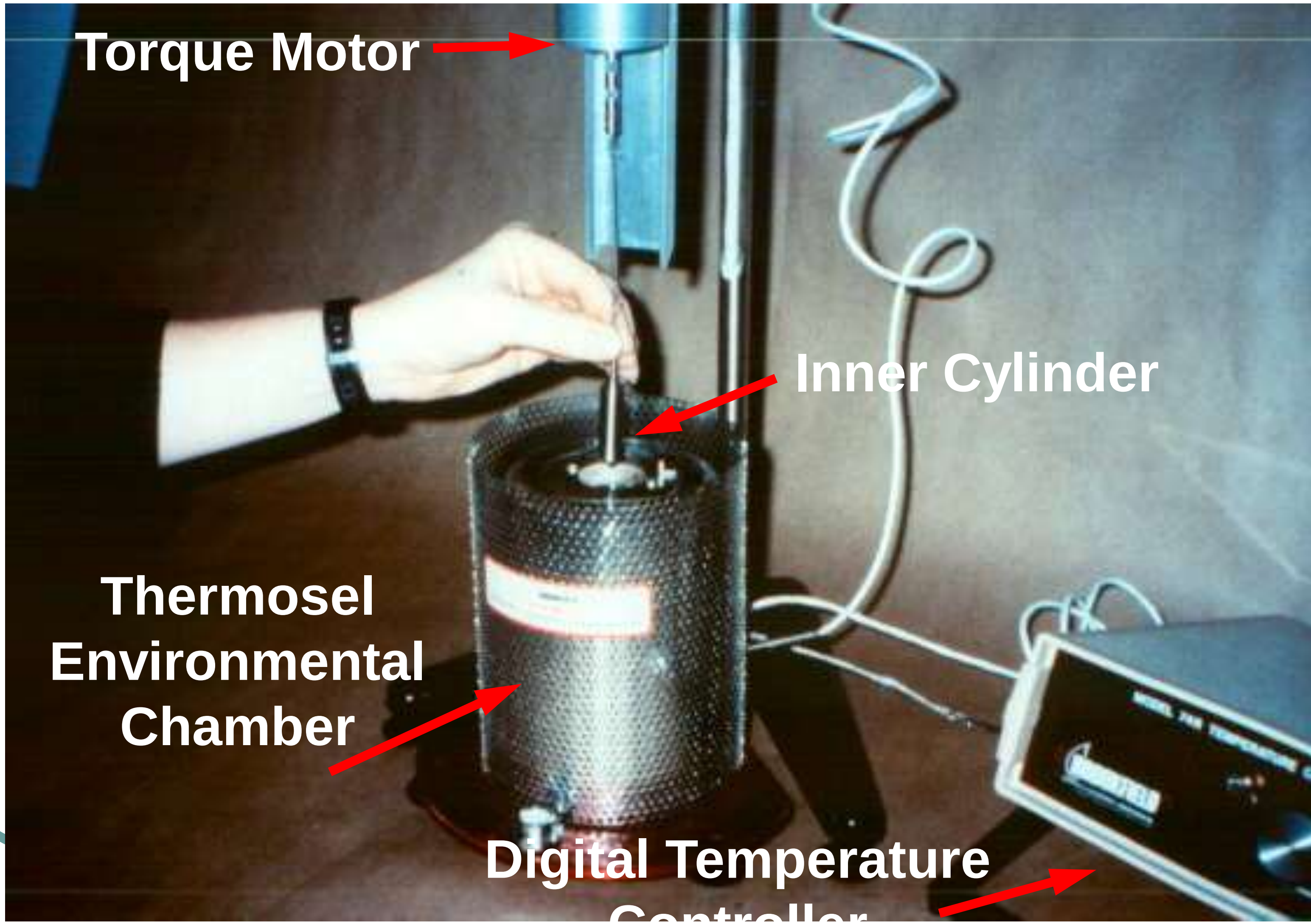
Zietfuchs Cross-Arm Tube

Viscosity Grades for AC

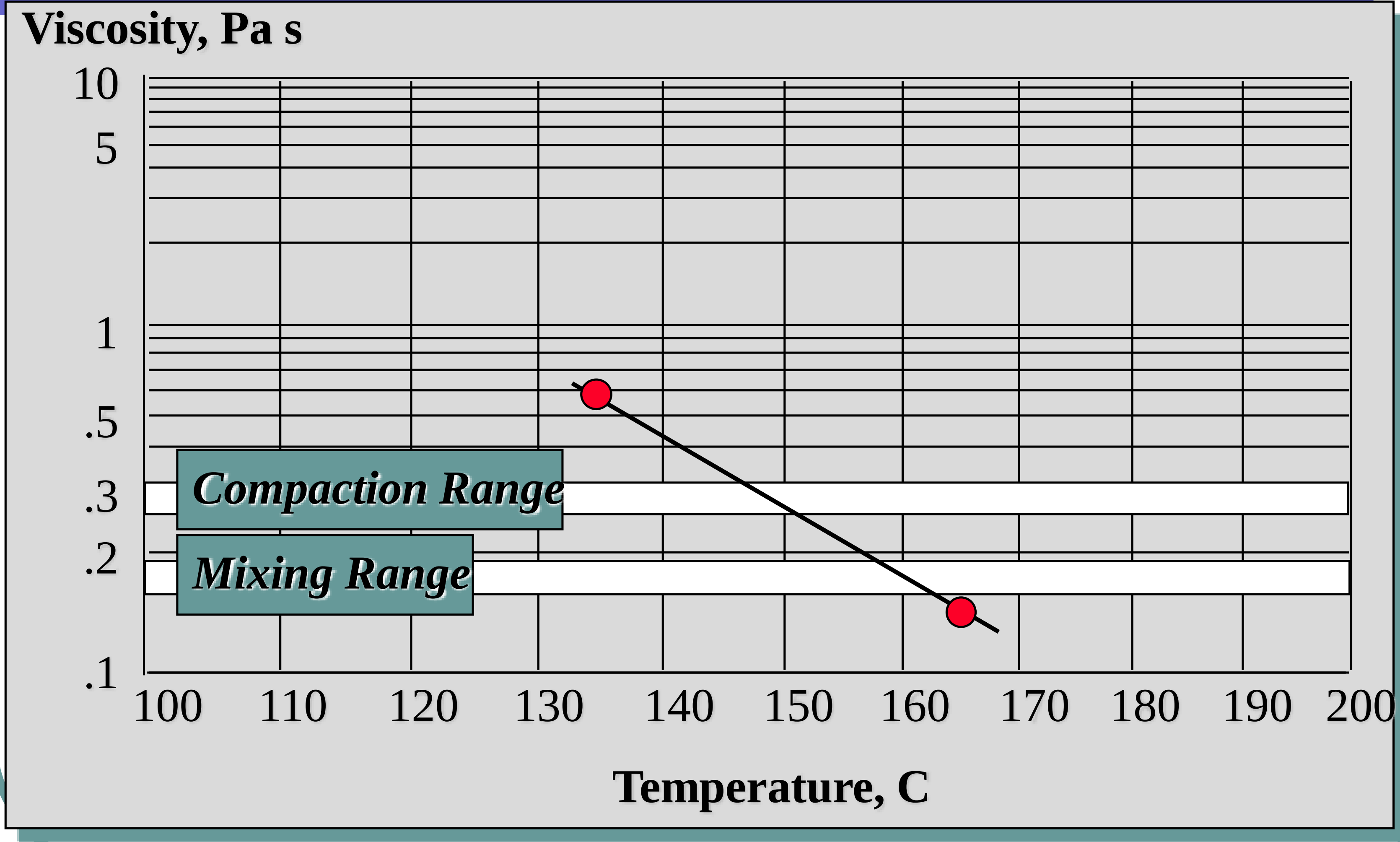
- Viscosity of normal AC based on 60c in poises

AC 2.5	250+- 50
AC 5	500 +- 50
AC 10	1000 +- 200
AC 20	2000 +- 400
AC 30	3000 +- 600
AC 40	4000 +- 800

Rotational Viscometer (Brookfield)



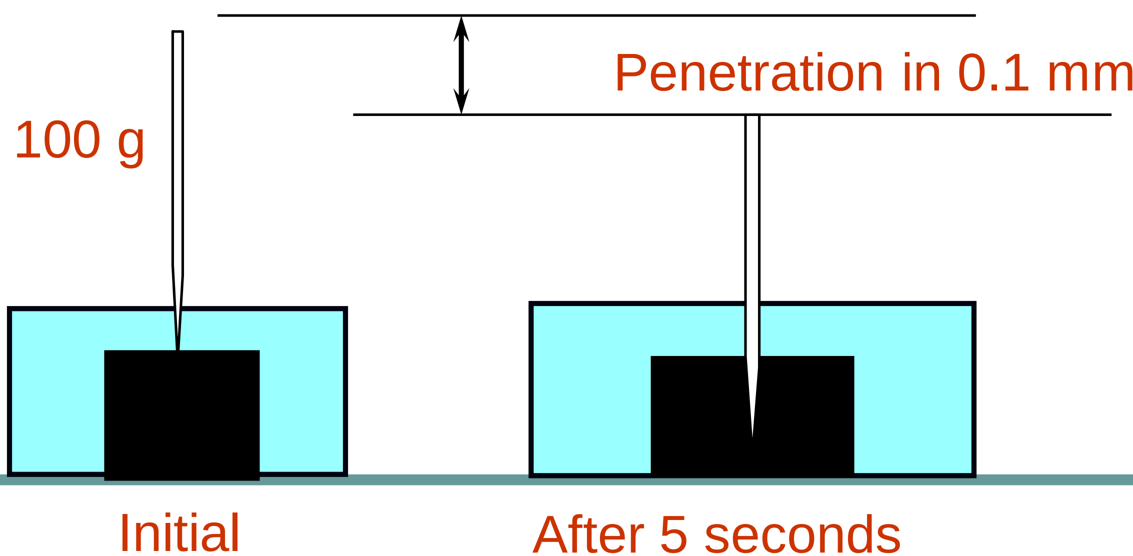
Mixing / Compaction Temps



Mixing viscosity range (170 +- 20 CSt)
Compaction viscosity range (280 +- 30 Cst).

Consistency Tests/ Penetration

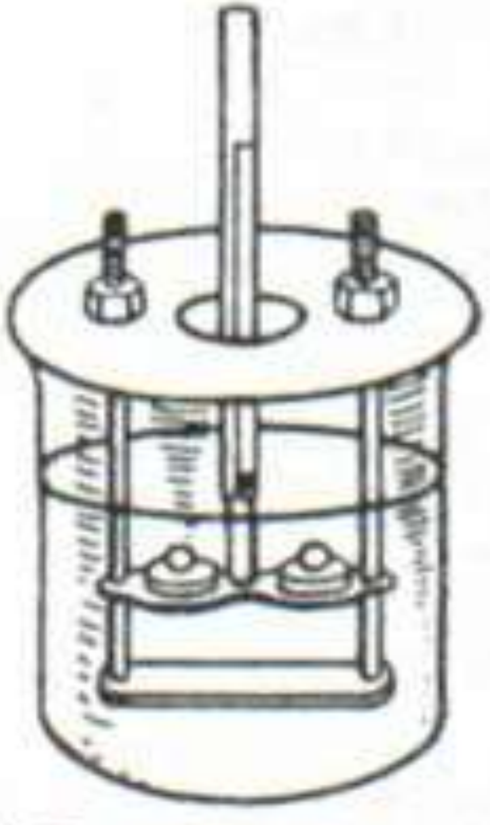
- The distance in hundredths of centimeters (or tenths of mm) to which a standard needle penetrates the material under known conditions of time, loading, and temp. (25)
- Penetration grades: (40-50) (60-70) (85-100) (120-150) and (200-300)



Consistency/ Softening Point

- Ring and Ball method
- Sample melted into a brass ring.
- Ring suspended in water bath.
- Steel balls placed on surface of bitumen in the ring.
- Elevate temp. at constant rate.
- The temp. at which balls touches the bottom of the ring after falling down a distance of 1 inch is reported.

Softening Point

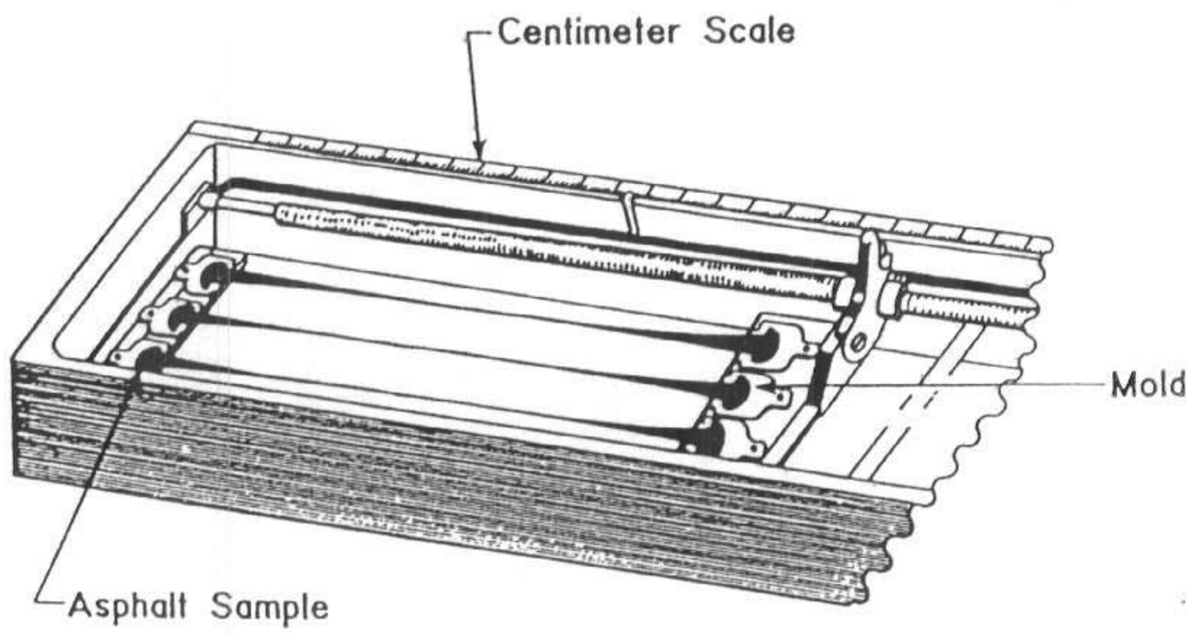


(d) Two-Ring Assembly

Consistency Tests/ Ductility

- Property of material that permits it to elongate (undergo great deformation) without breaking.
- Ductility: Distance in centimeters to which a standard sample may elongate without breaking.
- 25 c, 5 cm/min,
- Spec. +100 cm

Ductelometer



Volatility Tests/ Distillation & Loss on Heating

- Distillation: Used to separate volatile from nonvolatile substances.
- Distillation used in Cutback asphalt
- Loss on heating: determine % of volatile material.
- 50 g in container put in oven @ 163 c for 5 hrs, then find loss in wt.

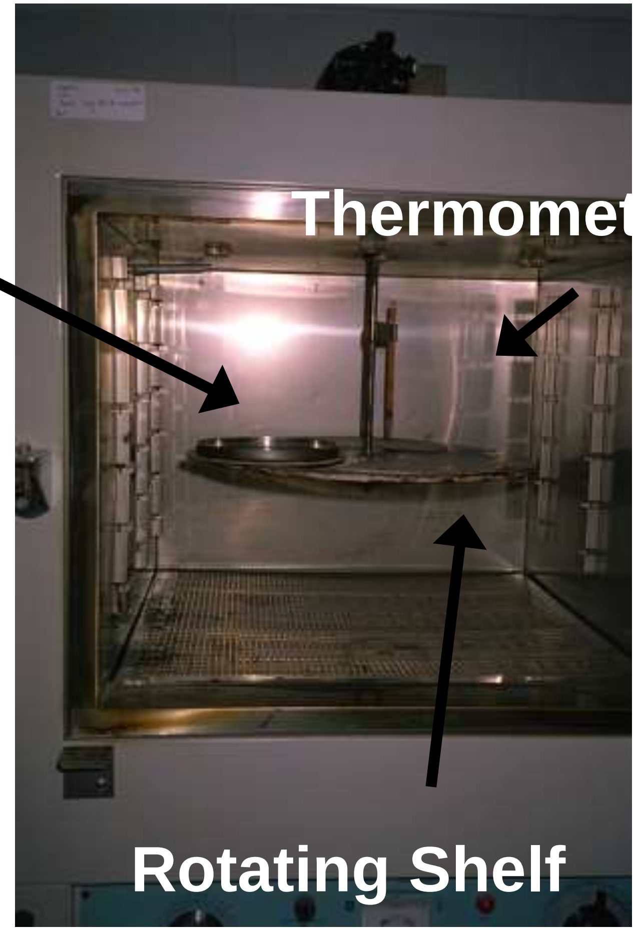
Volatility Tests/ Thin Film Oven Test

- Excessive high temp. during plant mixing will harden the mixture (i.e. age it) and reduce pavement life.
- In measuring hardening, penetration is conducted before & after aging.
- 50 cm3 poured in pan (bottle) for thin film thickness.
- Place in ventilated oven @163 c and rotated at specified rate for 5hrs.
- Penetration is found for aged samples.
- Calculate % penetration.

Thin Film Oven

Outside of Oven

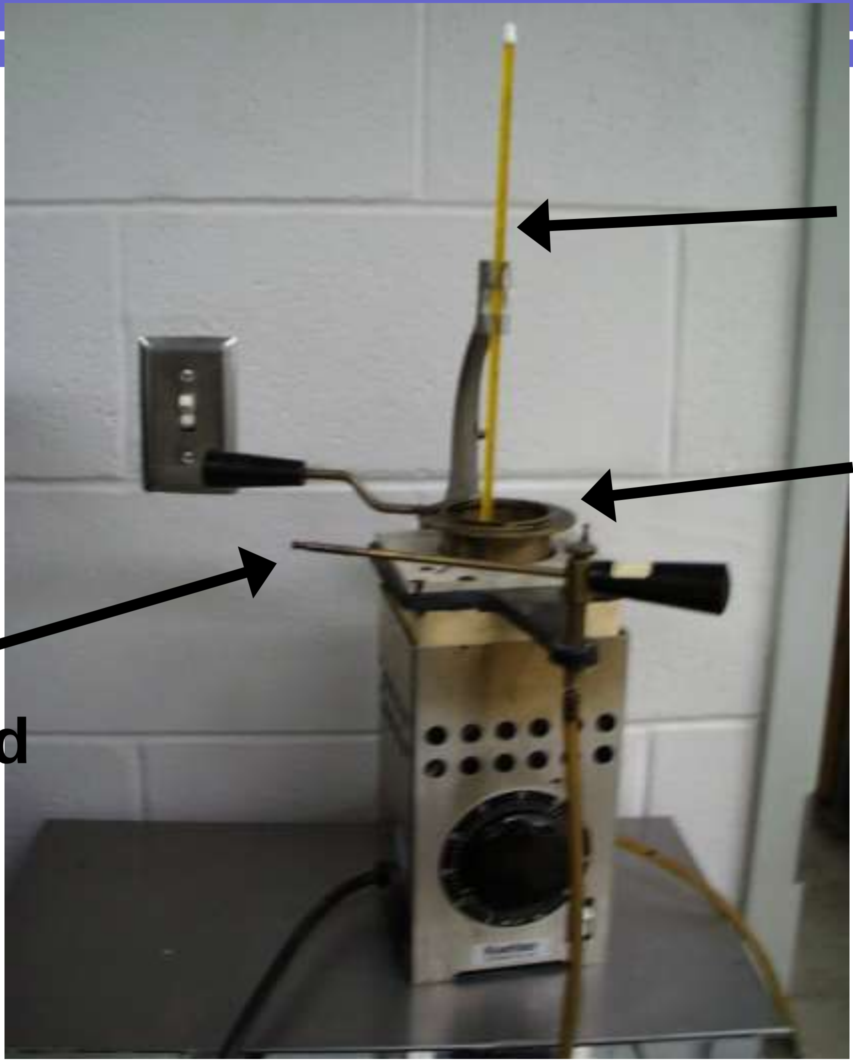
Pan



Volatility Tests / Flash Point

- Known as safety test.
- Cleveland Open cup.
- AC heated at specified rate.
- Flames pass across the surface.
- Min temp. at which sparks appear on the AC surface is reported as flash point.

Flash Point (Safety)



Thermometer

Cup filled with asphalt

Wand attached to gas line

Classification of Bituminous Materials

- See **Table 19.1** in Text for Asphalt grades.
- Viscosity Graded-Original:
  - AC-40, AC-20, AC-10, AC-5, AC-2.5.
- Viscosity Graded-Residual:
  - AR-16000, AR-8000, AR-4000, AR-2000, AR-1000.
- Penetration Grades:
  - AC-40-50, 60-70, 85-100, 120-150, 200-300.

- See Also Cutback and Emulsified Grades.

Specific gravity of Asphalt

- *Specific gravity* is defined as the ratio of the mass of the material at a given temperature to the mass of an equal volume of water at the same temperature.
- Specific gravity determinations are useful in:
  - Making temperature-volume corrections.
  - Determining the weight per unit volume of asphalt cement heated to its application temperature.

S.G. of Asphalt Cont.

- The pycnometer method is used to determine the specific gravity of asphalt cements.

Calculating S.G. of Asphalt

- Calculate the S.G. as indicated in the following equ:

S.G = (C-A) / [(B-A) – (D-C)]

where:

A = mass of pycnometer (plus stopper),

B = mass of pycnometer filled with water,

C = mass of pycnometer partially filled with asphal

D = mass of pycnometer plus asphalt plus water.

- Calculate density to the nearest 0.001 as follows:

Density = specific gravity * γ_w

- where, γ_w = density of water at the test temperature.
- At 25ºC, γ_w = 997.0 kg/m^3

Pavement Materials & Design (110401466) Aggregates

Source:

Chapter 15-8: Highway Engineering, by Paul Wright & Karen Dixon, 7th Edition, Wiley & sons

Chapter 3: Hot Mix Asphalt Materials, Mixture Design and Construction, by Robert, Kandhal, Brown, Lee, and Kennedy, 2nd Edition, NCAT

Instructor:

Dr. TALEB M. AL-ROUSAN

Highway Materials/ Aggregates

- Aggregates are granular mineral particles that are widely used for highway bases, subbases, and backfill.
- Aggregate are also used in combination with cementing materials (Portland cement and asphalt) to form concretes for bases, subbases, wearing surfaces, and drainage structures.

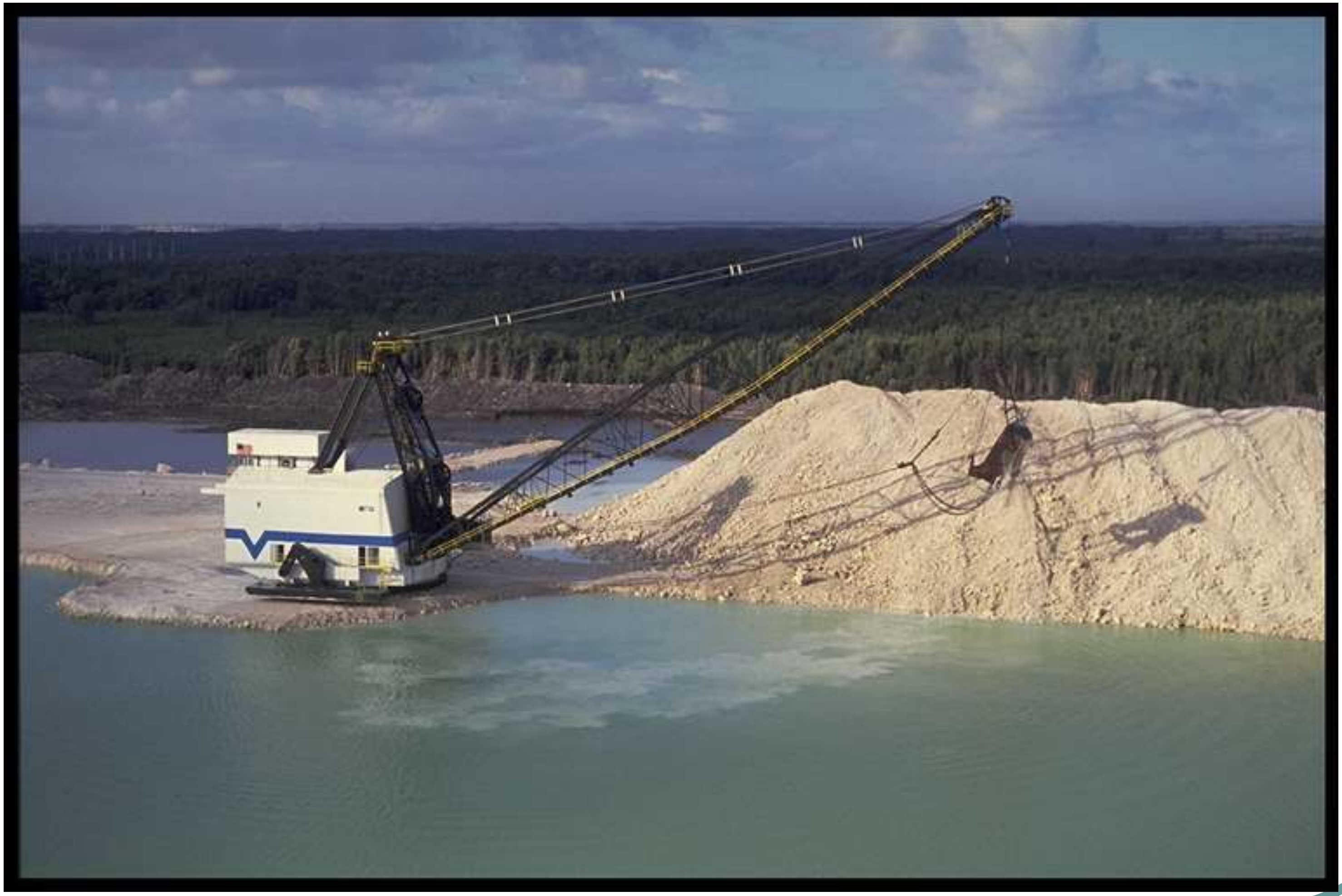
Aggregate Sources

- Natural deposits of sand and gravel.
- Pulverized concrete and asphalt pavements.
- Crushed stone
- Blast furnace slag

Aggregate processing

- Excavations
- Transportation
- Crushing
- Sizing
- Stockpiling

Excavation



Excavation


CAT


CAT
320 L
CAT
12 3 '00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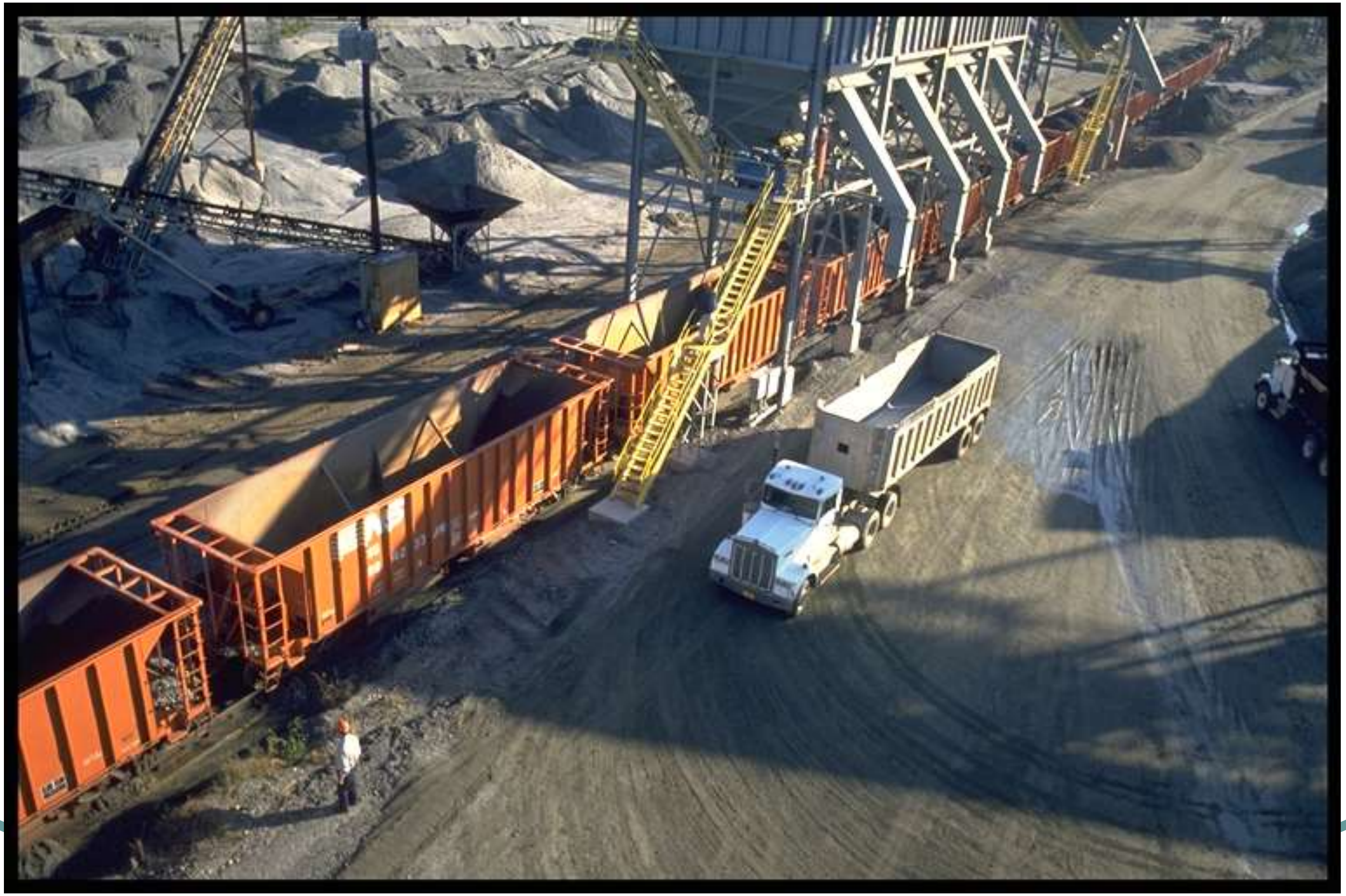
Crushing

Sizing

Stockpiling

Transportation

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'99 2 1

Properties of Aggregates

1. Particle size and gradation.
2. Hardness or resistance to wear.
3. Durability or resistance to weathering.
4. Specific gravity & absorption.
5. Chemical stability
6. Particle shape and surface texture.
7. Freedom from deleterious particles or substances.

Particle Size & Gradation

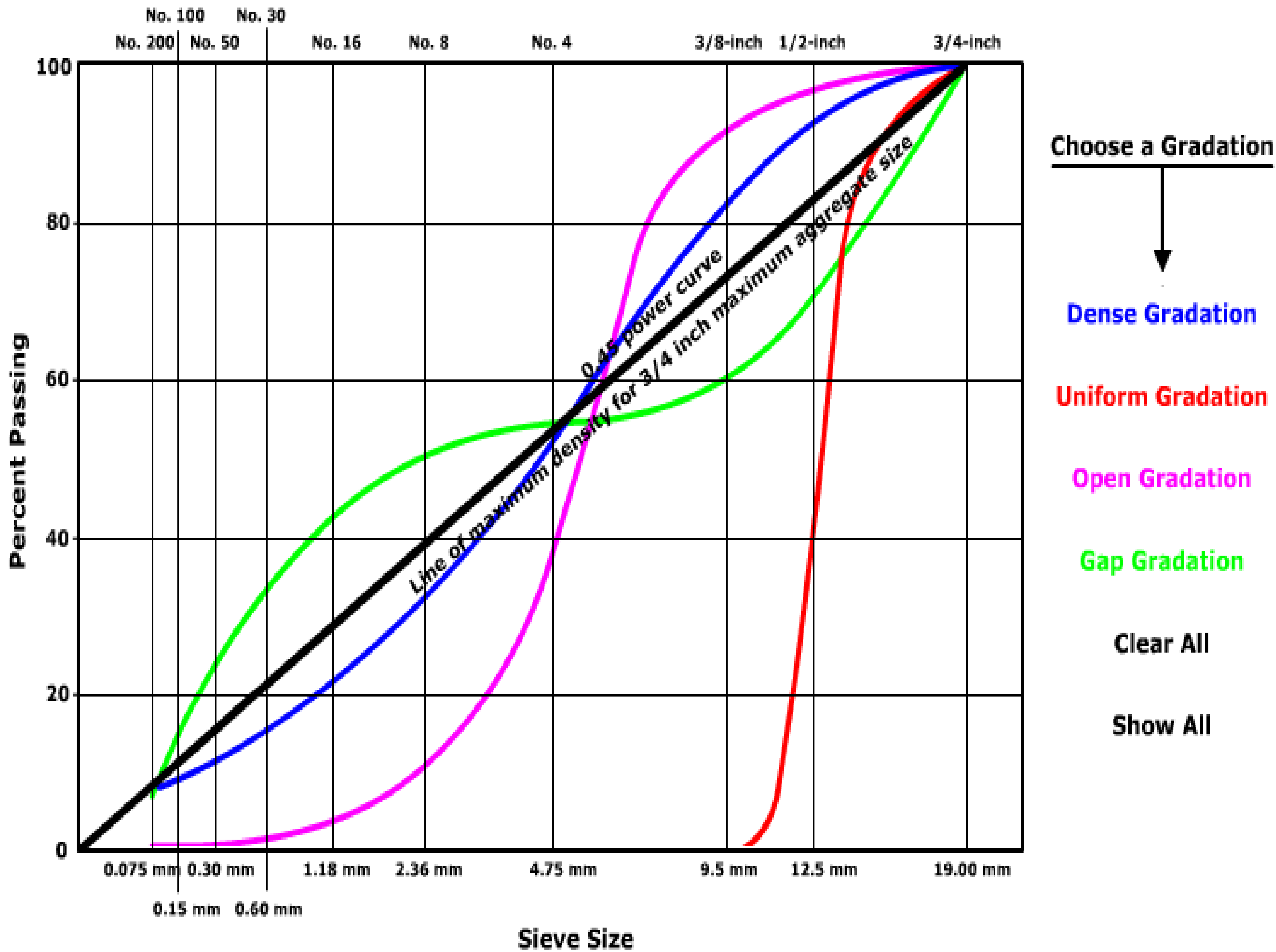
- Gradation: Blend of particle sizes in the mix.
- Gradation affects: Density; Strength; Economy of pavement structure.
- Particles are separated by sieve analysis.
- Sieve analysis: Determination of particle size distribution of fine and coarse aggregates by sieving, expressed as %.
- Grain size analysis data are plotted on aggregate gradation chart.
- Using the gradation chart engineer can determine a preferred aggregate gradation that meet spec..
- Coarse : Retain # 8 ……. Fine : pass # 8 Retain # 200 & fines : pass # 200

Mechanical Sieve

Mechanical Sieve

Typical Gradations

- *Dense or well-graded. Refers to a gradation that is near maximum density. The most common HMA mix designs in the U.S. tend to use dense graded aggregate.*
- *Gap graded. Refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range. The curve is flat in the mid-size range. These mixes can be prone to segregation during placement.*
- *Open graded. Refers to a gradation that contains only a small percentage of aggregate particles in the small range. This results in more air voids because there are not enough small particles to fill in the voids between the larger particles. The curve is flat and near-zero in the small-size range.*
- *Uniformly graded. Refers to a gradation that contains most of the particles in a very narrow size range. In essence, all the particles are the same size. The curve is steep and only occupies the narrow size range specified.*

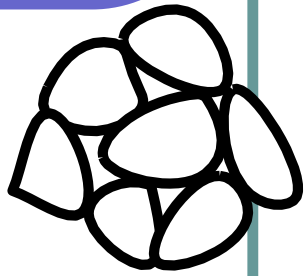


No. 100
No. 30
No. 200
No. 50
No. 16
No. 8
No. 4
3/8-inch
1/2-inch
3/4-inch
100
80
60
40
20
0
Percent Passing
0.45 power curve
Line of maximum density for 3/4 inch maximum aggregate size
0.075 mm
0.30 mm
1.18 mm
2.36 mm
4.75 mm
9.5 mm
12.5 mm
19.00 mm
0.15 mm
0.60 mm
Sieve Size
Choose a Gradation
Dense Gradation
Uniform Gradation
Open Gradation
Gap Gradation
Clear All
Show All

Types of Gradations

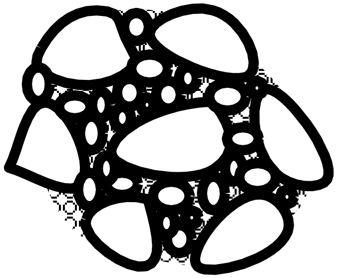
* Uniformly graded

- Few points of contact
- Poor interlock (shape dependent)
- High permeability



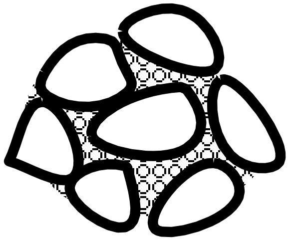
* Well graded

- Good interlock
- Low permeability



* Gap graded

- Only limited sizes
- Good interlock
- Low permeability



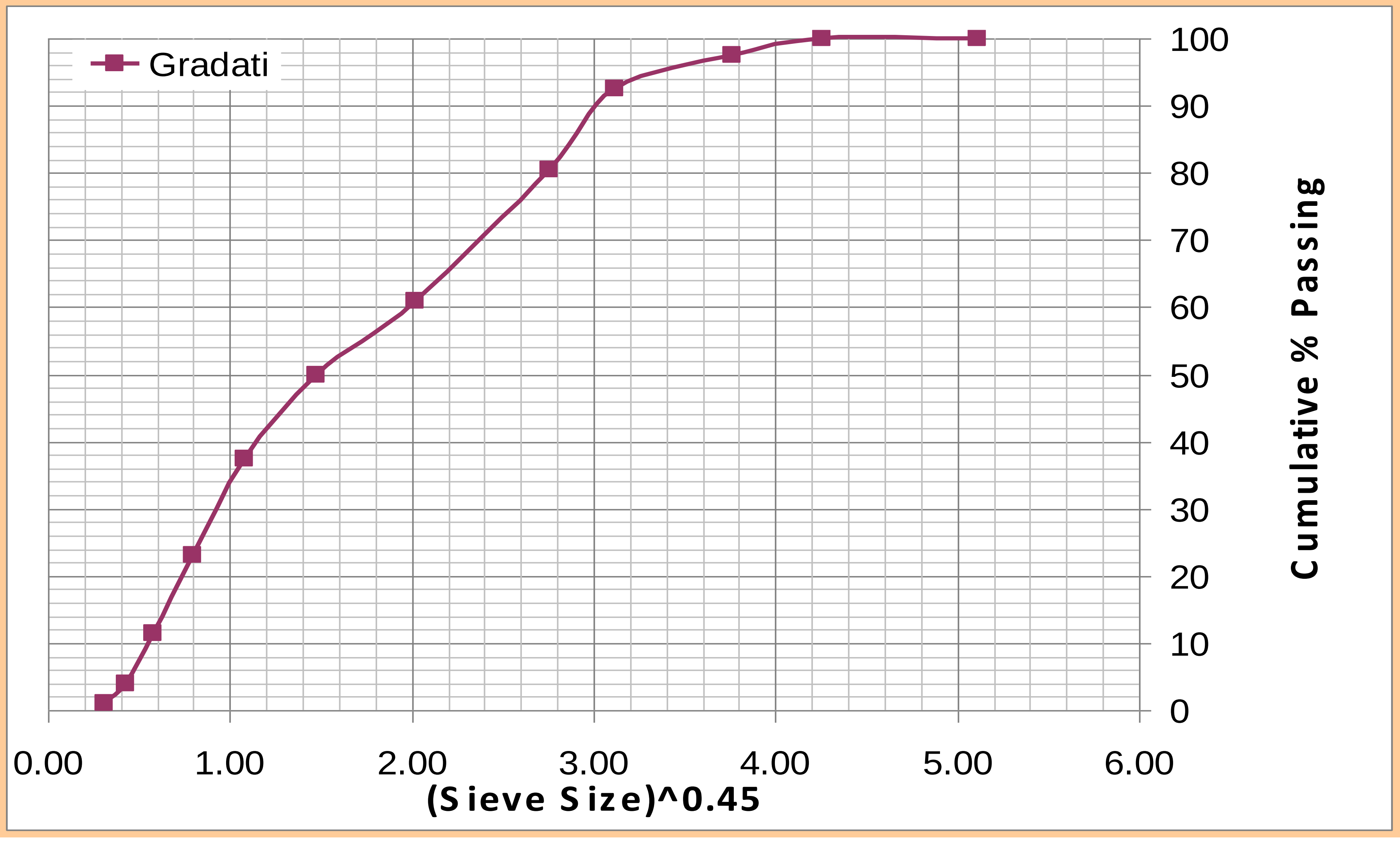
Sieve Analysis Example

Sieve No.	Sieve Size	Wt. Retained (g)	% Retained	Cumulative % Retained	Cum. % Passing
inch	mm		(wt. ret./ Total) 100%	Sum % Retained	100 - Cum. Ret.
1.5"	37.5	0	0	0	100
1"	25	0	0	0	100
3/4"	19	25	2.5	2.5	97.5
1/2"	12.5	50	5	7.5	92.5
3/8"	9.5	120	12	19.5	80.5
# 4	4.75	195	19.5	39	61
# 8	2.36	110	11	50	50
# 16	1.18	125	12.5	62.5	37.5
# 30	0.6	145	14.5	77	23
# 50	0.3	115	11.5	88.5	11.5
# 100	0.15	75	7.5	96	4
# 200	0.075	30	3	99	1
Pan	Pan	10	1	100	0
Total		1000	100		

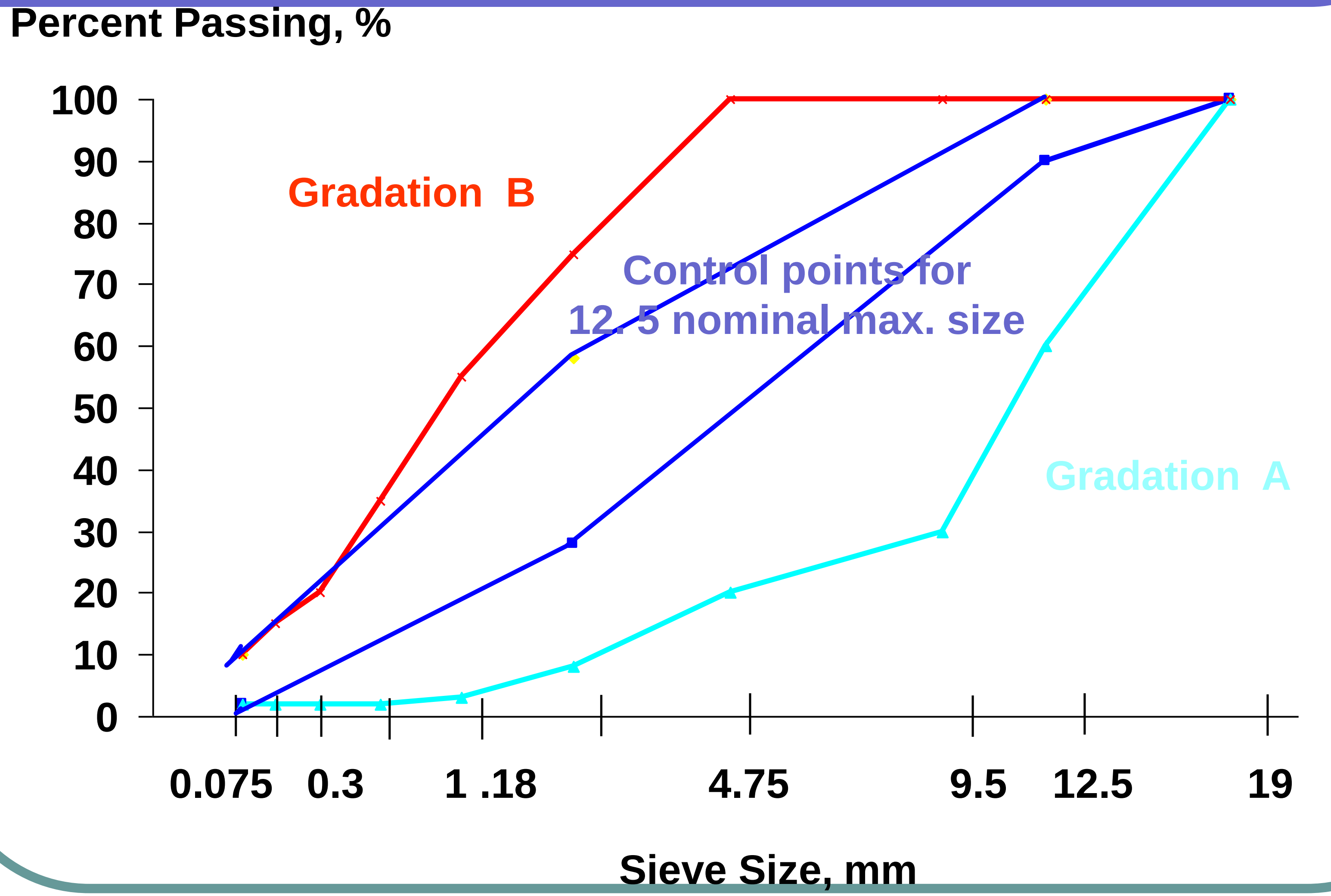
Gradation Chart Data

Sieve Size	Log (Sieve Size)	(Sieve Size)^0.45	Cum. % Passing
mm			100 - Cum. Ret.
37.5	1.57	5.11	100
25	1.40	4.26	100
19	1.28	3.76	97.5
12.5	1.10	3.12	92.5
9.5	0.98	2.75	80.5
4.75	0.68	2.02	61
2.36	0.37	1.47	50
1.18	0.07	1.08	37.5
0.6	-0.22	0.79	23
0.3	-0.52	0.58	11.5
0.15	-0.82	0.43	4
0.075	-1.12	0.31	1
Pan			0

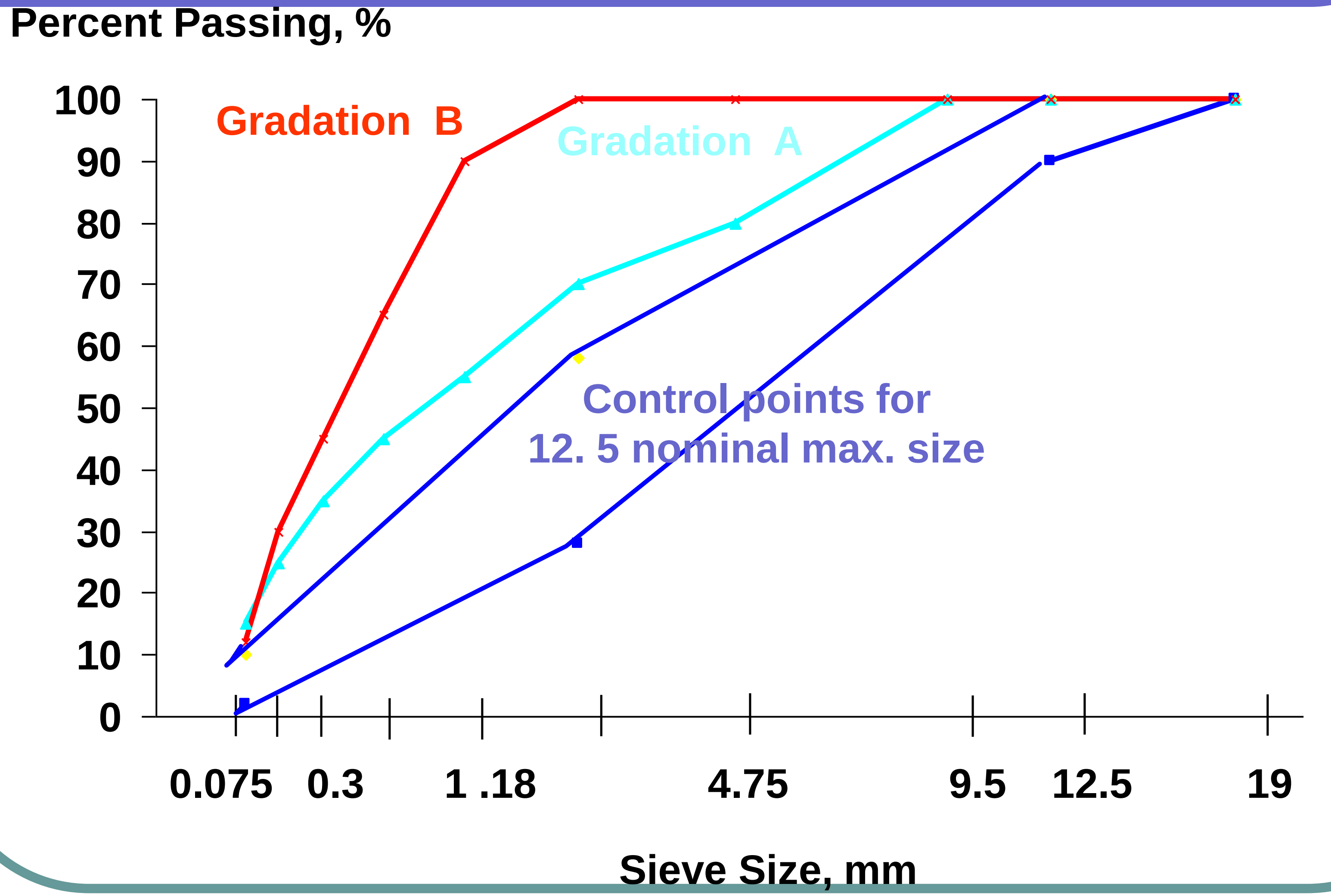
Gradation Chart



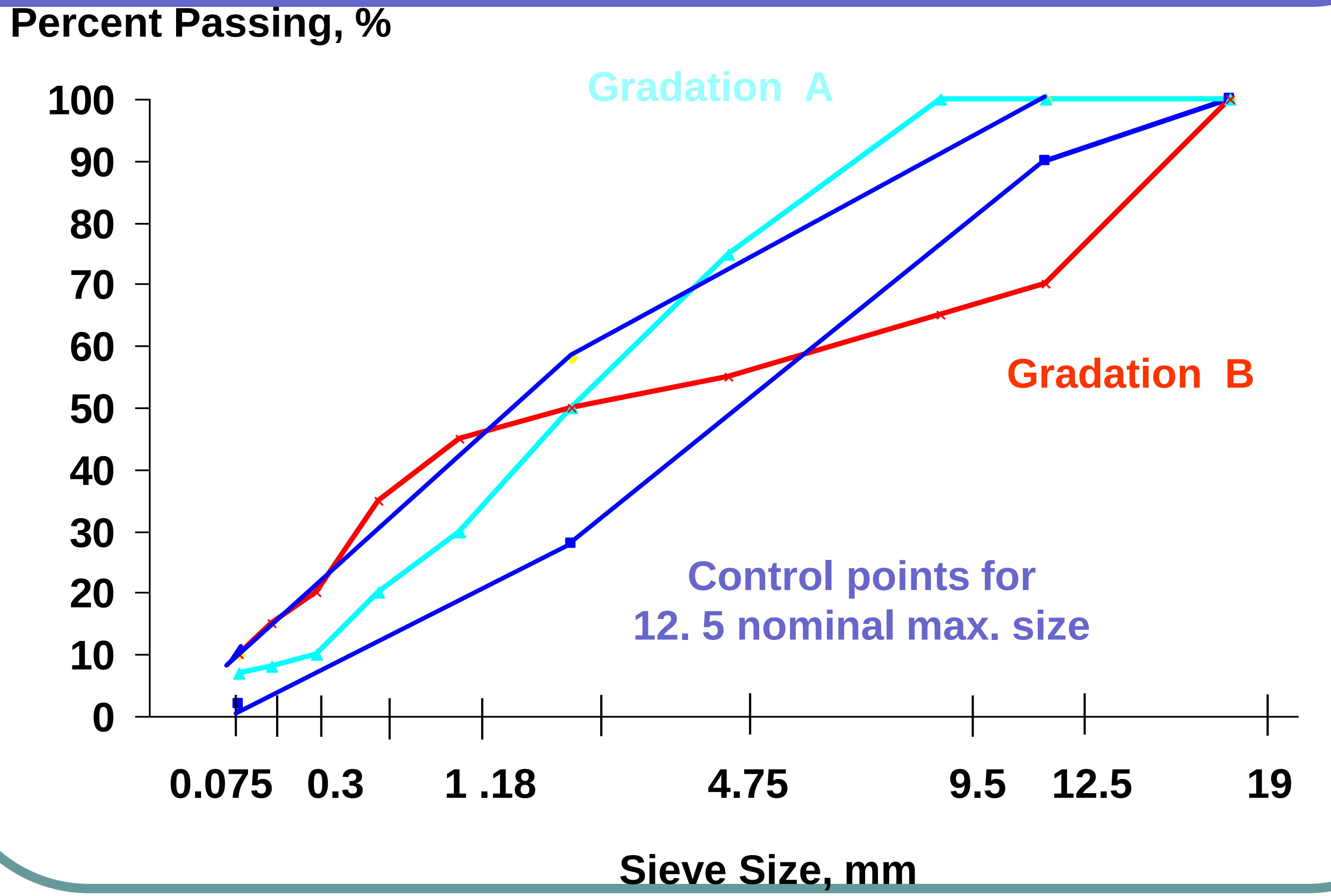
All possible combinations fall between A and B



No poss. combination of A and B will meet spec.



