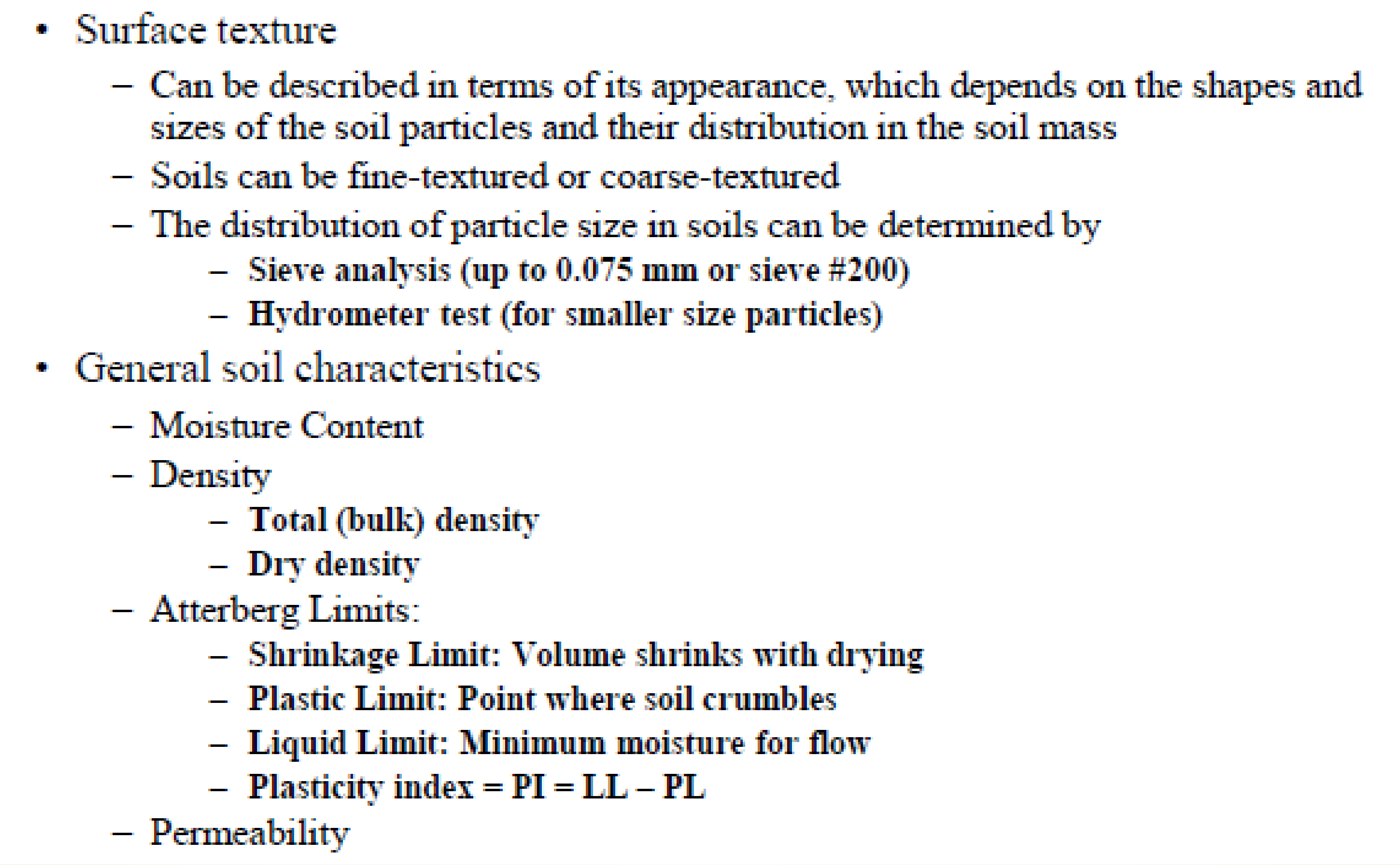
TOPIC 8

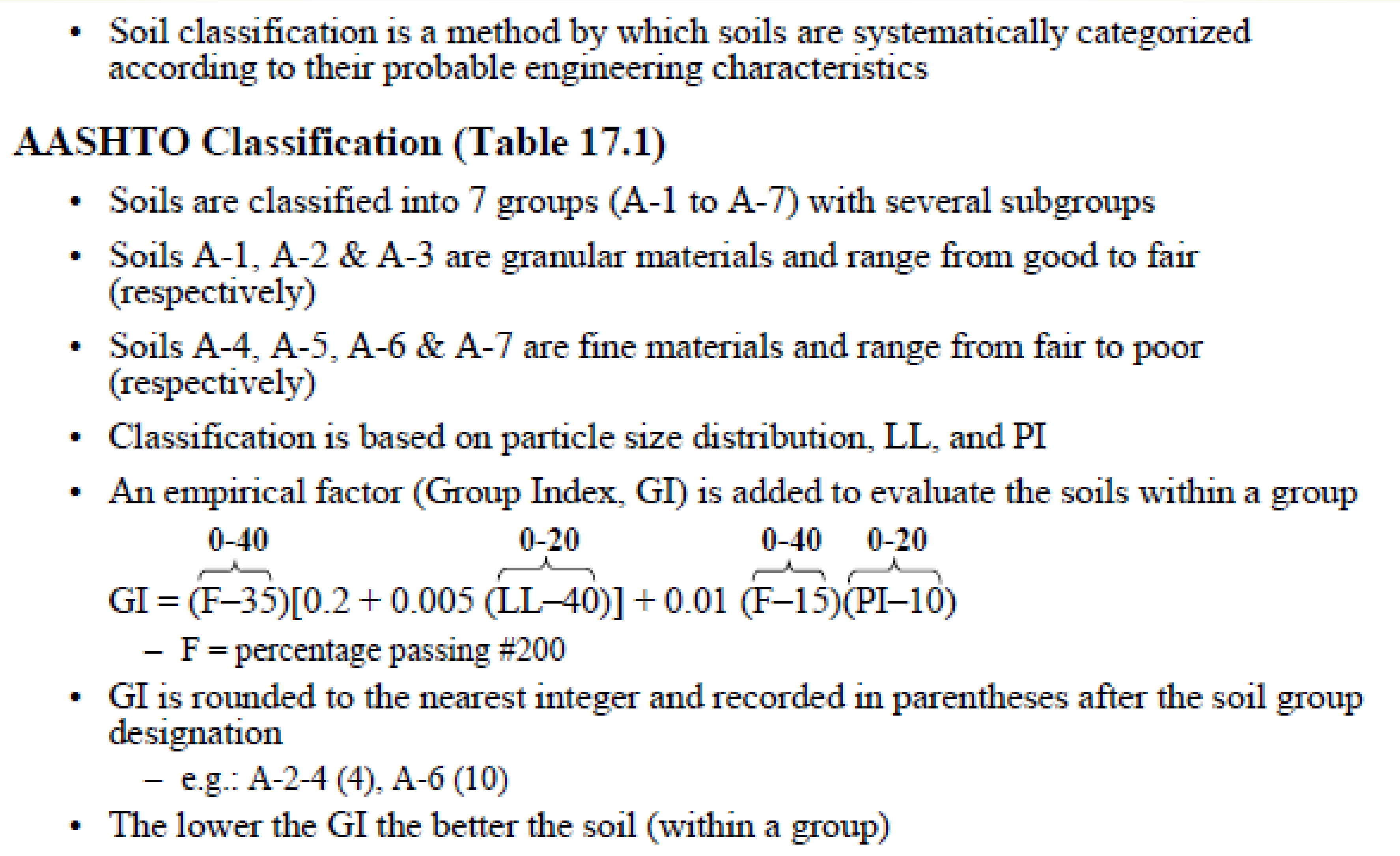
Highway Materials

Soil Characteristics



- Surface texture
  - Can be described in terms of its appearance, which depends on the shapes and sizes of the soil particles and their distribution in the soil mass
  - Soils can be fine-textured or coarse-textured
  - The distribution of particle size in soils can be determined by
    - **Sieve analysis (up to 0.075 mm or sieve #200)**
    - **Hydrometer test (for smaller size particles)**
- General soil characteristics
  - Moisture Content
  - Density
    - **Total (bulk) density**
    - **Dry density**
  - Atterberg Limits:
    - **Shrinkage Limit: Volume shrinks with drying**
    - **Plastic Limit: Point where soil crumbles**
    - **Liquid Limit: Minimum moisture for flow**
    - **Plasticity index = PI = LL – PL**
  - Permeability

Soil Characteristics



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

AASHTO Classification (Table 17.1)

- Soils are classified into 7 groups (A-1 to A-7) with several subgroups
- Soils A-1, A-2 & A-3 are granular materials and range from good to fair (respectively)
- Soils A-4, A-5, A-6 & A-7 are fine materials and range from fair to poor (respectively)
- Classification is based on particle size distribution, LL, and PI
- An empirical factor (Group Index, GI) is added to evaluate the soils within a group

$$GI = \overbrace{(F-35)}^{0\text{-}40}[0.2 + 0.005\,\overbrace{(LL-40)}^{0\text{-}20}] + 0.01\,\overbrace{(F-15)}^{0\text{-}40}\overbrace{(PI-10)}^{0\text{-}20}$$

  - F = percentage passing #200
- GI is rounded to the nearest integer and recorded in parentheses after the soil group designation
  - e.g.: A-2-4 (4), A-6 (10)
- The lower the GI the better the soil (within a group)

Soil Characteristics