All poss. combinations pass through cross-over point Blends containing more A than B will be closer to A



Resistance to Wear

- Material should be hard & resist wear due to:

1. The loading from compaction equipments.
2. The polishing effect of traffic.
3. Internal abrasive effects of repeated loading.

- Measure used for hardness of aggregate is Los Angelos (LA) abrasion test.

L A Abrasion Test

- Insert aggregate sample in a drum that rotates 30 – 33 rpm for 500 revolutions with steel spheres inside as an abrasive charge.
- Sample removed & sieved @ #12 sieve.
- Retained material are washed and dried.
- Difference between original mass and final mass expressed as percentage of original mass is reported as %wear.

- %wear = [(Original – Final)/ Original] 100%

LA Abrasion Test

- Approx. 10% loss for extremely hard igneous rocks
- Approx. 60% loss for soft limestones and sandstones

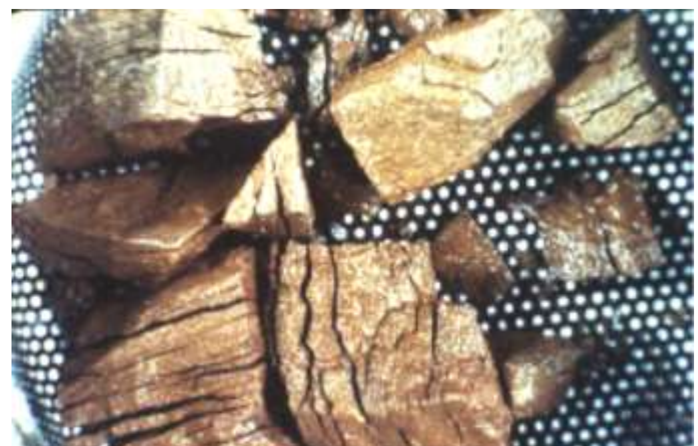
Durability & Resistance to Weathering (Soundness Test)

- Soundness Test AASHTO T104, ASTM C88
- Measures the resistance of aggregate to disintegration in a saturated solution of sodium or magnesium sulfate (Na_2SO_4, $MgSO_4$).
- It simulates the weathering of aggregates that occur in nature.
- It measures resistance to breakdown due to crystal growth.
- specify max % loss after X cycles
  - typical 10-20% after 5 cycles

Soundness Test

Before

After



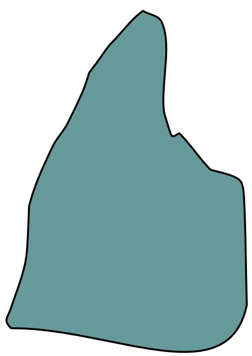
Specific Gravity & Absorption

- Required for the design of concrete & bituminous mixes.
- S.G. : Ratio of the solid mass to that of an equal volume of distilled water at a specific temperature.
- Due to permeable voids in aggregates, three types of S. G. are defined
  - apparent (G_{sa})
  - bulk (oven-dry) (G_{sb})
  - effective (G_{se})
- Gsb < Gse< Gsa

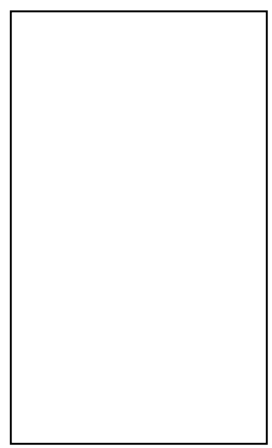
S.G. Cont.

Coarse Aggregate W_s or W_{ssd} W_{sub}

Fine Aggregate

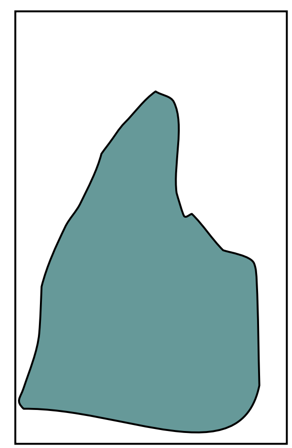


OD (W_s) or SSD (W_{ssd}) aggregate



Container filled with H_2O

W_{pyc+w1}

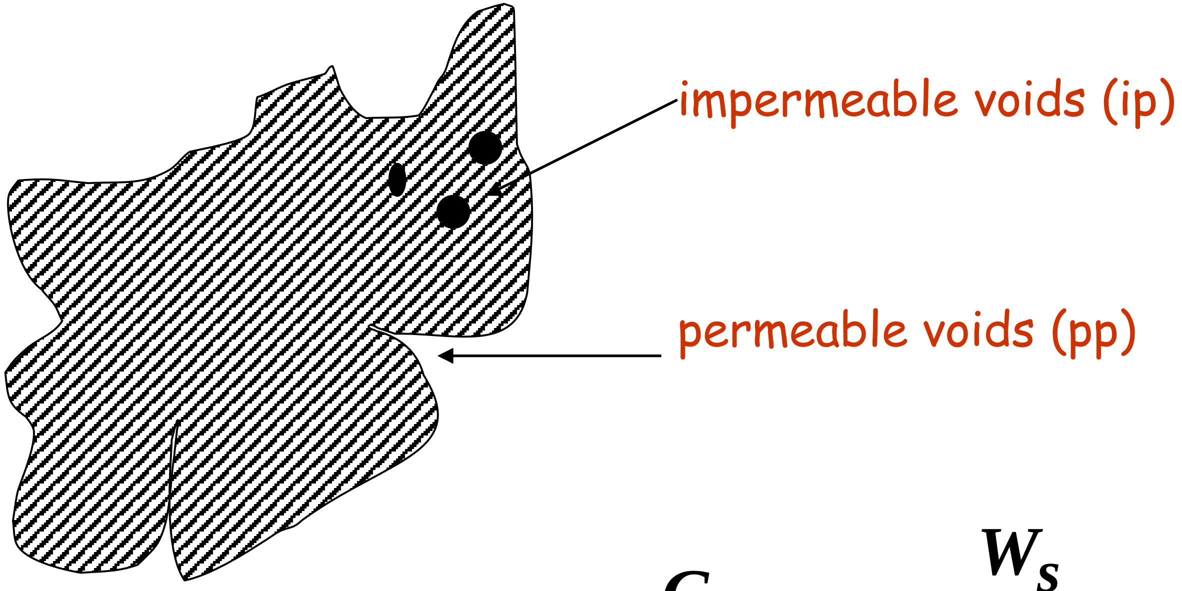


Container + agg + H_2O

$W_{pyc+agg+w2}$

Apparent Specific Gravity (G_{sa})

Computed based on net volume of the aggregates

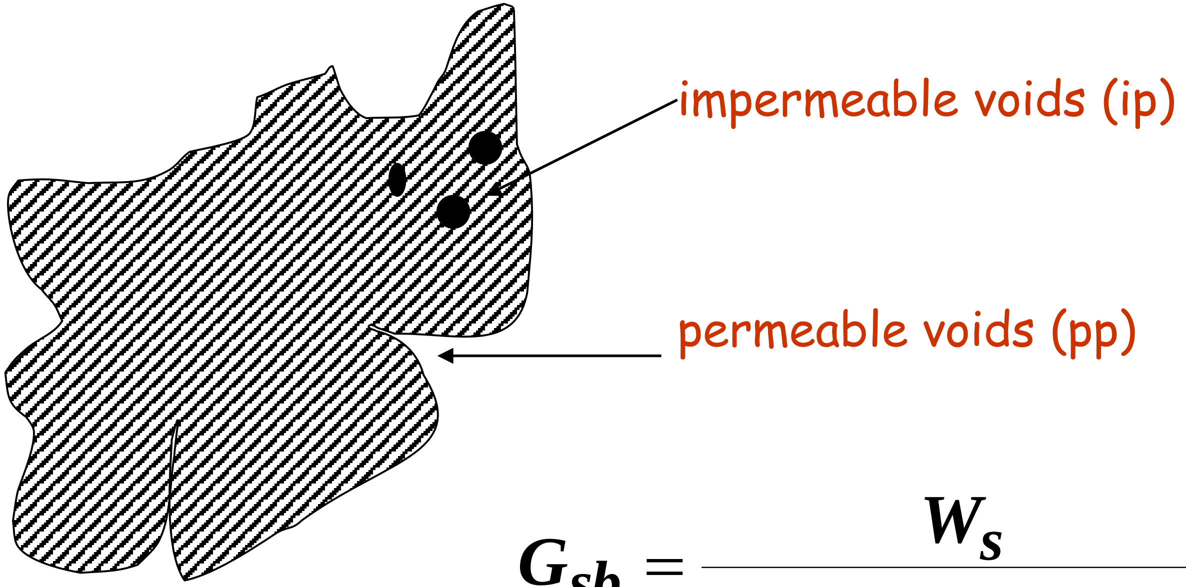


$$G_{sa} = \frac{W_s}{(V_s + V_{ip})\gamma_w}$$

$$G_{sa} = \frac{W_s}{W_s - W_{sub}} = \frac{W_s}{W_{pyc+w1} + W_s - W_{pyc+agg+w2}}$$

Bulk Specific Gravity (G_{sb})

Computed based on total volume of the aggregates



$$G_{sb} = \frac{W_s}{(V_s + V_{ip} + V_{pp})\gamma_w}$$

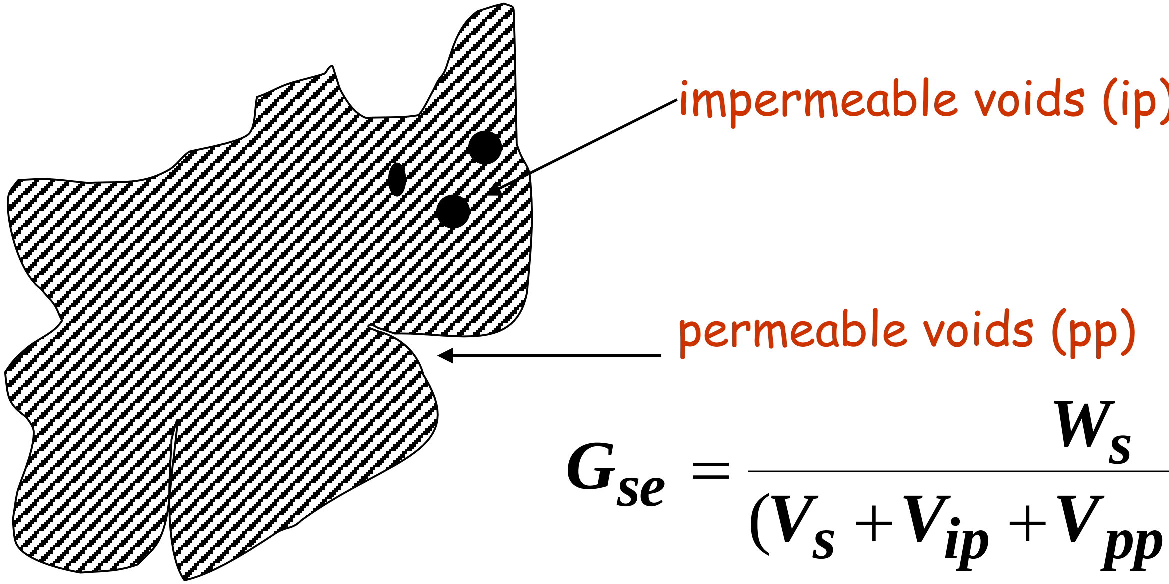
$$G_{sb} = \frac{W_s}{W_{ssd} - W_{sub}} = \frac{W_s}{W_{pyc+w1} + W_{ssd} - W_{pyc+agg+w2}}$$

Effective Specific Gravity (G_{se})

- Aggregate absorb some asphalt cement (ac).
- G_{sa} assumes all PP absorb ac ($V_{ap} = V_{pp}$)
- G_{sb} assumes no PP absorb ac ($V_{ap} = 0$)

- Neither is correct - G_{se} defined based on overall volume <u>exclusive</u> of those that absorb ac

Effective Specific Gravity (G_{se}), Cont.



$$G_{se} = \frac{W_s}{(V_s + V_{ip} + V_{pp} - V_{ap})\gamma_w}$$

Calculated from mixture information

$$G_{se} = \frac{100 - P_b}{\dfrac{100}{G_{mm}} - \dfrac{P_b}{G_b}} \text{ for } P_b = \text{by wt mix}$$

Chemical Stability

- Aggregate surface chemistry affects bonding to cement.
- Aggregates that have affinity to water are not desirable in the asphalt mixes.
- Stripping

- Hydrophobic Agg.: Water-hating such as limestone and dolomites have a positive surface charge. Work well in asphalt concrete (show little or no strength reduction)

- Hydrauphilic Agg.: Water-loving such as gravels and silicates (acidic) have a negative surface charge (show reduce strength).
- Gravels may tend to create a weaker interfacial zone in concrete than lime-stone aggregates.

- Surface coating (dust of clay, silt, gypsum) tend to reduce bond strength.
- Immersion stripping test

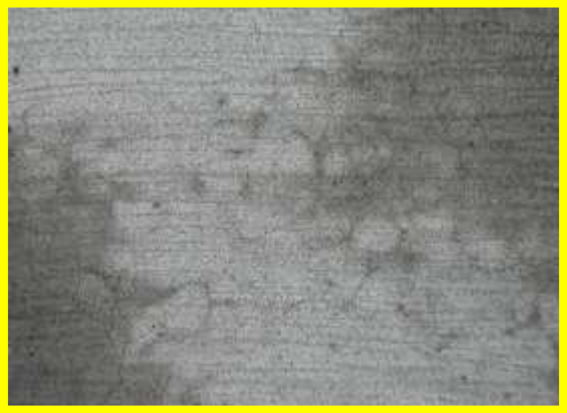
Chemical Stability Cont.

- Aggregates used in Portland cement concrete can also cause chemical stability problems.
- Aggregates containing deleterious substances (clay lumbs, chert, silt, organic impurities) which react harmfully with the alkalis present in the cement.
- Alkali Silicate Reaction (ASR) results in abnormal expansion of the concrete.

ASR

- Needs three factors:
  - Source of alkali - Internal and external
  - Reactive silica (aggregate)
  - Water (humidity) > 80 %
- ASR results in formation of expansive gels which produce internal stresses which may cause cracking of concrete.
- Environmental factors such as freeze-thaw cycles, wetting/drying cycles, and traffic loading propagate cracking.
- Deicing salts, marine environments, can accelerate ASR expansion and deterioration processes. ASR can accelerate corrosion deterioration

ASR Cont.



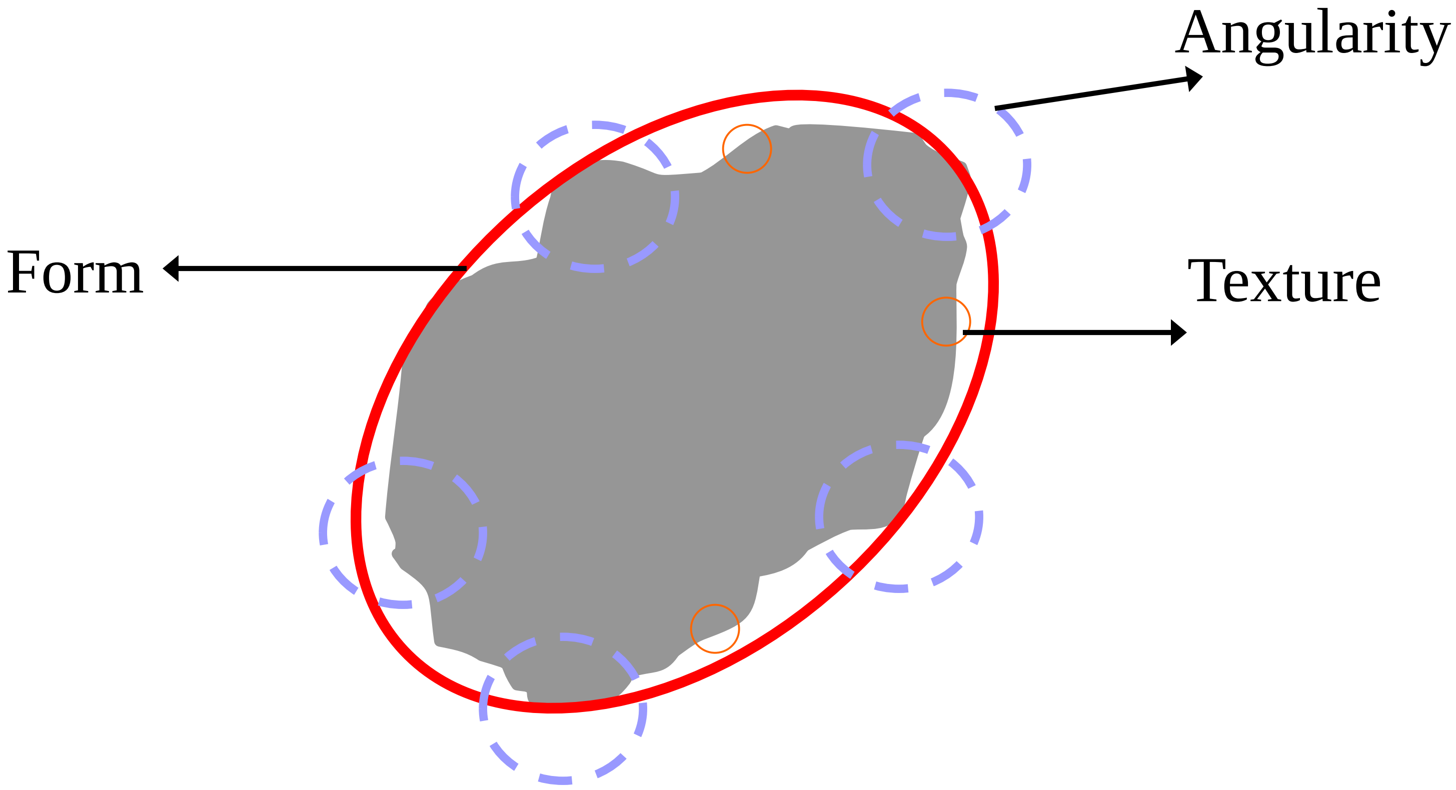
Aggregate Shape & Surface Texture

- Results from Processing
- Shape: rounded, sub-rounded, flat, elongated.
- Angularity: sub-angular, angular
- surface texture: very rough, rough, smooth, polished

Shape Classification

- Particles shape and surface texture are of great importance to the properties of fresh & hardened concretes.
- Form, the first-order property, reflects variations in the proportions of a particle.
- Angularity, the second-order property, reflects variations at the corners, that is, variations superimposed on shape.
- Surface texture is used to describe the surface irregularity at a scale that is too small to affect the overall shape.

Illustration of Aggregate Shape Properties



UNCOPMACTED VOID CONTENT OF FINE AGGREGATES AASHTO T304

UNCOPMACTED VOID CONTENT OF COARSE AGGREGATES AASHTO TP 56

Void Content

Voids ratio =

1- (bulk density/(S.G x U.Wt. water))

AASHTO TP56 Uncompacted Void Content of Coarse Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)

- This method was originally developed by the NAA and was later adopted by AASHTO as method TP56.
- It measures the loose uncompacted void content of a sample of coarse aggregate that falls from a fixed distance through a given-sized orifice.
- A decrease in the void content is associated with more rounded, spherical, smooth-surface coarse aggregate, or a combination of these factors.

% OF FRACTURED PARTICLES IN COARSE AGGREGATES ASTM D5821

- *ASTM D5821 Determining the Percentages of Fractured Particles in Coarse Aggregate*

- This test method is considered to be a direct method for measuring coarse aggregate angularity.

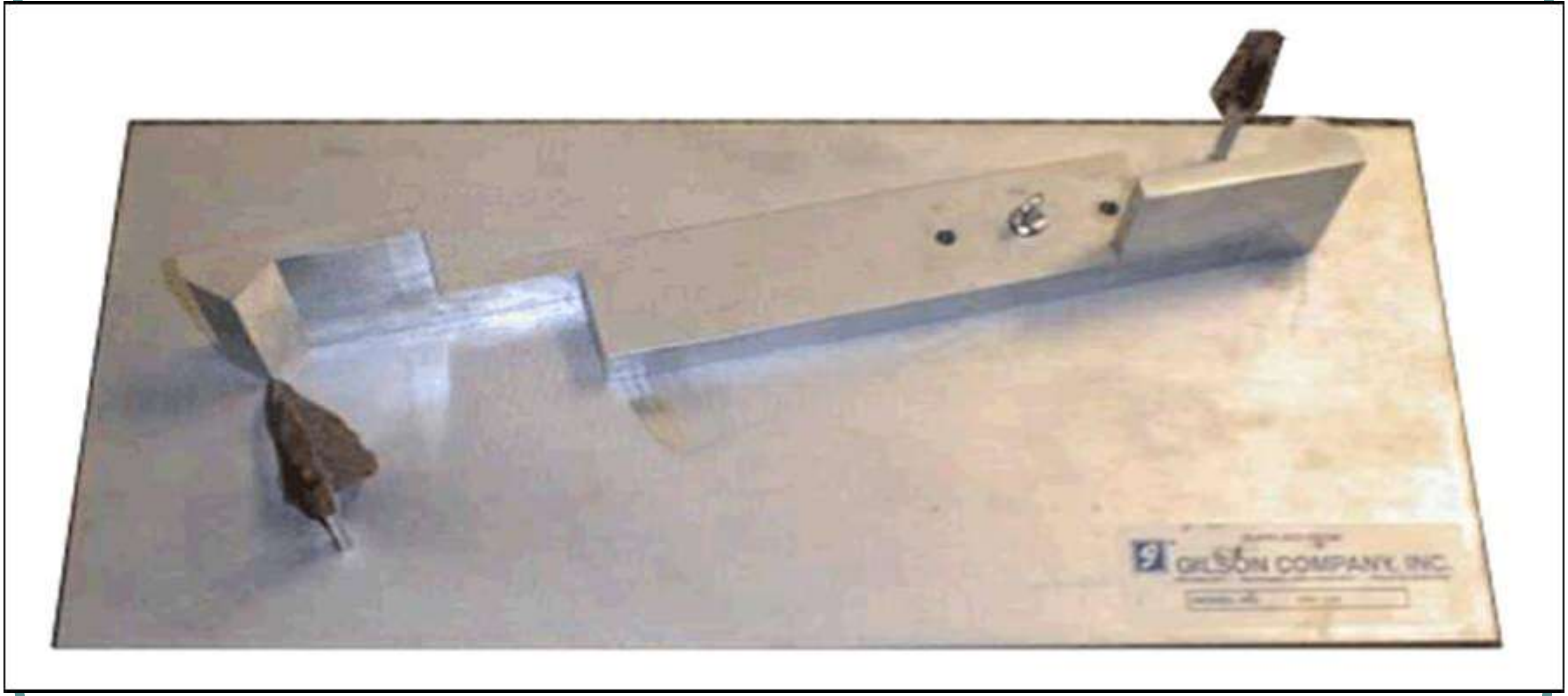
- The method is based on evaluating the angularity of an aggregate sample (mostly used for gravel) by visually examining each particle and counting the number of crushed faces,

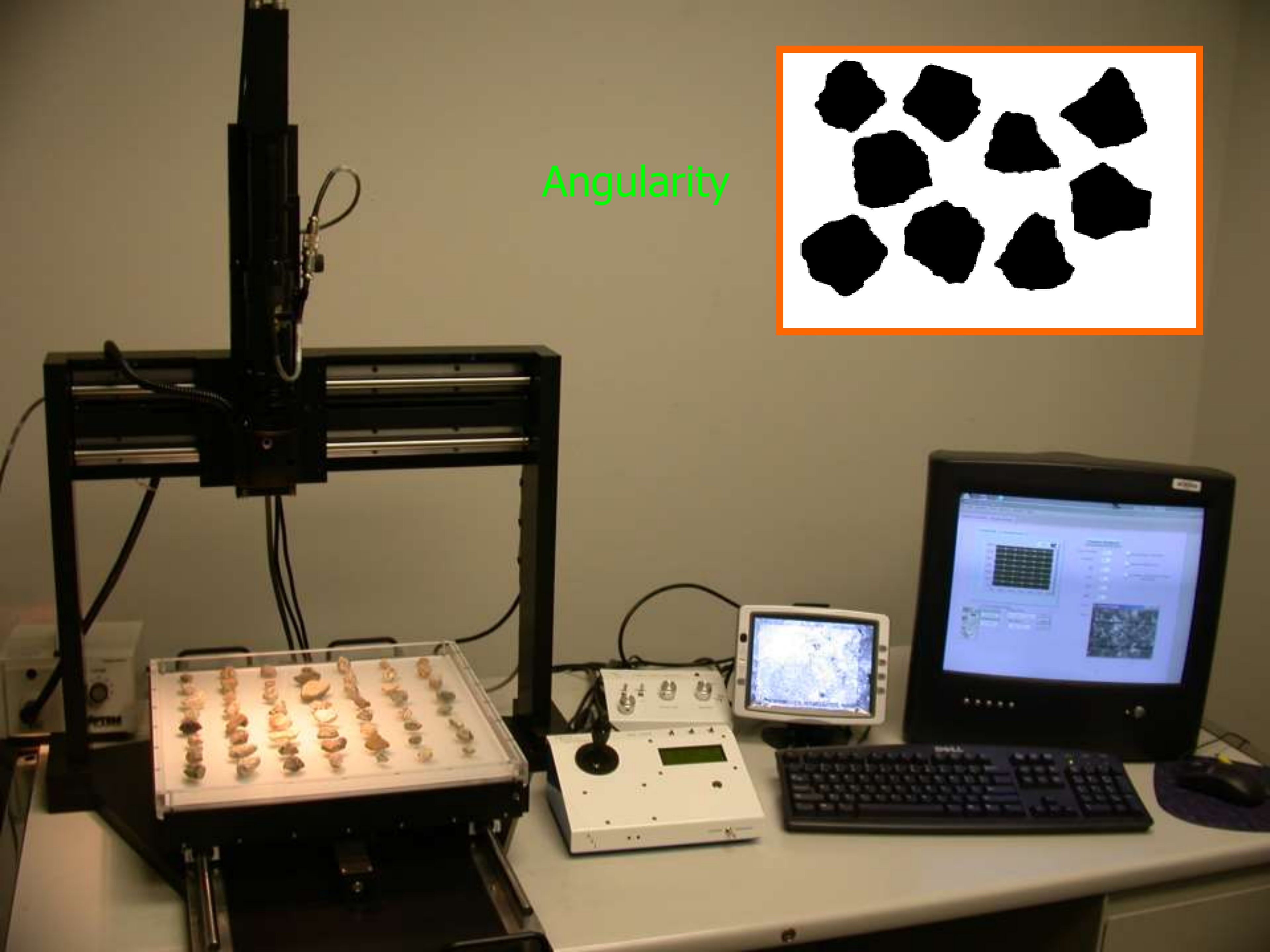
% OF FRACTURED PARTICLES IN COARSE AGGREGATES ASTM D5821

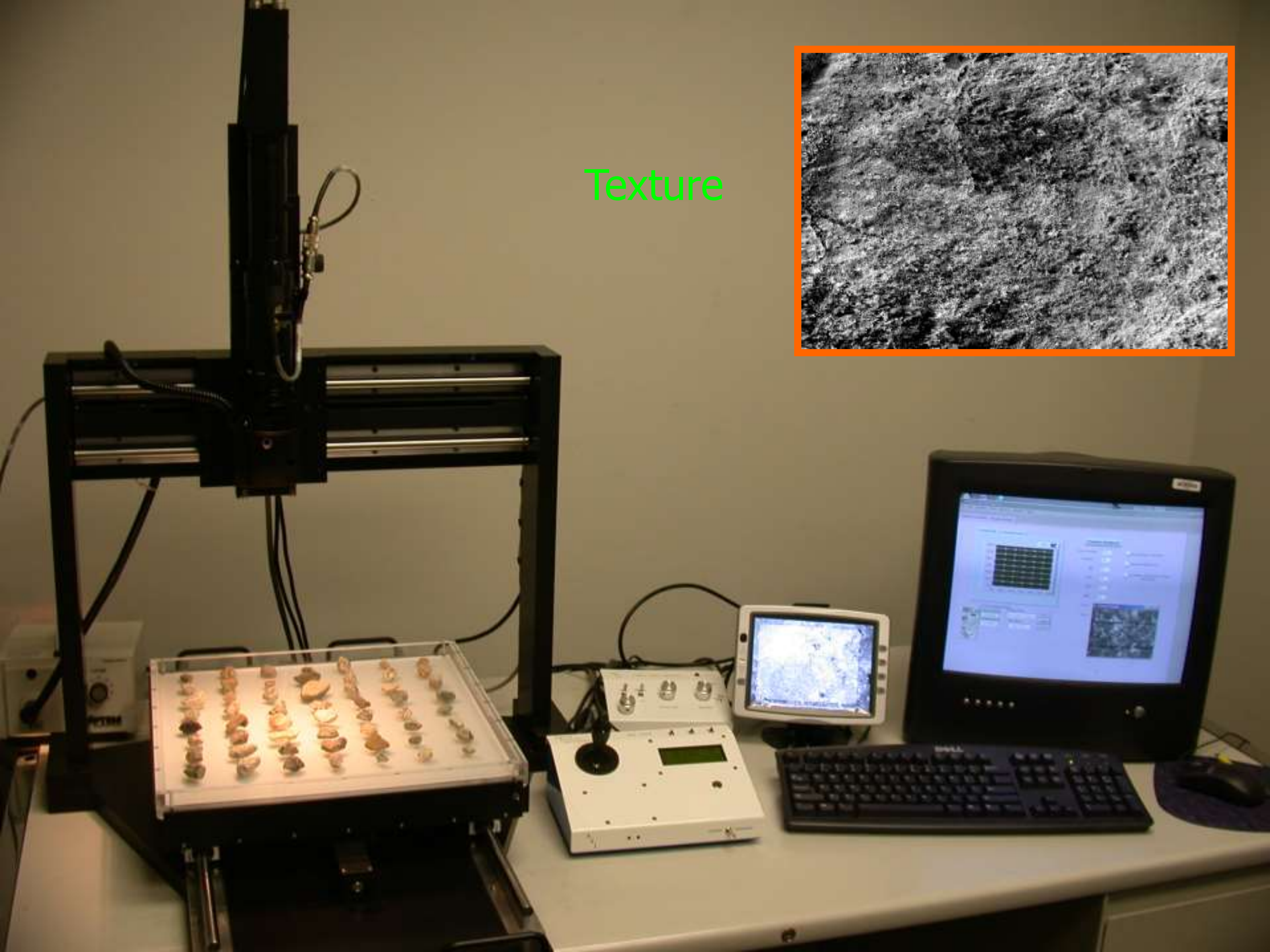
Form of Aggregates

- *ASTM D4791 Flat and Elongated Coarse Aggregates*
- This method provides the percentage by number or weight of flat, elongated, or both flat and elongated particles in a given sample of coarse aggregate.
- The procedure uses a proportional caliper device to measure the dimensional ratio of aggregates.
- The aggregates are classified according to the undesirable ratios of width to thickness or length to width, respectively.

Flat and Elongated Coarse Aggregate Caliper




Angularity

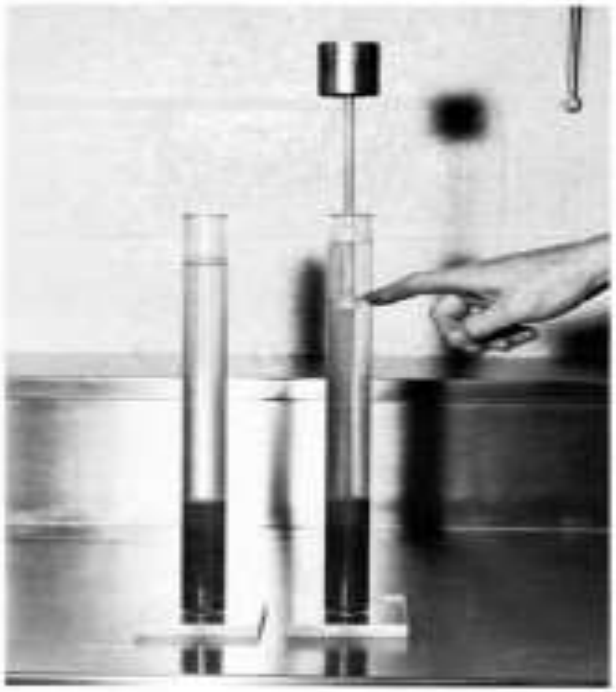

Texture

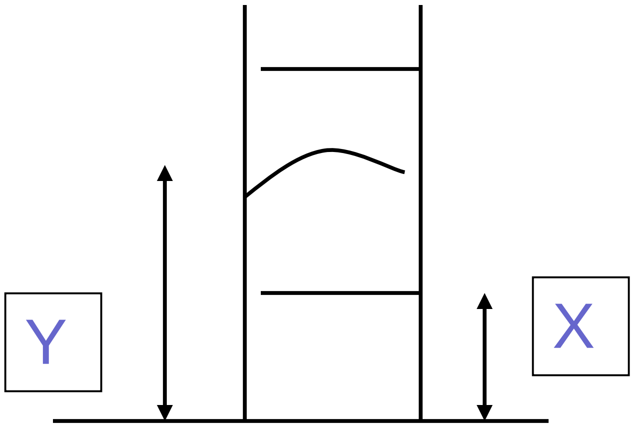
Disintegration/ Cleanliness

- Clay Lumbs & Friable Particle (ASTM C142, AASHTO T112).
- Specify max (typical 0.2 - 10%).
- Dries a given mass of agg., then soaks for 24, hr., and each particle is rubbed. A washed sieve is then performed over several screens, the aggregate dried, and the percent loss is reported as the % clay or friable particles.

Cleanliness of Aggregates/ SE

- sand equivalent (ASTM D2419)
  - SE = X/Y *100
  - specify min





Things to Remember

Aggregates should be clean, tough, durable, and free from :excess flat and elongated particles, dust, clay lumbs, and any other objectionable materials.

Pavement Materials & Design (110401466)
Soil

Text Book:

Traffic & Highway Engineering Nicholas Garber and Lester Hoel, Third Edition, Brooks/Cole.

Instructor:

Dr. TALEB M. AL-ROUSAN

Soil

- It has a broad definition.
- All earth materials (organic & inorganic) that blankets the rock crust of the earth.
- Soils are products of disintegration of the rocks of earth crust.
- Disintegration: Weathering caused by mechanical and chemical forces.
- Mechanical weathering = wind + running water+ freezing and thawing.
- Chemical weathering = decomposition due to oxidation + carbonation + other chemical actions).

Soil Types by Formation

- Two types = Residual + Transported
- **Residual soils**: Weathered in place and lies directly above the parent material.
- **Transported soils**: Those that have been moved by water, wind, glaciers, and are located far from their parent materials
  - Aeolin soils: Formed by action of wind (Also called wind blown) and typical fine grained (loes).
  - Glacial soils: Deposit of lightly bonded materials.
  - Sedimentary soils: formed by the action of water (setting of soil particles from a suspension existing in a river, lake, or ocean) range from beach or river sand to marine clay.

Soils Types/ Amount of Organic Materials

- Organic soils:
  - Large amount of organic matter.
  - Dark brown to black color and distinctive odor.
- Inorganic soils:
  - Mineral portion predominates

Soil Heterogeneity

- Soils are known for their normal lack of homogeneity.
- This is due to the random process of their formation (vary greatly in their physical and chemical composition) at different locations over the surface of the earth.

Soil Types / Surface Texture

- Texture of soil can be described by its appearance which depends on the size and shape of the soil particles and their distribution in the soil mass.
- Fine-textured soils:
  - Particle sizes < 0.05 mm
  - Silt & clay (particle are invisible with naked eye).
  - Water presence reduces its strength
- Coarse-textured soils:
  - Particle sizes > 0.05 mm (particles are visible with naked eye).
  - Sand & gravel
  - Water presence doesn’t affect its strength.

Soil Types / Surface Texture

- Distribution of particle sizes can be found using:
  - Sieve analysis for coarse-textured
  - Hydrometer test for fine-textured
- Soil Particles shape
  - Round, angular, and flat which are indication of strength
  - Round Coarse textured are generally strong due to extensive wear that it has been subjected to.
  - Fine-textured soils have generally Flat and flaky particle which are generally weak.
  - Angular particles are more resistance to deformation as they tend to lock together while round particle will roll over each other.

General Soil Types by Grain Size

I. Sand & Gravel

- (80 mm gravel to 0.08 mm fine sand).
- Can be identified visually.
- Have little or no cohesion.
- High permeability.
- Low shrinkage & expansion with change in moisture.
- Give stability under wheel load when confined.
- Gravel : used to name natural rounded river bank aggregates.
- Crushed gravel or crushed stone: term applied to products of crushing larger rocks into gravel sizes.

General Soil Types by Grain Size

II. Silt

- Fine grained (intermediate in size between sand & clay).
- Low-medium plasticity.
- Has little cohesion.
- Considerable shrinkage and absorption.
- Variable stability under wheel loads.
- If contains high % of flakes, silt is likely to be highly compressible and elastic.

General Soil Types by Grain Size

III. Clay

- Very fine grained (0.002 mm or finer).
- Medium- High plasticity.
- Extreme changes in volume with moisture changes.
- Considerable strength when dry.
- Impervious to the flow of water

More Soil Types

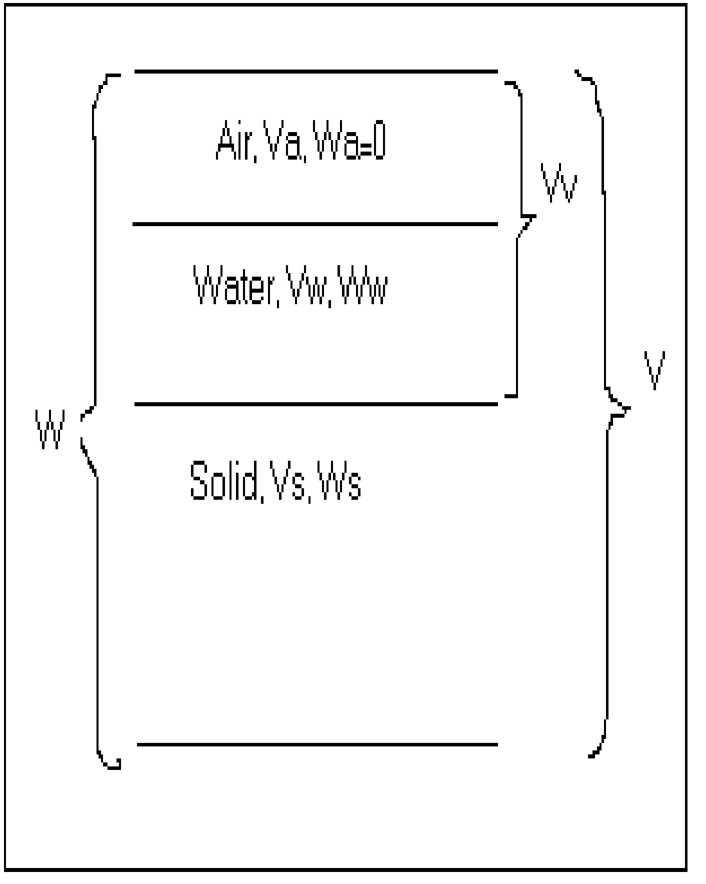
- Loam: Agricultural term used for well-graded soil that is productive for plant life (Sandy, silty, or clayey loam depending on predominant size).
- Loes: Fine-grained Aeolin soils, uniform size, predominantly silt, low density.
- Muck: Soft silt or clay, high organic content, swampy areas and lake bottoms.
- Peat: Soil composed of partially decomposed vegetable matter. Has high water content, woody nature, high compressibility, undesirable foundation material

Basic Engineering Properties of Soil

- Highway engineers must be familiar with those basic engineering properties of soils that influence their behavior when subjected to external loads.
- The determination of how soil will behave when subjected to external forces is complicated because soil have heterogeneous properties.
- Due to the heterogeneous character, it is recommended that the properties of any given soil depend not only on its general type but also on its condition at the time when it's being examined.

Basic Engineering Properties of Soil Cont.

- Phase relation:
  - Soil mass consist of :
    - solid particles + void spaces (filled with air or/and water).
    - Soils are three-phase system = solid + water + air.
    - Different minerals with spaces between them
- *See Figure 18.2 in text for schematic of three-phases of a soil mass.*



Basic Soil Properties Cont.

- **Porosity**
  - the ratio of the volume of voids to the total volume of soil.
    - **n = [Vv / V]**
- **Void Ratio**
  - The ratio of the volume of voids to the volume of solids.
    - **e = [Vv / Vs]**
  - *Note that :*
  - **n = [e / (1 + e)]**
  - **e = [n / (1- n)]**

Basic Soil Properties Cont.

Moisture Content

- Weight of water contained in a given soil mass compared with the oven dried weight of the soil, expressed as percentage.

$$\omega(\%) = [(\text{Wet wt.} - \text{Dry wt.}) / \text{Dry wt.}]\ 100\%$$

$$\omega = [W_w / W_s] \times 100\%$$

- In Lab: Representative sample….get wet wt.......oven dry sample…. Get dry wt.

Degree of Saturation

- The percentage of void spaces occupied by water.

$$S = [V_w / V_v] \times 100\%$$

- When void spaces are completely filled with water, the soil is said to be saturated (i.e. S = 100%)

Basic Soil Properties Cont.

Specific Gravity:

- Ratio of the weight of a unit volume of the material to the weight of an equal volume of water at approximately 23°C (73.4°F)
- Refer to ratio of the unit wt. of soil particles to the unit wt. of water at some known temp.
- It ranges numerically between 2.6 & 2.8.
- Determined by pycnometer method.

Basic Soil Properties Cont.

Unit Weight (Density)

- Weight of the soil mass per unit volume, expressed in lb/ft^3 (Kg/ m^3).
- Three densities are commonly used: Bulk density (γ), Dry density (γd), and submerged or buoyant density (γ'),.
- **Bulk density γ = [W/V] = [(Ws + Ww) / (Vs + Vw + Va)]**
- **Dry Density (γd) = [Ws/V] = [(Ws) / (Vs + Vw + Va)]**
- **Dry unit wt. = Wet unit wt. / [(100 + *ω* %)/ 100] = [γ / (1+*ω*)]**
- **Submerged density (γ') = γ sat - γ water**
- Saturated organic soils 1440 kg/m^3
- Well compacted soils 2240 kg/ m^3

Basic Soil Properties Cont.

Shear Resistance

- Failure that occur in soil masses due to high loads are principally shear failures.
- Shear forces existing in soils are attributed to Internal Friction & Cohesion

$$Sr = \sigma \tan \Phi + C$$

Sr : Shear resistance (evaluated in Lab by Unconfined compression test, Direct shear, Triaxial compression, Plate bearing or cone penetration test (in field)).

σ : Normal forces

Φ : Angle of internal friction

C : Cohesion

Basic Soil Properties Cont.

Shear Resistance Examples

1. Cohesionless Sand (i.e. C = 0)

Φ : Includes factors of resistance to sliding and rolling of soil particles over each other and any interlocking before slip can occur.

- Φ Increase as :
  - a) Void ratio decrease (i.e. density of soil mass increase)
  - b) Rough, angular particles
  - c) well graded sand

Basic Soil Properties Cont.

Shear Resistance Examples

2. High Cohesion Clay with negligible internal friction (i.e. Sr = C)

C : Resistance to sliding include intermolecular attraction and cohesion due to surface tension

- Factors that affect the shear strength of cohesive soils include:
  - Geologic deposit
  - Moisture content.
  - Drainage conditions
  - Density

Other Soil Properties

- **Permeability**: Property of soil mass that permits water to flow through it under the action of gravity or some other applied forces.

  u = K i …… D'Arcy law

  - u = velocity of water in soil
  - K = coefficient of permeability
  - i = hydraulic gradient = (h/l) head loss per unit length_
  - Found by conducting constant head or falling head test and in the field by pumping test.

- **Capillarity:** Property that permits water to be drawn from a free water surface through the action of surface tension and independent of the forces of gravity. Or it is the movement of free moisture by capillary forces through small diameter openings in the soil mass into pores that are not full of water. Can result in frost heave

- **Shrinkage:** Reduction of volume of soil mass that accompanies a reduction in moisture content when saturated or partially saturated.

Other Soil Properties Cont.

- **Swelling:** Expansion in volume of a soil mass that accompanies an increase in moisture content.

- **Compressibility:** Property of soil that permits it to consolidate under the action of applied compressive load.

- **Elasticity:** Property of soil that permits it to return to its original dimensions after the removal of an applied load.

Mr (Resilient Modulus) represent the elasticity of soils

Soil Classification for Highway Purposes

- Objective behind using any classification system for highway purposes is to predict the subgrade performance of a given soil on the basis of a few simple tests performed on the soil in a disturbed condition.

- On the basis of these results and their correlation with field experience the soil may be correctly identified and placed into a group of soils all of which have similar characteristics.

- Two methods:
  - American Association of State Highways and Transportation officials (AASHTO)
  - Unified Soil Classification System (USCS)

Tests for Soil Classification

1. **Mechanical Analysis** : Sieve analysis, wet sieve analysis, hydrometer analysis.
2. **Atterberg Limits**

Conducted on materials passing #40.

Liquid Limit: Min. moisture content at which the soil will flow under the application of a very small shear force (Soil assumed to behave like liquid).

Plastic Limit: Min. moisture content at which the soil remains in a plastic condition or

Plastic Limit : The lowest moisture content at which the soil can be rolled into a thread of (1/8”) diameter without crumbling.

Atterberg Limits

- **Shrinkage Limit (SL):** the moisture content at which further drying of soil will result in no additional shrinkage and the volume of soil will remain constant.

- **Liquid Limit (LL):** Min. moisture content at which the soil will flow under the application of a very small shear force (Soil assumed to behave like liquid).

- **Plastic Limit (PL):** Min. moisture content at which the soil remains in a plastic condition.

- **Plasticity Index (PI):** Numerical difference between LL and PL .
- **PI:** Indicates the range of moisture content over which the soil is in a plastic range.
  PI High……Soil is compressible, cohesion, highly plastic.
  Sand…….. Cohesion less……….Non Plastic (NP).

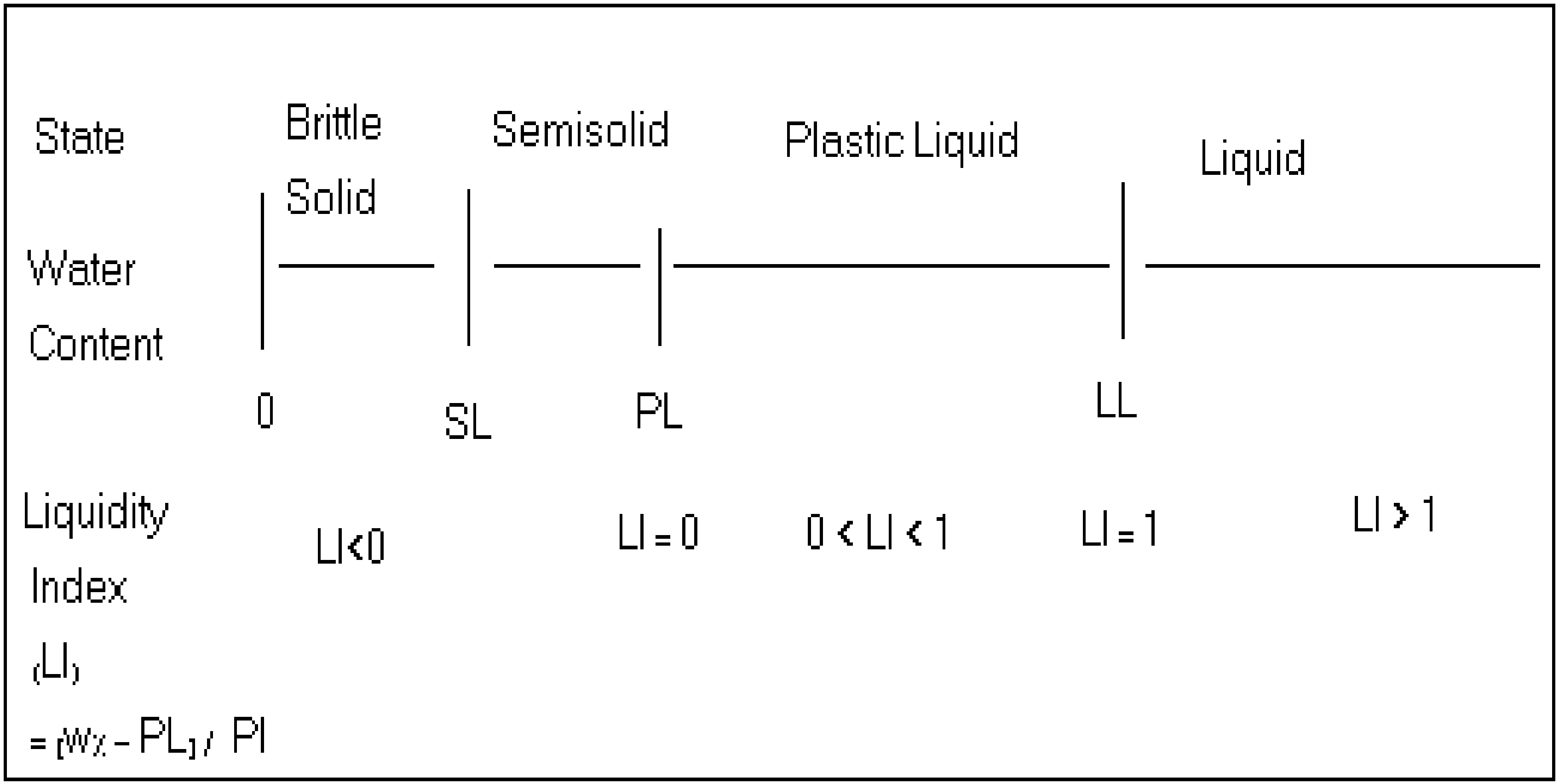
Atterberg Limits Cont.

- Liquidity Index (LI):
  - PL & LL can only be applied to disturbed soil samples.
  - Its highly possible that the undisturbed soil will not have the same liquid state as disturbed, therefore the liquidity index is used to reflect the properties of the natural soil.

$$LI = (\omega - PL) / PI$$

  - *See next slide for LI values and soil states*.
  - Soils with LI > 1.0 are known as quick clays which are relatively strong if undisturbed but become very unstable and can flow like liquid if they are sheared.

Consistency Limits



Casagrande Liquid Limit Apparatus

AASHTO Classification System

- Classifies soils into 7-groups based on laboratory determination of particle size distribution, liquid limit (LL), and Plasticity Index (PI).
- Evaluation of soils within each group is made by means of group index.
- *AASHTO classification in shown in Table 18.1(Text Book).*

TABLE 15-1 Classification of Highway Subgrade Materials (with Suggested Subgroups)[a]

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 (2.0 mm)	50 max.										
No. 40 (0.425 mm)	30 max.	50 max.	51 min.								
No. 200 (0.075 mm)	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.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.[b]
Usual types of significant constituent materials	Stone fragments, fine gravel, and sand			Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

[a]Classification procedure: With required test data available, proceed from left to right on the chart, and correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

[b]Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. PI of A-7-6 subgroup is greater than LL minus 30 (see Fig. 15-3).

Note: See group index formula and Figure 15-3 for method of calculation. Group index should be shown in parentheses after group symbol, such as A-2-6(3), A-4(5), A-6(12), A-7-5(17), and so forth.

Group Index (G)

$$G = (F-35)[0.2 + 0.005\,(LL - 40)] + [(0.01)\,(F - 15)\,(PI - 10)]$$

F : % passing sieve #200 (whole number).

LL : Liquid Limit.

PI : Plasticity Index (nearest whole number).

- If G is (-ve) …… Use G = 0.0
- For A-2-6 & A-2-7 subgroups, only the PI portion of the formula should be used.
- Inverse ratio of G indicate supporting value of subgrade (i.e. G = 0 good & G = 20 very poor)

Soil Classification Example1

% passing #10 = 100%

% passing # 40 = 85.2%

% passing # 200 = 52.1

LL = 29.2 & PI = 5.0

Solution: G = 1

A – 4 material

Soil Classification Example 2

% passing # 200 = 55 %

LL = 40 & PI = 25

Solution: G = 10

A – 6 material

Soil Compaction

- Soil is used as embankment or subbase materials which should be placed in uniform layers and compacted to high densities.
- Proper compaction of the soil will reduce settlement and volume change thus enhancing the strength of the soil layer.
- Compaction in field is achieved by hand operated tampers, sheepsfoot rollers, rubber-tired rollers, or other types of rollers.
- The strength of the compacted soil is directly related to the max. dry density achieved through compaction.

Moisture Density Relationship

- All soils exhibit a similar relationship between moisture content and density (dry unit wt.) when subjected to dynamic compaction.
- Dynamic compaction is achieved in fields by rollers and vibratory compactors in thin layers.
- Dynamic compaction in Lab is achieved by freely falling wt. on confined soil mass.

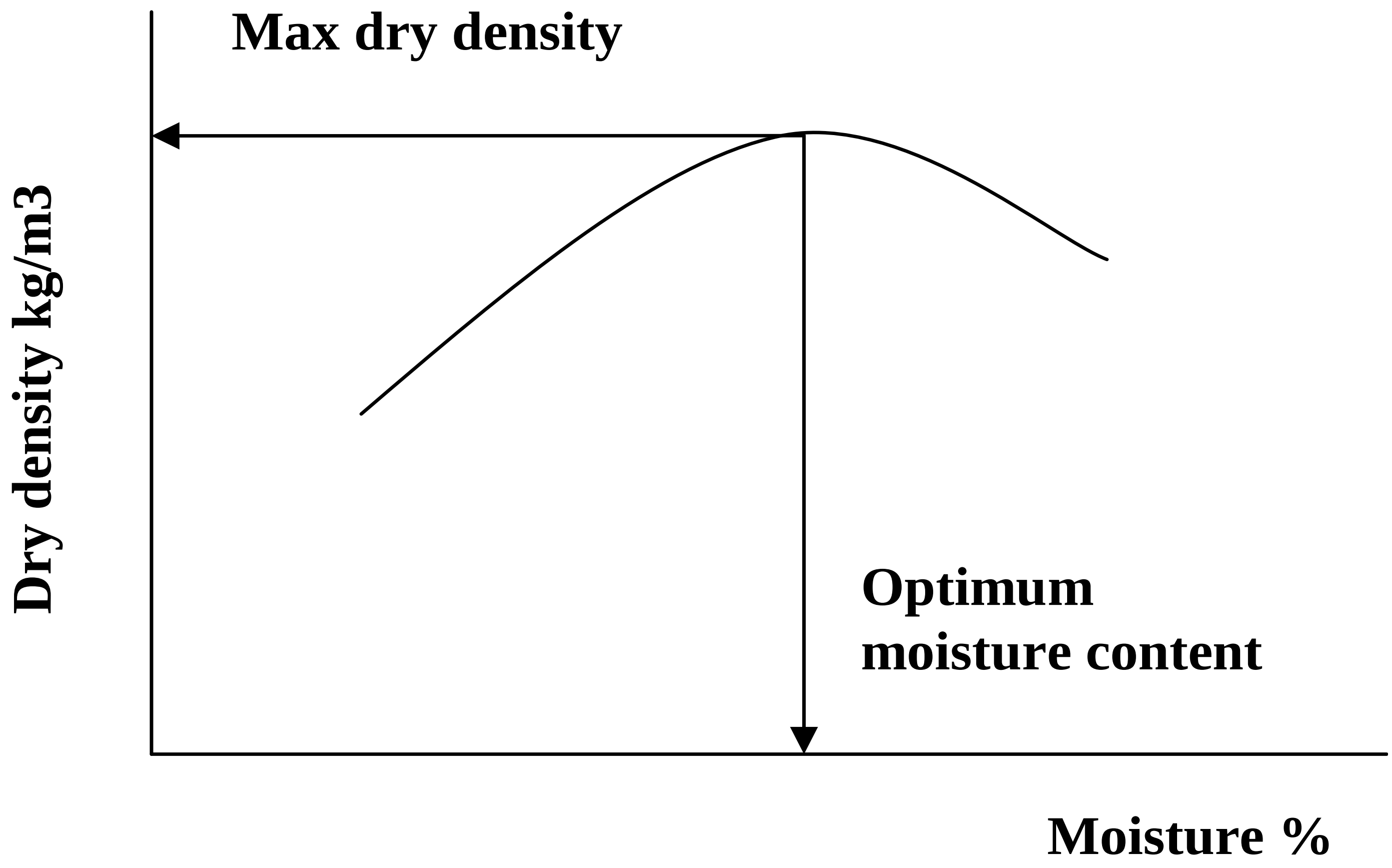
Dry unit wt. = Wet unit wt. / (1+ω%)

- Attempts are usually made to maintain soil at optimum moisture content so as to keep the soil at max density or some specified percentage.

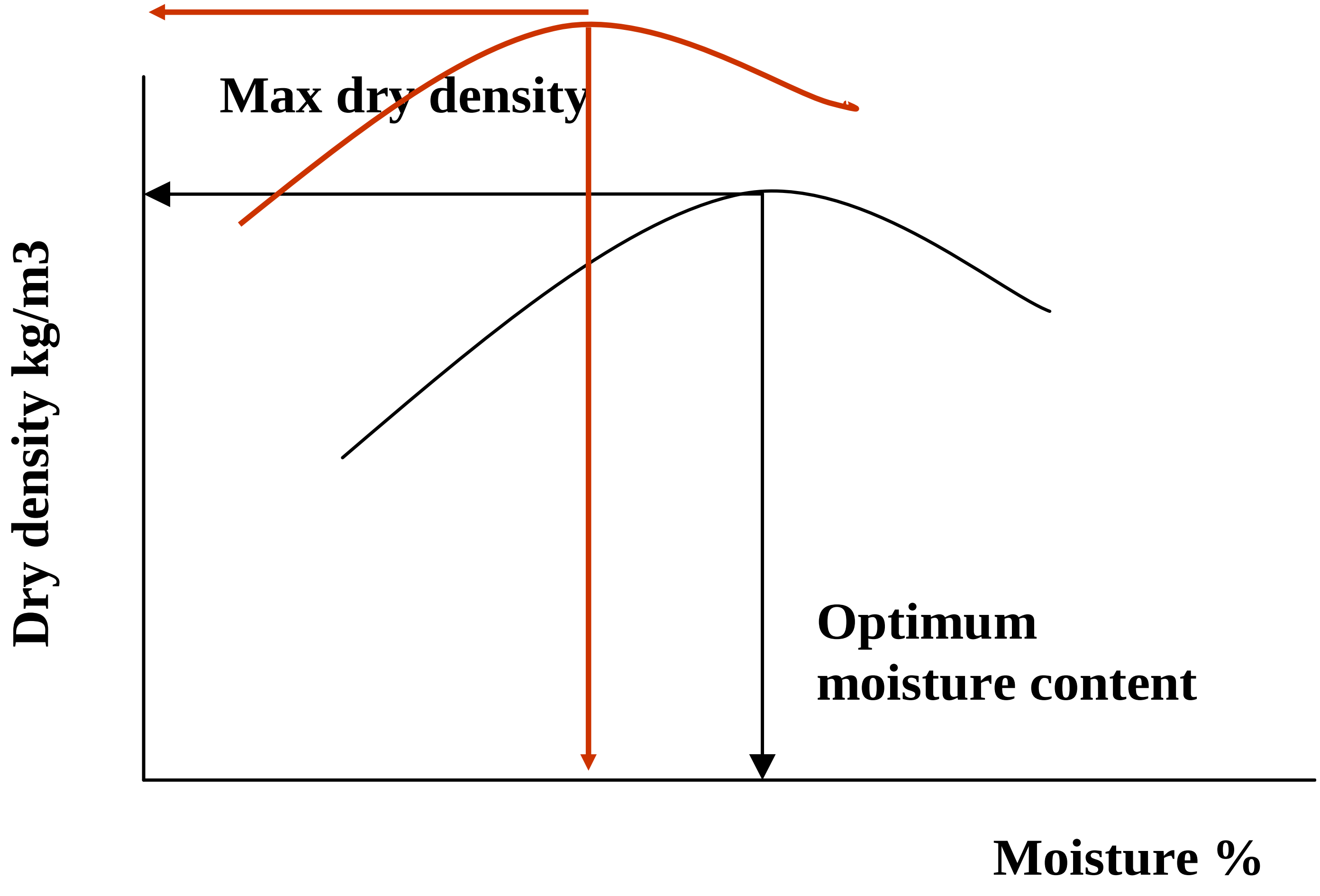
Proctor Test

Standard Proctor (Standard AASHTO T99)	Modified Proctor (Modified AASHTO T180)
Material Pass # 4	Material Pass # 4
4" Diameter mold	4" Diameter mold
3 Layers	5 Layers
5.5 lb (2.5 kg) Hammer with 2" face	10 lb (4.5 kg) Hammer with 2" face
12" Falling distance	18" falling distance
25 blows/ layer or 56	25 blows/ layer or 56

Moisture Density Relationship



Effect of Compactive Effort



Compaction Efforts

- As compactive effort increases, max density will increase and optimum moisture will decrease.
- If soil is too dry, more compactive effort is needed to achieve required density.
- Type of soil has great effect on density obtained under a given compactive efforts:
  - Moisture content is less critical for clay than plastic sand.
  - Granular and well graded soils react sharply with small changes in moisture.
  - Clean, poorly graded, non plastic sands are relatively insensitive to changes in moisture.
  - Amount of coarse aggregates.

Proctor test Procedure

- Soil sample pass # 4 with moisture less than optimum.
- Compact soil in mold at specified layers.
- Determine wet unit wt.
- Select small sample from interior of the compacted mass to find moisture content.
- Break soil into new sample.
- Add water (raise moisture content) by 1 – 2%.
- Repeat procedure until decrease is noted in the wet unit wt, or excess of water is noted.

Relation Explanation

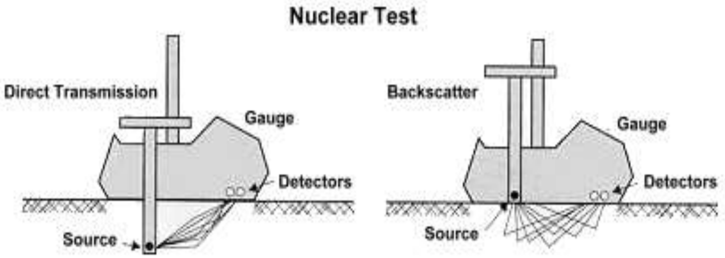
- When moisture is less than optimum, the soil doesn't contain sufficient moisture to flow readily under the blows of the hammer.

- As moisture increase, the soil flows more readily under the lubricating effect of the additional water, and soil particles move more closer together resulting in density increase. This effect continue until max density.

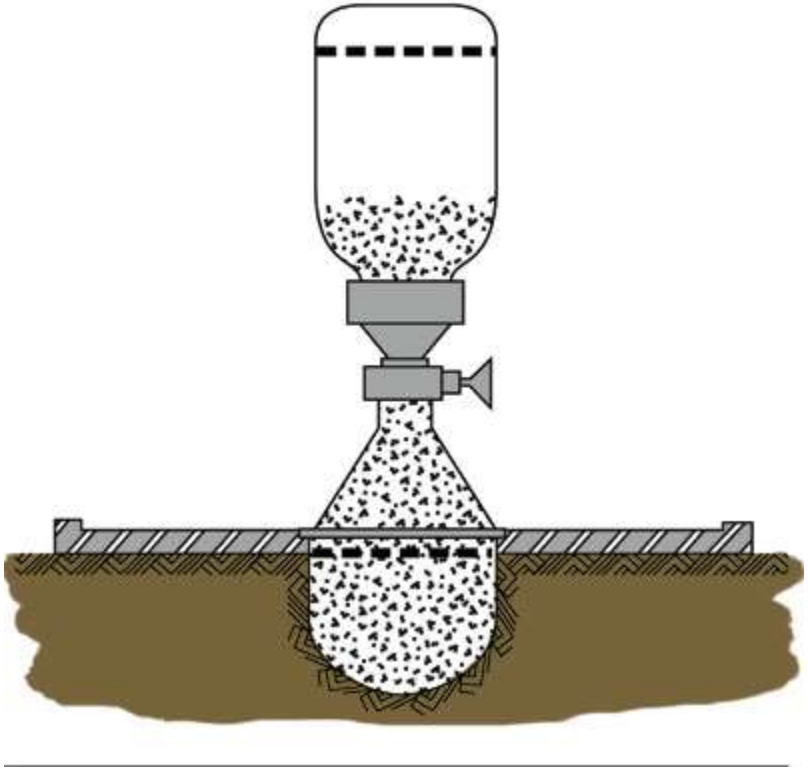
- Further increase tends to overfill the voids, forcing the soil particles to move apart and unit wt. decrease.

Control of Embankment Construction

- See Table 18.7 in text.
- % compaction can be found using:
  - Destructive methods
    - Field cone test using sand,
    - Oil method
    - Balloon method using water.
  - Nondestructive methods
    - Nuclear equipments



field density test using sand cone method



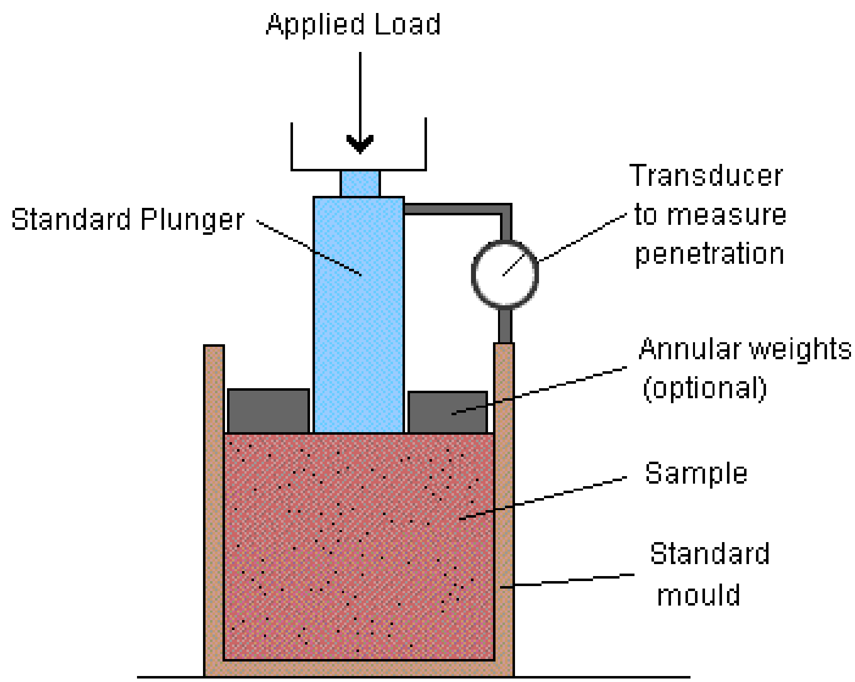
Special Soil Tests for Pavement Design

- California Bearing Ratio test (CBR):
  - Determine of the load-deformation curve of the soil in the lab. Using CBR standard testing equipments.
- Hveem Stabilometer Test:
  - Determine the resistance value (R) of the soil to the horizontal pressure obtained by imposing avertical stress on a sample of soil.
  - Both CBR and R values may be used to determine the pavement thickness above the soil to carry the estimated traffic load.

CBR

- It is a penetration test wherein a standardized piston, having an end diameter of 49.53mm (1.95in), is caused to penetrate the soil at a standard rate of 1.27mm/min (0.05in/min).
- The CBR value is calculated as the ratio of the load or stress at 2.54mm (0.1in) penetration to a standard load or stress.

CBR


Applied Load
Standard Plunger
Transducer
to measure
penetration
Annular weights
(optional)
Sample
Standard
mould

CBR Significance

- Although the CBR test is an empirical test, but it's widely used in:
  - Used in evaluating the strength of the compacted soil.
  - Used in pavement design for both roads and airfields

- Some design methods use the CBR values directly. Others convert the CBR value to either the modulus of subgrade reaction *ks*, or to the resilient modulus (MR) using empirical relationships. For example the Asphalt Institute design procedure uses the following formulas to convert CBR to MR:
    - MR (MPa) = 10.342 CBR
      - MR (lb/in2) = 1500 CBR

CBR Test Procedure

- The selected sample of subgrade soil (pass Sieve ¾”) is compacted in a mold that is 152 mm (6 in) in diameter and 152 to 178 mm (6 to 7 in) high.
- The moisture content, density, and compactive effort used in molding the sample are selected to correspond to expected field conditions (i.e. standard or modified Proctor).
- After the sample has been compacted (three molds with 10, 25, and 55 blows /layer), a surcharge weight equivalent to the estimated weight of pavement, base, and subbase layers is placed on the sample, and the entire assembly is immersed-in water for 4 days.

CBR Test Procedure

- At the completion of this soaking period the sample is removed from the water and allowed to drain for a period of 15 min. The sample, with the same surcharge imposed on it, is immediately subjected to penetration by a piston 49.53 mm (1.95 in) in diameter (cross section area = 3 square inches) moving at a speed of 1.27 mm/min (0.05 in/min). The total loads corresponding to penetrations of 2.5, 5.0, 7.5, 10.0, and 12.5 mm (0.1, 0.2, 0.3, 0.4, and 0.5 in) are recorded.

- A load-penetration curve is then drawn, any necessary corrections made, and the corrected value of the unit load corresponding to 2.5 mm (0.1 in) penetration determined. This value is then compared with a value of 6.9 MPa (1000 lb/in2) required to produce the same penetration in standard crushed rock.

CBR Determination

- The CBR is then calculated by the expressions:

$$CBR\,(\%) = \frac{\text{unit load at 2.5 mm penetration (MPa)}}{6.9\ \text{MPa}} \times 100$$

$$CBR\,(\%) = \frac{\text{unit load at 5.0 mm penetration (MPa)}}{10.3\ \text{MPa}} \times 100$$

- Or

$$CBR\,(\%) = \frac{\text{Stress at 0.1 in penetration (psi)}}{1000\ \text{psi}} \times 100$$

$$CBR\,(\%) = \frac{\text{Stress at 0.2 in penetration (psi)}}{1500\ \text{psi}} \times 100$$

CBR Determination Cont.

- The CBR value is usually based on the load ratio for a penetration of 2.5 mm (0.1 in).
- If however, the CBR value at a penetration of 5.0 mm (0.2 in) is higher than the obtained value at 2.5 mm (0.1 in) penetration, the test should be repeated. If the repeated test also yields a larger value, then the CBR at 5.0 mm (0.2 in) penetration should be used.

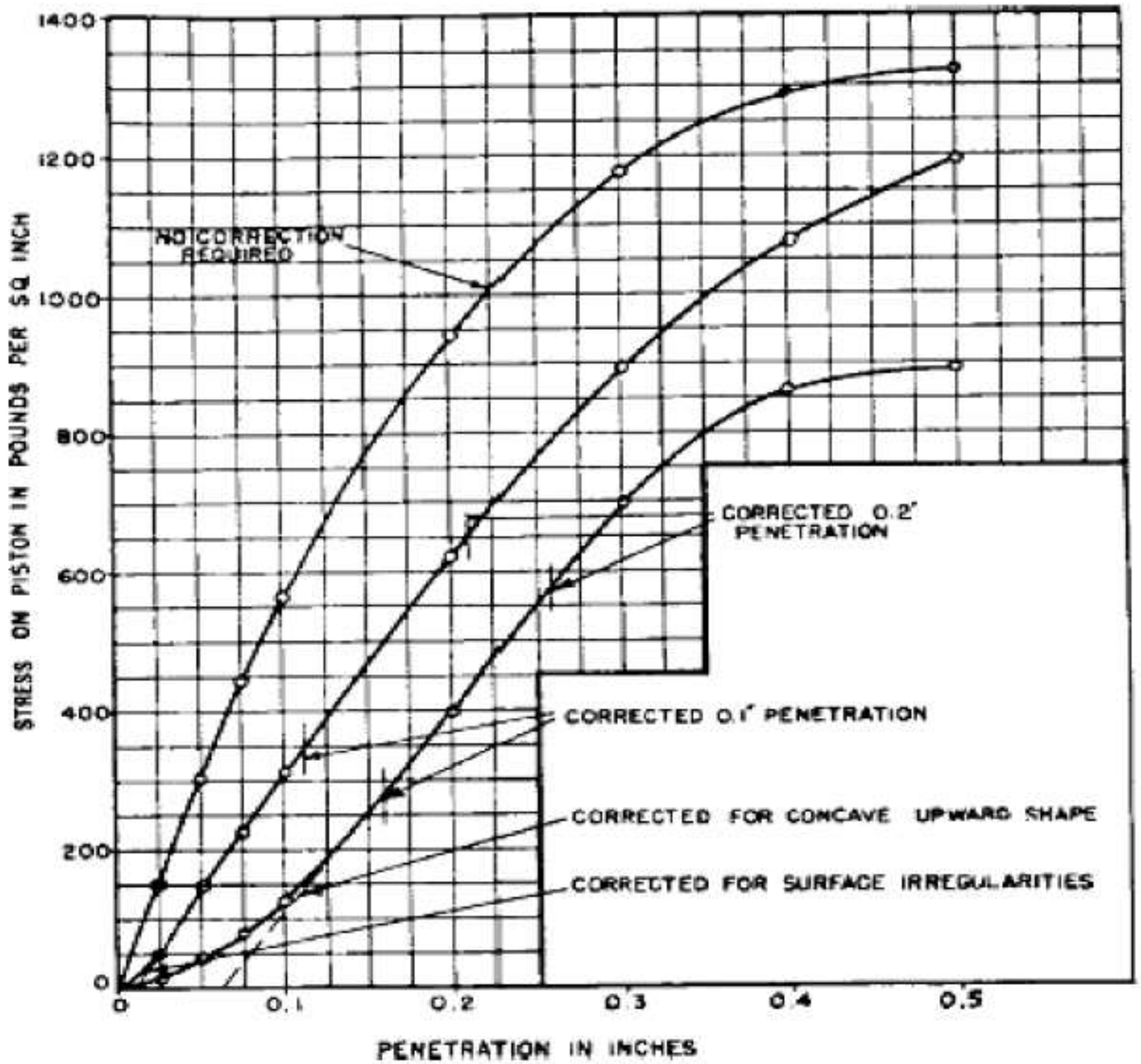
The CBR Plot

- Plot the readings of load against the penetration readings and draw a smooth curve through the points.
- The curve is normally concave downward, although the initial portion might concave upward due to surface irregularity. In this case, correction should be done by drawing a tangent to the curve at the point of greatest slope. The corrected curve will be used in all further calculations.
- From the obtained curve make a computation of the load at the corrected penetration of 2.5mm (0.1 in) and 5.0mm (0.2 in).
- The obtained values (in kg) are expressed as percentages of the standard loads of 3000lb and 4500 lb respectively.

$$CBR\,(\%) = \frac{\text{Load at 2.5mm penetratio n (kg)}}{1364\ \text{kg}} \times 100$$

$$CBR\,(\%) = \frac{\text{Load at 5.0mm penetratio n (kg)}}{2045\ \text{kg}} \times 100$$

CBR Plot

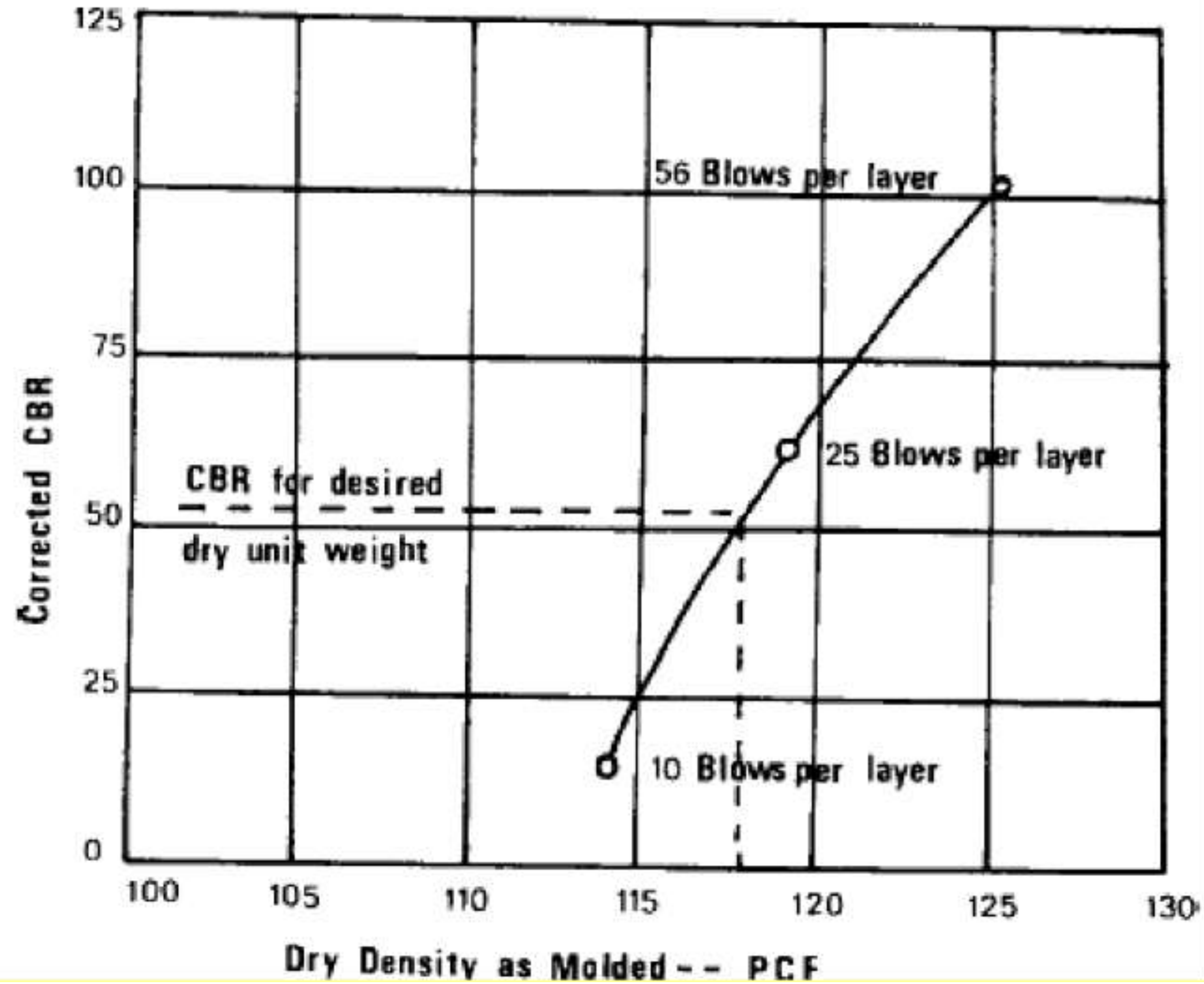


1400
1200
1000
800
600
400
200
0
STRESS ON PISTON IN POUNDS PER SQ INCH
0
0.1
0.2
0.3
0.4
0.5
PENETRATION IN INCHES
NO CORRECTION REQUIRED
CORRECTED 0.2" PENETRATION
CORRECTED 0.1" PENETRATION
CORRECTED FOR CONCAVE UPWARD SHAPE
CORRECTED FOR SURFACE IRREGULARITIES

CBR Determination Cont.

- Usually the value at 2.5mm (0.1 in) is greater than that at 5.0mm (0.2 in) penetration and the former is taken as the CBR value.
- If CBR2.5 < CBR5.0 repeat the test on another soil sample. In the case that the second test still gives CBR2.5 < CBR5.0 , then take the CBR value as the value corresponding to 5.0mm penetration.

Dry Density vs CBR



Swell Determination

- While the molded CBR sample are immersed in water, periodically take the swell readings and record them in the data sheet.
- At the end of the soaking period, take a final dial reading and calculate the swell as a percentage of the height of the specimen (125 mm).

$$Swell\,(\%) = \frac{Amount\,of\ Swell}{Original\ Specimen\,height\,(125mm)} \times 100$$

- Weigh the specimen (Wwet filled) and determine the soil density after soaking.

Frost Action in Soils

- Sever damages to pavement layers may result from frost action (Freeze & Thaw).
- Due to freezing soil volume increase and causue ice crystals and lenses.
- Frost Heave: Distortion or expansion of the subgrade soil or base during freezing temperatures.
- During spring (thawing) ice lenses melt which result in water content increase which in turns reducing the strength of the soil causing structural damage (spring break-up).

Frost Action in Soils

- Occurrence require:
  - Shallow water table that provides capillary water to the frost line;
  - Frost susceptible soil (*most sever in silty soils because upward movement of water in silt is faster than in clay*);
  - Ambient temperature must be lower than zero for several days.
- Treatment:
  - Remove soil subjected to frost action;
  - Replace with suitable granular backfill to the depth of frost line;
  - Installation of drainage facilities to lower water table,
  - Restricting truck traffic during spring thaw..

Pavement Materials & Design (110401466)
Pavement Types

Dr. TALEB M. Al-ROUSAN

Pavement Types

1. Flexible Pavement: Pavement constructed of bituminous and granular materials.
2. Rigid pavement: Pavement constructed of Portland cement concrete.

Flexible Pavement Types

1. Conventional flexible pavements, discussed in detail.
2. Full-depth asphalt pavements.
3. Contained rock asphalt mat (CRAM), not widely accepted for practical use .

Conventional Flexible Pavements

- Are layered systems with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low.
- Adherence to this design principle makes the use of local materials possible and usually result in the most economical design.

Conventional Flexible Pavements Cont.

- Cross section consist of (from top):
  1. Seal coat
  2. Surface course
  3. Tack coat
  4. Binder course
  5. Prime coat
  6. Base course
  7. Subbase course
  8. Compacted subgrade
  9. Natural subgrade
- The use of various courses is based on either necessity or economy, and some of the courses may be omitted.

Conventional Flexible Pavements Cross Section

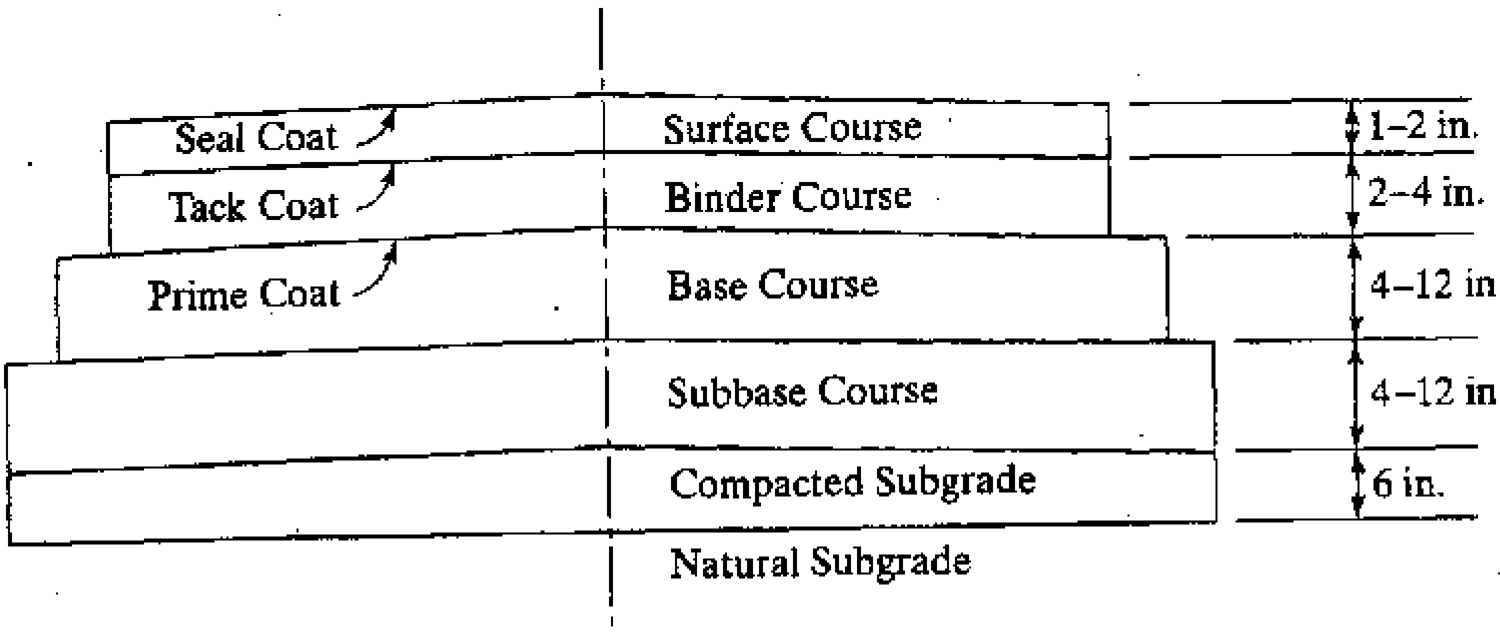


FIGURE 1.2

Typical cross section of a conventional flexible pavement (1 in. = 25.4 mm).

Conventional Flexible Pavements Cont./ Seal Coat

- Seal coat: Thin asphalt surface treatment used to:
  1. Waterproof or seal the surface.
  2. Rejuvenate or revitalize old bituminous wearing surfaces.
  3. To nonskid slippery surfaces.
  4. Improve night visibility.

- Single Surface treatment = single application of bituminous material that is covered by a light spreading of fine aggregate or sand (spread mechanically) then compacted with pneumatic tired rollers.

Conventional Flexible Pavements Cont./ Surface Course

- Is the top course of asphalt pavement (Wearing course).
- Constructed of dense graded HMA.
- Must be:
  1. Tuff to resist distortion under traffic
  2. Provide smooth and skid resistant riding surface.
  3. Water proof to protect the entire pavement from the weakening effects of water.
- If the above requirements can not be met, the use of seal coat is recommended.

Conventional Flexible Pavements Cont./ Binder Course

- Binder course (known also as Asphalt base course) is the asphalt layer beneath the surface course.
- Reasons for use:
  1. HMA is too thick to be compacted in one layer (*if the binder course is more than 3" it is placed in two layers*).
  2. More economical design, since binder course generally consist of larger aggregates and less asphalt and doesn't require high quality.

Conventional Flexible Pavements Cont./ Tack & Prime Coats

- Tack coat: Very light application of asphalt (emulsion) to ensure a bond between the surface being paved and the overlying course. Binds asphalt layer to PCC base or to an old asphalt pavement.
- Prime coat: Application of low viscosity Cutback asphalt to an absorbent surface such as untreated granular base on which asphalt layer will be placed on. It binds the granular base to the asphalt layer.
- Tack coat doesn’t require the penetration of asphalt into the underlying layer, while prime coats penetrates into the underlying layer, plugs the voids , and form a watertight surface.
- Both are spray application.

Conventional Flexible Pavements Cont./ Base & Subbase Courses

- Base course: Layer immediately beneath the surface or binder course.
- Composed of crushed stone, crushed slag, or other untreated or stabilized materials.
- Subbase course: Layer beneath the base course, used mostly for economy purposes since it can be of lower quality.

Conventional Flexible Pavements Cont./ Subgrade

- Subgrade can be either in situ soil or a layer of selected materials.
- The top 6” of subgrade should be scarified and compacted to the desired density near the optimum moisture content.

Full-Depth Asphalt Pavements

- Are constructed by placing one or more layers of HMA directly on the subgrade or improved subgrade.
- Used for heavy traffic.
- When local materials are not available to minimize the administration and equipment costs.
- Typical cross section: Asphalt surface, tack coat, asphalt base, and prepared subgrade.

Full-Depth Asphalt Cross Section

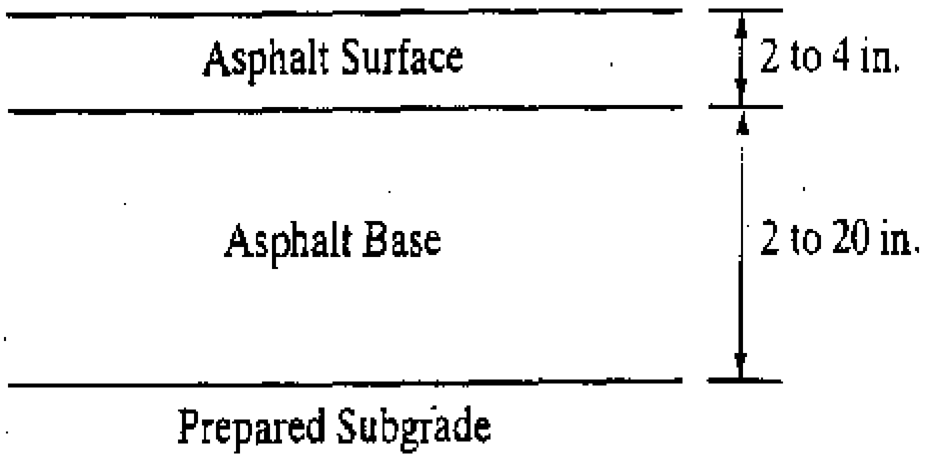


FIGURE 1.3

Typical cross-section of a full-depth asphalt pavement (1 in. = 25.4 mm).

Advantages of Full-depth Asphalt Pavements

1. Have no permeable granular layers to entrap water and impair performance.
2. Reduced construction time.
3. Construction seasons may be extended.
4. Provide & retain uniformity in the pavement structures.
5. Less affected by moisture or frost.
6. Little or no reduction in subgrade strength because moisture do not build up in subgrade when full-depth asphalt is used.

Contained Rock Asphalt Mats

- Composed of 4 layers:
  1. Dense-graded HMA (wearing 1.5 – 4”).
  2. Dense-graded aggregates (4 – 8”).
  3. Open-graded aggregates (4 – 8”).
  4. Modified dense-graded HMA (2 -6”).
  5. Prepared subgrade.
- Reduce vertical comp. strain on subgrade & Horizontal tens. Stress in the overlying granular layer will decrease which make these layers stronger, thus leading to reduction in the tensile stresses and strains in the surface layer.

Rigid Pavements

- Rigid pavements are placed either directly on the prepared subgrade or on a single layer of granular or stabilized materials (called base course or subbase).
- Use of base course in rigid pavements:
  1. Control of pumping (ejection of water and subgrade soil through joints, cracks, and along the edges. stabilized base are less erodible).
  2. Control of frost action.
  3. Improvement of drainage (raise pavement from water table).
  4. Control of shrinkage and swell (work as waterproof and as surcharge load).
  5. Expedition of construction (working platform).

Rigid Pavement Cross Section

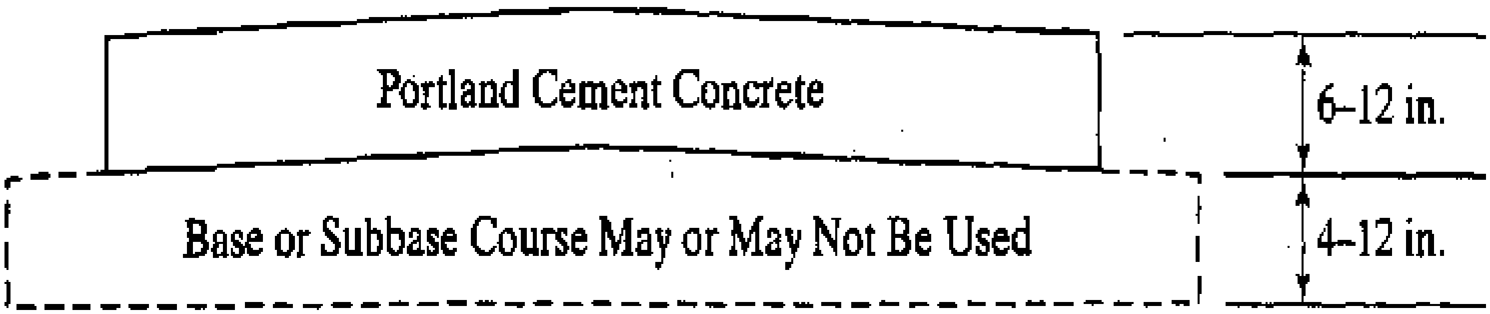


FIGURE 1.4

Typical cross section of a rigid pavement (1 in. = 25.4 mm).

Types of Rigid Pavements

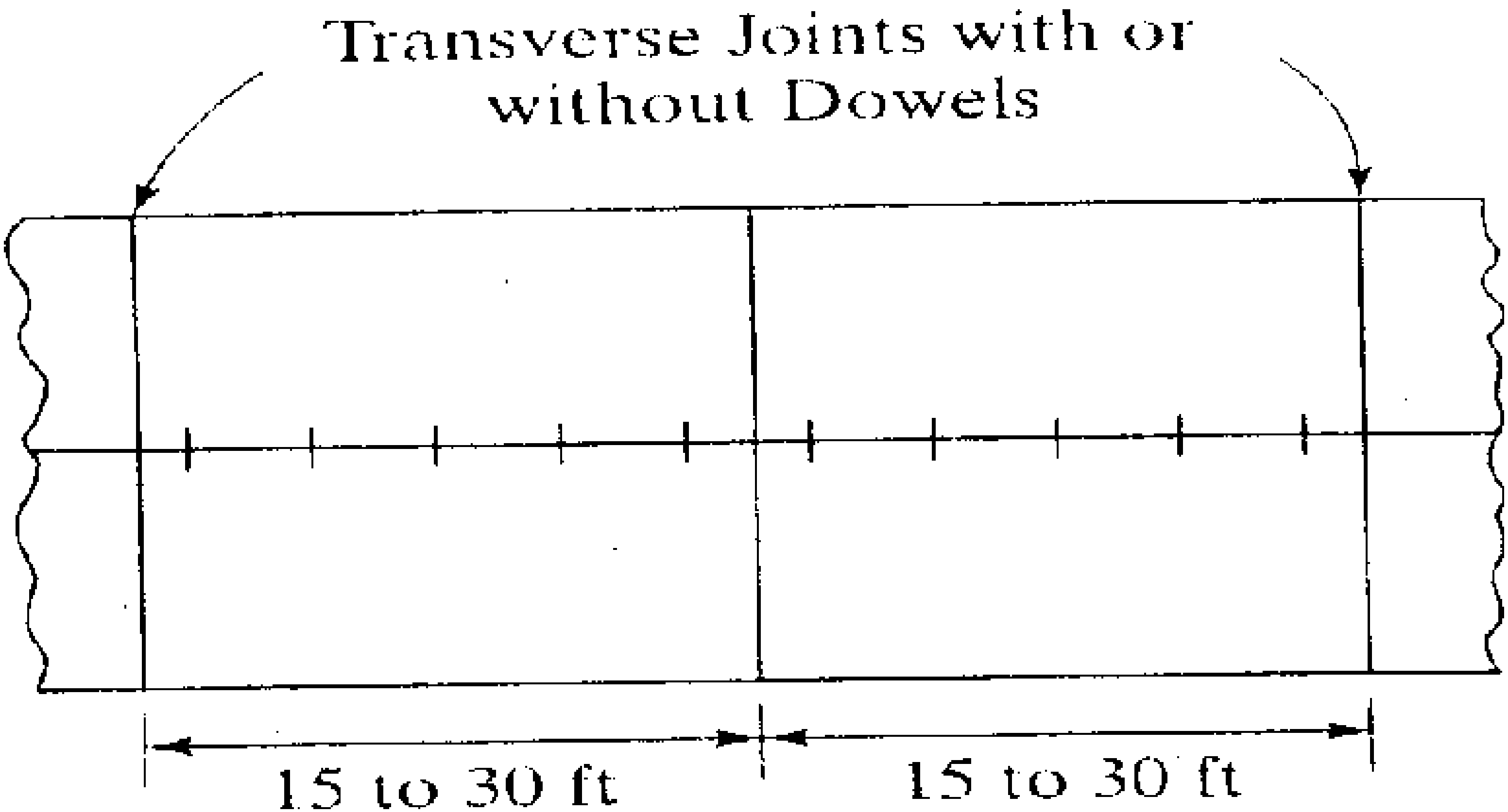
1. Joint Plain Concrete Pavements (JPCP).
2. Jointed Reinforced Concrete Pavements (JRCP).
3. Continuous Reinforced Concrete pavements (CRCP).
4. Prestressed Concrete Pavements (PCP).

- A longitudinal joint should be installed between the two traffic lanes to prevent longitudinal cracking.

Joint Plain Concrete Pavements (JPCP).

- Constructed with closely spaced contraction joints.
- Dowels or aggregates interlock may be used for load transfer across the joints.
- Joint spacing (15 to 30 ft)
- Tie bars are used for longitudinal joints.

JPCP



Transverse Joints with or without Dowels
15 to 30 ft
15 to 30 ft

(a) JPCP

JPCP

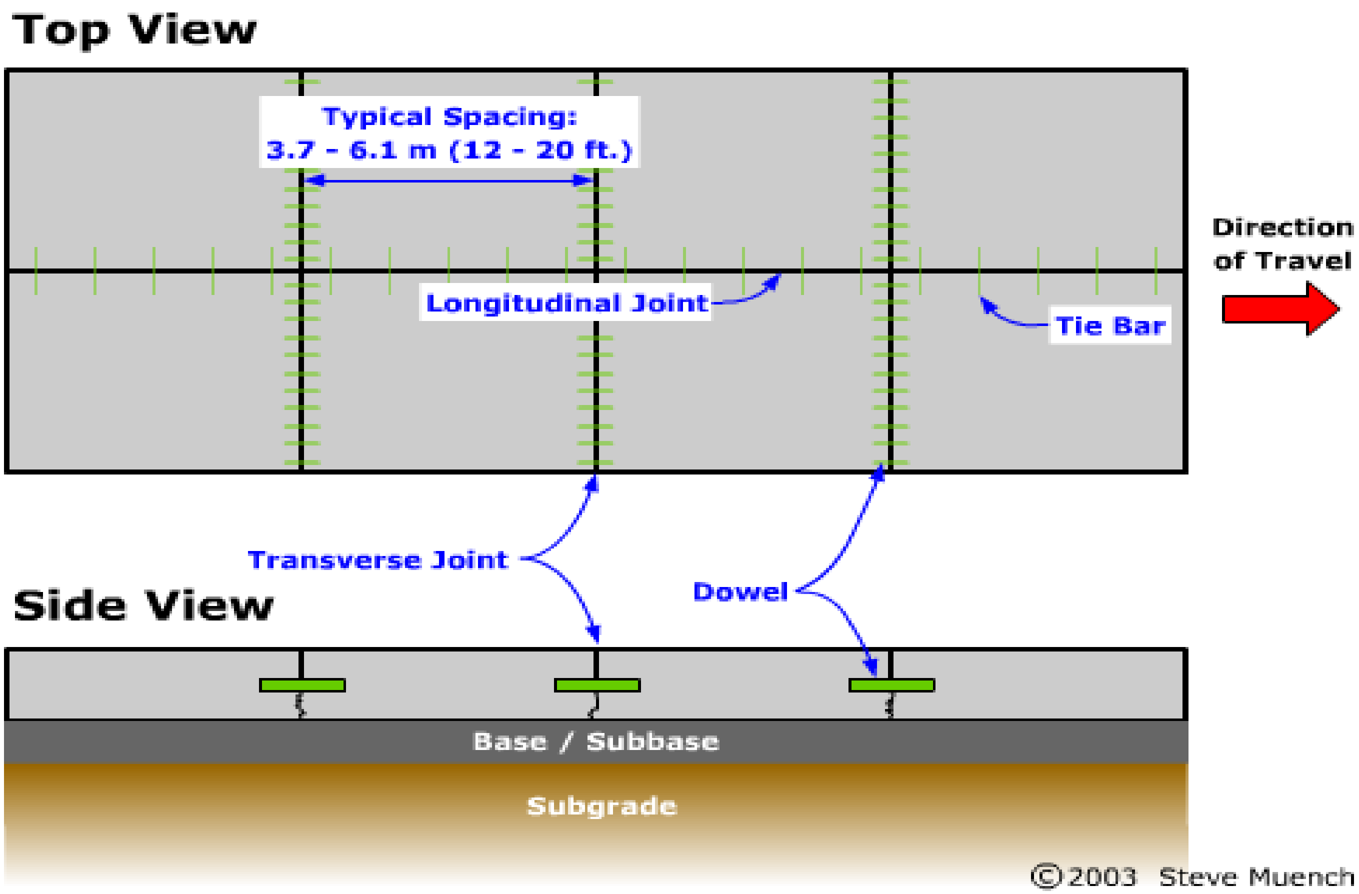
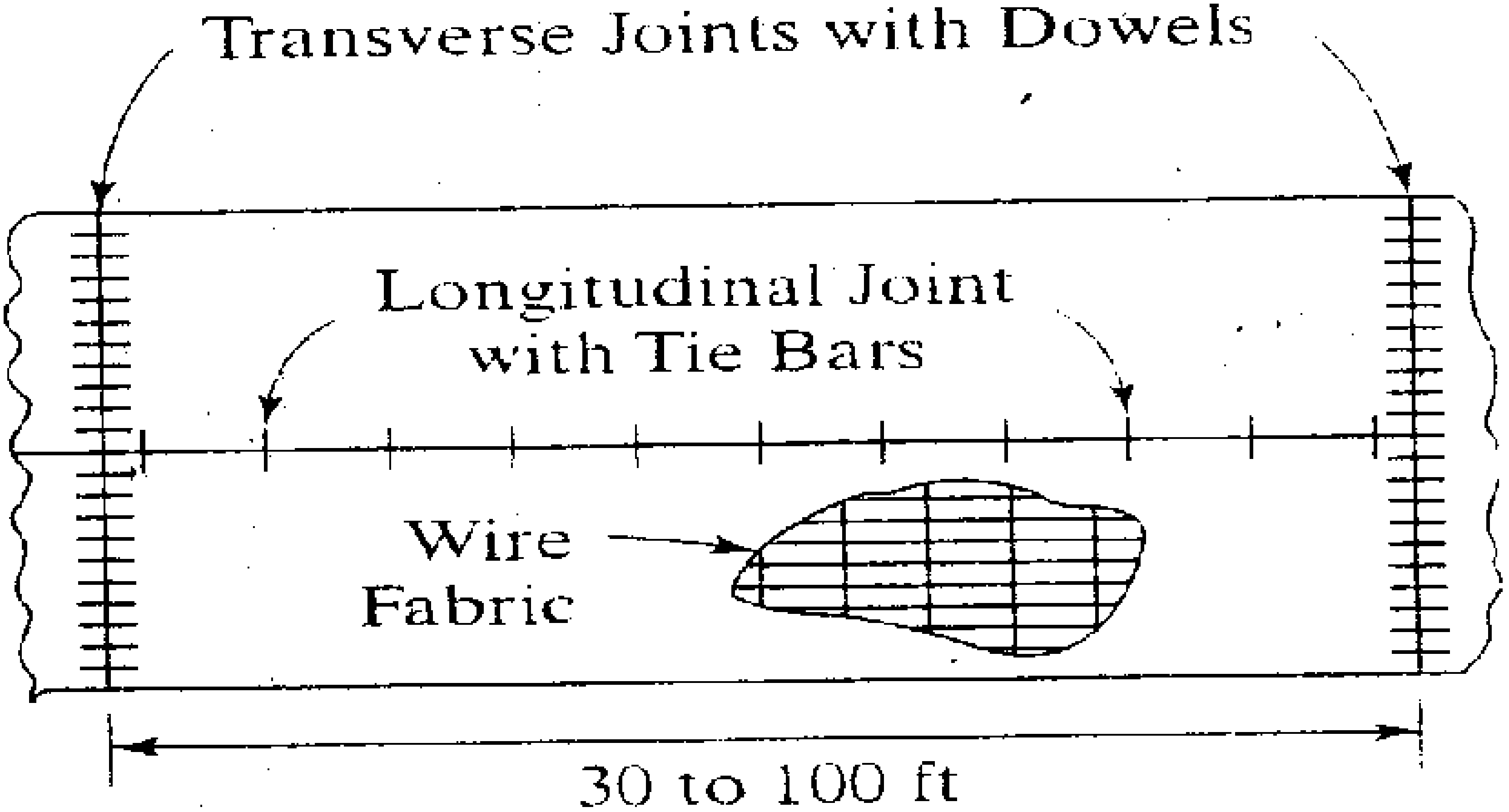


Figure 2.39: Jointed Plain Concrete Pavement (JPCP)

Jointed Reinforced Concrete Pavements (JRCP).

- Steel reinforcement in the form of wire mesh or deformed bars do not increase the structural capacity of pavements but allow the use of longer joint spacing.
- Joint spacing (30- 100 ft).
- Dowels are required for load transfer across the joints.
- The amount of distributed steel increase with the increase in joint spacing and is designed to hold the slab together after cracking.

JRCP


Transverse Joints with Dowels
Longitudinal Joint
with Tie Bars
Wire
Fabric
30 to 100 ft

(b) JRCP

JRCP

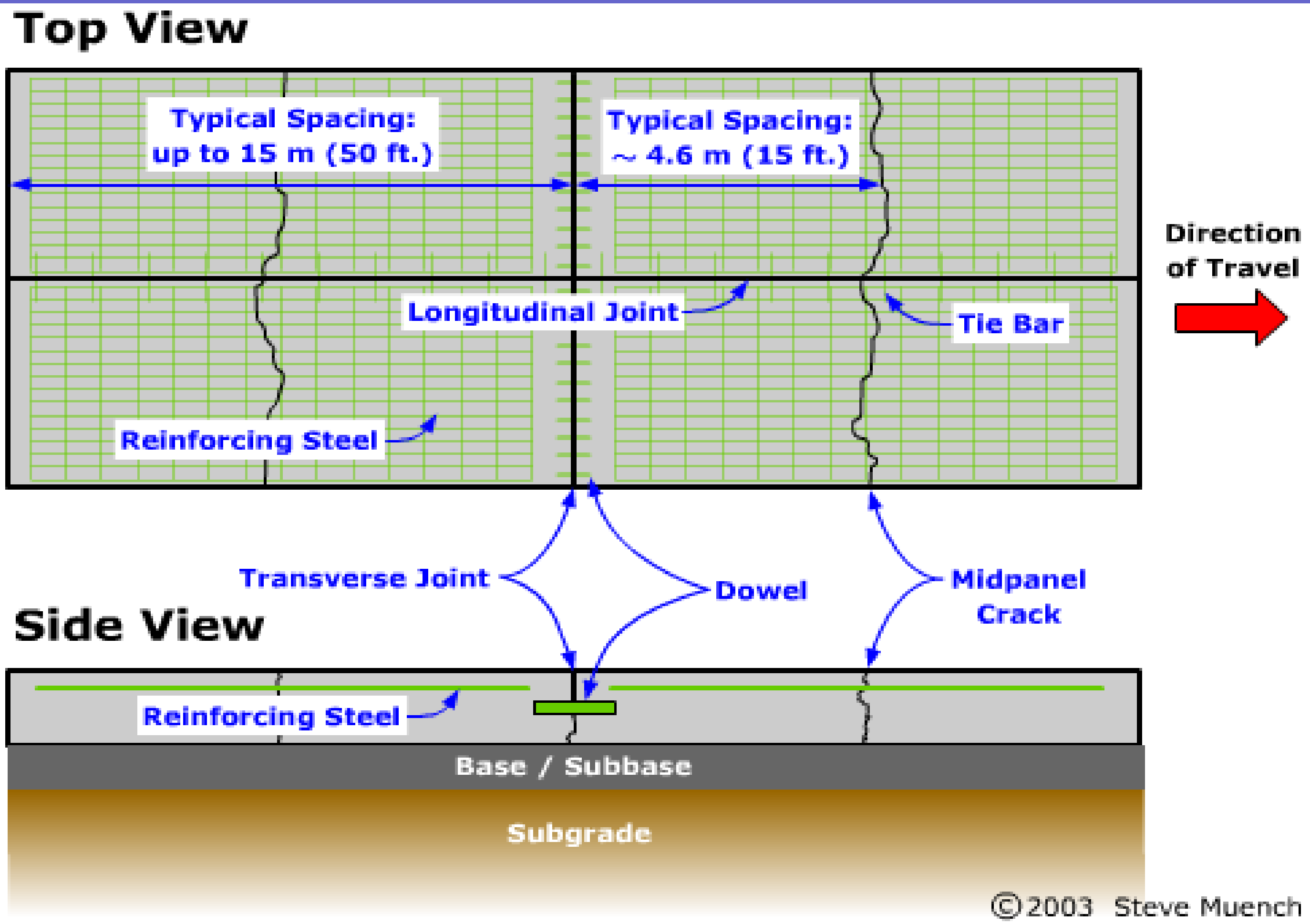
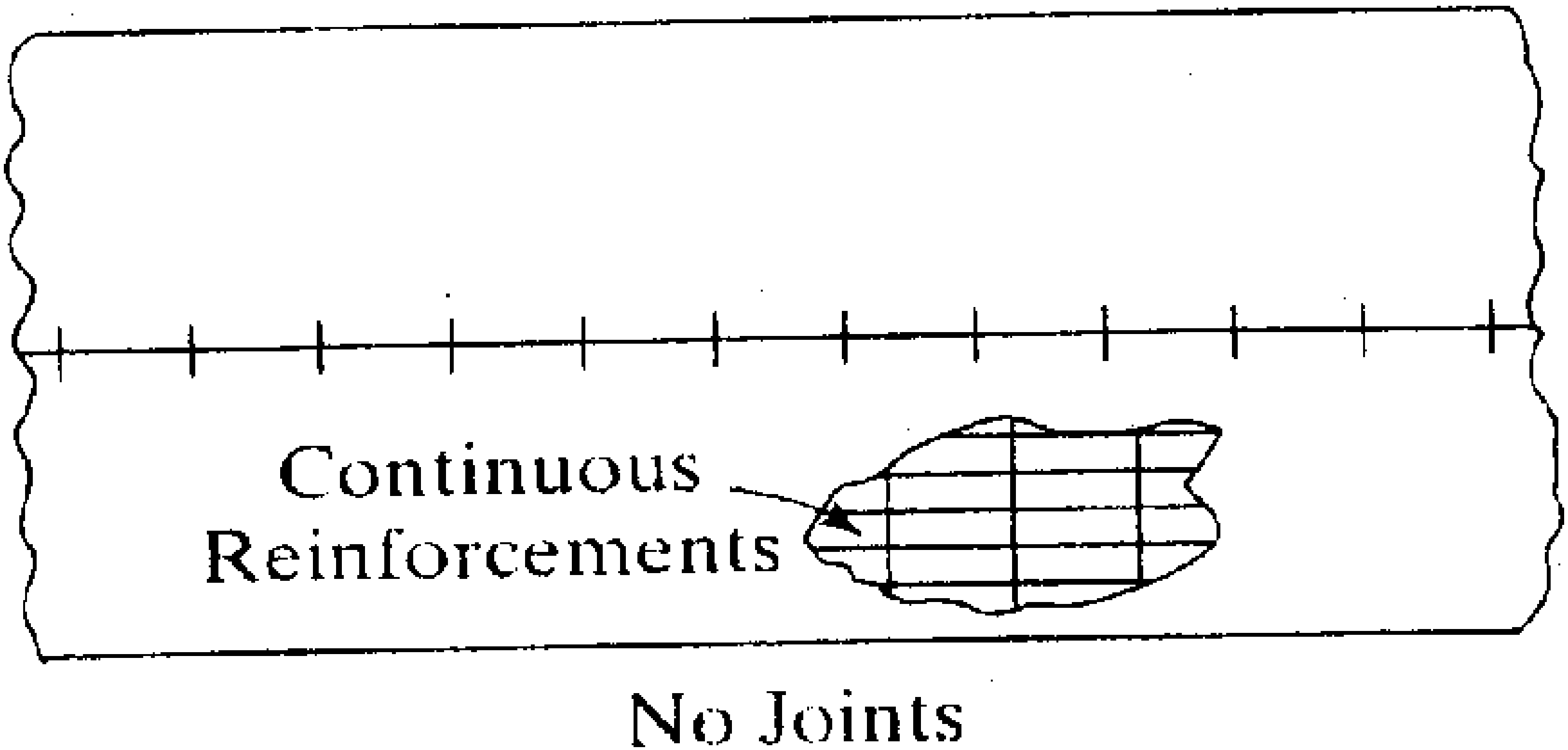


Figure 2.40: Jointed Reinforced Concrete Pavement (JRCP)

Continuous Reinforced Concrete pavements (CRCP).

- It has no joints.
- Joints are the weak spots in rigid pavements.
- Eliminating joints reduced thickness of pavement by 1 to 2”.
- Most frequent distress is punchout at the pavement edge.

CRCP



(c) CRCP

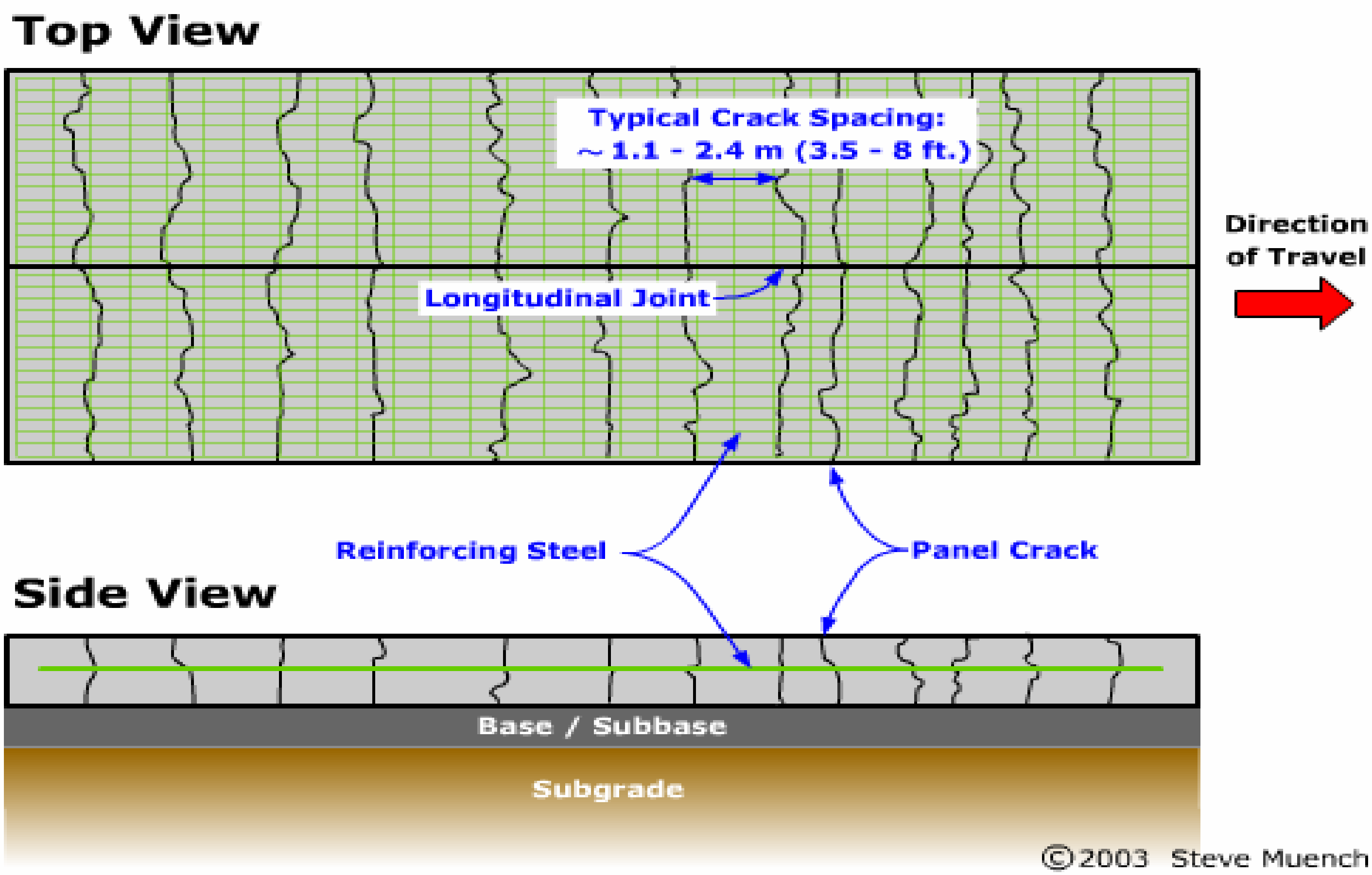
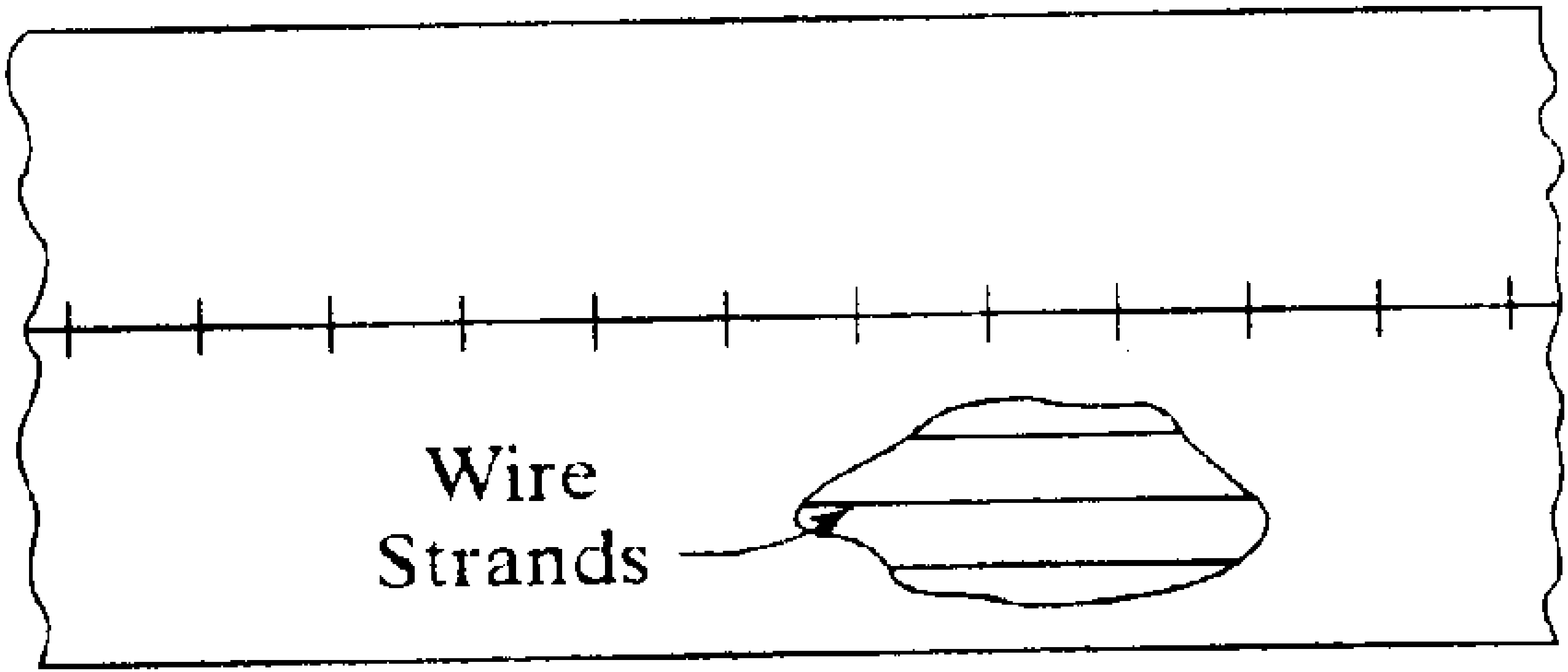


Figure 2.41: Continuously Reinforced Concrete Pavement (CRCP)

Prestressed Concrete Pavements (PCP).

- The pre application of a compressive stress to the concrete greatly reduces the tensile stresses caused by traffic and thus decrease the thickness of concrete required.
- Has less probability of cracking and fewer transverse joints and therefore results in less maintenance and longer pavement life.
- Used more frequently for airport pavements than for highway pavements because the saving of thickness for airport pavements is much greater than for highways.

PCP



Slab Length 300 to 700 ft

(d) PCP

Composite Pavements

- Composed of both HMA & PCC.
- Using PCC bottom layer & HMA top layer results in an ideal pavement with most desirable characteristics.
- PCC provide strong base
- HMA provides a smooth non-reflective surface.
- Very expensive and rarely used.
- Most of the available are the rehabilitation of PCC using asphalt overlays.

Pavement Materials & Design (110401466)
High-Type Bituminous Pavements

Text Book chapter 19: Traffic & Highway Engineering by Nicholas Garber and Lester Hoel, Third Edition, Brooks/Cole.

Reference Book Chapter 19: Highway Engineering, by Paul Wright & Karen Dixon, 7th Edition, Wiley & sons

Dr. TALEB M. AL-ROUSAN

Asphaltic Concretes

- Asphaltic concrete is a uniformly mixed combination of asphalt cement, coarse aggregate, fine aggregate, and other materials depending on the type of the asphalt concrete.
- Types of asphalt concrete commonly used:
  - Hot-mix, hot laid
  - Hot-mix, cold laid
  - Cold-mix, cold laid
  - Asphalt concrete should resist deformation from imposed traffic, skid resistance even when wet, and not be easily affected by weathering forces.

Hot-Mix, Hot-Laid Asphalt Concrete

- Produced by properly blending AC + C.Agg + F. Agg + Filler (Dust) at temperature ranging between 170 -325 F.
- Used for high-type pavement construction.
- Mixture can be described as:
  - Open-graded: max size 3/8” to 3/4”
  - Coarse-graded : max size 1/2” to 3/4”
  - Dense-graded: max size 1/2” to 1”
  - Fine-graded: Max Size 1/2” to 3/4”
  - The above max sizes of aggregates are for high-type surfaces , bur when used as base the max size used can be larger.

High-Type Bituminous Pavement (Hot-Mix, Hot Laid)

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

Fundamental Properties of Design

1. Stability: Property of compacted mixture that enables it to withstand the stresses imposed on it by moving wheel loads with sustaining substantial permanent deformation.
2. Durability: Property of compacted mixture to withstand the detrimental effects of air, water, & temperature changes.

Density of HMA

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

Goal of Mix Design

Determine the best or optimum asphalt content that will provide the required stability & durability as well as additional desirable properties such as impermeability, workability, & resistance to bleeding.

Stability & Density

- Density & stability increase as AC% increase up to a point where they will start to decrease because aggregates will be forced apart by excess of bituminous materials.
- It is not practical to say that the best AC would be the one that would just fill the voids in the compacted mixture.
- Raise in Temperature……AC expand…..AC overfill the voids……Bleeding…… loss in stability.
- Traffic……Raise density……Reduce voids……Excess AC…….. Bleeding…….Loss in stability.
- Compromise is needed when selecting optimum AC%.

Requirements of HMA

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

Classification of Hot-Mix Paving

- According to Asphalt Institute: Asphalt paving mixtures are designed & produced using wide range of aggregate types & sizes.
- Asphalt concrete = HMA= Intimate mixture of coarse & fine aggregates, mineral filler, and asphalt cement.
- Mixes are classified based on aggregate gradation used in the mix (i.e. Uniform graded, Open graded, Gap graded, Coarse graded, fine graded.

Classification of Hot-Mix Paving Cont.

- Other grades
  - Sheet asphalt: AC + Fine Agg. + Mineral filler (Surface mixtures)
  - Sand asphalt: AC + Sand (with/without mineral filler)
- Mixes are designated also according to use in layered system:
  - Surface mixes: Upper layer
  - Base mixes: Layer above subbase or subgrade
  - Leveling mixes: Intermediate (to eliminate irregularities in existing surfaces prior to new layer).

Materials for Asphalt Concrete Paving Mixes

- Coarse Aggregates
  - Retain #8 (Asphalt Institute), or #10.
  - Function in stability by interlocking & frictional resistance.
  - Crushed stone, crushed gravel, crushed slag.
  - Should be hard, durable, and clean.
- Fine Aggregates
  - Pass #8 retained # 200
  - Function in stability by interlocking & frictional resistance.
  - Crushed materials and sand.
  - Void filling of coarse aggregates.

Materials for Asphalt Concrete Paving Mixes

- Mineral Filler
  - Pass # 200
  - Function in voids filling
  - Limestone dust, Portland cement, Slag, Dolomite dust.
  - Required to be dry & free from lumps.
  - Hydrophobic in nature
- Bituminous Materials
  - Semi solid asphalt cement (AC)
  - More viscous grade (AC-20, AC-40) recommended for high traffic & hot climates.
  - AC-2.5, AC-5 used in medium or low traffic in cold regions.

- ***Various Specifications are available for aggregate gradations and composition for base, binder, and surface course (see Table 19.1 in Reference book).***
- ***See Table 19.4 in Text.***

Job Mix Formula

- Composition of the mix must be established
- Job Mix Formula (JMF) = Design of the mixture.
- See *Table 19.2 in Reference book* for JMF tolerance.
- JMF is determined in two steps:
  1. Selection & combination of aggregates to meet limits of specifications.
  2. Determination of optimum asphalt content.

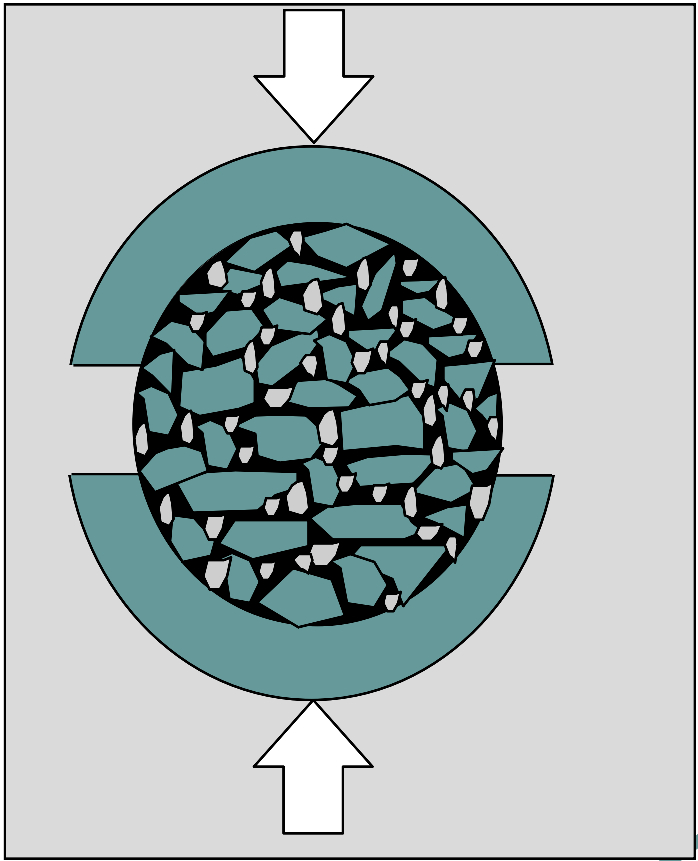
Selection & Combination of Aggregates

- In normal procedure…..coarse & fine aggregates in the vicinity of the project site are sampled & examined…..If suitable can be used…… Economical alternative….. If not…….Suitable aggregate source should be found.
- Combine aggregates (Determine proportions of the separate aggregates to give a combination that meet spec.)
- Proportions must be far from extreme to provide room for JMF tolerance.
- Process: Trial & Error with critical sieve selection for start with values.
- Spread sheet (Excel)
- *See Tables 19.4 & 19.5 in Reference book for example.*
- *See Example 19.1 in text.*

Determination of Optimum Asphalt Content

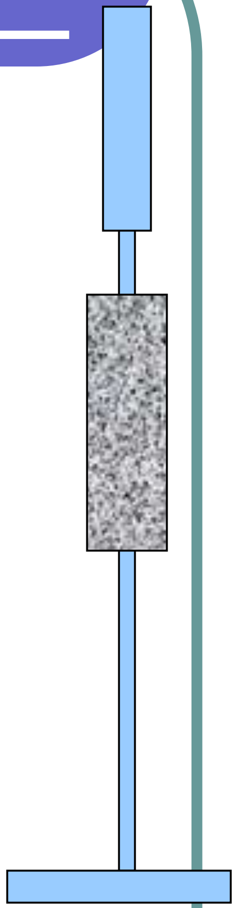
- Lab procedure: Prepare trial mixtures using selected aggregate proportions with various percentages of AC within limits of mix spec.
- Each trial mix is prepared to secure high density.
- Density, stability, and other properties are then determined
- Three mix design methods:
  1. Marshall
  2. Hveem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

MARSHALL MIX DESIGN



Marshall Mix Design

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



Marshall Mix Design Procedure

Step 1: Aggregate Evaluation

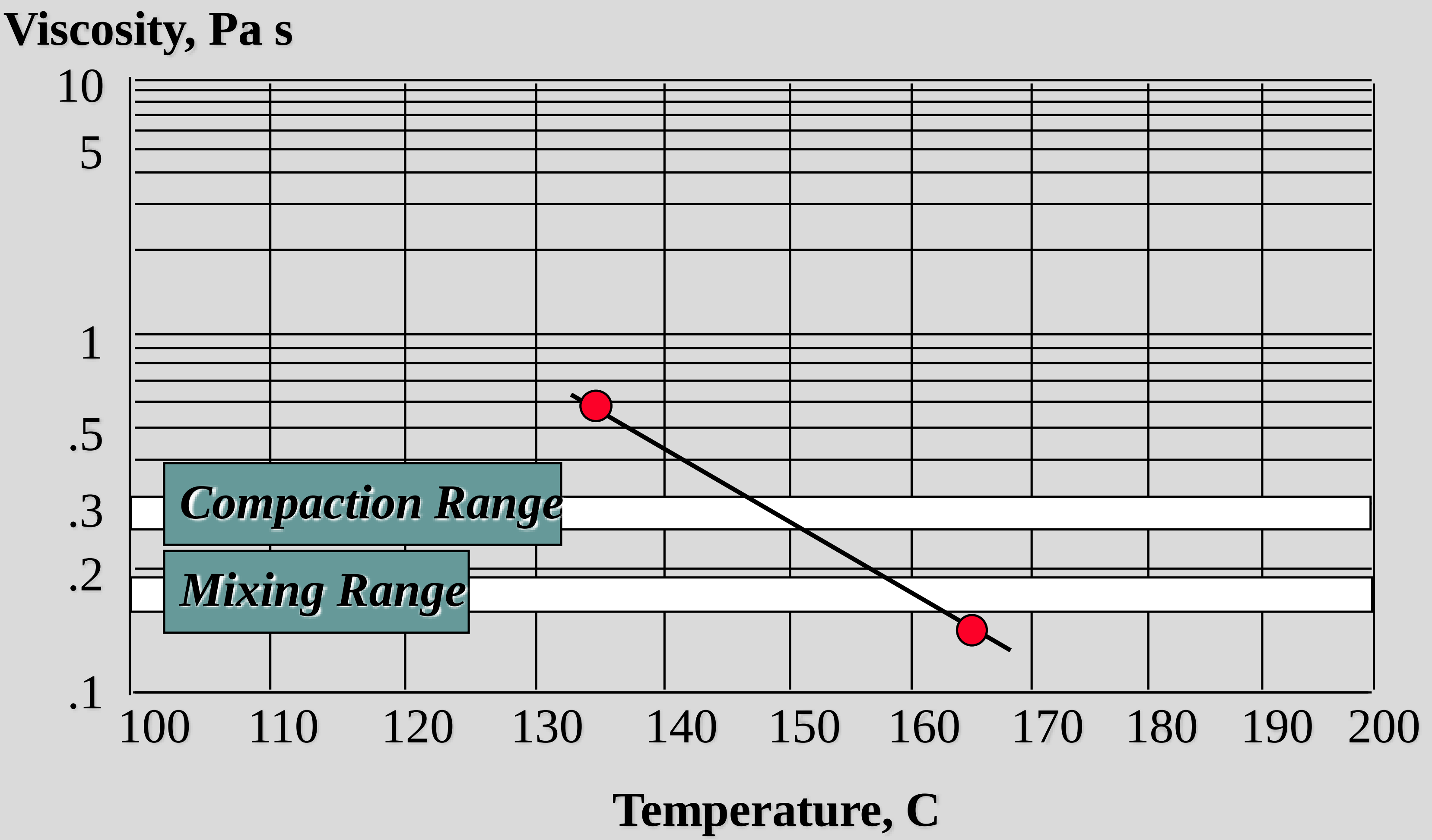
- Determine acceptability of aggregate for use in HMA (L.A. Abrasion, Soundness, Sand Equivalent, Flat & Elongated, % Crushed faces, …).
- If aggregate accepted, perform the following aggregate tests: Gradation, S.G.,& absorption.
- Perform blending calculations (deviate from max. density line to increase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

Marshall Mix Design Procedure Cont.

Step 2: Asphalt cement evaluation

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

Mixing/Compaction Temps



Marshall Mix Design Procedure Cont.

Step 3: Preparation of Marshal Specimen

- Dry, then sieve aggregates into sizes (individual sizes), at least 18 samples (1150 g), total of 25 kg & 4 liters of AC.
- Weigh out 18 specimens in separate containers and heat to mixing temperature.
- Prepare trial mix to check specimen height (2.5 inch +- 0.2), adjust quantity of aggregate by Q = (2.5/h1)* 1150.
- Heat sufficient AC to prepare a total of 18 specimens

Marshall Mix Design Procedure Cont.

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

Marshall Mix Design Procedure Cont.

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

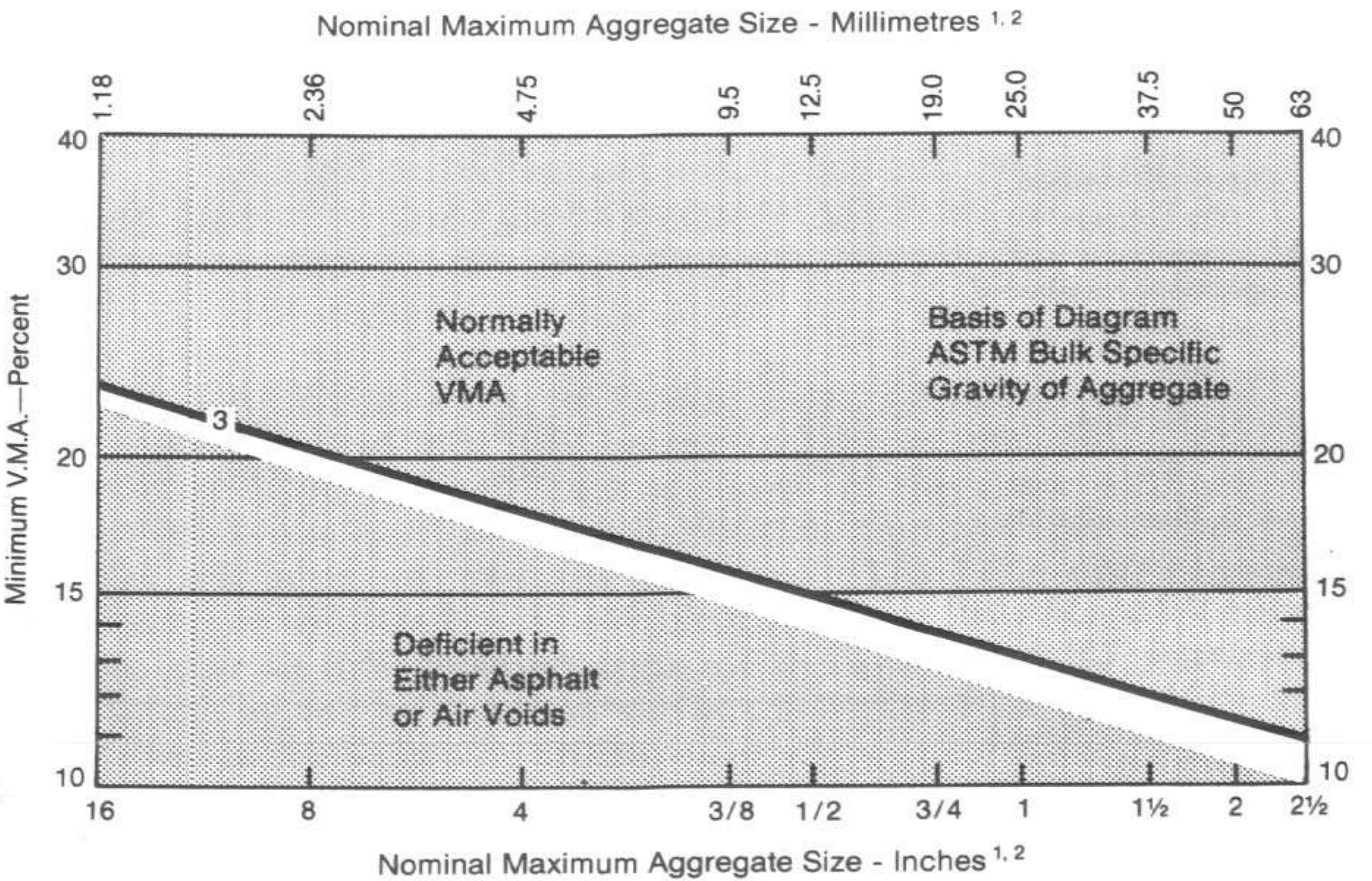
Mixing

Place bowl on mixer and mix until aggregate is well-coated

Marshall Design Criteria

	Light Traffic ESAL < 10^4	Medium Traffic 10^4 < ESAL< 10^6	Heavy Traffic ESAL > 10^6
Compaction	35	50	75
Stability N (lb.)	3336 (750)	5338 (1200)	8006 (1800)
Flow, 0.25 mm (0.1 in)	8 to 18	8 to 16	8 to 14
Air Voids, %	3 to 5	3 to 5	3 to 5
Voids in Mineral Agg. (VMA)	Varies with aggregate size		
Voids Filled w/Asph (VFA) [some agencies]	70 to 80	65 to 78	65 to 75

Minimum VMA Requirements



Marshall Mix Design Procedure Cont.

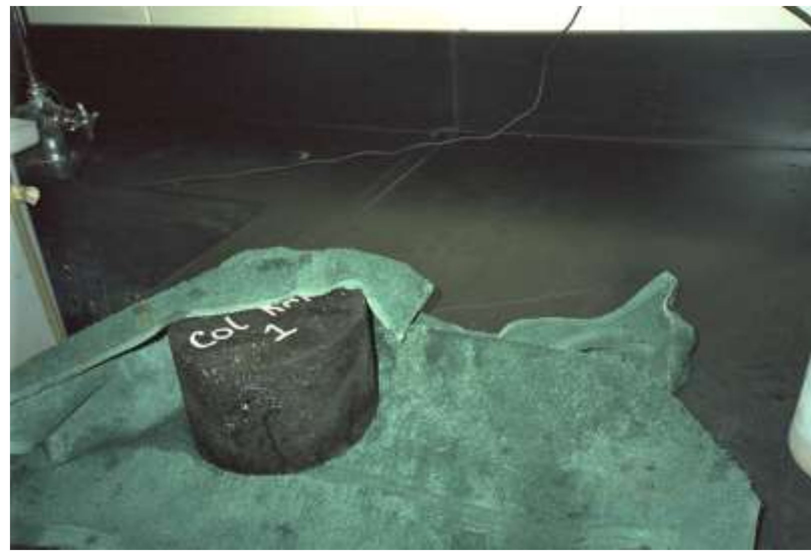
- Remove paper filter from top & bottom of specimen and allow to cool then extrude from mold using hydraulic jack.
- Mark and allow to sit @ room temp. overnight before further testing.
- Determine Bulk S.G. of each compacted specimen.
- Measure Rice S.G. for the loose mix specimen.

Bulk S.G. of Compacted Mix

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

$$\boxed{G_{mb} = \frac{W_{dry}}{W_{ssd} - W_{sub}}}$$

Bulk S.G. of Compacted Mix Cont.



Rice S.G. of Loose Mix

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

Rice S.G. of Loose Mix

- Fill pycnometer with water….dry outside…..take wt. (***E***) = Wt of Pycnometer + Aspahlt mix sample + water.
- G_{mm} = ***TMD*** = [***A*** / (***A + D – E***)]

$$\boxed{G_{mm} = \frac{Wt_{mix-loose}}{Wt_{pyc+w1} + Wt_{loose} - Wt_{pyc+w2+mix}}}$$

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

Rice S. G. of Loose Mix

% Weights of Total Mix

$$\boxed{Wt_{mix} = Wt_{asp} + Wt_{agg}}$$

$$\boxed{P'_{Wt_{asp}} = \frac{Wt_{asp}}{Wt_{mix}} * 100 = P_b}$$

$$\boxed{P'_{Wt_{agg}} = \frac{Wt_{agg}}{Wt_{mix}} * 100 = P_s = 100 - P_b}$$

S.G. of Aggregates

Bulk S.G. of combined aggregates

$$G_{sb,comb} = \frac{\sum_{i=1}^{n} P_{Wt_i}}{\sum_{i=1}^{n} \frac{P_{Wt_i}}{G_{sb,i}}}$$

P_{Wt_i} = % by wt of material i

Gsb = [(P1 +P2 +P3)/ ((P1/G1) + (P2/G2) + (P3/G3))]

P1,2,3 = % by wt of aggregates 1,2, and 3

G1,2,3 = Bulk S.G. of aggregates 1, 2, and 3

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

Where A1,2,3 = Absorption of aggregates 1,2, and 3

Effective S.G. of Aggregates

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

$$G_{se,comb} = \frac{P_s}{\dfrac{100}{G_{mm}} - \dfrac{P_b}{G_{asp}}}$$

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

Pb = % of asphalt by total wt. of mixture

Gmm = Max. theoretical S.G

Gasp = Gb = S.G. of asphalt

Max. Theoretical S.G

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

Gmm = (Pmm =100) / [((100 – Pb) /Gse) + ((Pb /Gb))]

= (100) / [((Ps) /Gse) + ((Pb /Gb))]

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

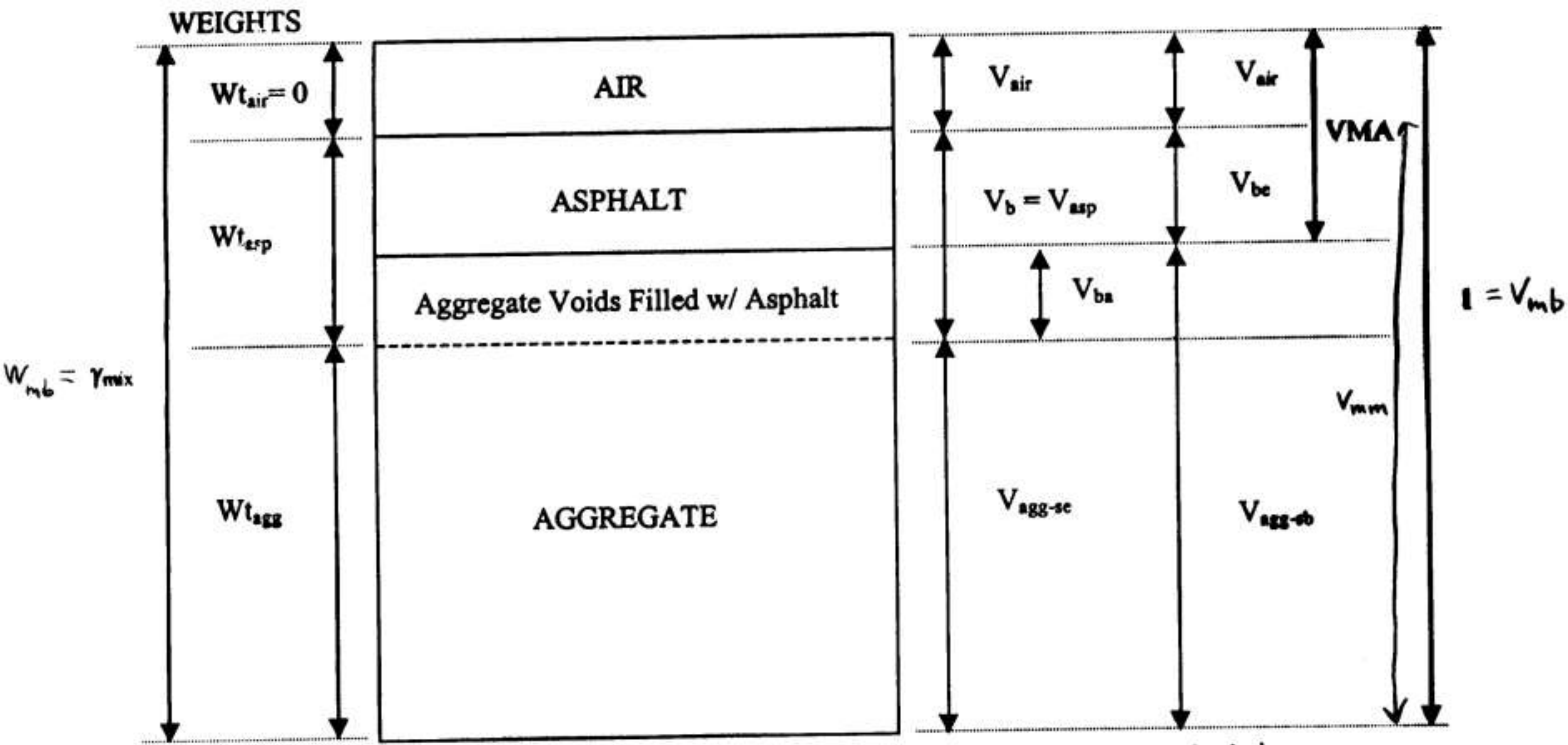
Pb = % of asphalt by total wt. of mixture

Gse = Effective S.G. of aggregates

Gb = S.G. of asphalt

Density Void Analysis

WEIGHT-VOLUME RELATIONSHIPS FOR ASPHALT CONCRETE



given γ_{mix}, % a.c. $\longrightarrow$ weights

to convert to volumes $\longrightarrow$ $G_{sb\text{-}od}$, G_{se}, G_{mm}, G_{asp}

Density & Void Analysis (Volumetrics)

$$V_{asp} = V_b = \frac{Wt_{asp}}{G_{asp} * \gamma_w}$$

$$V_{agg-se} = \frac{Wt_{agg}}{G_{se,comb} * \gamma_w}$$

$$V_{agg-sb} = \frac{Wt_{agg}}{G_{sb-od,comb} * \gamma_w}$$

$$V_{ba} = V_{agg-sb} - V_{agg-se}$$

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

% Air Voids

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

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

$$\%V_{air} = P_a = VTM = \frac{G_{mm} - G_{mb}}{G_{mm}} * 100$$

$$\%V_{air} = 100 * (1 - V_b - V_{agg-se})$$

$3 \leq \%Vair \leq 8$

Density of Compacted Mix

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

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

Density of water = 1000 kg/ m^3 (62.4 lb/ft^3)

Voids In Mineral Aggregates (VMA)

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

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

$$\%VMA = 100 * (1 - V_{agg-sb})$$

Voids Filled with Asphalt (VFA)

- The % of the volume of the VMA that is filled with asphalt cement.
- VFA = [Veb/ ((Veb + Vair) = VMA)]100

$$\%VFA = \frac{VMA - VTM}{VMA} * 100$$

$$\%VFA = \frac{V_{be}}{1 - V_{agg-sb}} * 100$$

Effective Asphalt (Pbe)

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

$$\%P_{be} = P_b - \frac{P_{ba} * P_s}{100}$$

$$\%P_{be} = \frac{V_{be} G_{asp} \gamma_w}{Wt_{agg} + Wt_{asp}} * 100$$

Density

- used to control quality during construction
  - % of max theoretical lab density

$$D_{mm} = G_{mm}\gamma_w$$

- % of optimum lab density

$$D_{mb} = G_{mb}\gamma_w$$

  - compare with field density
    - nuclear density meter (non-destructive)
    - cores

$$D_{mb-field} = G_{mb-field}\gamma_w$$

Marshal Stability & Flow

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

Marshal Stability & Flow Cont.

- Heights
  - Used to correct stability measurements
- Stability and flow
  - Specimen immersed in water bath @ 60^{o}C for 30 to 40 minutes.
  - Remove from bath…. Pat with towel….. Then place in Marshal Testing head.
  - Apply load @ 2 inch (50 mm)/min loading rate
  - Max. load = uncorrected stability (N or Lb)
  - Corresponding vertical deformation = flow (0.01 inch or 0.25 mm)
  - When load start to decrease, remove flowmeter.
  - Note: Test should be completed in 60 sec.

Marshall Stability and Flow

Tabulating & Plotting Test Results

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

Test Results & Mix Properties for Marshall mix

Sample #	%AC	Wt. in Air (Dry)	Wt. in water (SSD)	Wt. in air (SSD)	Volume	Bulk Density	Theor. Max Density	Air Voids	VMA	VFA	Measured Stability	Corrected Stability	Flow
1	5.0	1167.8	650.7	1169.0	518.3	140.6					2400	2400	11
2		1164.9	647.0	1166.2	519.2	140.0					2630	2630	11
3		1165.1	651.0	1167.0	516	140.9					2560	2560	11
Avg						140.5	153.1	8.2	18.3	55.2		2530	11

Table 4–16. Test Results and Mix Properties for Marshall Mix I

Sample No.	Asphalt Content	Weight in Air (Dry)	Weight in Water (SSD)	Weight in Air (SSD)	Volume	Bulk Density	Theoretical Max. Density	Air Voids	VMA	Voids Filled	Measured Stability	Corrected Stability	Flow
1	5.0	1167.8	650.7	1169.0	518.3	140.6					2400	2400	11
2		1164.9	647.0	1166.2	519.2	140.0					2630	2630	11
3		1165.1	651.0	1167.0	516.0	140.9					2560	2560	12
Average						140.5	153.1	8.2	18.3	55.2		2530	11
1	5.5	1166.4	652.4	1167.5	515.1	141.3					2520	2520	11
2		1179.0	661.4	1180.6	519.2	141.7					2690	2690	12
3		1169.4	650.9	1171.0	520.1	140.3					2650	2650	13
Average						141.1	152.5	7.5	18.4	59.2		2620	12
1	6.0	1170.4	656.7	1171.0	514.3	142.0					2620	2620	13
2		1181.1	664.7	1181.9	517.2	142.5					2710	2710	13
3		1187.3	670.9	1189.0	518.1	143.0					2980	2980	12
Average						142.5	151.3	5.8	18.1	68.0		2770	13
1	6.5	1174.2	661.6	1174.7	513.1	142.8					2800	2800	12
2		1185.3	667.7	1186.0	518.3	142.7					2730	2730	13
3		1182.3	667.7	1182.9	515.2	143.2					2900	2900	14
Average						142.9	149.9	4.7	18.3	74.3		2810	13
1	7.0	1177.3	663.0	1177.9	514.9	142.7					2820	2820	14
2		1183.4	665.4	1183.6	518.2	142.5					2730	2730	14
3		1192.8	675.7	1193.3	517.6	143.8					2790	2790	15
Average						143.0	148.5	3.7	18.6	80.1		2780	14
1	7.5	1181.9	663.3	1182.3	519.0	142.1					2650	2650	16
2		1173.0	660.2	1173.5	513.3	142.6					2380	2380	16
3		1182.2	666.1	1182.7	516.6	142.8					2590	2590	14

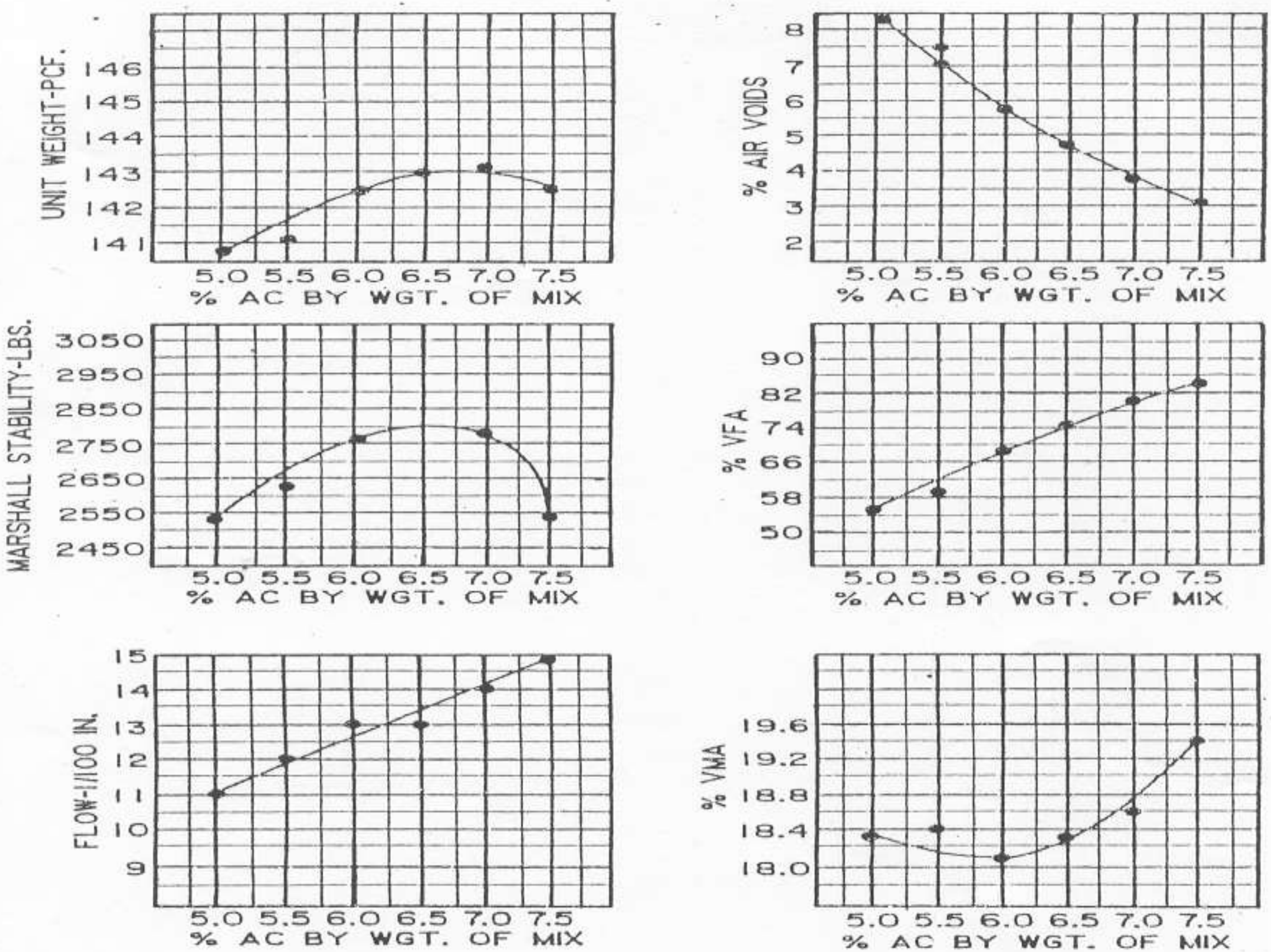
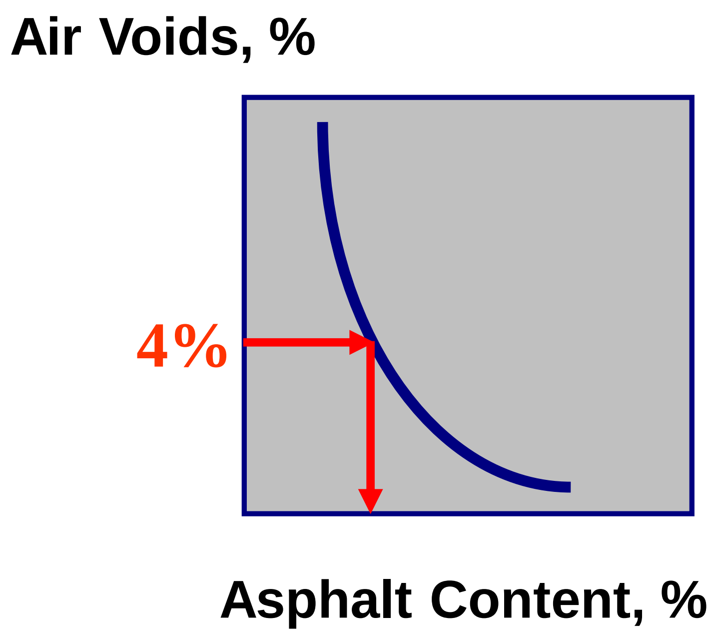


Figure 4–24. Graphical Illustration of HMA Design Data by Marshall Method

Determination of Optimum AC Content

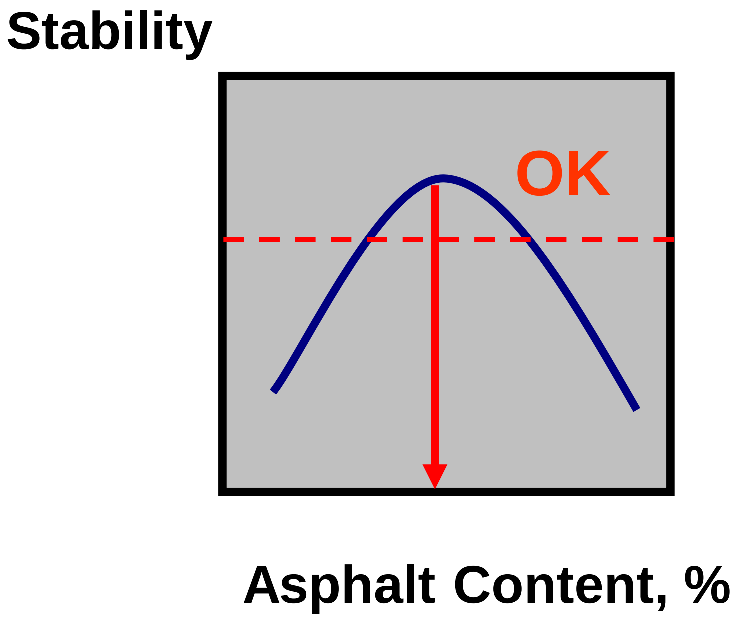
- National Asphalt Pavement Association (NAPA) Procedure
- Asphalt Institute Procedure

(NAPA) Procedure



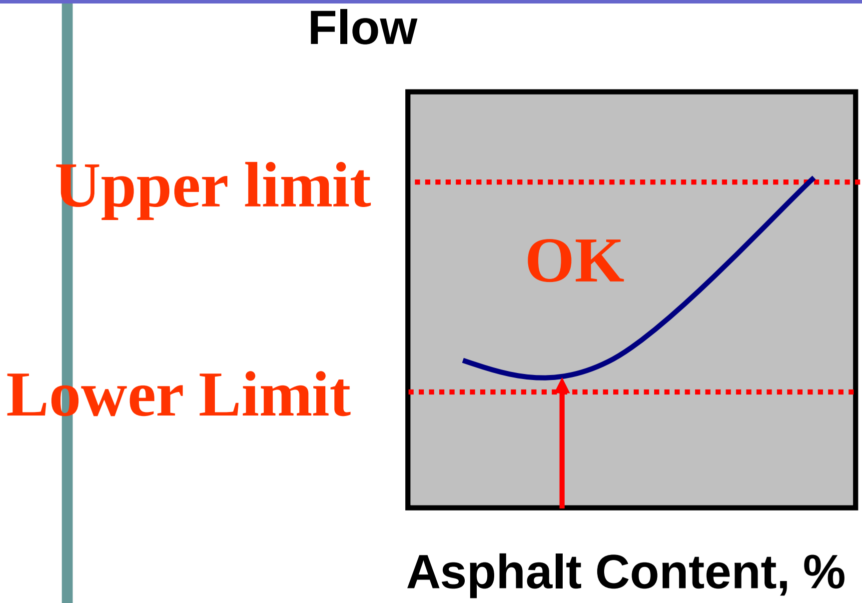
Target optimum asphalt content = the asphalt content at 4% air voids

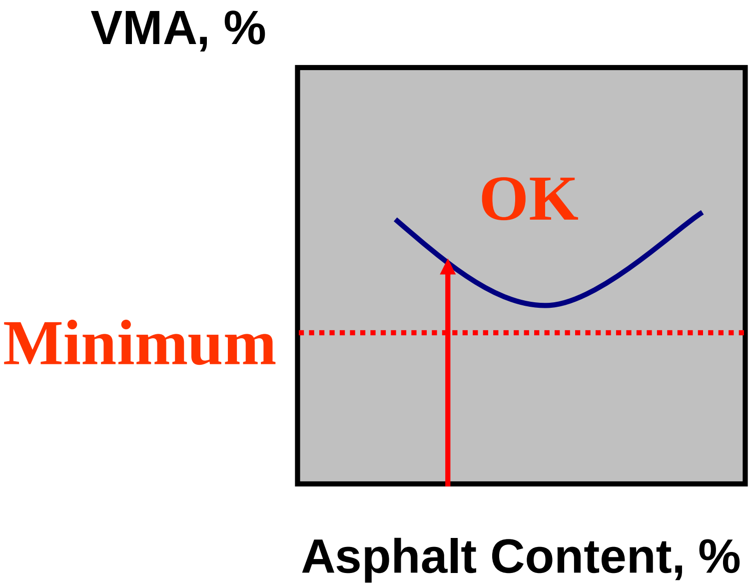
Marshall Design Use of Data
NAPA Procedure



The target stability is checked

Marshall Design Use of Data
NAPA Procedure

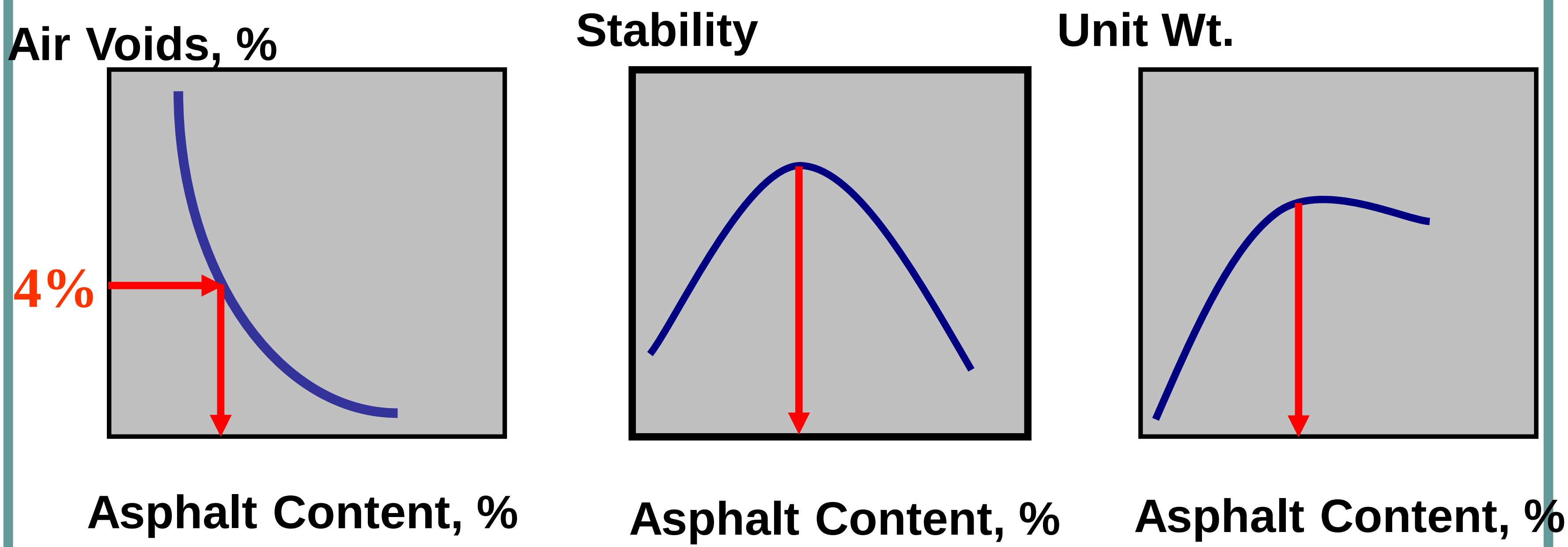




Use target optimum asphalt content to check if these criteria are met

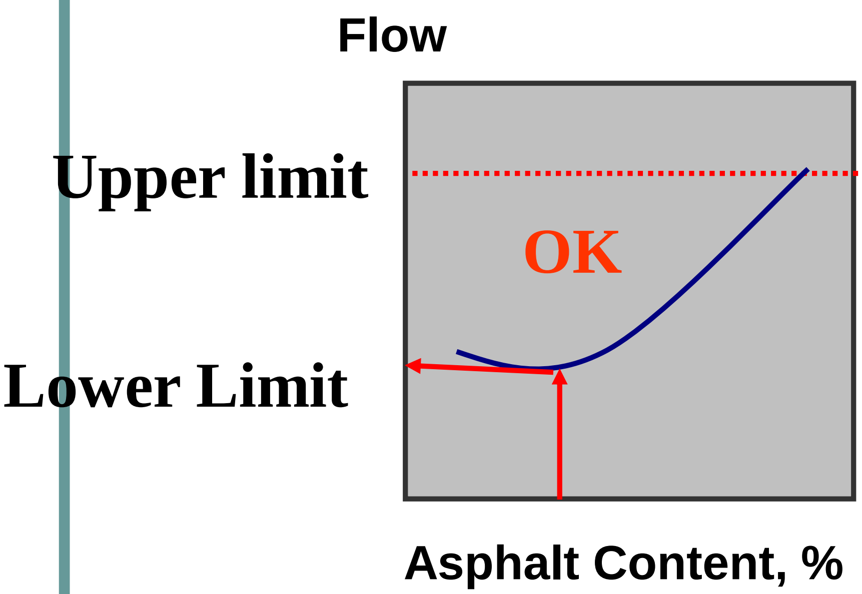
If not - adjust slightly to meet all criteria if possible; else change gradation and repeat analysis

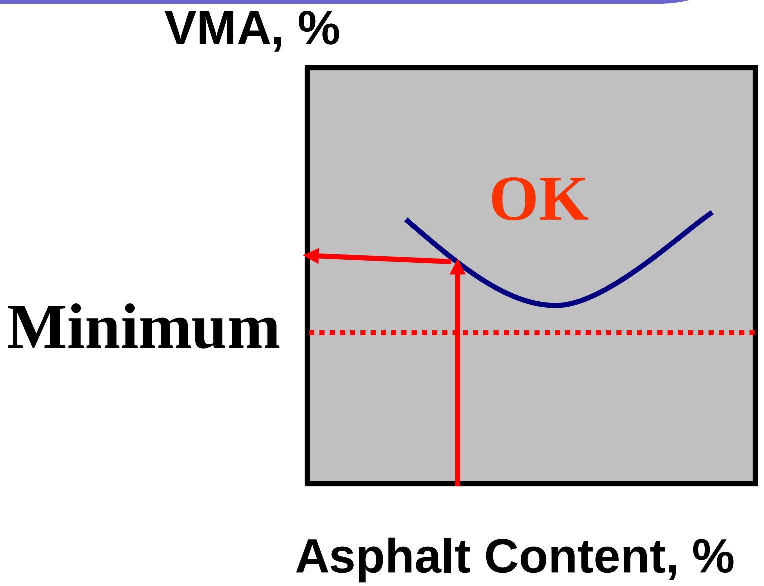
Marshall Design Use of Data
Asphalt Institute Procedure



Target optimum asphalt content = average

Marshall Design Use of Data
Asphalt Institute Procedure





Use target optimum asphalt content to check if ALL criteria are met

(If not - adjust slightly to meet all criteria if possible; else change gradation and repeat analysis)

Guidelines for Adjustments

- When mix design for optimum asphalt content does not satisfy all the requirements, it is necessary to adjust the original blend of aggregates.
- Trial mixes can be adjusted using the following general guidelines.

Low Voids & Low Stability

- VMA can be increase by adding more coarse aggregates.
- Or, Alternatively, asphalt content can be reduced (only if the asphalt is more than what is normally used, and if the excess is not required as replacement for the amount absorbed).
- Reducing asphalt should be done in care since this might reduce durability and increase permeability.

Low Voids & Satisfactory Stability

- This mix can lead to reorientation of the particles and additional compaction due to traffic can lead to bleeding of asphalt.
- This cam be solved by adding more aggregates.

High Voids & Satisfactory Stability

- High voids increase permeability.
- Air and water can circulate through the pavement causing hardening of the asphalt.
- This can be solved by increasing the amount of mineral filler in the mix.

Satisfactory Voids & Low Stability

- This condition suggest low quality aggregates,
- The aggregate quality should be improved.

High Voids & Low Stability

- Two steps can be carried out:

1- Adjust the voids (increase mineral filler).

- If stability is not improved

2- Consider improvement of the aggregate quality.

- ***See Example 19.2 & 19.3 in text***

Marshall Design Method

- Advantages
  - Attention on voids (volumetrics), strength, durability
  - Inexpensive equipment
  - Easy to use in process control/acceptance
- Disadvantages
  - Impact method of compaction
  - Does not directly consider shear strength
  - Load perpendicular to compaction axis
  - developed for dense grad, $\leq$ 1”max size, viscosity or pen graded ac

Hot-Mix, Cold-Laid Asphalt Concrete

- Manufactured hot, can be immediately laid or can be stockpiled for use at future date.
- Suitable for small jobs where it may be uneconomical to setup a plant.
- Marshall method can be used for mix design but high penetration asphalt is normally used (AC 200-300).
- Aggregates dries, then cooled to , the mixed with about 0.75% MC-30 + wetting agent.
- After that the high penetration asphalt is added (optimum content as found by Marshall).
- The addition of water is necessary to ensure that the materials remains workable.
- 2% water added if material is to be used in 2 days.
- 3% water added if to be stockpiled.
- The mix the then thoroughly mixed to produce uniform mix.

Cold-Mix, Col-Laid Asphalt Concrete

- Emulsified asphalt and low viscosity cut back asphalt are used to produce this type.
- They can be used after production or stockpiled for later use.
- The production process is similar to hot mix asphalt, except that the mixing is done at normal temperatures and it is not always necessary to dry the aggregate.
- Saturated aggregates and aggregates with surface moisture should be dried.
- Type and grade of asphalt material used depends on the gradation, the used of the materials, and whether the material is to be stockpiled for long times.
- See ***Table 19.1*** in text for suitable types of asphalt for different types of cold mixes.

Pavement Materials & Design (110401466) Flexible Pavement Thickness Design / AASHTO Method

Source:

Chapter 20: Traffic & Highway Engineering by Nicholas Garber and Lester Hoel, Third Edition, Brooks/Cole.

Chapter 16: Highway Engineering, by Paul Wright & Karen Dixon, 7th Edition, Wiley & sons

Instructor:

Dr. TALEB M. AL-ROUSAN

Pavement Types

Flexible Pavement:

- Pavement constructed of bituminous & granular materials.
- A structure that maintains intimate contact with subgrade and distribute loads to it, and depends on aggregate interlock, particle friction, and cohesion for stability.

Rigid pavement:

- Pavement constructed of Portland cement concrete.
- It is assumed to posses considerable flexural strength that will permit it to act as a beam and allow it to bridge minor irregularities in base and subgrade.

Typical Cross Section for Conventional Flexible Pavement

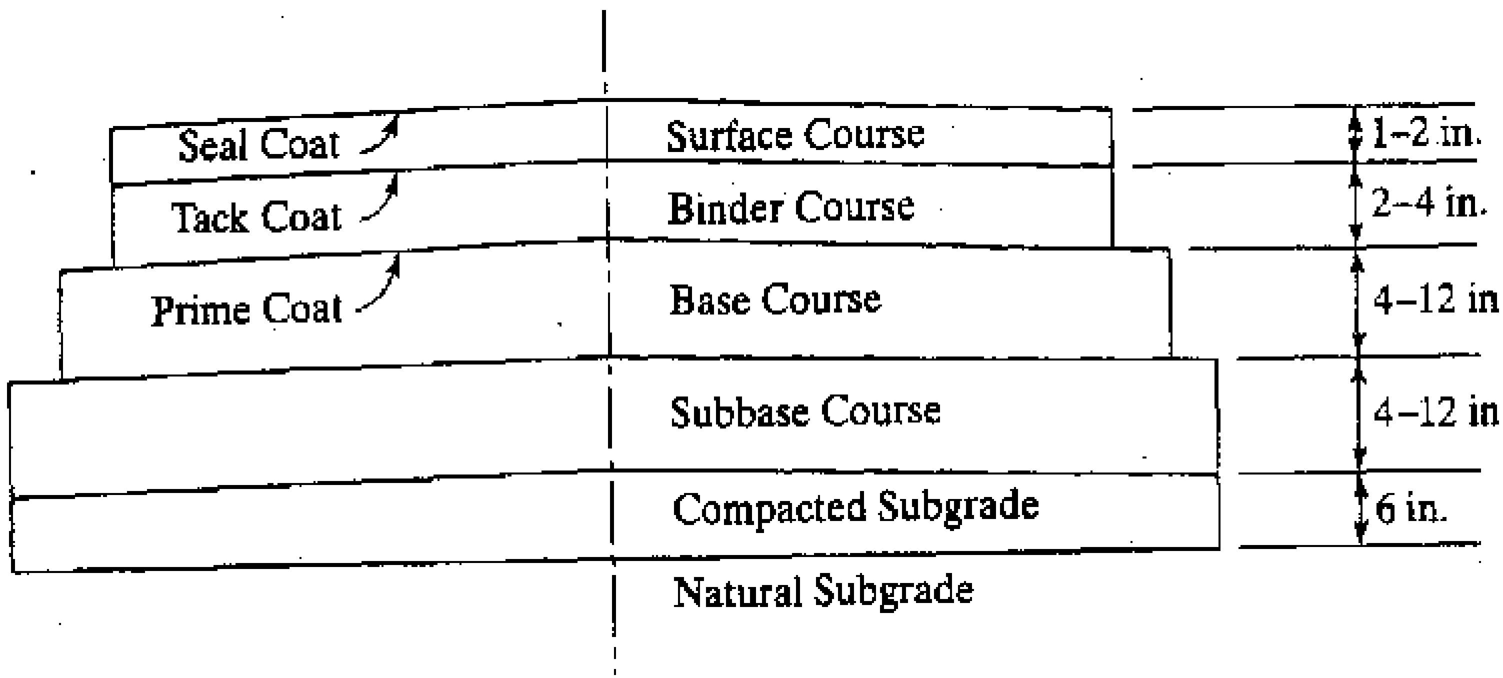


FIGURE 1.2

Typical cross section of a conventional flexible pavement (1 in. = 25.4 mm).

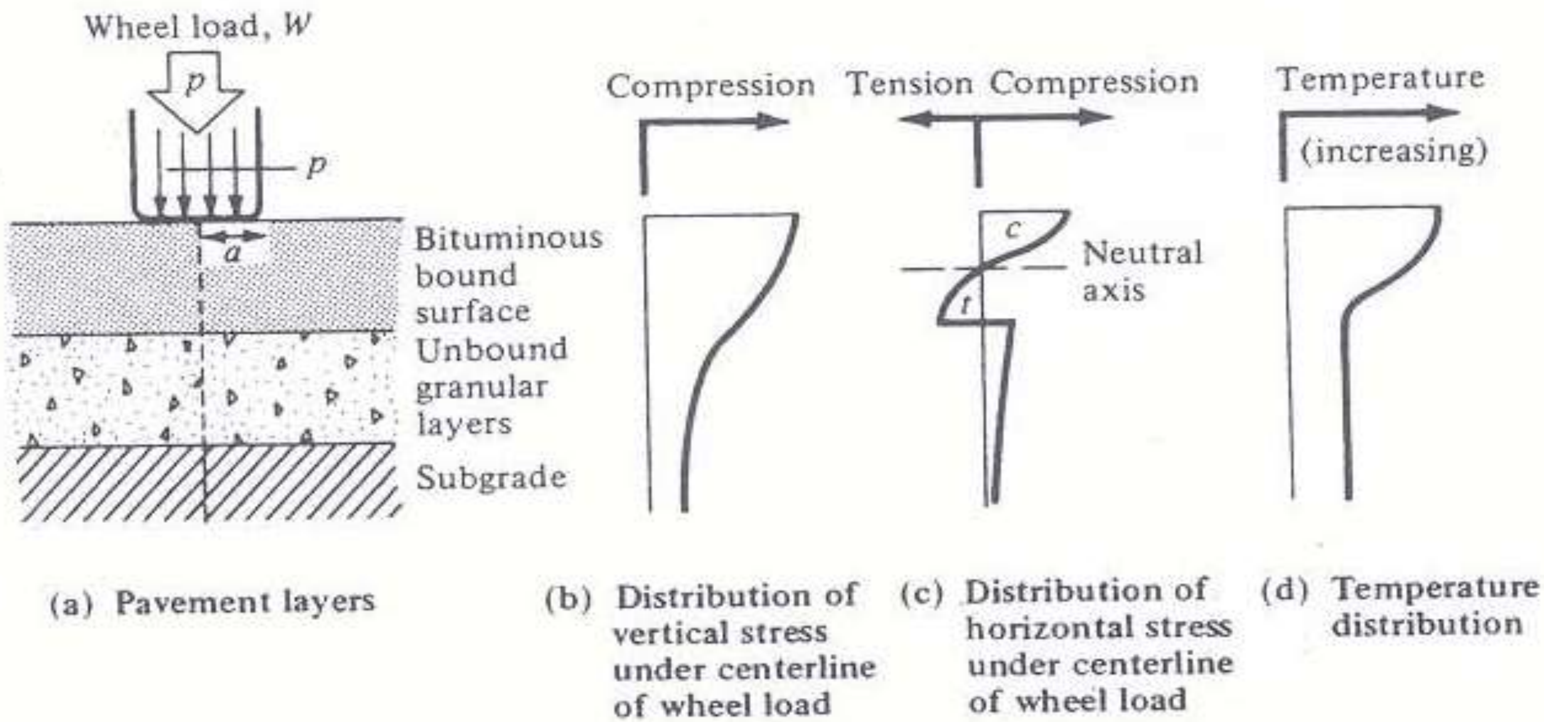
Principles of Flexible Pavement Design

- Pavement structure is considered as a multilayered elastic system.
- Materials in each layers is characterized by certain physical properties (Mr, E,….).
- It assumes that subgrade is infinite in both the vertical and horizontal directions.
- Other layers are finite the vertical direction and infinite in the horizontal direction.
- The application of the wheel load causes a stress distribution (See **Figure 20.2**)..

Principles of Flexible Pavement Design Cont.

- The maximum vertical stresses are compressive and occur directly under the wheel load.
- Stresses decrease with increase in depth from the surface.
- The maximum horizontal stress also occurs directly under the wheel load but can be either tensile or compressive.
- When the load and pavement thickness are within certain ranges, horizontal compressive stresses will occur above the neutral axis, whereas horizontal tensile stresses will occur below the neutral axis.
- The temperature distribution within the pavement structure will also have an effect on the magnitude of the stresses

Figure 20.2 Typical stresses and temperature distribution in flexible pavements under wheel load



p = wheel pressure applied on pavement surface

a = radius of circular area over which wheel load is spread

c = compressive horizontal stress

t = tensile horizontal stress

Figure 20.2 Typical Stress and Temperature Distributions in a Flexible Pavement Under a Wheel Load

Principles of Flexible Pavement Design

- The design of the pavement is therefore generally based on on strain criteria that limit both horizontal and vertical strain below those that will cause excessive cracking and permanent deformation.
- These criteria are considered in terms of repeated load applications.
- Most commonly used methods:
  - Asphalt Institute Method
  - AASHTO method
  - California method

Elements of Thickness Design

1. Traffic Loading
2. Climate or Environment
3. Material Characteristics
4. Others: Cost, Construction, Maintenance, Design period.

Traffic Loading

- Pavement must withstand the large umber of repeated loads of variable magnitudes
- Primary loading factors:
  1. Magnitude of axle loads *(controlled by legal load limits).*
  2. Volume & composition of axle load *(Traffic survey, load meters, & growth rate).*
  3. Tire pressure & contact area.

- Equivalent Standard Axle Load ESAL (80 kN (18,000 lb or 18 kips) single axle load.
- The total no. of ESAL is used as a traffic loading input in the design of pavement structure.

Climate or Environment

- Climate or environment affect the behavior & performance of materials used in pavements

1. Temperature: high temp. cause asphalt to loose stability, low temp. cause asphalt to become hard & stiff, and frost heave.
2. Moisture: Frost related damage, volume changes due to saturation, chemical stability problems with moisture existence (Stripping).

Material Characteristics

- Required materials characteristics:

1. Asphalt surface: Material should be strong & stable to resist repeated loading (fatigue).
2. Granular base & subbase: gradation, stable & strong to resist shears from repeated loading.
3. Subgrade: soil classification, strong & stable.

- Various standard tests are available for determination of desired properties.
- CBR, Marshal stability, Resilient Modulus, Shear strength.
- Mr (psi) = 1500 CBR   or Mr (Mpa) = 10.3 CBR

Figure 20.3 Spread of wheel load pressure through pavement structure

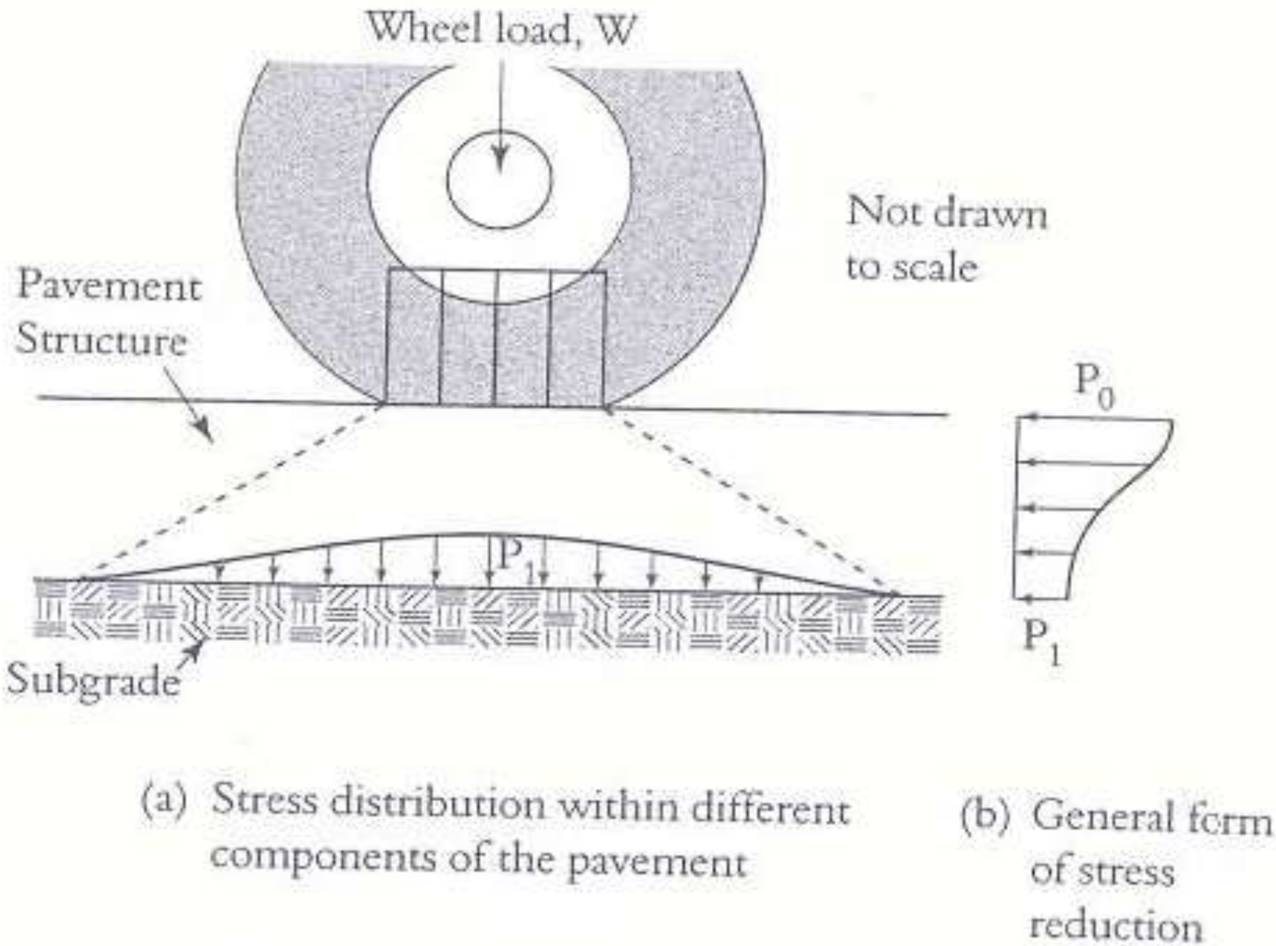


Figure 20.3 Soread of Wheel Load Pressure Through Pavement Structure

Figure 20.4 Tensile and compressive stresses in pavement structure

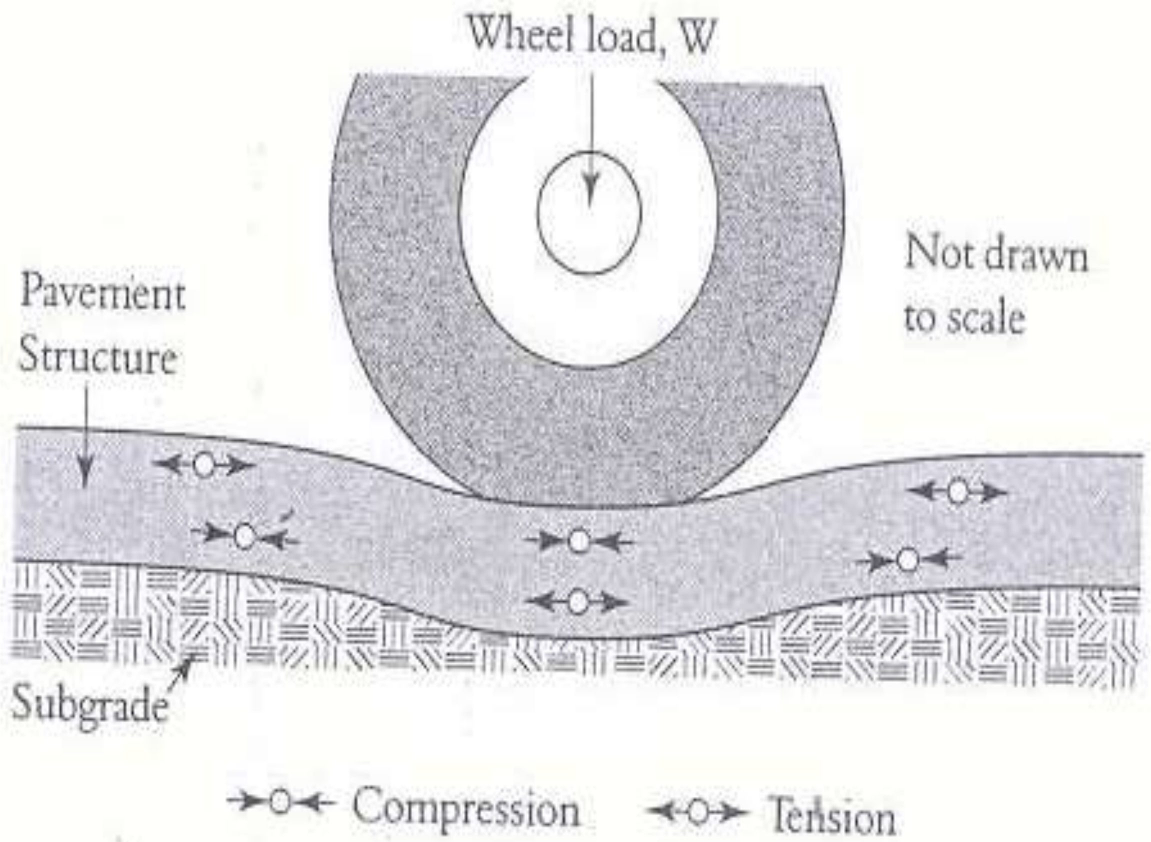


Figure 20.4 Schematic of Tensile and Compressive Stresses in Pavement Structure

AASHTO Method/ Introduction

- Based on the results of AASHTO road test conducted on Ottawa, Illinois.
- It is an effort that was carried out with the cooperation of all states and several industry groups.
- Many types of test section were prepared and tested.
- Rigid & flexible
- A-6 subgrade
- Four lane divided highway loops.
- Tangents sections with different lengths (> 100 ft).
- Flexible: HMA surface (1 - 6 “), well-graded crushed limestone base (0 - 9”), and uniformly graded sand-gravel subbase (0 - 6”).
- Vehicles were driven for thousand repetitions (single axle (2,000 – 30, 000 lb) and tandem (24,000 – 48,000 lb).

AASHTO Method/ Introduction

- Data were collected from pavement with respect to extent of cracking and amount of patching required to maintain the section in service.
- Longitudinal and transverse profiles were obtained to determine extent of rutting, surface deflection caused by loaded vehicles moving at very low speeds,
- Pavement curvature at different speeds, stress imposed on the subgrade and temperature distribution in the pavement layers.
- Data were thoroughly analyzed and the results formed the basis for the AASHTO method
- Interim guide was published in 1961, revised in 1972, further edition 1986, then 1993

AASHTO Design Method/ Design Considerations

- This method Incorporates various design inputs including :
  - Pavement Performance (Loss of serviceability).
  - Traffic
  - Subgrade soil properties
  - Materials of construction
  - Environmental effects
  - Drainage
  - Reliability

Pavement Performance

- Structural and functional performances.
- Structural performance: related to the physical condition of the pavement with respect to the factors that have negative impact on the capability of the pavement to carry the traffic load.
  - These factors include: cracking, faulting, raveling, and so forth.
- Functional performance: is an indication of how effectively the pavement serves the user.
  - The main factor considered under functional performance is riding quality.

Functional Performance

- To quantify pavement performance, a concept known as the serviceability performance was developed.
- Procedure was developed to determine the present serviceability index ***(PSI)*** of the pavement based on its roughness and distress which were measured in terms of extent of cracking, patching, and rut depth for flexible pavements.
- ***PSI*** is a surrogate measure for PSR (present serviceability rating)
- ***PSR*** is based on panel of engineers rating (subjective)
- PSI is based on physical measurement of pavement roughness using special equipments (objective)

Serviceability

- Pavement ability to serve traffic at some instances during its life.
- Initial & terminal serviceability indices must be established to compute the change in serviceability (***ΔPSI***) in the design equation.
- Initial PSI = F(Pavement type & construction quality) [4.2 for flexible & 4.5 for rigid).
- Terminal PSI = Lowest index that is tolerable for a pavement before it require rehabilitation [2.5 for major highways & 2.0 for other roads].

Pavement Serviceability Concept

- It involves the measurement of the behavior of the pavement under traffic and its ability to serve traffic at some instance during its life.
- The evaluation is systematic but subjective.
- Evaluated by rating of the riding surface by individuals who travel over it.
- Can be evaluated also by means of certain measurements made on the surface.
- Scale: 0 (very poor) to 5 (very good).
- ***PSI*** = F (Roughness or slope variance in the two wheel paths, the extent & type of cracking or patching, and the pavement rutting displayed at the surface].

Traffic Characteristics

- Determined in terms of number of repetitions of an 18,000 lb (80)kN single axle load applied to the pavement on two sets of dual tires ***(Equivalent Single Axle Load (ESAL)).***
- *See next slides for the determination of the ESAL.*

Traffic Analysis

1. Estimate the number of vehicles of different types (Passenger cars, single unit trucks, multi unit trucks of various sizes) expected to use the pavement over the design period.

In case data are not available, estimates can be made from ***Table 20.4 in text*** *which gives representative values for the united states.*

Traffic Analysis Cont.

2. Estimate the (%) of total truck traffic expected to use the design lane.

Design lane: Lane expected to receive the severe service.

- % of trucks is found by observation

- *In case data are not available, estimates can be made from **Table 20.4** which gives representative values for truck distribution in the united states.*
- (see ***Table 16.1*** also in the Reference text).

Table 20.4 Distribution of Trucks

Table 20.4 Distribution of Trucks on Different Classes of Highways—United States*

Truck Class	Rural Systems: Interstate	Rural: Other Principal	Rural: Minor Arterial	Rural: Collectors Major	Rural: Collectors Minor	Rural: Range	Urban Systems: Interstate	Urban: Other Freeways	Urban: Other Principal	Urban: Minor Arterial	Urban: Collectors	Urban: Range
Single-unit trucks												
2-axle, 4-tire	43	60	71	73	80	43–80	52	66	67	84	86	52–86
2-axle, 6-tire	8	10	11	10	10	8–11	12	12	15	9	11	9–15
3-axle or more	2	3	4	4	2	2–4	2	4	3	2	<1	<1–4
All single-units	53	73	86	87	92	53–92	66	82	85	95	97	66–97
Multiple-unit trucks												
4-axle or less	5	3	3	2	2	2–5	5	5	3	2	1	1–5
5-axle**	41	23	11	10	6	6–41	28	13	12	3	2	2–28
6-axle or more**	1	1	<1	1	<1	<1–1	1	<1	<1	<1	<1	<1–1
All multiple units	47	27	14	13	8	8–47	34	18	15	5	3	3–34
All trucks	100	100	100	100	100		100	100	100	100	100	

(Column heading above all data columns: Percent Trucks)

* Compiled from data supplied by the Highway Statistics Division, Federal Highway Administration.
**Including full-trailer combinations in some states.
SOURCE: *Thickness Design—Asphalt Pavements for Highways and Streets,* Manual Series No. 1, The Asphalt Institute, Lexington, Ky., February 1991.

Traffic Analysis Cont.

3. **When the axle load of each vehicle type is known**, these can be converted to ESAL using the equivalency factors given in ***Table 20.3*** in text or ***Table 16.3*** in Ref

If the axle load is unknown, the ESAL can also be found from the vehicle types by using a truck factor for that vehicle type.

Truck Factor (TF): The no. of ESALs contributed by passage of a vehicle.

For each weight class, determine the truck factor.

Traffic Analysis Cont.

TF = [SUM (No. of axles in each wt. class **X** EALF)] **/** Total No. of vehicles

- Truck factor can be estimated Using ***Table 20.5*** in text or ***Table16.2*** from ref.
- Equivalent Axle Load factor or Load equivalency factor (EALF) presented in ***Table 20.3*** in text or ***Table 16.3*** in Ref.
- EALF: Defines the damage per pass to a pavement by the axle of question relative to the damage per pass of a standard axle load (80 kN or 18-kip)
- EALF depends on type of pavement, thickness or structural capacity, and failure conditions (based on experience).
- See Truck Factor Example provided in ***Figure 16.8*** Ref. and example in ***Table 20.8*** in text.

Table 20.3 Load Equivalency Factors

Gross Axle Load		*Load Equivalency Factors*		
kN	*lb*	*Single Axles*	*Tandem Axles*	*Tridem Axles*
4.45	1,000	0.00002		
8.9	2,000	0.00018		
17.8	4,000	0.00209	0.0003	
26.7	6,000	0.01043	0.001	0.0003
35.6	8,000	0.0343	0.003	0.001
44.5	10,000	0.0877	0.007	0.002
53.4	12,000	0.189	0.014	0.003
62.3	14,000	0.360	0.027	0.006
71.2	16,000	0.623	0.047	0.011
80.0	18,000	1.000	0.077	0.017
89.0	20,000	1.51	0.121	0.027
97.9	22,000	2.18	0.180	0.040
106.8	24,000	3.03	0.260	0.057
115.6	26,000	4.09	0.364	0.080
124.5	28,000	5.39	0.495	0.109
133.4	30,000	6.97	0.658	0.145
142.3	32,000	8.88	0.857	0.191
151.2	34,000	11.18	1.095	0.246
160.1	36,000	13.93	1.39	0.313
169.0	38,000	17.20	1.70	0.393
178.0	40,000	21.08	2.08	0.487
187.0	42,000	25.64	2.51	0.597
195.7	44,000	31.00	3.00	0.723

Table 20.3 Load Equivalency Factors (*continued*)

Gross Axle Load		*Load Equivalency Factors*		
kN	*lb*	*Single Axles*	*Tandem Axles*	*Tridem Axles*
204.5	46,000	37.24	3.55	0.868
213.5	48,000	44.50	4.17	1.033
222.4	50,000	52.88	4.86	1.22
231.3	52,000		5.63	1.43
240.2	54,000		6.47	1.66
249.0	56,000		7.41	1.91
258.0	58,000		8.45	2.20
267.0	60,000		9.59	2.51
275.8	62,000		10.84	2.85
284.5	64,000		12.22	3.22
293.5	66,000		13.73	3.62
302.5	68,000		15.38	4.05
311.5	70,000		17.19	4.52
320.0	72,000		19.16	5.03
329.0	74,000		21.32	5.57
338.0	76,000		23.66	6.15
347.0	78,000		26.22	6.78
356.0	80,000		29.0	7.45
364.7	82,000		32.0	8.2
373.6	84,000		35.3	8.9
382.5	86,000		38.8	9.8
391.4	88,000		42.6	10.6
400.3	90,000		46.8	11.6

TABLE 16-3 Typical Load-Equivalency Factors

Gross Axle Load				
(KN)	*(lb)*	*Single Axle*	*Tandem Axles*	*Tridem Axles*
26.7	6,000	0.01043	0.001	0.0003
44.5	10,000	0.0877	0.007	0.002
53.4	12,000	0.189	0.014	0.003
62.3	14,000	0.360	0.027	0.006
71.2	16,000	0.623	0.047	0.011
80.0	18,000	1.000	0.077	0.017
89.0	20,000	1.51	0.121	0.027
97.9	22,000	2.18	0.180	0.040
106.8	24,000	3.03	0.260	0.057
115.6	26,000	4.09	0.364	0.080
133.4	30,000	6.97	0.658	0.145
151.2	34,000	11.18	1.095	0.246
178.0	40,000	21.08	2.08	0.487
222.4	50,000	52.88	4.86	1.22
267.0	60,000		9.59	2.51
311.5	70,000		17.19	4.52
356.0	80,000		29.0	7.45
400.3	90,000		46.8	11.6

Source: Thickness Design—Asphalt Pavements for Highways and Streets, 9th ed., Manual Series No. 1, Asphalt Institute, Lexington, KY (1999).

Axle & Wheel Configurations

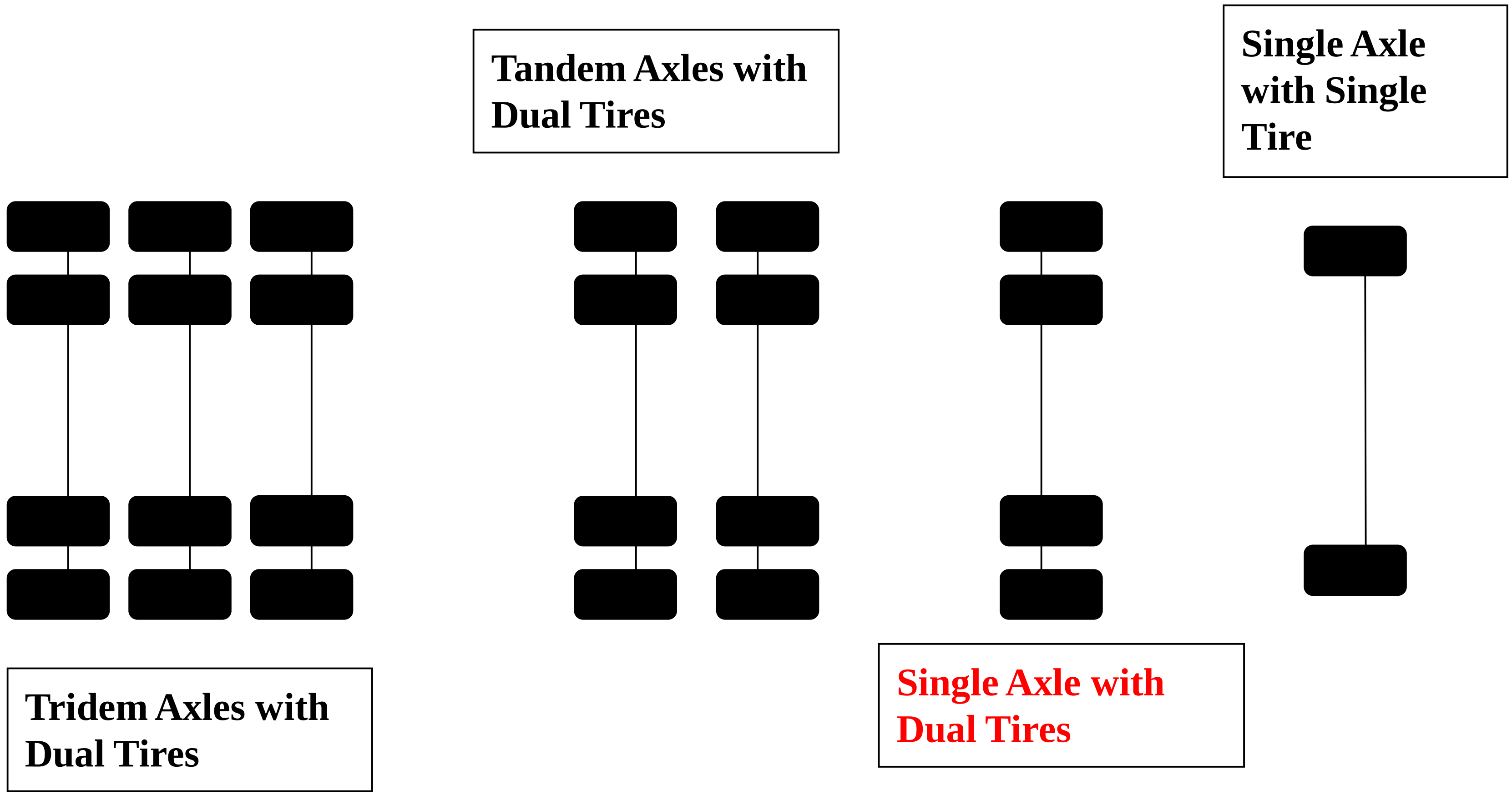


Table 20.5 Distribution of Truck Factors (TF) for Different Classes of Highways and Vehicles–United States*

Vehicle Type	Truck Factors											
	Rural Systems						*Urban Systems*					
	Interstate	*Other Principal*	*Minor Arterial*	*Collectors Major*	*Collectors Minor*	*Range*	*Interstate*	*Other Freeways*	*Other Principal*	*Minor Arterial*	*Collectors*	*Range*
Single-unit trucks												
2-axle, 4-tire	0.003	0.003	0.003	0.017	0.003	0.003–0.017	0.002	0.015	0.002	0.006	—	0.006–0.015
2-axle, 6-tire	0.21	0.25	0.28	0.41	0.19	0.19–0.41	0.17	0.13	0.24	0.23	0.13	0.13–0.24
3-axle or more	0.61	0.86	1.06	1.26	0.45	0.45–1.26	0.61	0.74	1.02	0.76	0.72	0.61–1.02
All single units	0.06	0.08	0.08	0.12	0.03	0.03–0.12	0.05	0.06	0.09	0.04	0.16	0.04–0.16
Tractor-semitrailers												
4-axle or less	0.62	0.92	0.62	0.37	0.91	0.37–0.91	0.98	0.48	0.71	0.46	0.40	0.40–0.98
5-axle**	1.09	1.25	1.05	1.67	1.11	1.05–1.67	1.07	1.17	0.97	0.77	0.63	0.63–1.17
6-axle or more**	1.23	1.54	1.04	2.21	1.35	1.04–2.21	1.05	1.19	0.90	0.64	—	0.64–1.19
All multiple units	1.04	1.21	0.97	1.52	1.08	0.97–1.52	1.05	0.96	0.91	0.67	0.53	0.53–1.05
All trucks	0.52	0.38	0.21	0.30	0.12	0.12–0.52	0.39	0.23	0.21	0.07	0.24	0.07–0.39

Note: Compiled from data supplied by the Highway Statistics Division, Federal Highway Administration.

*Including full-trailer combinations in some states.

**For values to be used when the number of heavy trucks is low, see original source.

SOURCE: *Thickness Design—Asphalt Pavements for Highways and Streets*, Manual Series No. 1, The Asphalt Institute, Lexington, Ky., February 1991.

TABLE 16-2 Distribution of Truck Factors for Different Classes of Highways and Vehicles in the United States

Vehicle Type	*Highway System Type*			
	Rural		*Urban*	
	Interstate	*Minor Arterial*	*Interstate*	*Minor Arterial*
Single-unit trucks				
Two-axle, four-tire	0.003	0.003	0.002	0.006
Two-axle, six-tire	0.21	0.28	0.17	0.23
Three-axle or more	0.61	1.06	0.61	0.76
Tractor-semitrailers				
Four-axle or less	0.62	0.62	0.98	0.46
Five-axle	1.09	1.05	1.07	0.77
Six-axle or more	1.23	1.04	1.05	0.64

Source: Thickness Design—Asphalt Pavements for Highways and Streets, Manual Series No. 1, 9th ed., Asphalt Institute, Lexington, KY.

TABLE 16-3 Typical Load-Equivalency Factors

Gross Axle Load				
(KN)	*(lb)*	*Single Axle*	*Tandem Axles*	*Tridem Axles*
26.7	6,000	0.01043	0.001	0.0003
44.5	10,000	0.0877	0.007	0.002
53.4	12,000	0.189	0.014	0.003
62.3	14,000	0.360	0.027	0.006
71.2	16,000	0.623	0.047	0.011
80.0	18,000	1.000	0.077	0.017
89.0	20,000	1.51	0.121	0.027
97.9	22,000	2.18	0.180	0.040
106.8	24,000	3.03	0.260	0.057
115.6	26,000	4.09	0.364	0.080
133.4	30,000	6.97	0.658	0.145
151.2	34,000	11.18	1.095	0.246
178.0	40,000	21.08	2.08	0.487
222.4	50,000	52.88	4.86	1.22
267.0	60,000		9.59	2.51
311.5	70,000		17.19	4.52
356.0	80,000		29.0	7.45
400.3	90,000		46.8	11.6

Source: Thickness Design—Asphalt Pavements for Highways and Streets, 9th ed., Manual Series No. 1, Asphalt Institute, Lexington, KY (1999).

Truck Factor Example

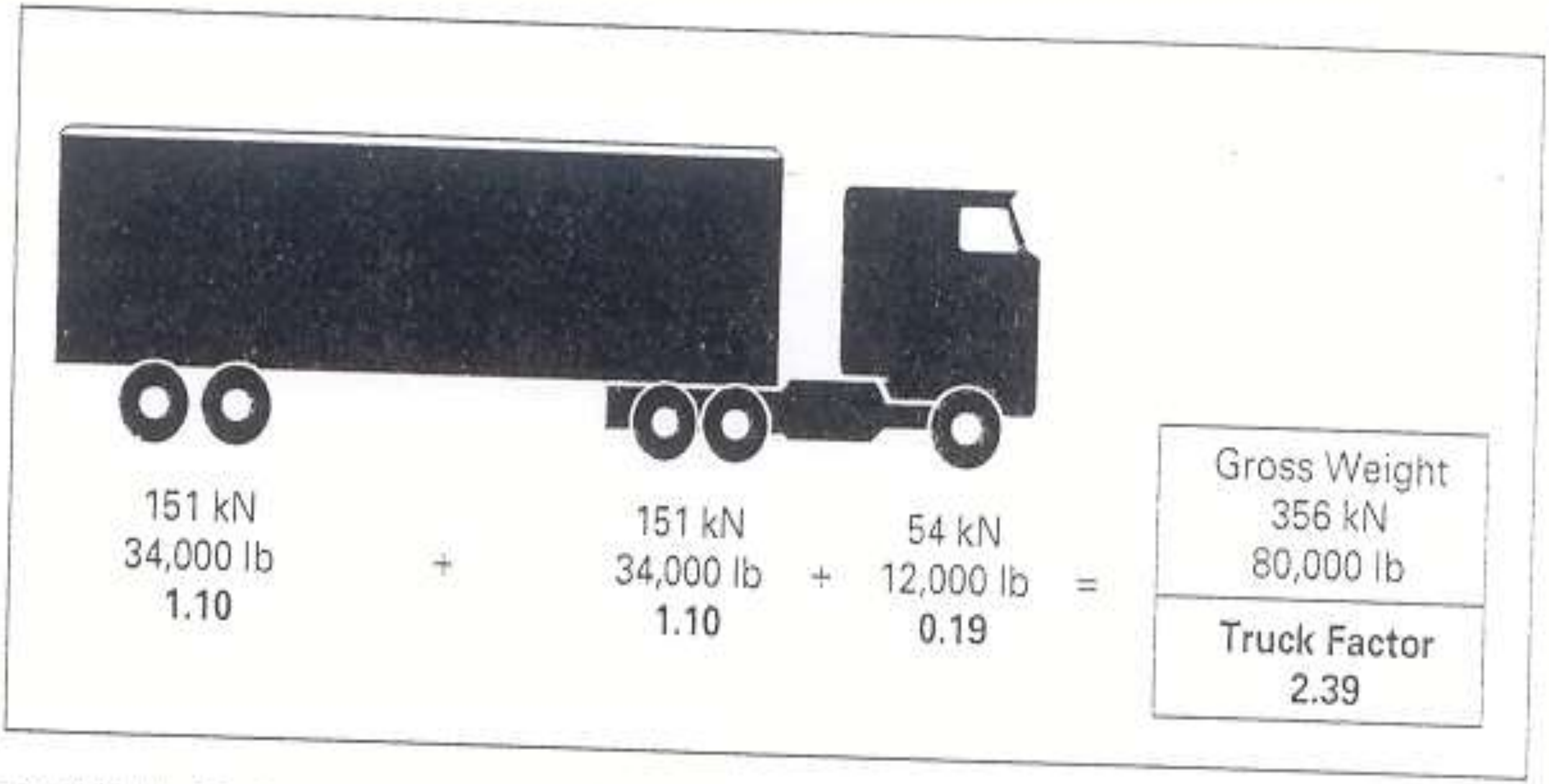


FIGURE 16-8 Load-equivalency factors and the truck factor for a single-tractor semitrailer truck. (Courtesy the Asphalt Institute.)

Traffic Analysis Cont.

4. Multiply (Tf) by the no. of vehicles in each group and get the sum for all groups.

ESAL = Sum (TF X No. of vehicles) all groups.

See Example provided in next slides.

Example on Computation of ESAL

EXAMPLE 16-1 **Computation of Equivalent 18,000-lb Load Applications** During the first year of service, a pavement on a rural Interstate highway is expected to accommodate the following numbers of vehicles in the classes shown. Estimate the ESALs.

Vehicle Type	*No. of Vehicles*	*Truck Factors*	*Product*
Single-unit trucks			
Two-axle, four-tire	87,600	0.003	283
Two-axle, six-tire	23,600	0.21	4,956
Three-axle or more	4,400	0.61	2,684
Tractor-semitrailers			
Four-axle or less	2,100	0.62	1,302
Five-axle	7,300	1.09	7,957
Six-axle or more	50,200	1.23	61,476
			ESAL = Sum = 78,900

Total ESAL Calculation

- The total ESAL applied on the highway during its design period can be determined only if the following are known:
  - Design period
  - Traffic growth factor
- Traffic growth factor is estimated using historical records or comparable facilities or obtained from studies made by specialized agencies.
- It is advisable to determine annual growth rates for trucks and passenger cars separately.
- Design period: Number of years the pavement will effectively continue to carry the traffic load without requiring an overlay. (usually 20 years).

Expected Traffic Volume During Design Period

See ***Table 20.6*** for growth factors, or calculate it using:

$$\mathbf{G_{jt} = ((1 + j)^t - 1)/ j)}$$

j: Rate of growth.

t: Design period (yrs).

Table 20.6 for growth factors

Table 20.6 Growth Factors

Design Period, Years (n)	*Annual Growth Rate, Percent (r)*							
	No Growth	*2*	*4*	*5*	*6*	*7*	*8*	*10*
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.02	2.04	2.05	2.06	2.07	2.08	2.10
3	3.0	3.06	3.12	3.15	3.18	3.21	3.25	3.31
4	4.0	4.12	4.25	4.31	4.37	4.44	4.51	4.64
5	5.0	5.20	5.42	5.53	5.64	5.75	5.87	6.11
6	6.0	6.31	6.63	6.80	6.98	7.15	7.34	7.72
7	7.0	7.43	7.90	8.14	8.39	8.65	8.92	9.49
8	8.0	8.58	9.21	9.55	9.90	10.26	10.64	11.44
9	9.0	9.75	10.58	11.03	11.49	11.98	12.49	13.58
10	10.0	10.95	12.01	12.58	13.18	13.82	14.49	15.94
11	11.0	12.17	13.49	14.21	14.97	15.78	16.65	18.53
12	12.0	13.41	15.03	15.92	16.87	17.89	18.98	21.38
13	13.0	14.68	16.63	17.71	18.88	20.14	21.50	24.52
14	14.0	15.97	18.29	19.16	21.01	22.55	24.21	27.97
15	15.0	17.29	20.02	21.58	23.28	25.13	27.15	31.77
16	16.0	18.64	21.82	23.66	25.67	27.89	30.32	35.95
17	17.0	20.01	23.70	25.84	28.21	30.84	33.75	40.55
18	18.0	21.41	25.65	28.13	30.91	34.00	37.45	45.60
19	19.0	22.84	27.67	30.54	33.76	37.38	41.45	51.16
20	20.0	24.30	29.78	33.06	36.79	41.00	45.76	57.28
25	25.0	32.03	41.65	47.73	54.86	63.25	73.11	98.35
30	30.0	40.57	56.08	66.44	79.06	94.46	113.28	164.49
35	35.0	49.99	73.65	90.32	111.43	138.24	172.32	271.02

Note: Factor = $[(1 + r)^n - 1]/r$, where $r = \frac{\text{rate}}{100}$ and is not zero. If annual growth is zero, growth factor = design period.

SOURCE: *Thickness Design—Asphalt Pavements for Highways and Streets*, Manual Series No. 1, The Asphalt Institute, Lexington, Ky., February 1991.

Computing Design ESAL (Projected)

EXAMPLE 16-2 **Design ESAL for 20-Year Design Period** If the traffic using the pavement grows at an annual rate of 4 percent, determine the design ESAL for a 20-year design period.

Solution By Eq. 16-6,

$$\text{design ESAL} = \left[\frac{(1 + 0.04)^{20} - 1}{0.04}\right] 78{,}900 = 2{,}349{,}000$$

Note that if the traffic is expected to grow nonuniformly among weight classes, Eq. 16-6 should be applied to each weight class using appropriate rates of growth.

Total ESAL Calculation Cont.

- the portion of the ESAL acting on the design lane is used in the determination of pavement thickness.
- Either lane of a two-lane highway is a design lane.
- In multilane highways the outer lane is the design lane.
- See ***Table 20.7*** for percentage of total truck traffic on design lane.
- The initial daily traffic is in two directions over all traffic lanes.
- Must be multiplied by direction distribution & Lane distribution to obtain initial traffic on design lane.
- Traffic to be used in design is the average traffic during design period (i.e. multiply by growth factor).

Table 20.7 for percentage of total truck traffic on design lane

Table 20.7 Percentage of Total Truck Traffic on Design Lane

Number of Traffic Lanes (Two Directions)	*Percentage of Trucks in Design Lane*
2	50
4	45 (35–48)*
6 or more	40 (25–48)*

*Probable range.

SOURCE: Adapted from *Thickness Design—Asphalt Pavements for Highways and Streets*, Manual Series No. 1, The Asphalt Institute, Lexington, Ky., February 1991.

Total ESAL Calculation Cont.

$$ESAL_i = (AADT_i)\,(F_d)\,(G_{jt})\,(N_i)\,(F_{Ei})\,(365)$$

$ESAL_i$: ESAL for axle category i

$AADT_i$: First year annual average daily traffic for axle category i.

(F_d): Design lane factor

(G_{jt}): growth rate factor for a given growth rate j and design period t.

(N_i): number of axles on each vehicle in category i.

(F_{Ei}): load equivalency factor for axle category i.

Total ESAL Calculation Cont.

When truck factors are used

$$ESAL_i = (AADT_i)\ (F_d)\ (G_{jt})\ (f_i)\ (365)$$

$ESAL_i$: ESAL for axle category i

AADT: First year annual average daily traffic for axle category i.

(F_d): Design lane factor

(G_{jt}): growth rate factor for a given growth rate j and design period t.

(f_i): Truck factor for vehicle in truck category i.

Total ESAL Calculation Cont.

When truck factors are used

$$ESAL = SUM\ [ESAL_i\ ]$$

from i =1 to n

n= number of truck categories

ESAL : ESAL for all vehicles during the design period.

ESAL Example

- An 8-lane divided highway is to be constructed on a new alignment. Traffic volume forecast indicates that AADT in both direction during the first year of operation will be 12,000 with the following vehicle mix:
  - Passenger cars (1000 lb/axle) = 50%
  - 2-axle single unit trucks (6000 lb/axle) = 33%
  - 3-axle single unit trucks (10,000 lb/axle) = 17%

  If the expected annual traffic growth rate is 4% for all vehicles,

  Determine the design ESAL for a design period of 20 years.

ESAL Example

Solution

- Growth Factor = G_{jt} ***= [(1 + j)^t - 1]/ j = [(1 + 0.04)^{20} - 1]/ 0.04 = 29.78 (or see Table 20.6)***
- ***% truck volume on design lane = 45 (assumed, Table 20.7)***
- ***Load equivalency Factors (Table 20.3)***
  - **Passenger cars (1000 lb/axle) = 0.00002 (negligible)**
  - **2-axle single unit trucks (6000 lb/axle) = 0.01043**
  - **3-axle single unit trucks (10,000 lb/axle) = 0.0877**

ESAL Example

- ***Solution***

$$ESAL_i = (AADT_i)\ (F_d)\ (G_{jt})\ (N_i)\ (F_{Ei})\ (365)$$

For passenger cars…… ESAL = 0 or negligible

For 2-axle single unit trucks

ESAL = (12,000 X 0.33) X 0.45 X 29.78 X 2 X 0.01043 X 365

= 0.4041 X 10^6

For 3-axle single unit trucks

ESAL = (12,000 X 0.17) X 0.45 X 29.78 X 3 X 0.0877 X 365

= 0.2.6253 X 10^6

Total ESAL = 3.0294 X 10^6

Traffic

- Treatment of traffic load in AASHTO is similar to that presented in the Asphalt Institute method.
- The total load applications due to all mixed traffic within the design period are converted to 18-kip ESAL using the EALF.

- $\mathbf{ESAL_i = (AADT_i)\,(F_d)\,(G_{jt})\,(N_i)\,(F_{Ei})\,(365)}$

Or

- $\mathbf{ESAL_i = (AADT_i)\,(F_d)\,(G_{jt})\,(f_i)\,(365)}$
- $\mathbf{G_{jt} = (\,(1 + j)^t\ -1)/\,j\,)}$

$$\mathbf{ESAL = SUM\,[ESAL_i\,]}$$

from i =1 to n

n= number of truck categories

ESAL : ESAL for all vehicles during the design period.

Roadbed Soils (Subgrade Materials)

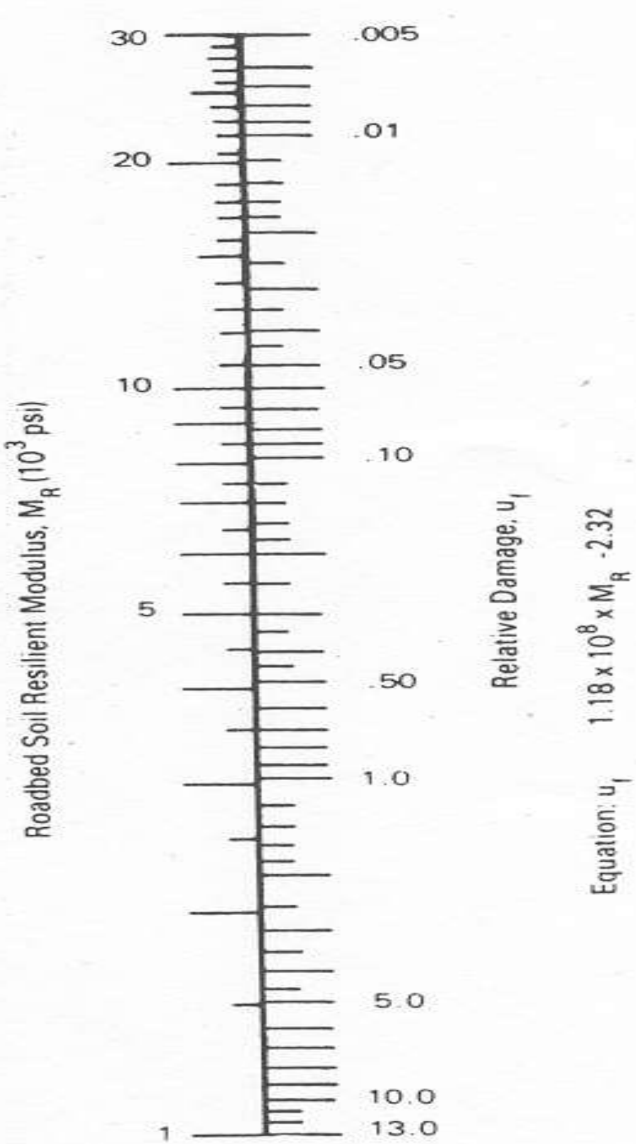
- AASHTO method used the subgrade Mr to define its property.
- Mr (psi) = 1500 CBR (for fine-grained soil with CBR <10)
- Mr (psi) = 1000 + 555 (R value) (for R <=20)

- Normal Mr (During summer and fall) for materials susceptible to frost action can reduce by (50 – 80%) during the thaw period.
- Also Mr of subgrade can vary through the year even when there is no thaw period/
- In order to take these variations into consideration it is to determine and effective annual roadbed soil resilience modulus.
- An effective roadbed (Mr) should be found that is equivalent to combined effect of the subgrade (Mr) of all the seasonal (Mr).
- ***See Fig. 20.18 in text and Fig. 16.12*** in ref. book

Effective Roadbed Resilient Modulus

1. Find (Mr) for subgrade once/twice a month during the whole year.
2. Compute Relative damage using equation or scale. ***See Fig. 20.18 in text and Fig. 16.12 in ref. book***
3. Compute the average relative damage value.
4. Use the average relative damage value to determine the effective roadbed (Mr) using the formula or the scale.

Month	Roadbed Soil Modulus, M_R (psi)	Relative Damage, u_f
Jan.	20,000	0.01
Feb.	20,000	0.01
Mar.	2,500	1.51
Apr.	4,000	0.51
May	4,000	0.51
June	7,000	0.13
July	7,000	0.13
Aug.	7,000	0.13
Sept.	7,000	0.13
Oct.	7,000	0.13
Nov	4,000	0.51
Dec.	20,000	0.01
Summation: Σu_f =		3.72



Average: $\bar{u}_f = \frac{\Sigma u_f}{n} = \frac{3.72}{12} = 0.31$

Effective Roadbed Soil Resilient Modulus, M_R (psi) = 5,000 (corresponds to $\bar{u}_f$)

FIGURE 16-12 Chart for estimating effective roadbed soil resilient modulus for flexible pavements designed using the serviceability criteria. (Courtesy American Association of State Highway and Transportation Officials.)

Materials of Construction

- Subbase Construction Materials
  - Quality of the material is determined in terms of the layer coefficient, (**a_3**).
  - See ***Figure 20.15 in text.***
- Base Course Construction Materials
  - Materials should satisfy general requirements for base course.
  - Quality of the material is determined in terms of the layer coefficient, (**a_2**).
  - See ***Figure 20.16.***
- Surface Course Construction Materials
  - Usually HMA with dense-graded aggregate and max size of 1”.
  - Quality of the material is determined in terms of the layer coefficient, (**a_1**).
  - See ***Figure 20.17.***

Layer Coefficient (a_i)

- Is a measure of the relative effectiveness of a given material to function as a structural component of the pavement.
- See ***Figures in Ref. book***:
- **16.13** : Asphalt concrete surface course ($\mathbf{a_1}$)
- **16.14** : Bituminous treated base ($\mathbf{a_2}$)
- **16.15** : Granular base ($\mathbf{a_2}$)
- **16.16** : Granular subbase ($\mathbf{a_3}$)
- **16.17** : Cement treated bases ($\mathbf{a_2}$).

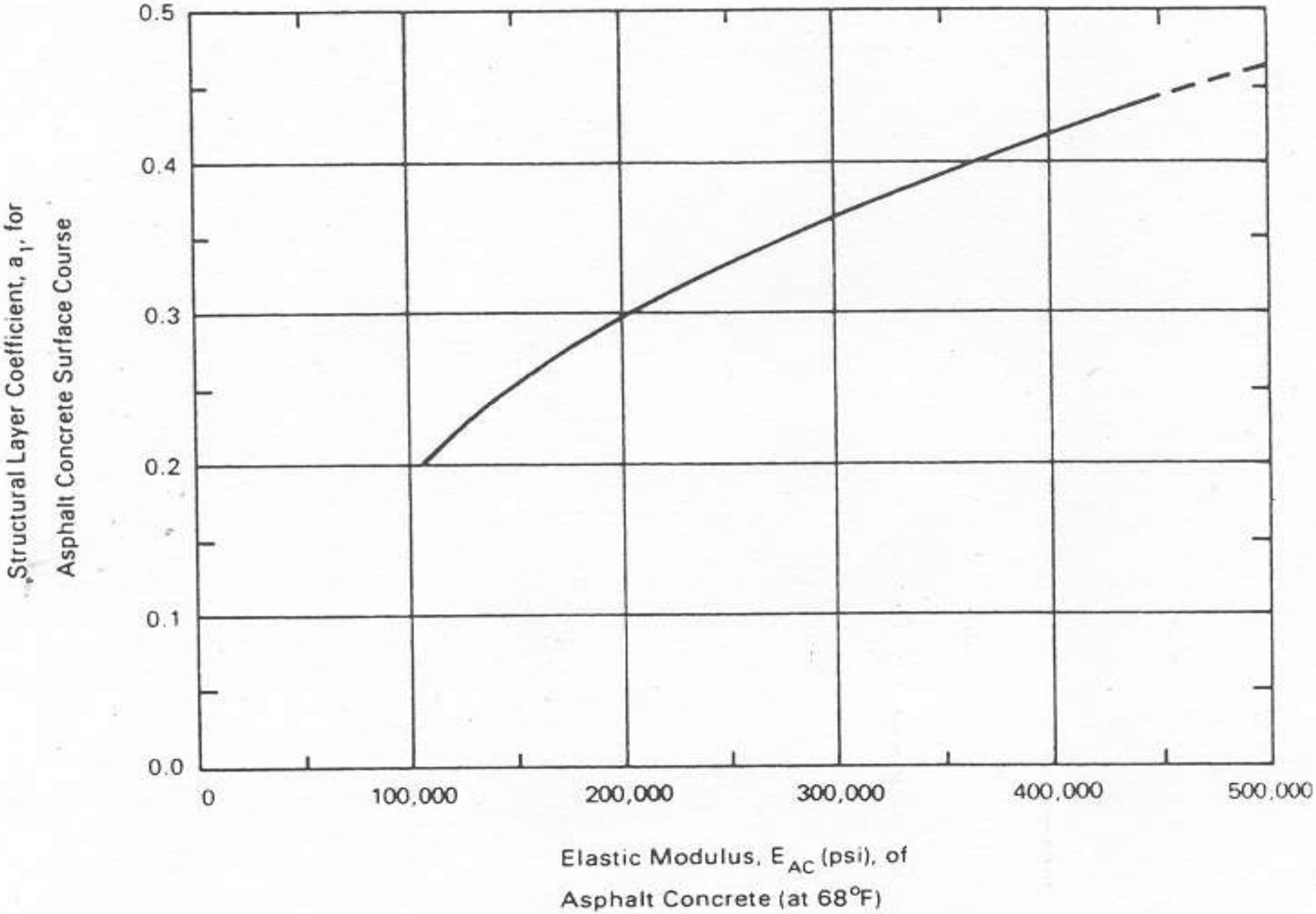
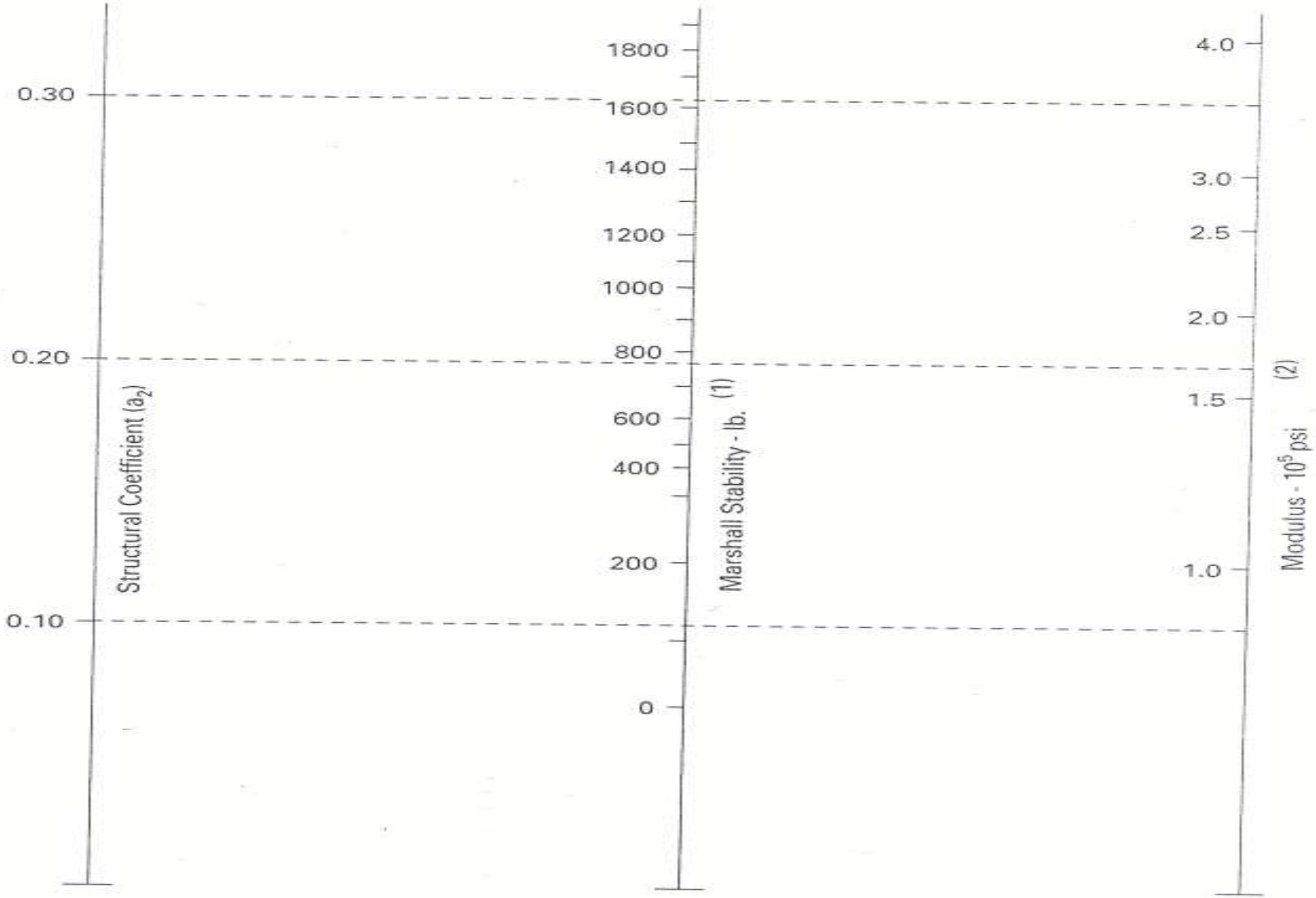


FIGURE 16-13 Chart for estimating structural layer coefficient of dense-graded asphalt concrete based on the elastic (resilient) modulus. (Courtesy American Association of State Highway and Transportation Officials.)

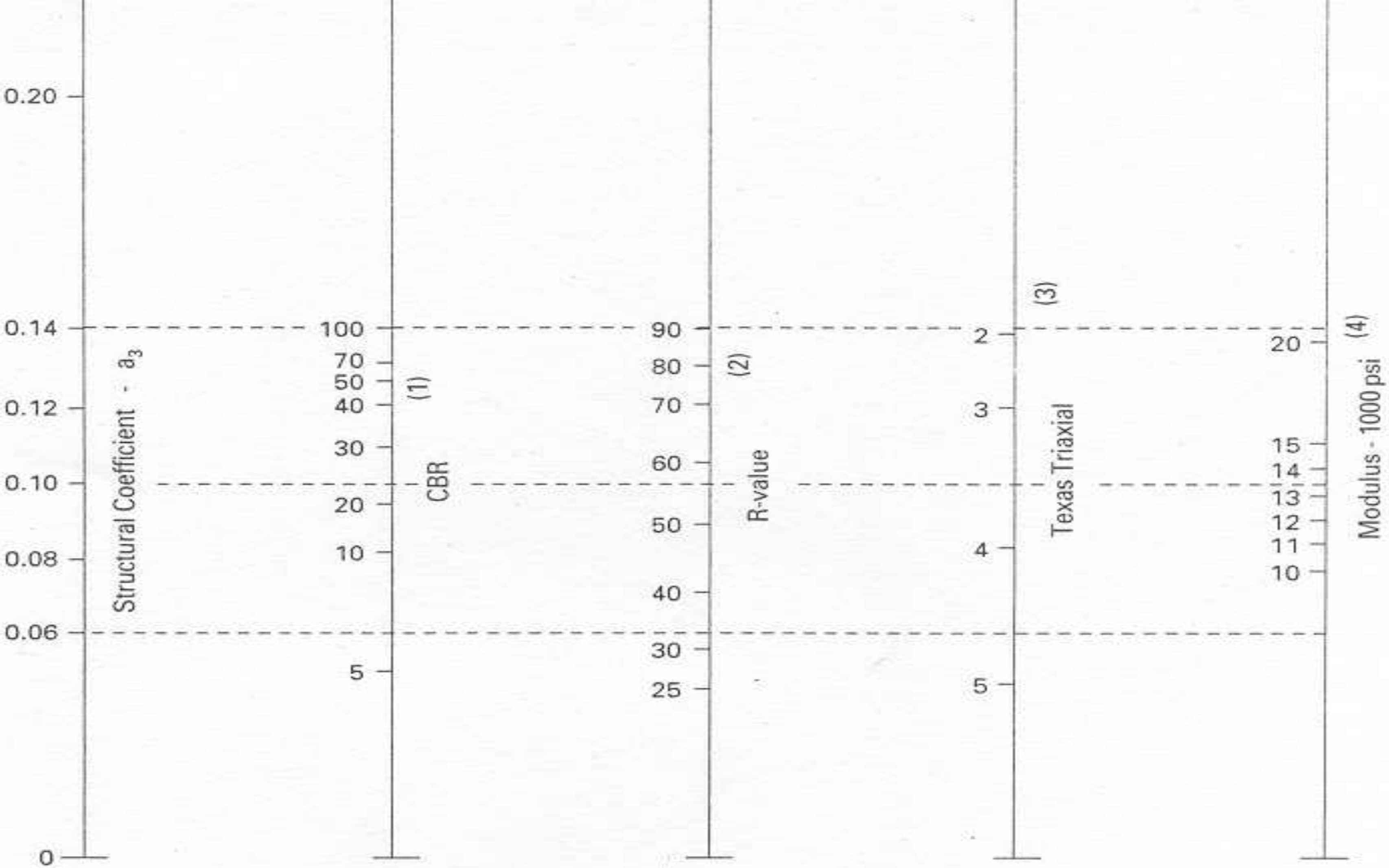


(1) Scale derived by correlation obtained from Illinois.
(2) Scale derived on NCHRP project (4).

FIGURE 16-14 Variation in a_2 for bituminous-treated bases with base strength parameter. (Courtesy American Association of State Highway and Transportation Officials.)

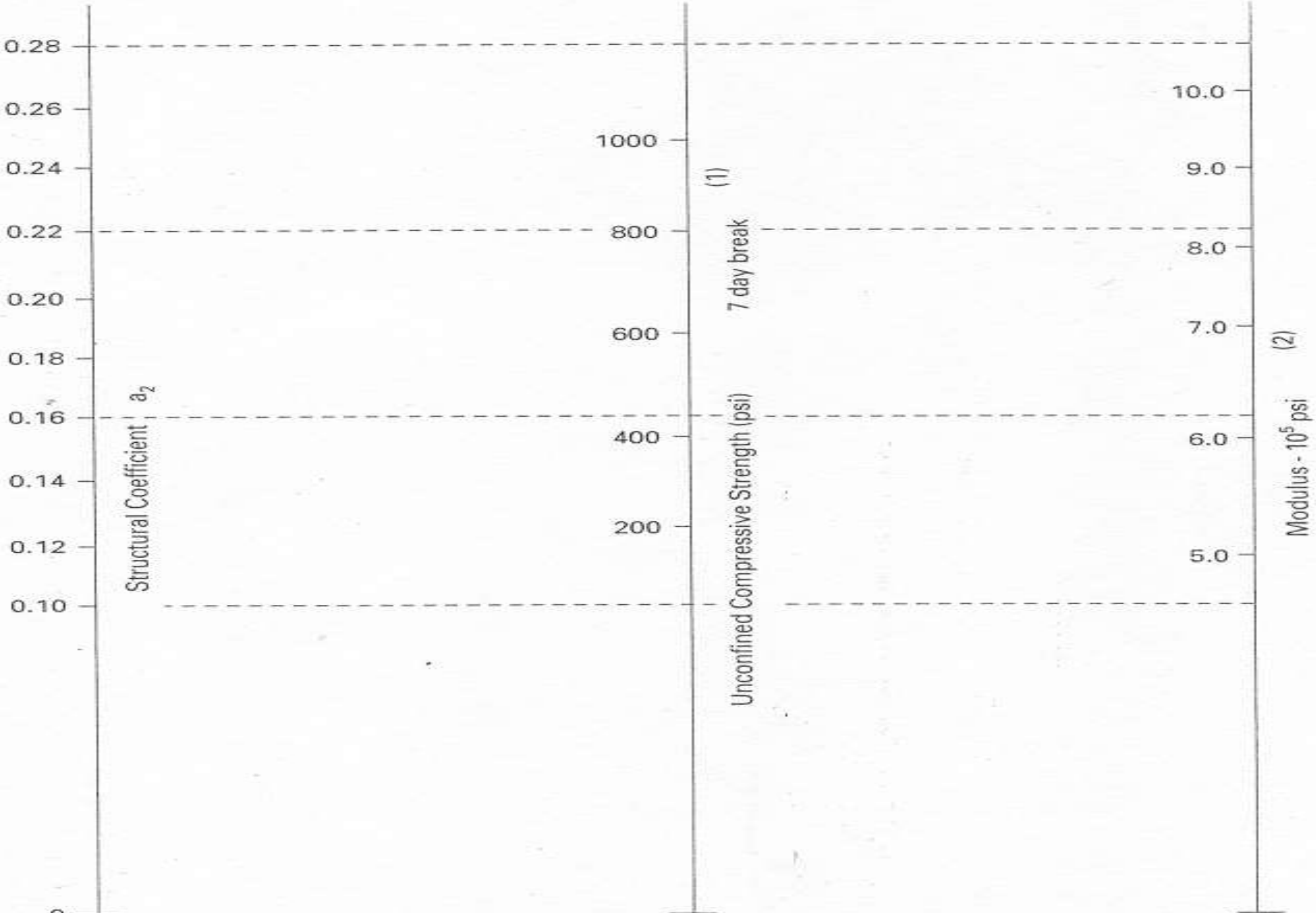
(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on NCHRP project *(4)*.

FIGURE 16-15 Variation in granular base layer coefficient (a_2) with various base strength parameters. (Courtesy American Association of State Highway and Transportation Officials.)



(1) Scale derived from correlations from Illinois.
(2) Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico and Wyoming.
(3) Scale derived from correlations obtained from Texas.
(4) Scale derived on NCHRP project *(4)*.

FIGURE 16-16 Variation in granular subbase layer coefficient (a_3) with various subbase strength parameters. (Courtesy American Association of State Highway and Transportation Officials.)



(1) Scale derived by averaging correlations from Illinois, Louisiana and Texas,
(2) Scale derived on NCHRP project *(4)*.

FIGURE 16-17 Variation in *a* for cement-treated bases with base strength parameter. (Courtesy American Association of State Highway and Transportation Officials.)

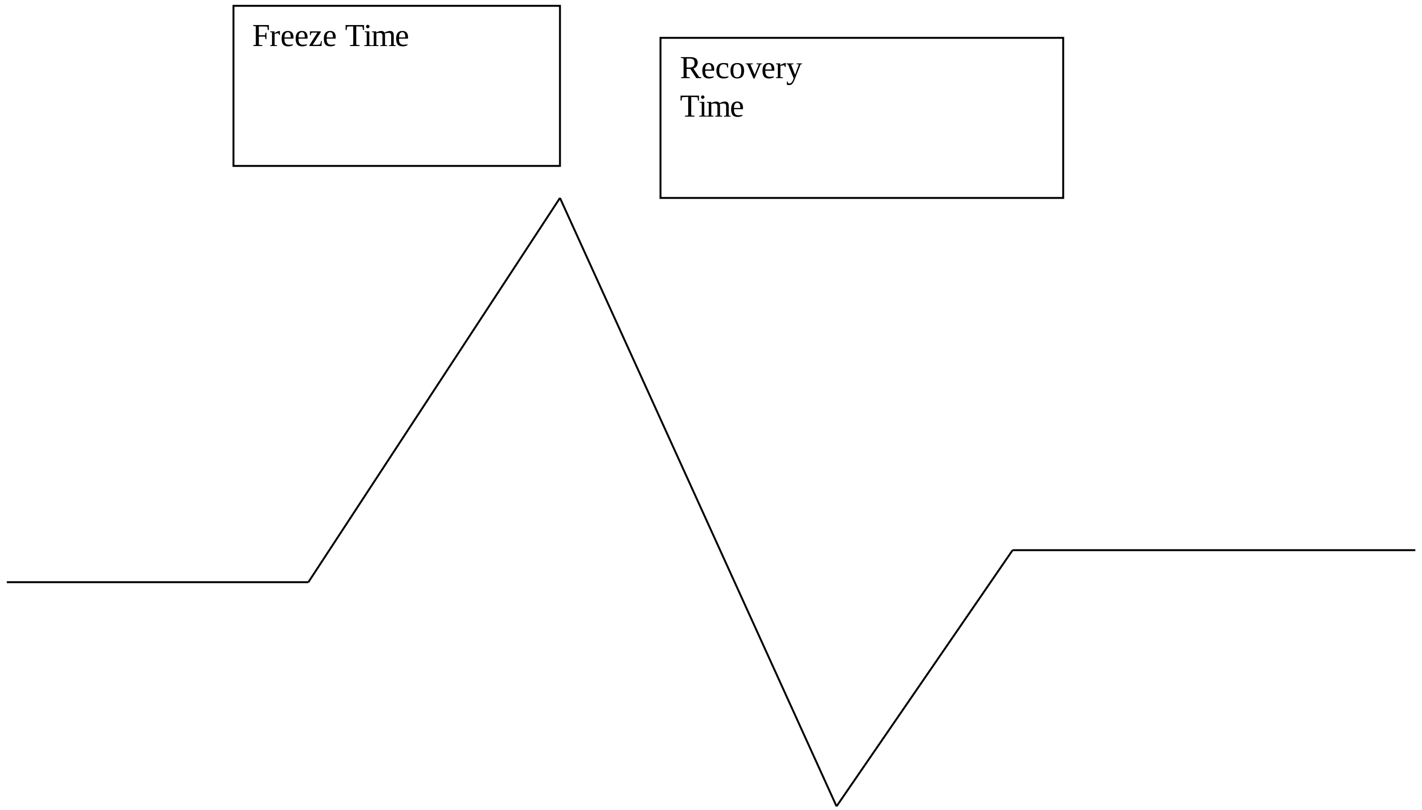
Environment

- Temperature and Rainfall are the two main environmental factors used in evaluating pavement performance in the AASHTO method.
- Effect of temperature includes:
  - Stresses induced by thermal action
  - Changes in creep properties
  - Effect of freezing and thawing on subgrade soil.
- Effect of rainfall is due mainly to penetration of the surface water to the underlying material.
- If penetration occur the properties of the underlying material will significantly altered.

Environment

- Normal Mr (During summer and fall) for materials susceptible to frost action can reduce by (50 – 80%) during the thaw period.
- Also Mr of subgrade can vary through the year even when there is no thaw period/
- In order to take these variations into consideration is to determine and effective annual roadbed soil resilience modulus.
- This was discussed earlier in the roadbed soil section.
- Effect of moisture, temperature, and material aging should be accounted for by adding it to the loss of serviceability over the design period along with serviceability loss due to traffic.

Subgrade Mr Seasonal Variation



Drainage

- Water affect the strength of base and roadbed soil.
- The approach is to provide a suitable drainage layer (see ***Fig. 20.19***) , and by modifying the structural layer coefficient by incorporating the factor (m_i) for the base and subbase layer coefficients (a_2 & a_3).
- The coefficient depends on:

1. Quality of drainage: measured by the length of time it takes water to be removed from base or subbase up to (50% of saturation). see ***Table 20.14 in text*** for definitions of drainage quality.
2. Percent of time the pavement structure is saturated.

- See ***Table 20.15 in text and Table 16.7 in Ref.*** For recommended (m) values for different levels of drainage quality.

Definition of Drainage Quality*

* time required to drain base layer to 50% saturation

Quality of drainage	Water removed within
Excellent	2 hours
Good	1 Day
Fair	1 week
Poor	1 Month
Very poor	Water will not drain

TABLE 16-7 Recommended m_i Values for Modifying Structural Layer Coefficients of Untreated Base and Subbase Materials in Flexible Pavements

	Percent of Time Pavement Structure Is Exposed to Moisture Levels Approaching Saturation			
Quality of Drainage	*Less Than 1%*	*1%–5%*	*5%–25%*	*Greater Than 25%*
Excellent	1.40–1.35	1.35–1.30	1.30–1.20	1.20
Good	1.35–1.25	1.25–1.15	1.15–1.00	1.00
Fair	1.25–1.15	1.15–1.05	1.00–0.80	0.80
Poor	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very poor	1.05–0.95	0.95–0.75	0.75–0.40	0.40

Reliability

- It provides a predetermined level of assurance (R) that the pavement section will survive the period for which they were designed.
- Reliability Design Factor: Accounts for chance variations in both traffic prediction & performance prediction.
- (***R***) is a mean of incorporating some degree of certainty into the design to ensure that the various design alternatives will last the analysis periods.
- (***R***) is a function of the overall standard deviation (***So***).
- See ***Table 20.16 in text or Table 16.6 in Ref.*** for suggested levels of Reliability for various functional classifications.

TABLE 16-6 Suggested Levels of Reliability for Various Functional Classifications

Functional Classification	Recommended Level of Reliability	
	Urban	*Rural*
Interstate and other freeways	85–99.9	80–99.9
Principal arterials	80–99	75–95
Collectors	80–95	75–95
Locals	50–80	50–80

Source: AASHTO Guide for Design of Pavement Structures, American Association of State Highway and Transportation Officials, Washington, DC (1993).

Overall So

- ***So***: Overall standard deviation that accounts for standard deviation (or variation) in materials & construction, chance variation in traffic prediction, and normal variation in pavement performance.
- So = 0.45 for flexible pavement (0.40 - 0.50)
- So = 0.35 for rigid pavements (0.30 -0.40).
- Reliability Factor (Fr >= 1.0)
- Log (Fr) = - (Zr) (So)
- Zr = Standard Normal Variate for a given reliability (R%).
- See ***Table 20.17*** in text for Zr values for different Reliability levels.

Structural Design

- The objective of the AASHTO method is to determine a flexible pavement structural number (***SN***) adequate to carry the projected design ESAL.
- It is left to the designer to select the type of surface used, which can be either asphalt concrete, a single surface treatment, or a double surface treatment.
- The design procedure is used for ESAL>50,000 for the performance period.

Basic Design Equation

The basic design equation given in the 1993 guide is

$$\log_{10}W_{18} = Z_R S_o + 9.36 \log_{10}(\mathrm{SN}+1) - 0.20 + \frac{\log_{10}[\Delta\mathrm{PSI}/(4.2-1.5)]}{0.40 + [1094/(\mathrm{SN}+1)^{5.19}]} + 2.32 \log_{10}M_r - 8.07 \quad (19.7)$$

where

W_{18} = predicted number of 18,000-lb (80 kN) single-axle load applications
Z_R = standard normal deviation for a given reliability
S_o = overall standard deviation
SN = structural number indicative of the total pavement thickness
$\Delta\mathrm{PSI} = p_i - p_t$

Structural Number (SN)

- ***SN*** = F (pavement layer thickness, layer coefficient, & drainage coefficient)
- Required Inputs (See ***Fig.20.20 in text and 16.11 in Ref***.):
  - ESAL
  - Reliability
  - So
  - Effective roadbed (Mr)
  - ΔPSI

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R * S_o + 9.36 * \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\dfrac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \dfrac{1094}{(SN+1)^{5.19}}} + 2.32 * \log_{10} M_R - 8.07$$

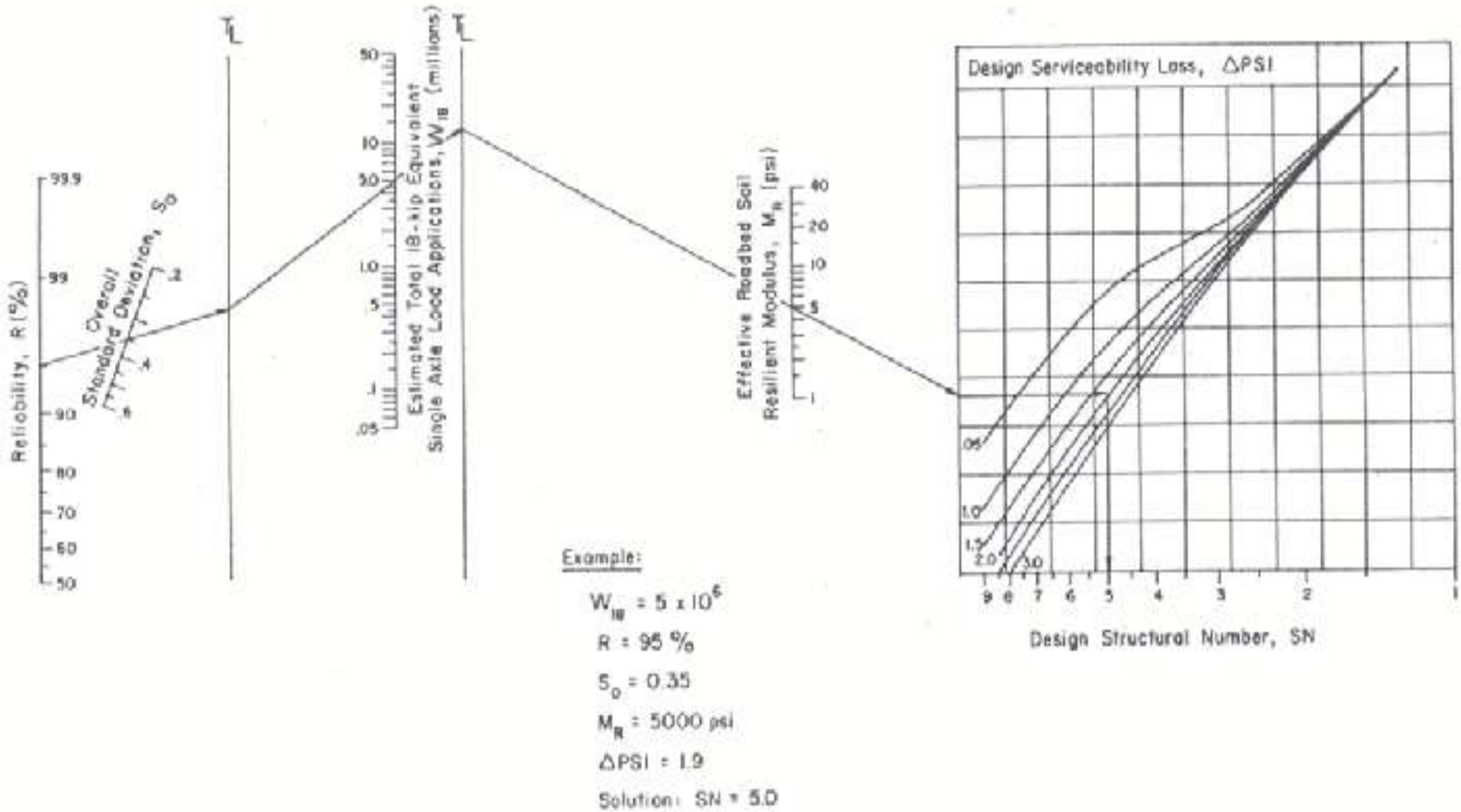


FIGURE 16-11 AASHTO design chart for flexible pavements based on using mean values for each input. (Courtesy American Association of Highway and Transportation Officials.)

Selection of Pavement Thickness Design

- Once ***SN*** is determined, it is necessary to determine the thickness of various Layers.

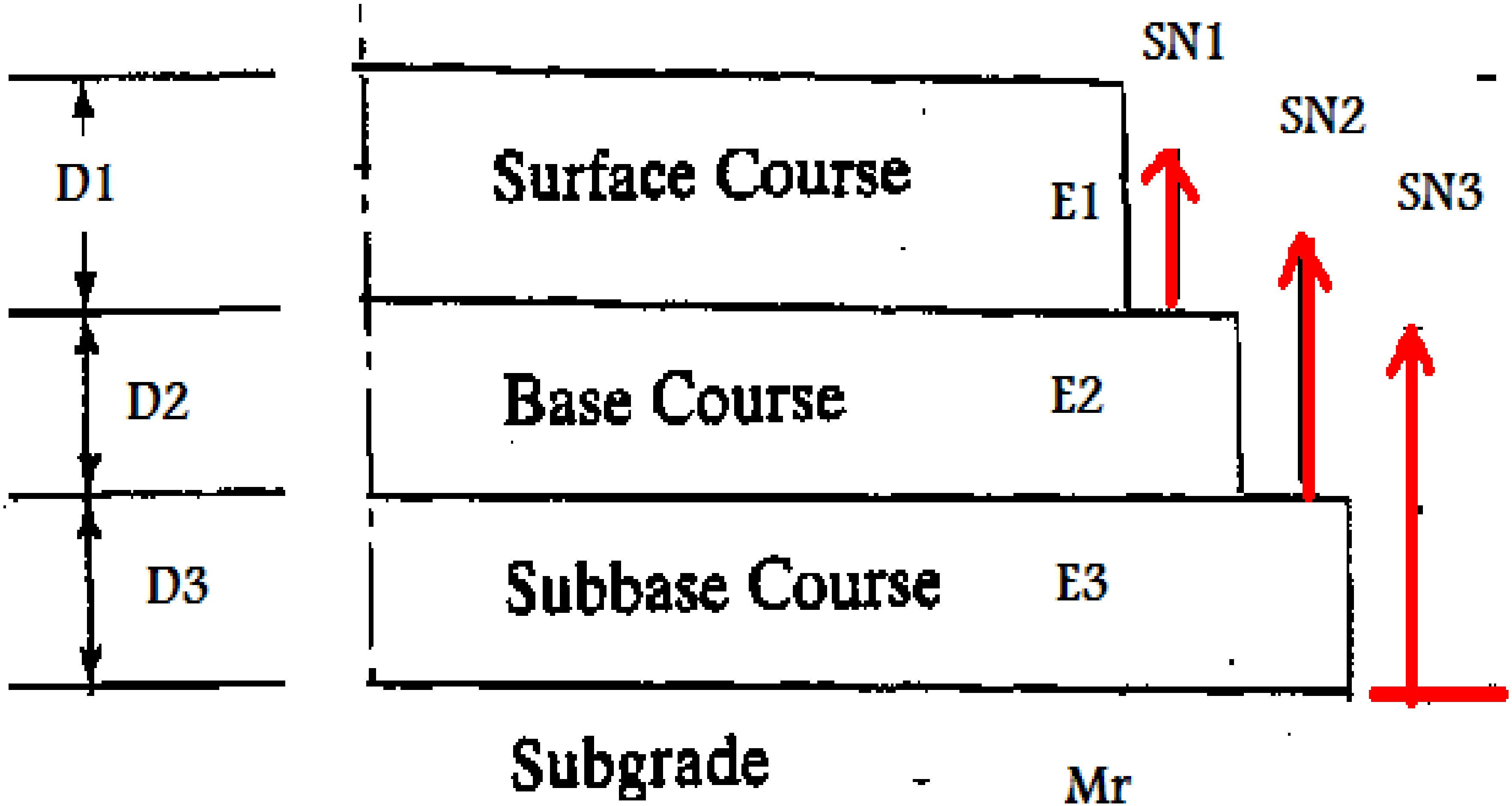
$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

a_i : Coefficient of layer i

D_i : Thickness of layer i

m_i : Drainage Modifying Factor for layer i.

General Procedure for Selection Layer Thickness



General Procedure for Selection Layer Thickness Cont.

1. Using (E_2) as Mr and (***Fig. 20.20 or16.11***), determine SN_1 required to protect base. Then compute thickness of Layer D_1 as:

$$D_1 >= SN_1 / a_1$$

2. The computed thickness D_1 is usually rounded up to the nearest one-half inch.
3. In addition for purpose of practicality and economy, certain min. thicknesses are recommended (***Table 20.18 in Text and 16.8 in Ref***).
4. The rounded value of (D_1) will be used in the preceding calculations as (D_1").

TABLE 16-8 Recommended Minimum Thicknesses of Pavement Layers

	Minimum Thickness (in.)	
Traffic ESALs	*Asphalt Concrete*	*Aggregate Base*
Less than 50,000	1.0 or surface treatment	4
50,001–150,000	2.0	4
150,001–500,000	2.5	4
500,001–2,000,000	3.0	6
2,000,001–7,000,000	3.5	6
Greater than 7,000,000	4.0	6

Source: Adapted from *AASHTO Guide for Design of Pavement Structures*. American Association for Highway and Transportation Officials. Washington. DC (1993).

General Procedure for Selection Layer Thickness Cont.

1. Using (E_3) as Mr and ***(Fig. 20.20 or16.11)*** , determine (SN_2) required to protect the subbase. Then compute thickness of Layer D_2 as:

$$D_2 >= (SN_2 - a_1 D_1'')/ a_2 m_2$$

2. The computed thickness (D_2) is also rounded up to the nearest one-half inch.
3. The rounded value of (D_2) will be used in the preceding calculations as (D_2 ”).

General Procedure for Selection Layer Thickness Cont.

1. Using the roadbed soil (Mr) and (***Fig. 20.20 or16.11)*** , determine SN_3 required to protect the roadbed soil (subgrade). Then compute thickness of Layer D_3 as:

$$D_3 >= (SN_3 - a_1 D_1'' - a_2 D_2'' m_2)/ a_3 m_3$$

2. The computed thickness (D_3) is also rounded up to the nearest one-half inch.

Example 1 (20.8 in text)

- A flexible pavement for an urban interstate highway.
- ESAL = 2x 10^6
- It takes about a week for water to be drained from within the pavement.
- The pavement structure will be exposed to moisture levels approaching saturation for 30% of time.
- Resilience modulus of asphalt concrete = 450,000 psi.
- Base course: CBR = 100 , Mr = 31,000 psi
- Subbase course: CBR = 22, Mr = 13,500 psi
- Subgrade: CBR = 6
- Determine a suitable pavement structure.

Example 1/ Solution

- The following assumption are made for an interstate highway:
- R = 99 (from 80 – 99.9 Table 20.16)
- So = 0.49 (range 0.4 – 0.5)
- Initial PSI = 4.5
- Terminal PSI = 2.5
- ΔPSI = 2
- Mr for subgrade = (1500 x 6)= 9000 psi
- From Figure 20. 17 with Mr = 450,000 psi find a_1 = 0.44
- From Fig. 20. 16 with CBR = 100 find a_2 = 0.14
- From Fig. 20. 15 with CBR = 22 find a_3 = 0.10
- From Table 20.14 find drainage quality = Fair
- From Table 20.15 find m_i = 0.80 (for base and subbase).

Example 1 Solution

- Using E2 as Mr & Fig. 20.20

SN1 = 2.6

D1>= SN1/a1 = 2.6/ 0.44 = 5.9 –in…. use 6 -in.

- Using E3 as Mr & Fig. 20.20

SN2 = 3.8

D2>= [SN2 – (a1 D1")] / (a2 m2)

D2>= [3.8 – (0.44 * 6)] / (0.14 * 0.80)

D2>= 10.36- in…….. use 12 -in

Example 1 Solution

- Using subgrade Mr & Fig. 20.20

SN3 = 4.4

D3>= [SN3 – (a1 D1”)- (a2 D2” m2)] / (a3 m3)

D3>= [4.4 – (0.44 * 6) – (0.14* 12* 0.80)]/ (.01 * 0.80)

D3>= 5.25 –in……. use 6 -in

The pavement has a 6-in surface, an 12 -in base, and a 6 -in subbase.

Example 2

Given:

- Flexible pavement in Rural interstate highway.
- Design ESAL 3000,000
- Subbase exposed to moisture saturation 5% of time & drainage quality is Fair.
- Base saturation level 10% of time (Fair drainage quality).
- Mr (HMA) = 420,000 psi …………..*(a_1 = 0.42).*
- Mr (base) = 24,000 psi ……………*(a_2 = 0.13).*
- Mr (subbase) = 10,000 psi ………*(a_3 = 0.075).*
- CBR (Subgrade) = 1.0 …*thus Mr =1500 (1) = 1500 psi*
- Reliability Level R = 85%
- So = 0.45
- ΔPSI = 2
- Required: Design the pavement by the AASHTO method

Example 2 Solution

- Using E2 as Mr & Fig. 20.20

$$SN1 = 2.45$$

$$D1 >= SN1/a1 = 2.45/\ 0.42 = 5.8 \text{ -in use 6 -in.}$$

- Using E3 as Mr & Fig. 20.20

$$SN2 = 3.5$$

$$D2 >= [SN2 – (a1\ D1")] / (a2\ m2)$$

$$D2 >= [3.5 – (0.42 * 6)] / (0.13 * 0.95)$$

$$D2 >= 7.9\text{- in use 8 -in}$$

Example 2 Solution

- Using subgrade Mr & Fig. 20.20

SN3 = 6.5

D3>= [SN3 – (a1 D1”)- (a2 D2” m2)] / (a3 m3)

D3>= [6.5 – (0.42 * 6) – (0.13* 8* 0.95)]/ (0.075 * 0.90)

D2>= 44.44 -in use 44.5 -in

The pavement has a 6-in surface, an 8 -in base, and a 44.5 -in subbase.

Highway Draingae

Source:

Chapter 16/ Traffic & Highway Engineering (5th Edition, 2015) by Nicholas Garber and Lester Hoel

Dr. TALEB M. AL-ROUSAN

Drainage

- One of most important considerations in locating and designing streets and HWYS
- Adequate and economical drainage will protect highway structures and save people.
- About 25% of highway construction dollars are spent for erosion control and drainage structures (culverts, bridges, channels, and ditches).
- Inadequate drainage can result in:
  - Serious damage to pavement.
  - Traffic accidents due to hydroplaning and loss of visibility from splash & spray of accumulated water.
- Surface water: Rain, snow, melting ice, & artificial.
- Surface Drainage: Measures taken to control flow of surface water.
- Under ground water.
- Subsurface drainage (Sub drainage): Measures taken to control flow of underground water.

Surface Drainage/ Rural

- **Rural:**

  1. Transverse slopes (Roadway crown) on both pavements and shoulders (recommended 2-6%)

  2. Side slope

     (Table ***12.1 in Ref*** Ranges for cross slopes for pavements & Shoulders)

     - *Steep to drain but safe and comfortable for driver.*

  3. Longitudinal slopes on both pavements and shoulders (> 0.5%)

  4. Ditches (longitudinal open channels)

  - *Mostly In cut sections,*
  - *Flat bottomed or Vee*
  - *Grades similar to center line.*
  - (Table 8.2-3 in Ref. for recommended cross sections)

  5. Culverts, Bridges

  - *Cross-Drainage .*

  See ***Chapter 16 in text*** for details of cross and side slopes

- **Rural (Divided):**

1. + Previous
2. Inlets and storm drains (*Underground pipes in medians*).

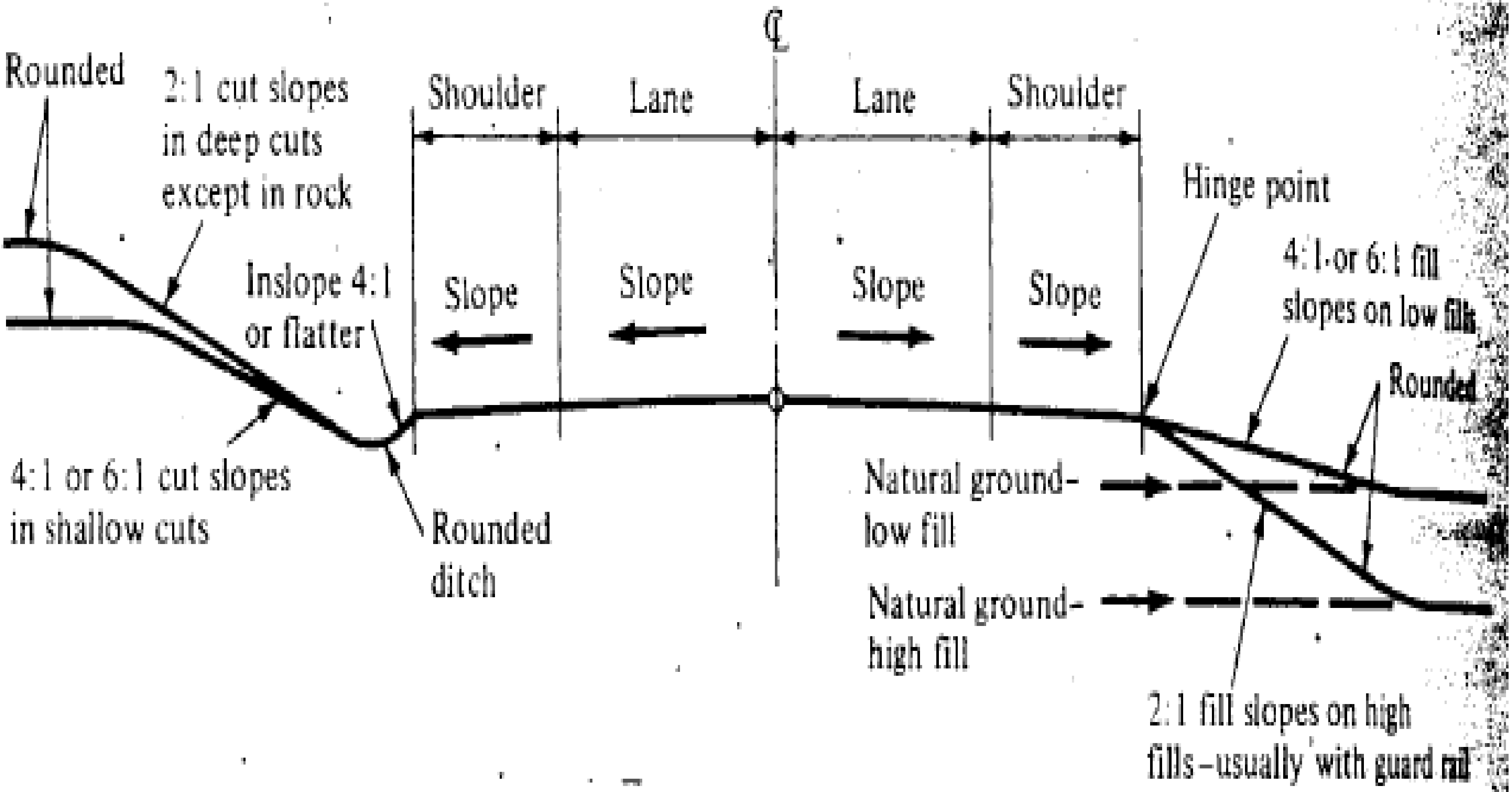


Figure 16.4 Typical Cross Section for Two-Lane Highways

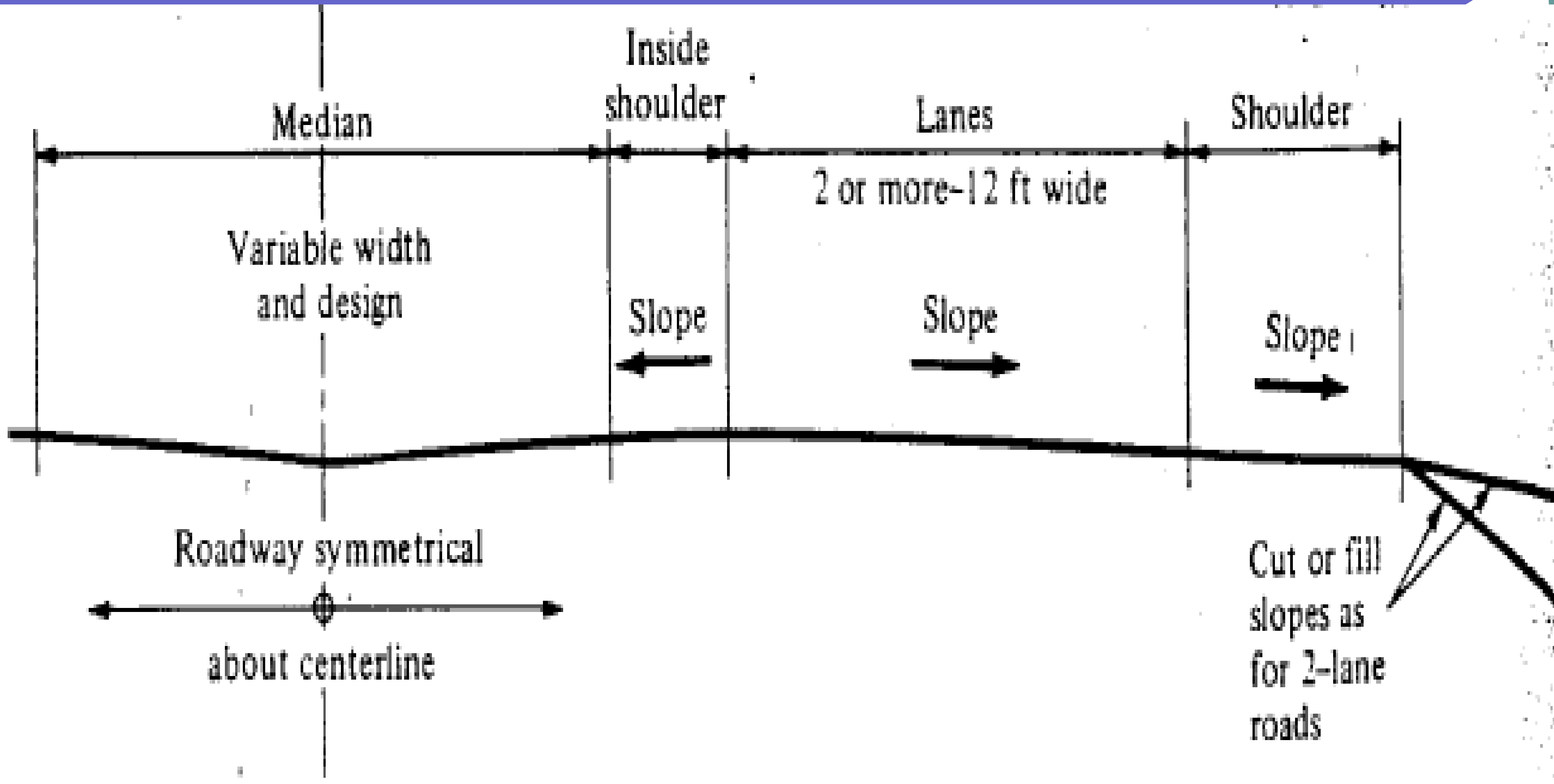
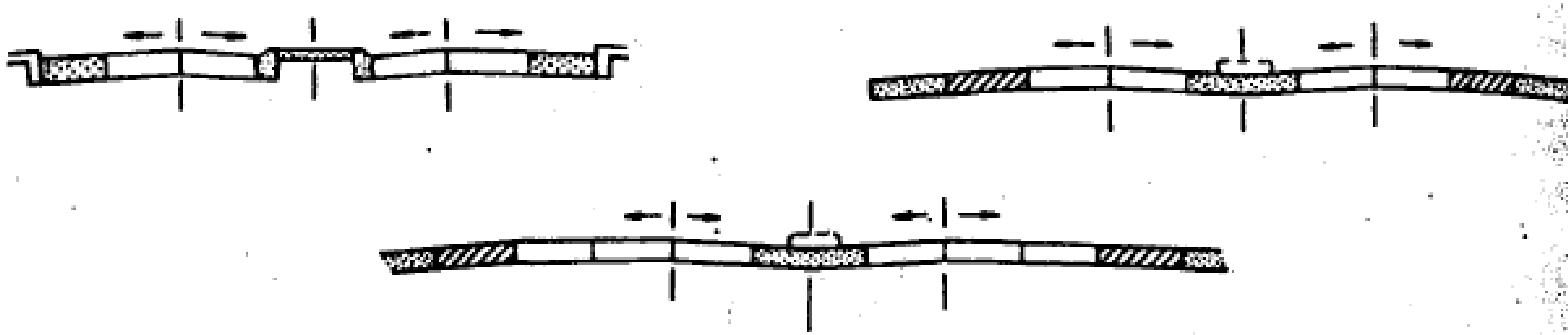


Figure 16.5 Typical Cross Section for Multilane Highways (half section)



(a) Each pavement slopes two ways.

(b) Each pavement slopes one way.

Figure 16.9 Basic Cross Slope Arrangements for Divided Highways

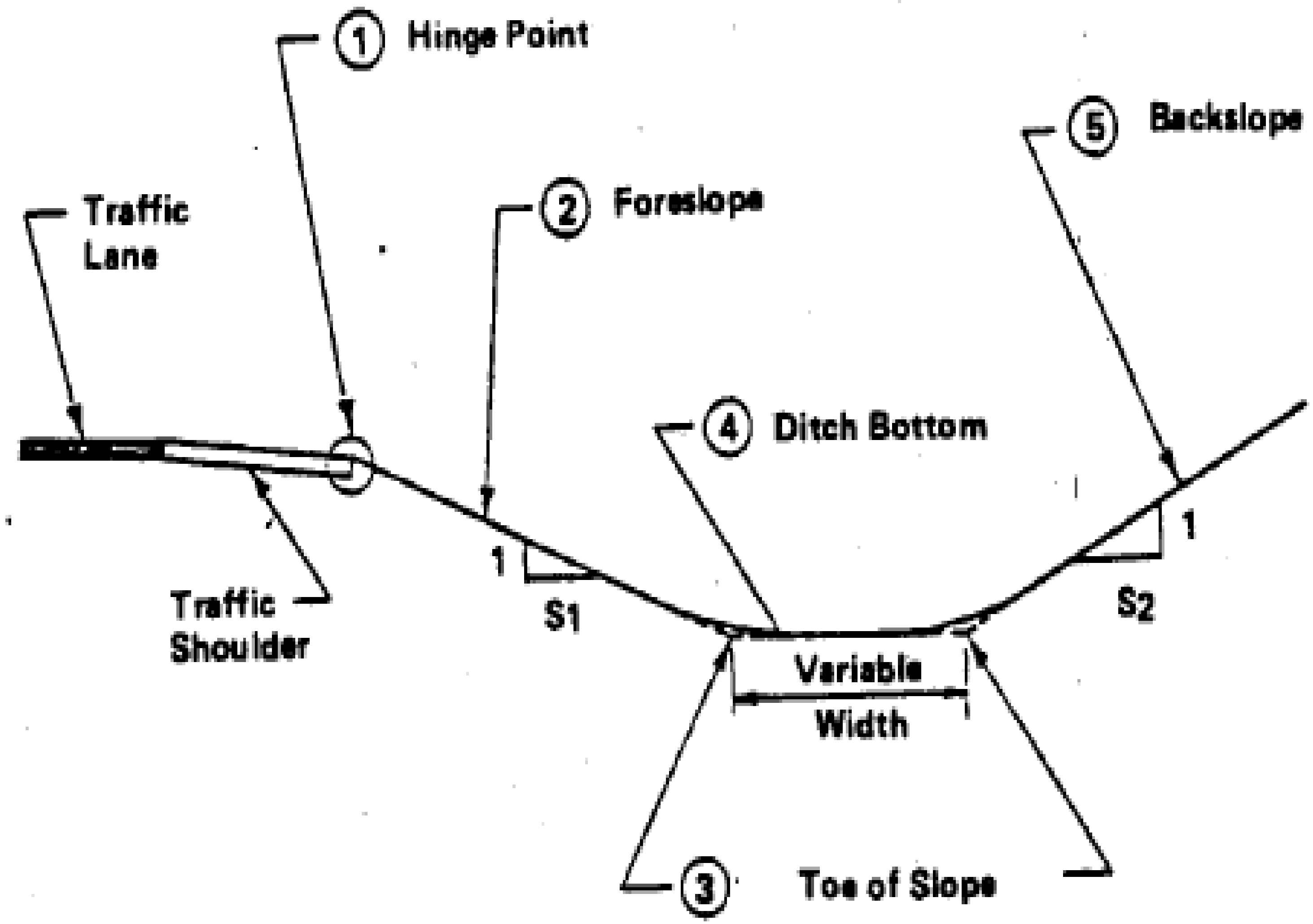


Figure 16.10 Designation of Roadside Regions

Table 16.3 Guide for Earth Slope Design

Height of Cut or Fill (ft)	Earth Slope, for Type of Terrain		
	Flat or Rolling	Moderately Steep	Steep
0–4	6 : 1	6 : 1	4 : 1
4–10	4 : 1	4 : 1	2 : 1*
10–15	4 : 1	2.50 : 1	1.75 : 1*
15–20	2 : 1*	2 : 1*	1.75 : 1*
Over 20	2 : 1*	2 : 1*	1.75 : 1*

*Slopes 2 : 1 or steeper should be subject to a soil stability analysis and should be reviewed for safety.

SOURCE: *Roadside Design Guide*, American Association of State Highway and Transportation Officials D.C., 1996. Used by permission.

Surface Drainage/ Urban (City Streets)

- Cross Slopes (Pavement crowns)
- Longitudinal slopes
- Curbs, and gutters (function as side ditches in addition to preventing the encroachment of the vehicles on adjacent areas and delineating pavement edges)
- Inlets and storm drains (*Underground pipes in medians)*
- Inlets
  - *At intersections to intercept water flowing in gutters before it reached sidewalks.* **(See Figure 12-19)**
- Catch basin
  - *Similar to inlet but trap debris before entering storm sewer*.
- Manholes
  - *Facilities used to clean clogging storm sewer systems.*
  - *Placed @ (Grade change, junctions, intermediate points 90 -150 m)*
  - *1.2m D, Concrete blocks, masonry, bricks*
  - *Cast iron circular cover 60 cm.*

Drainage Structures

- Are constructed to carry traffic over natural waterways that flow below the right of way of the highway.
- They also provide the flow of water below the highway, along the natural channel without disturbing its course.
- Concern is always to provide adequate size structure (opening is sufficiently large to discharge expected flow of water).
- Major Structures: Bridges
- Minor Structures: short-span bridges and culverts

Culverts

- Its top doesn’t form part of the traveled way as bridges.
- Span length =< 20ft
- Designed to flow full under certain conditions.
- Bridges designed to pass floating debris or vessels.

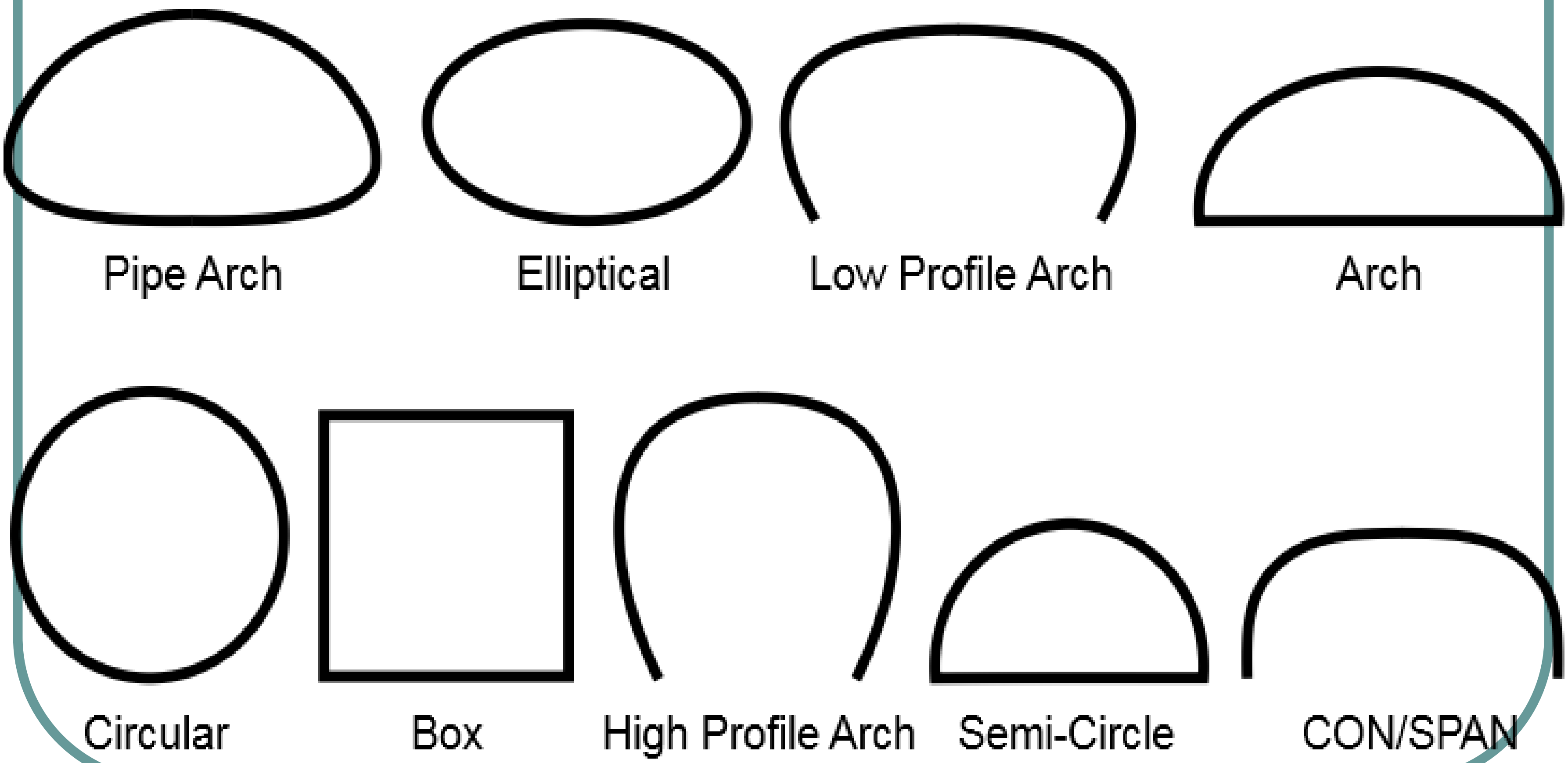
Culverts Location & Shape

- Important to select culvert location (Station no.), alignment, and grade
- Location:
  1. *Bottom of depression where no natural water course exist.*
  2. *Where natural stream intersect the roadway*.
- Alignment:
  1. *Conform with natural stream*
  2. *Cross roadway at right angles (economy)*
  3. *Skew culverts are needed sometimes*
- *Grade:*
  1. ***Conform to existing grade of stream***
  2. ***Reduced grades through culverts…..velocity reduction…..sediments deposition….reduce capacity***
  3. ***Increasing culvert grade…..velocity increase…..erosion at outlet and beyond.***

Culverts Shape & Materials

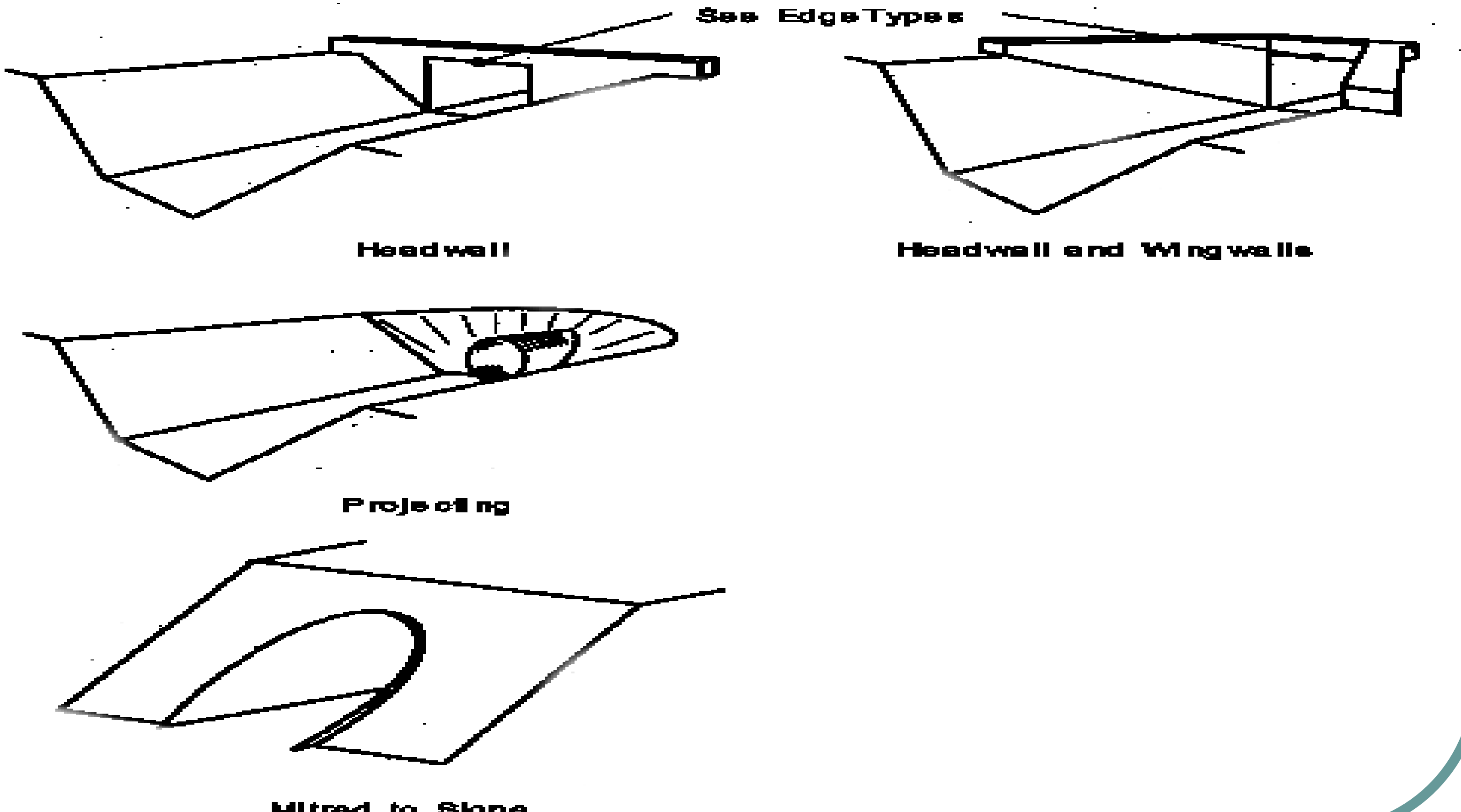
- Shapes (***See Figure 12-6 in Ref.***):
  1. ***Circular***
  2. ***Box (rectangular)***
  3. ***Elliptical***
  4. ***Pipe Arch***
  5. ***Arch***
  6. ***Metal Box***
- Materials:
  1. ***Concrete (reinforced & unreinforced)***
  2. ***Corrugated metal (Steel & Aluminum)***
- Inlet Types (***See Figure 12-7 in Ref.***):
  1. ***Projecting barrel.***
  2. ***Cast in place concrete headwall & wingwalls.***
  3. ***Precast end section.***
  4. ***End mitered to the slope.***

Culverts Shapes



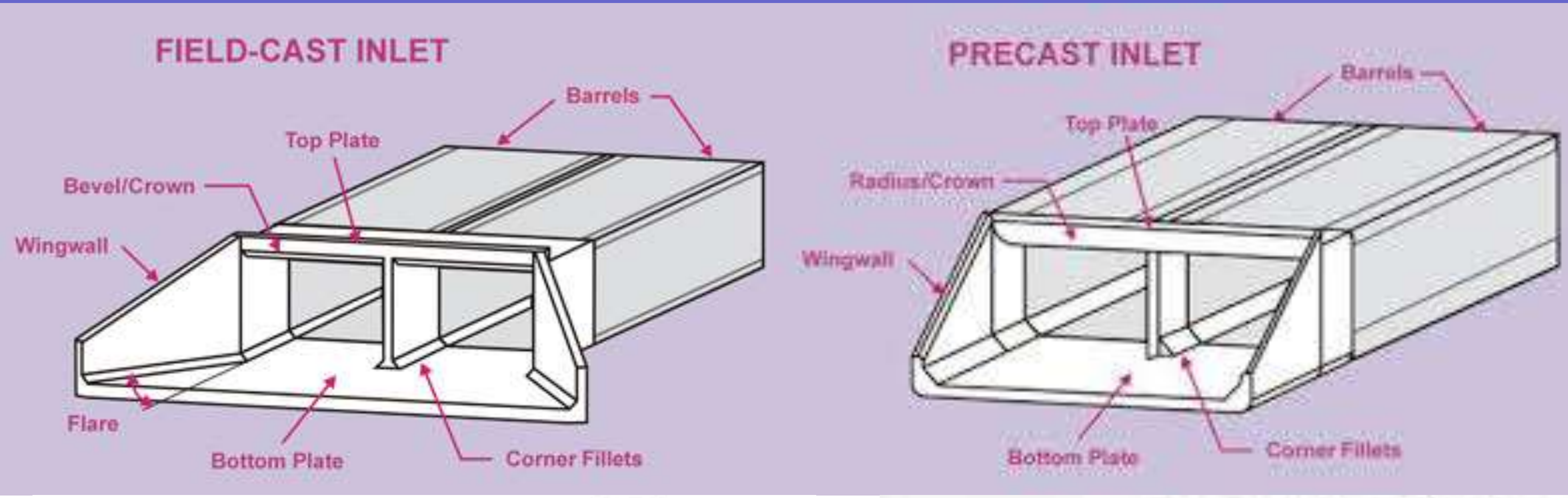
Culverts Shapes

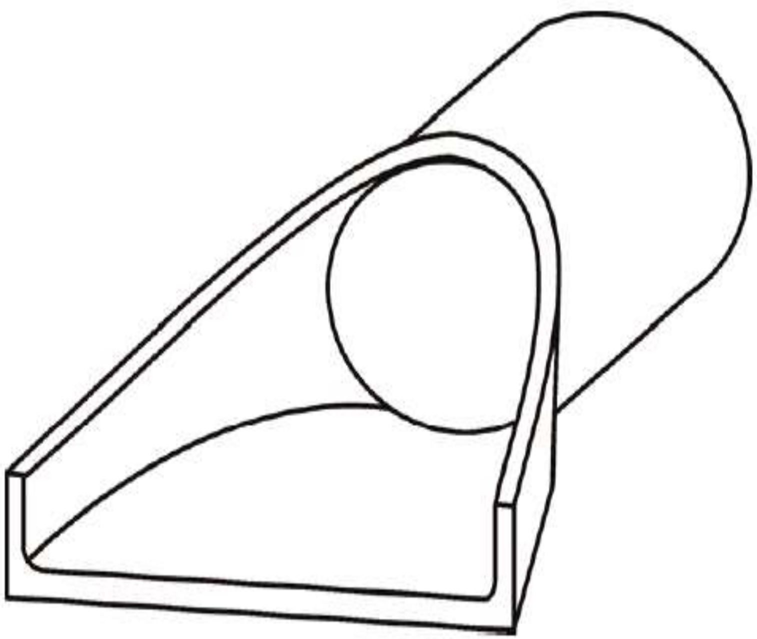
Inlet Types

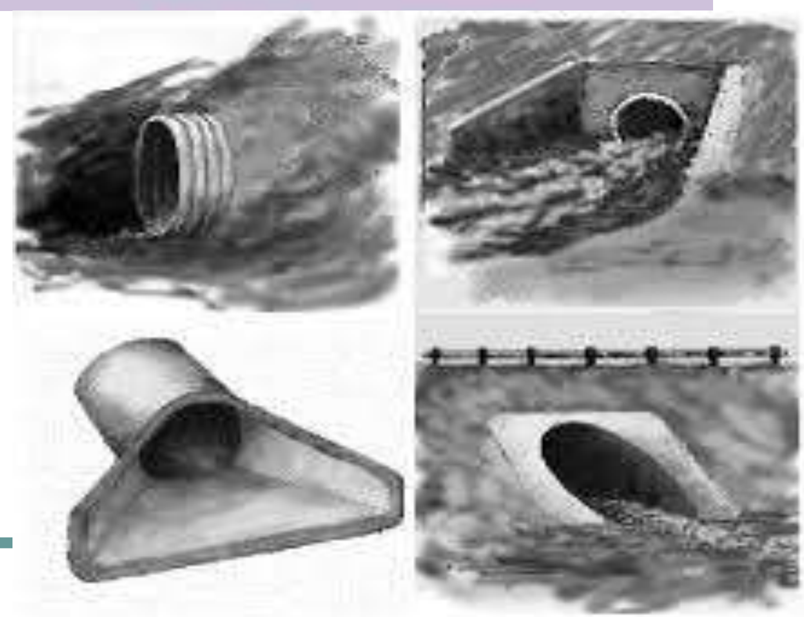


INLET TYPES

Inlet Types


FIELD-CAST INLET
Barrels
Top Plate
Bevel/Crown
Wingwall
Flare
Bottom Plate
Corner Fillets
PRECAST INLET
Barrels
Top Plate
Radius/Crown
Wingwall
Bottom Plate
Corner Fillets





Prevention of Erosion and Sedimentation

- Soil adjacent to roadways can be subjected to erosion by surface water.
- Erosion results in :

1. *Destruction of productive soil*
2. *Clogging of ditches & drainage structures*
3. *Unsightly & hazardous ditches*
4. *Endangering stability of side slopes (failure of embankments and cut sections)*.
5. *Pollution of nearby lakes and streams.*
6. *Increase maintenance cost because of sedimentation*

Measures to Prevent Erosion & Control Sediment

1. *Intercepting drains: prevent erosion of side slopes of cut sections.*
   1. ***Water is collected and transported in the intercepting drain to paved spillways.***
   2. ***Water in spill ways are then transported to longitudinal ditches alongside the highway***
2. *Curbs & Gutters:*
   1. *used to protect unpaved shoulder on rural highways.*
   2. *Used to protect embankment slopes when pavement shoulders are used.*
3. *Turf culture (growing grass on slopes < 3:1).*

Disadvantage: Can not resist continued traffic and loses its firmness under heavy traffic

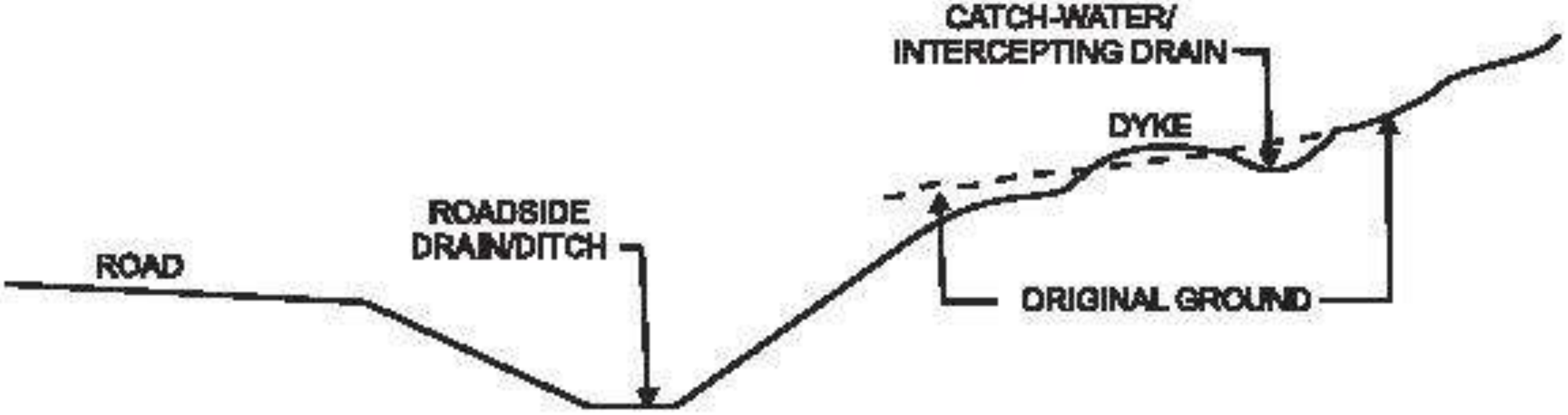


FIG. 2: INTERCEPTING/ CATCH-WATER DRAIN ON A HILL SLOPE

Measures to Prevent Erosion & Control Sediment Cont.

4. Slope or channel lining;

- ***Provide Rip-rap, or hand placed rocks in steep slope where erosion is sever***
- ***Provide protective lining along bottom & sides of ditches.***

5. Erosion Control during construction

- ***Sediment basins**: allows runoff to pond*
- ***Check dams**: used to slow velocity of concentrated flow and is made of local materials (rocks, logs, or straw bales)*
- ***Silt fence/filter barriers**: fabric reinforced by wire mish*
- ***Brush barriers**: made of construction spoil material from construction site.*
- ***Diversion dikes**: earthen berm that diverts water to a sediment basin*
- ***Slope drains**: used to convert water down a slope.*
- ***Dewatering basins**: detention areas to which sediment-laden water is pumped.*

Channel Lining




Lining Types

- Rigid: *Portland cement concrete + soil cement.*
  - *More expensive but more effective.*
  - *Smoother… could cause high velocities which might required energy dissipaters to reduce erosion.*
  - *Used in sever service conditions.*
- Flexible: *Dense-graded bituminous mixtures + rock Rip-rap + vegetations.*
  - *Inexpensive & easy to maintain.*
  - *Aesthetically pleasing.*
  - *Unsuitable for sever service conditions.*
  - *Used with gradients up to 10%.*

Lining Design

- Type of lining based on:
  - Before: Max. allowable velocities.
  - Recently: Max. permissible shear stress

- Computed/ Permissible
- Computed shear = F (flow depth, channel slope)
- Max shear is at edges
- Design flow rate (5 – 10) yrs
- Assume shape for design

Subsurface Drainage

- Subsurface drainage systems are provided within the pavement structure to drain water in one or more of the following forms:

1. Water that has permeated through cracks and joints in the pavement to the underlying strata.
2. Water that has moved upward through the underlying soil strata as a result of capillary action.
3. Water that exist in the natural ground below the water table (ground water).

- Effect of inadequate sub drainage:
  - Poor pavement performance:
    - Saturated subgrade will be weak in resisting traffic loads
    - Frost heave
  - Instability of slopes:
    - Reduce of shear strength of the embankment soil and increase of stresses to be resisted which will result in slope crumbling or failure.

Highway Sub-drainage Systems

- Five general categories:

1- Longitudinal drains:

- pipes laid in trenches within the pavement structure and parallel to the center line of the HWY.
- Used to lower the water table below the pavement structure (**see Fig. 17.29 in Text**)
- Used to remove seeping water into the pavement (***see Fig. 12.30 in text***)
- When water table is very high, two rows of longitudinal drains can be used.

2- Transverse drains:

- Place transversely below the pavement, perpendicular to the center line.
- ***See Fig. 17.32 in Text***.

Highway Sub-drainage Systems

3- Horizontal drains:

- Used to relieve pore pressure at slopes of cuts and embankments on the highway.
- Consist of small-diameter perforated pipes inserted into the slopes of the cut or fill.

4- Drainage blankets:

- Is a layer of material that has very high coefficient of permeability laid beneath or within pavement structure.
- ***See Fig. 17.33 in text***

5- Well systems:

- Consist of a series of vertical well, drilled into the ground, into which the ground water flows, thereby reducing the water table and releasing the pore pressure.

Subsurface Drainage

- Control of groundwater encountered in highway locations.
- Purpose: control seepage, lowering ground water table, base and shallow subgrade drains.
- Circular pipes laid at suitable depth in a trench, which is then backfilled with porous granular material.
- Pipes materials: Porous concrete, perforated metal, or vitrified clay
- 6 – 8 inches reach up to 24inches.
- Slope: steep enough to prevent deposition or setting of materials entering the pipe through joints or perforations.
- Intercepting drains, lowering water table, and base drainage.

Design of Surface Drainage

- Major Phases
  1. Estimate quantity of water that is expected to reach the system.
  2. The hydraulic design of each element in the system.
  3. The comparison of alternative system to select most economical system.

Hydrologic Considerations

Hydraulic Approach & Concept

- Estimate of Run Off
- Existing stream…..use available records.
- Return Period (RP): Estimated frequency for rare events (floods) (i.e. peak design flow).
- Higher R P = More sever storm = More costly system.
- R P = 50yrs for interstate, = 10 – 25 yrs for streets and roads, and 5 – 10 yrs for light traffic facilities.

Hydraulic Approach & Concept Cont.

- Flood frequency
  - Statistical based
  - Indicate mean annual flood as a function of the size of the drainage area for each hydrological region.
  - Regional flood curves are available (Flood Hydrographs (flow vs. time) ***see Fig. 12-1***.
  - Engineers design drainage facilities to accommodate the peak flow.

Hydraulic Approach & Concept Cont.

- Rain fall intensity is function of
  1. Duration of rainfall.
  2. Occurrence (return period).

See Figure 12-2

Note: *Small durations provide higher rainfall intensity.*

- Duration of rainfall is chosen based on the time of concentration

Hydraulic Approach & Concept Cont.

- Time of concentration: It is the duration of rainfall required to produce the max. rate of run off.
- Time of concentration = Time of flow (over land + in drainage system)
- Time of over land flow: time for a water particle to travel from most remote point in drainage area to point where it enters the drainage system.
- Time of over land flow = F (Slope, type of surface, length,…)
- Estimates of flow in drainage system can be made from observed or computed velocities of flow.

Surface Run Off

- Rains fall on pervious surfaces : Pass into soil, disappear (evaporation and/or run off)
- Water lost by evaporation is negligible.
- Drainage must be provided for all water not infiltrating into the soil or not stored temporarily in surface depressions.
- Infiltration rate of water = F (Type and gradation of soil, soil covers, moisture content, temperature of water, air, and soil, impervious layer presence or absence).
- Frozen soil is impervious.
- Rate of infiltration is assumed to be constant during design storm

Surface Run Off Cont.

- Rate of Run off = F (Land nature, degree of saturation, Slope of surface).
- Small where vegetations present.
- Large for smooth surfaces.
- *Table 12-2 Run off Coefficients values*.
- If drainage area is composed of several types of surfaces, the run off coefficient to be used is the weighted average.

Rational method

- Most Common
- Used for small areas (200 acres)
- Q = C I A
- Q = Run off (Ft^3/sec)
- C = Run off Coeff. (ratio (run off/ rain fall)
- I = Rain Fall Intensity (in./ hr) for the estimated time of concentration.
- A= Drainage Area (acres).
- 1 acre = 4046.87 m^2

Rational method

- Most Common
- Used for small areas (80 hectares)
- $Q = C\ I\ A / 360$
- Q = Run off (m^3/sec)
- C = Run off Coeff. (ratio (run off/ rain fall)
- I = Rain Fall Intensity (mm/ hr) for the estimated time of concentration.
- A= Drainage Area (hectares)
- 1 hectare = 10,000 m^2

Manning's Formula

$$V = [R^{2/3} * S^{1/2}] / n$$

V = Mean Velocity (m/s).

R = Hydraulic radius (m) = [Area / wetted perimeter].

S = Slope of channel.

n = Manning's roughness coefficient.

$$Q = A\ V$$

Run Off for Large Rural Drainage Basins

- Software, National Flood Frequency Program (NFF), available from U.S. Geological Survey (USGS).
- It provides a mean for computing the peak discharge for any place in US.

$$Q_T = a\ A^b\ S^c\ P^d$$

Q_T= Rural Flood Peak discharge for a reoccurrence interval T.

A = Drainage Area

S= Channel Slope

P = Mean annual precipitation

A, b, c, d = regression coefficients ***(See Table 12-3)***

Run Off from Urbanized Areas

- In urban areas growth & development may contribute to flooding & unexpected failures of highway drainage facilities.
  - Removal of vegetation & replacement by impervious pavements & buildings.
  - Improvement of natural watercourses by channelization.
  - Enhancement of the natural drainage system by storm sewer & open channels.
- These improvements decrease infiltration rate& travel time and increase peak discharge.
- The NFF program provides equations for estimating flood run offs from urbanized areas.
- ***See Table 12-4.***

Energy of Flow in Open Channels

- Flowing water energy
  1. Potential (Depth of water + Elev. Of channel bottom above datum plane).
  2. Kinetic (velocity head $v^2/2\ g$).

$$\text{Specific head} = (d + V^2/2g)$$

- Lowest specific head = flow with min. energy. The depth at this point is the critical depth (dc), and the velocity is the critical velocity (Vc).

Energy Flow

- Sub-Critical Flow

1. *Large depth & Low velocity.*
2. *$d_n > d_c$ & $V_n < V_c$.*
3. *Flow is Tranquil.*
4. *Observed in broad valleys and plains.*
5. *Slope flatter than critical slope.*

- Super Critical Flow

1. *Shallow depths and high velocities.*
2. *$d_n < d_c$ & $V_n > V_c$.*
3. *Slope steeper than critical.*
4. *Observed in mountainous areas.*

Design Procedure

- Select Channel cross section that will carry the discharge on the available slope.
- *Figure 12-3 gives direct solution of Manning Equation* (Trapezoidal with 2:1 side slopes and fixed bottom width).
- Find (Qn) project vertical line up to intersect with slope….. Read depth.
- From intersection project horizontal line and read (Vn)….. Find V.
- Compare V and D with critical V &D to decide type of flow.
- Vc & Dc are independent of value of n.
- (***See Examples 12-1 & 12-2***)

Culverts

- Its top doesn’t form part of the traveled way as bridges.
- Span length =< 20ft
- Designed to flow full under certain conditions.
- Bridges designed to pass floating debris or vessels.

Culverts Location & Shape

- Important to select culvert location (Station no.), alignment, and grade
- Location:
  1. *Bottom of depression where no natural water course exist.*
  2. *Where natural stream intersect the roadway*.
- Alignment:
  1. *Conform with natural stream*
  2. *Cross roadway at right angles (economy)*
  3. *Skew culverts are needed sometimes*
- *Grade:*
  1. *Conform to existing grade of stream*
  2. *Reduced grades through culverts…..velocity reduction…..sediments deposition….reduce capacity*
  3. *Increasing culvert grade…..velocity increase…..erosion at outlet and beyond.*

Culverts Shape & Materials

- Shapes (***See Figure 12-6 in Ref.***):
  1. *Circular*
  2. *Box (rectangular)*
  3. *Elliptical*
  4. *Pipe Arch*
  5. *Arch*
  6. *Metal Box*
- Materials:
  1. *Concrete (reinforced & unreinforced)*
  2. *Corrugated metal (Steel & Aluminum)*
- Inlet Types (***See Figure 12-7 in Ref.***):
  1. *Projecting barrel.*
  2. *Cast in place concrete headwall & wingwalls.*
  3. *Precast end section.*
  4. *End mitered to the slope.*

Hydraulic Design of Culverts

- Purpose:

  To provide a drainage facility or system that will adequately and economically drain the estimated flow throughout the design life without unreasonable risks to the roadway structure or nearby property.

Culvert Design Procedure

1. Obtain all site data & plot a roadway cross section at the culvert site, including a profile of the stream channel.
2. Establish the culvert elevations, inlets and outlets, and determine culvert length and slope.
3. Select a type and size of culvert.
4. Examine the need for energy dissipaters.

Culvert Design

- The allowable level of headwater upstream of the culvert entrance is generally the principal control of the culvert size and inlet geometry
- The allowable headwater depth depend on the topography and nature of land use.

Types of Culverts Flow

- Type of flow depends on the total energy available between inlet and outlet.
- Available energy consist of the Potential energy or the difference in head water and tail water elevation.
- Energy expended at the entrance in friction, velocity head, and in depth.
- Flow characteristics & capacity are determined by location of control section.
- Control section: Section of the culvert that operate at max flow.
- Types of control: Inlet control & outlet control.
- ***Figures 12-8 & 12-9***

Culverts with inlet control

- Discharge capacity depends on the depth of Head Water (HW) at the entrance, the entrance geometry, and type of inlet edge.
- Occurs when slope of the culvert is steep and outlet is not submerged.
- ***Series of nomographs (Fig. 12-10,11)***

Culverts with Outlet Control

- Max flow depends on the depth of HW and geometry of entrance in addition to the elevation of tail water at the outlet, slope, roughness, and length of culvert.
- Occurs in flat slopes especially when down streams conditions cause tail water depth to be greater than the critical depth.

Culvert Design

- See example 12-3.
- Inlet control : Find HW & control HW Elev.
- Outlet: TW, dc, ho = TW or [(D+dc)/2] which is greater, ke, Find H= energy loss
- HW Elevation at outlet = ELo + ho + H
- Compare control HW Elev. For inlet and out let Elev. The higher controls the flow.

Improved Culvert Inlet Design & Type Selection

- Bevel-Edge Inlet
- Side-Tapered Inlet
- Slope-Tapered Inlets.
  - ***See Fig. 12-15***

- Selection of Culvert Type: Depends on
  1. *Hydraulic requirements*
  2. *Strength (support fill & traffic loads)*
  3. *Economics*

Hot Mix Asphalt Production and Placement

Dr. TALEB M. AL-ROUSAN

Central Mixing Plants

- Central Mixing Plant: Plant or factory at which the bituminous paving mixture is produced, in a process beginning with the aggregates and bituminous materials and ending with the discharge of the mixture into hauling units for transportation to the job site.

- Preparation of the paving mixture at a central plant offers the advantages of:
  - More careful proportioning of the ingredients.
  - More uniform and thorough mixing with consequent production of more uniform mixtures.
  - Less dependence on favorable weather conditions.
  - Use of more viscous bituminous materials.

High-Type, Intermediate & Low-Type Surfaces

- High-type mixtures uses semi-solid binders that are mixed and laid at elevated temperatures, whereas intermediate type mixtures uses softer bituminous materials that require a moderate amount of heating (or no heating as in emulsions).
- Grading of aggregate components are more carefully controlled for high-type mixtures than in intermediate and low type mixtures.
- Density & stability requirements of the compacted mixture are much rigid for high-type pavement than intermediate pr low-type mixtures.

Central Mixing Plants

- Central Mixing Plants are described as:
  - **Portable** : *Small units, self contained, & wheel mounted. Or large mixing plants in which separate units are easily moved from one place to another*
  - **Semi-portable**: *Plants in which separate units must be taken down, transported (trailer, trucks, or railroad cars) to new location, and then reassembled.*
  - **Stationary**: *Plants permanently constructed in one location and are not designed to be moved from place to another.*

- Portable & semi-portable are numerously used and have capacity range up to 400 tons/hr.

Types of Central Mixing Plants

- **Batch Plants**:
  - *The correct amount of aggregate & bituminous materials, determined by weight, are fed into the mixing unit of the plant.*
  - *The batch is then mixed and discharged from the mixers into trucks before additional materials is introduced.*

- **Drum Mix Plants**:
  - *the aggregates are proportioned prior to entry in the mixing drum by means of precision belt feeders which control the amount of each class of aggregate entering the drum.*
  - *Drum feeder dries the aggregate & blends it with asphalt.*
  - *The HMA discharge continuously into a surge silo, where it is temporarily stored and later loaded into trucks.*

HMA Plant Functions

- Aggregate and asphalt storage.
- Aggregate drying.
- Dust collection, air pollution control.
- Aggregate and asphalt proportioning.
- Mixing.
- Mixture discharge/storage.

Aggregate Storage

- Separated stockpiles
- Good drainage
- Minimize segregation

Cold Feed System

- Provide uniform flow of various aggregates
- Flow generally controlled by:
  - Gate opening
  - Belt speed
- Coarse aggregate typically flows better
- Uniform feed rate is essential.

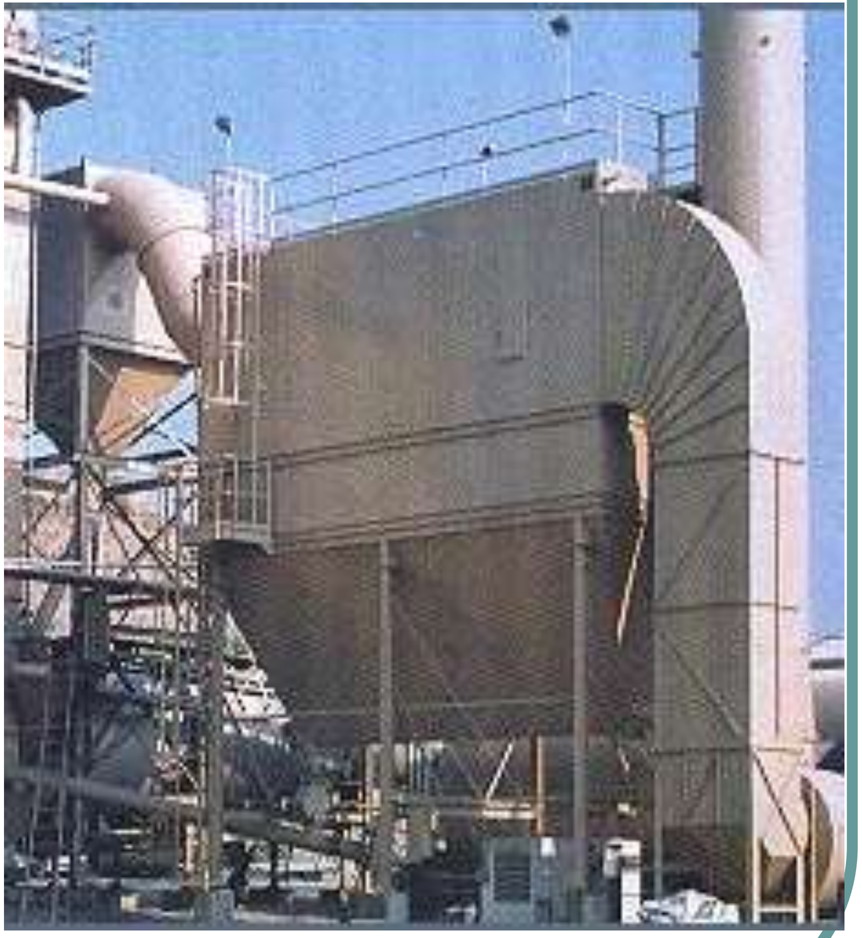
Cold Feed Bins

Aggregate Drying & Heating

- Dry and heat aggregates from cold feed.
- Large rotating metal drum.
- Oil or gas burner, or heater (generally located at the lower end).
- Drum mounted on a slope (angle to the Horizontal)
- Flights (steel angles or blades) in drum lift aggregates
  - Aggregate falls in veil through hot air stream
- Hot aggregates are then discharged from lower end, generally onto an open conveyor or enclosed hot elevator that transport it to the screens & storage bins.

Dust collection Dust collection

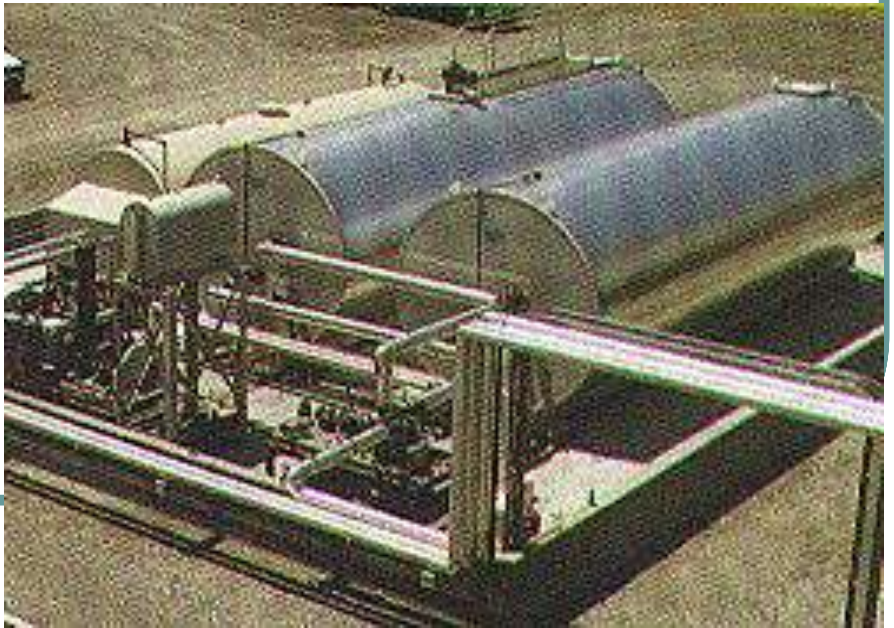
- Works with the drying system
- Eliminates dust from plant exhaust
- Two basic types:
  - Wet scrubber
  - Baghouse
    - Collected dust may be returned to drum if desired



Asphalt Storage

- Provides heated asphalt for mixing
  - Steam or hot oil circulates through coils in tank.
  - Electric heating jackets.
- Tanks, lines, pumps should be heated
- Tanks should be calibrated to allow for content determination.

Asphalt Storage Tanks



Control facility

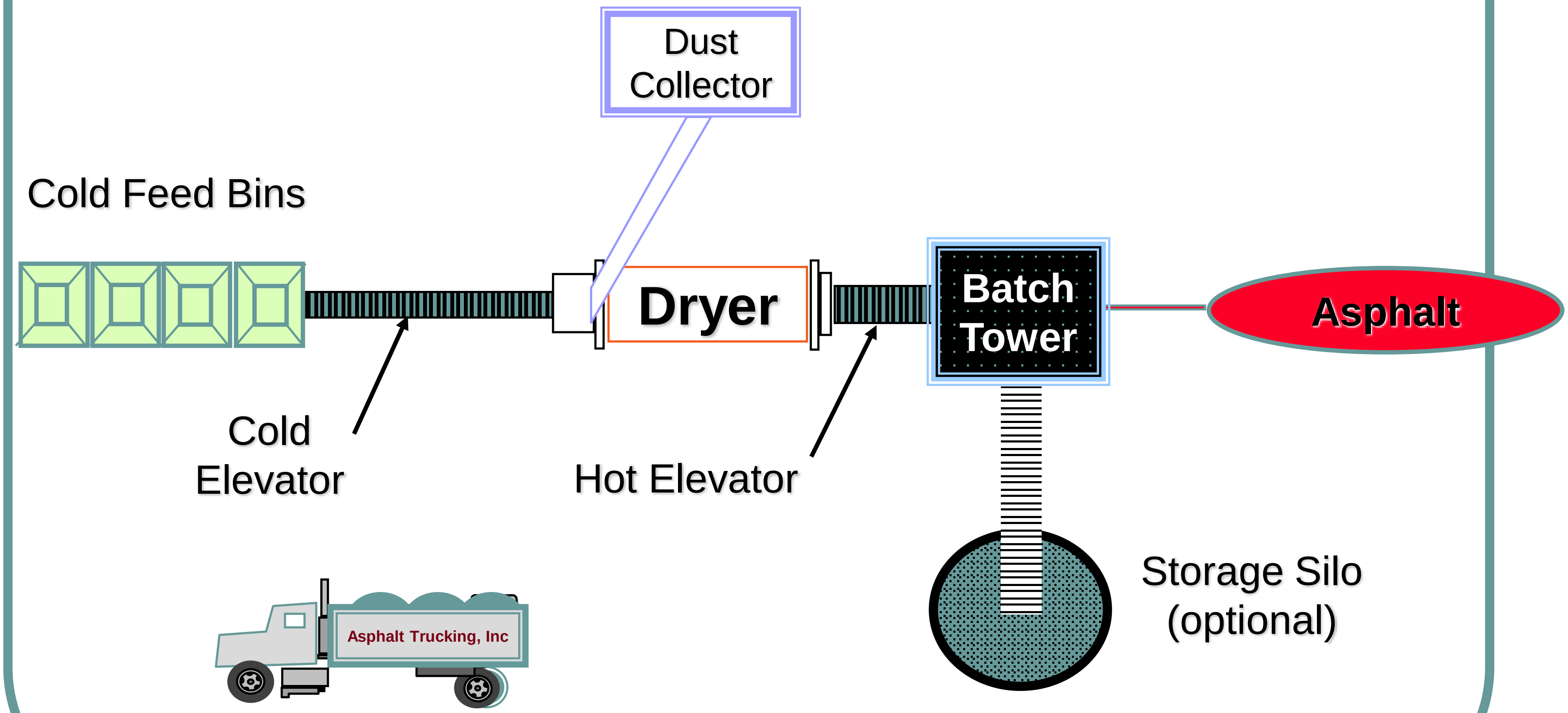
- Plant operations are monitored
  - Aggregate feed rate (s)
  - Asphalt feed
  - Burner control
- Truck loading

Batch Plant

Batch Plants-Features

- Aggregates dried, separated by size.
- Aggregates recombined by weight in weigh hopper.
- Aggregates introduced into pugmill, briefly mixed.
- Asphalt introduced by weight, mixed with aggregates.
- Completed HMA discharged or stored.

Batch Plant Layout



Batch Plant/ Asphalt Delivery System

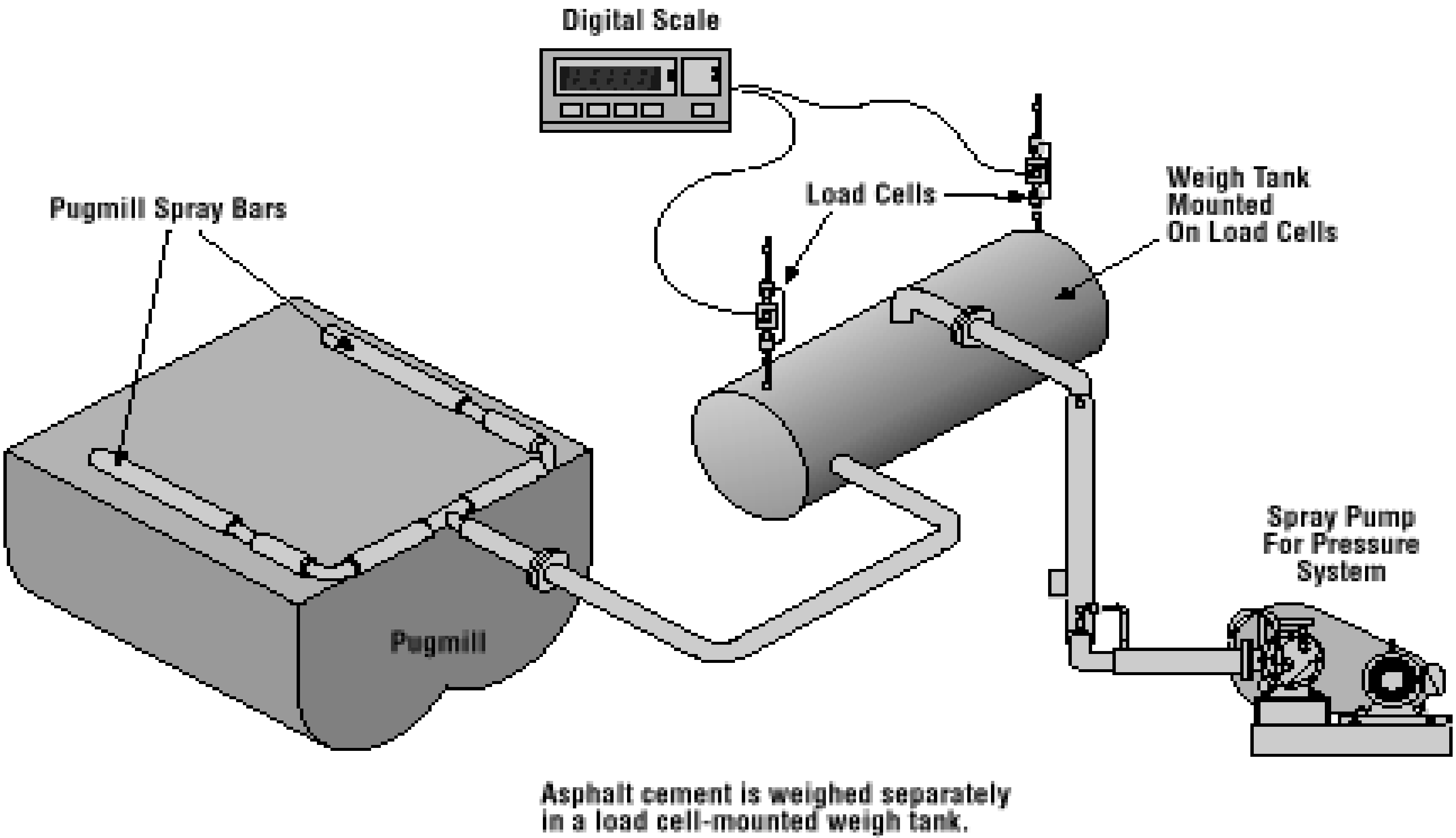


Figure 4.35 Asphalt Weighing and Delivery System in a Batch Plant (Courtesy of GenTec)

Batch Plant Typical Mixing Cycle

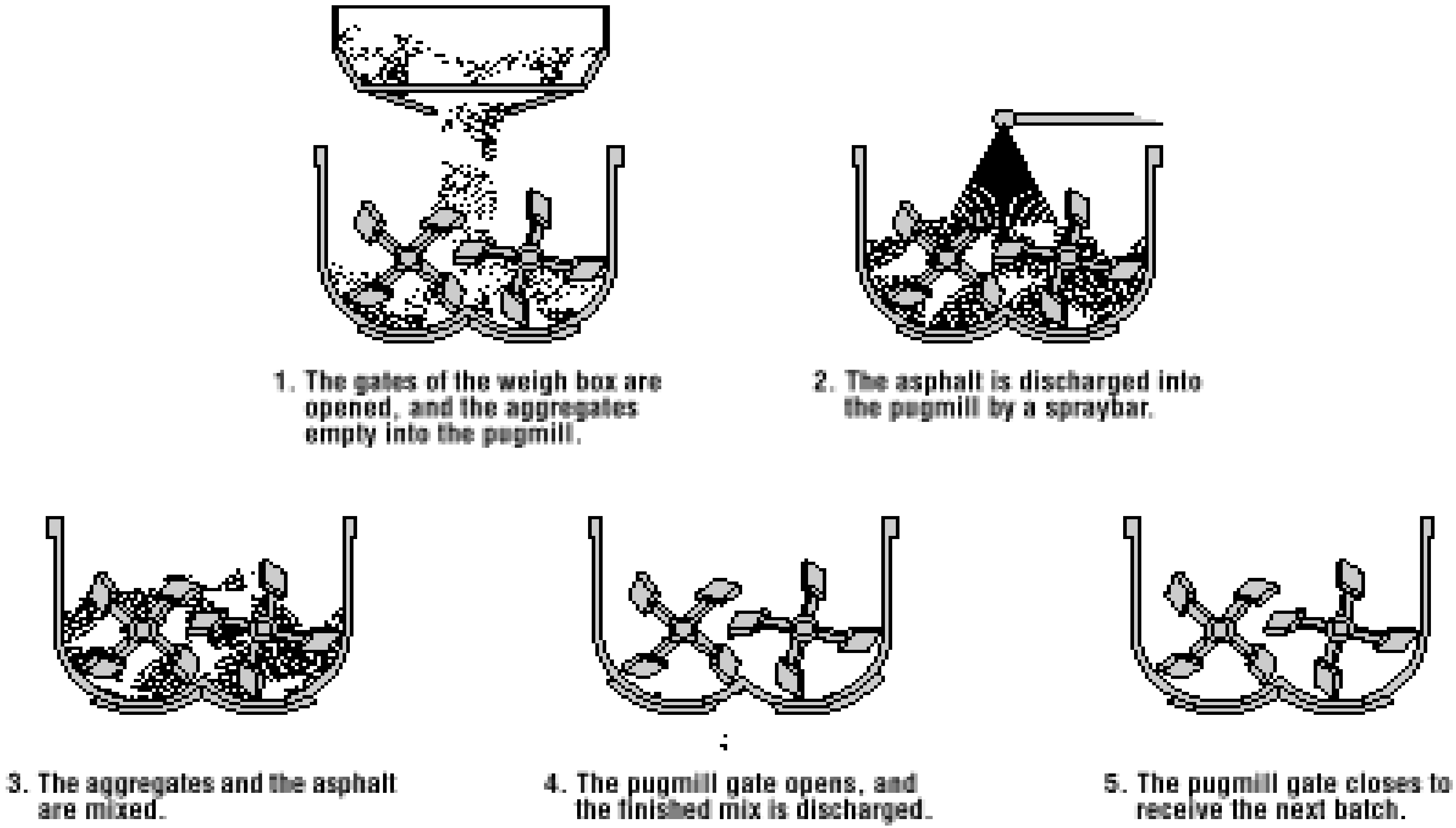


Figure 4.39 Steps in a Typical Batch Plant Mixing Cycle

Drum Plants

- Aggregates are dried, mixed with asphalt in a continuous operation
- Quality control entirely dependent on:
  - stockpile management
  - plant calibration
- Mixture must be stored in surge bin or silo.
- Plant consist of : (Aggregate Cold feed bins; Conveyor & aggregate weight system, Drum mixer, liquid asphalt storage tank & pump; hot mix conveyor; mix surge silo; control van; dust collection system).

Drum Plant Layout

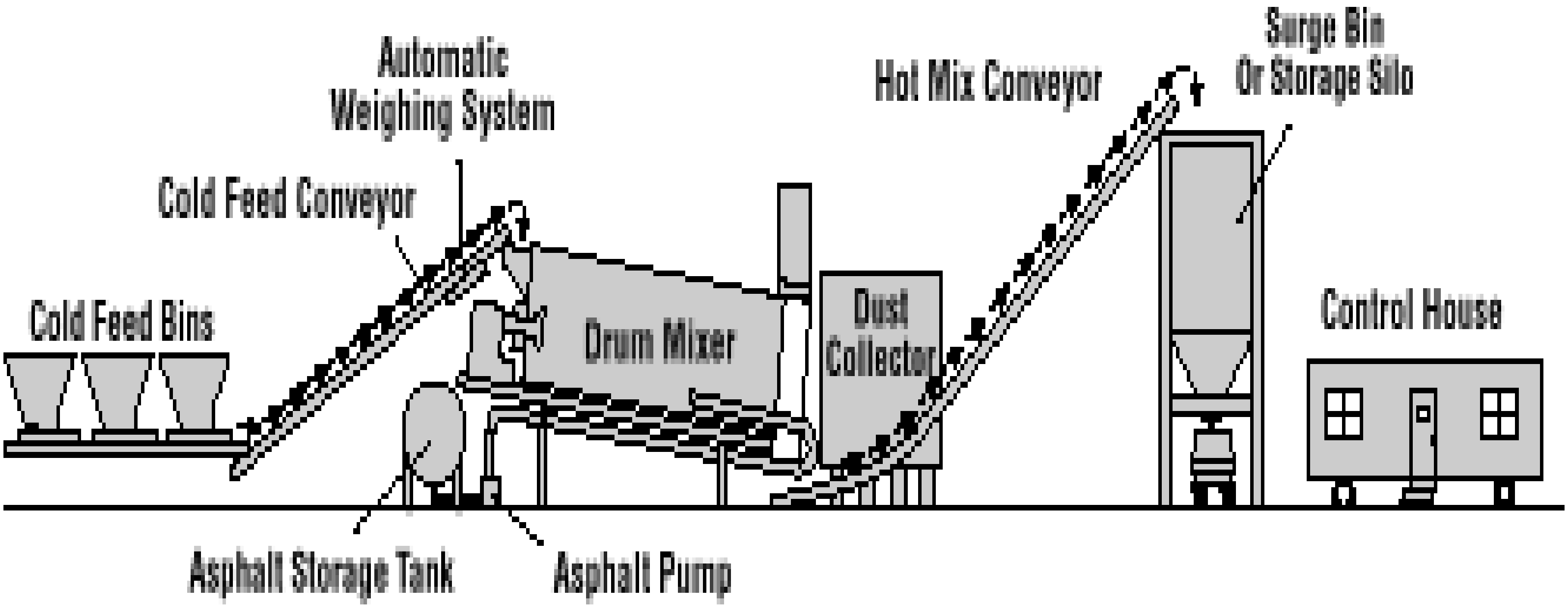


Figure 4.43 Basic Drum Mix Plant

Drum Plant-Knippa, Texas

HMA Placement

Self Propelled Paving Machine

THE BASIC PRINCIPLE HAS NOT CHANGED MUCH

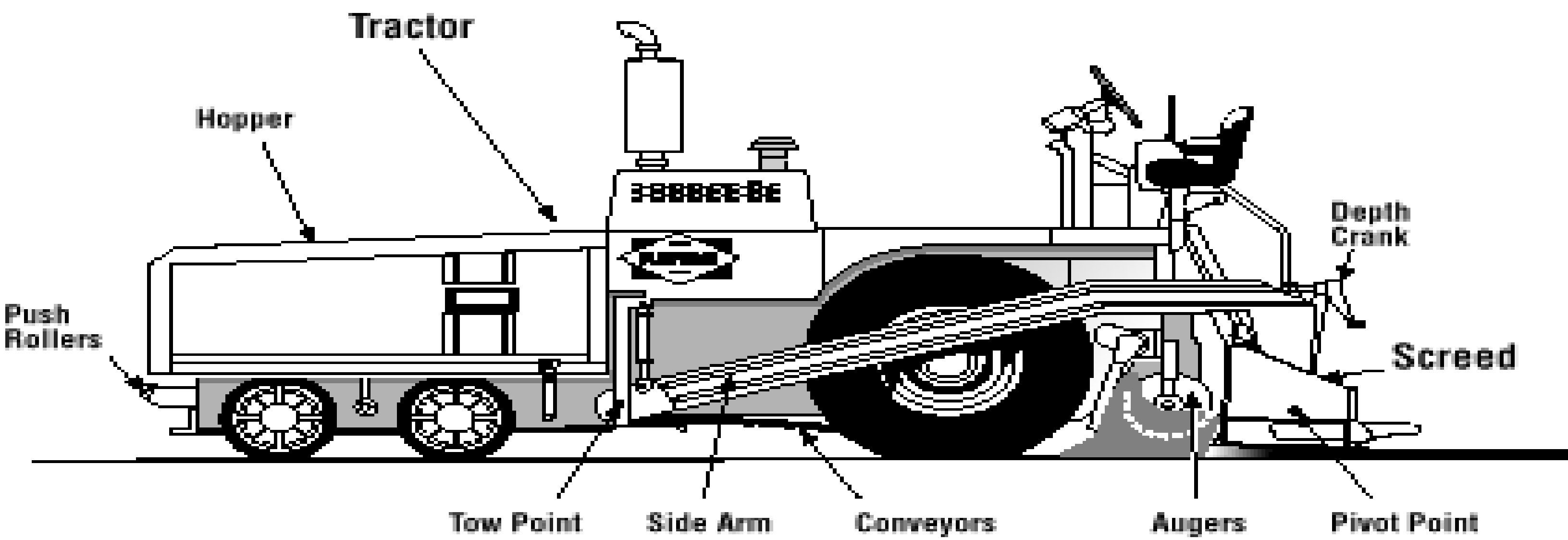
Paving Equipments

Paving Machine Components

- Tractor unit
- Screed
- Electronic grade controls

HMA Delivery

- Paver pulls up to meet the truck
  - **DON'T BUMP THE PAVER!**
- Break the load before opening tailgate.
- Charge the hopper before it's empty.



DON'T BUMP THE PAVER!

Automatic Screed Controls

- Electronic adjustment to screed height using sensing and reference system
- Sensor detects elevation changes, adjusts height of tow point
- Slope (transverse) controls

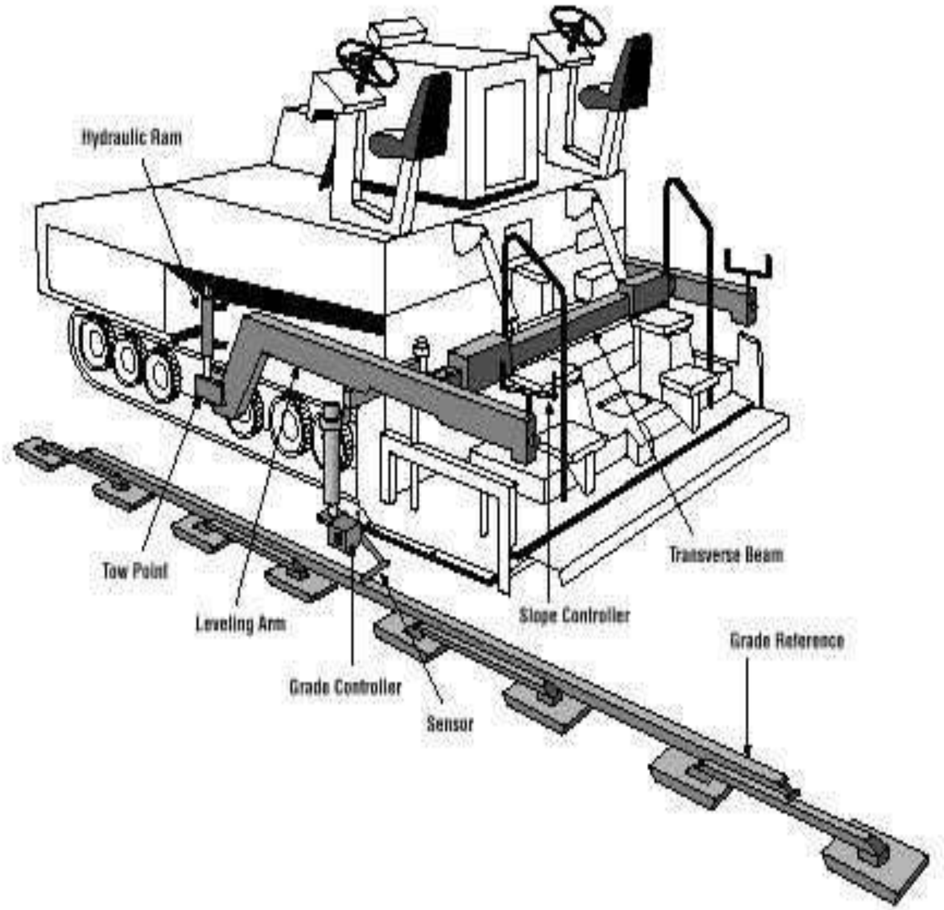


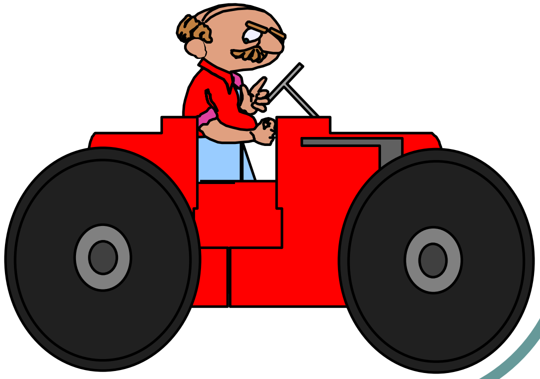
Figure 5.17 Automatic Screed Reference System

Paving Operations

- Maintain uniform resistance to face of screed!
  - Keep Paver in motion 75% of the time
  - Keep augers turning 85% of the time
- Coordinate mixture delivery, Paver speed and compaction operations

Compaction

- The process of compressing a material into a smaller volume while maintaining the same mass.
- Essential to good performance!
  - *To provide shear strength or resistance to rutting*
  - *To ensure the mixture is waterproof*
  - *To prevent excessive oxidation of the asphalt binder*
- Need to compact to desirable air voids level
  - *conventional dense-grade mixtures: 4-8%*
  - *gap-grade mixtures: 3-6%*
- Compaction can only achieved if:
  - *mixture is confined*
  - *mixture is hot (workable)*



Factors Affecting Compaction

- Mixture properties
  - *Aggregate*
  - *Asphalt*
  - *Mix Temperature*
- Base/subgrade support (confinement)
- Ambient conditions
- Lift thickness:
  - *Compacted lift thickness at least 3 X nominal maximum aggregate size*
  - *particularly important for gradations below maximum density line*
  - *0.5 in nom max ➔ use 1.5 in minimum lift thickness (prefer 2 inches, especially for coarse-graded mixtures)*
  - *Thicker lifts conserve heat longer, provide more time for compaction*
- Rollers

Temperature Is Critical

Compaction Equipments

- Screed unit on paver
  - weight of screed
  - tamping/vibratory unit
- Rollers
  - vibratory steel-wheeled
  - static steel-wheeled
  - pneumatic

Vibratory Rollers

- Commonly used for initial (breakdown) rolling
- 8-18.5 tons, 57-84 in wide (“heavy” rollers)
  - 50-200 lbs/linear inch (PLI)
- Frequency: 2700-4200 impacts/min.
- Amplitude: 0.016-0.032 in.
  - For thin overlays (≤ 2 in.) use low amplitude or static mode
- Operate to attain at least 10 impacts/ft
  - 2-4 mph

Vibratory Rollers

Static Steel-Wheeled Rollers

- 10-14 ton rollers normally used for HMA compaction
  - Commonly use vibratory rollers operated in static mode
- Lighter rollers used for finish rolling
- Drums must be smooth and clean
- For initial compaction, drive wheel must face paver

Three-Wheel Static Roller

Pneumatic-Tired Rollers

- Reorients particles through kneading action
- Load/tire: 1050 – 6730 Lb/tire depending on model/ballast
- Tire pressures:
  - ~70 psi (cold) for compaction
  - ~50 psi (cold) for finish rolling
- Tires must be hot to avoid pickup
- Not used for open-graded mixes or SMA

Pneumatic-Tired Rollers

Dynapac CP 132
5-13 tons
69 inch width

Dynapac CP 271
12-30 tons
93” width

Pneumatic as Breakdown Roller

Rolling Pattern

- Speed & lap pattern for each roller
- No. of passes for each roller
- Min. temperature by which each roller must complete pattern

IMPORTANT:

Paver speed must not exceed that of the compaction operation!!!

Checking Density With Nuclear Gauge

Extracting A Core

The dry mass of a sample of aggregate is 1982.0 g. The mass in a saturated surface dry condition is 2006.7 g. The net volume of the aggregate is 734.4 cm3. Consider the unit weight of water as 1 g/cm3, Find:

- The apparent specific gravity.
- The bulk specific gravity.
- The percentage absorption

- *Mass of absorbed water = wt. SSd – wt. Dry*
  = 2006.7 – 1982.0 = 24.7 g

- *Volume of absorbed water = 24.7 / (1 g/ cm3)*
- *= 24.7 cm3*

- *Bulk volume of aggregate = Vagg + Vwater*
  = 734.3 + 24.7 = 759.1 cm3

- *Apparent S.G = mass of dry Agg/ Agg volume*
- *= 1982 / 734.4 = 2.699*

- *Bulk S.G = mass of dry Agg / Bulk volume of Agg*
  = 1982 / 759.1 = 2.611

- *% Absorption = (Mass of absorbed water / Mass of Agg)*
- *= (24.7 / 1982) 100% = 1.25%*

- ***Example 2:***
- **Specific gravity test was conducted for a fine aggregate. If the following data was obtained during the test:**
  - **the saturated surface dry weight of the sample = 500 g.**
  - **Weight of pycnometer full of water= 750 g**
  - **Weight of pycnometer and sample and water= 1050 g.**
  - **Oven dry weight of the sample is 475 g. for this aggregate, FIND**
- **The apparent specific gravity.**
- **The bulk specific gravity on an ssd basis.**
- **Percentage of absorption.**

- **Solution**
- The apparent specific gravity =
  - (475/(750 + 475 – 1050) = 2.71

- The bulk specific gravity on an ssd basis.
  - = (0 / (750 + 500 – 1050) = 2.50
- Percentage of absorption.
  - ((500 – 475)/ 475) * 100% = 5.26%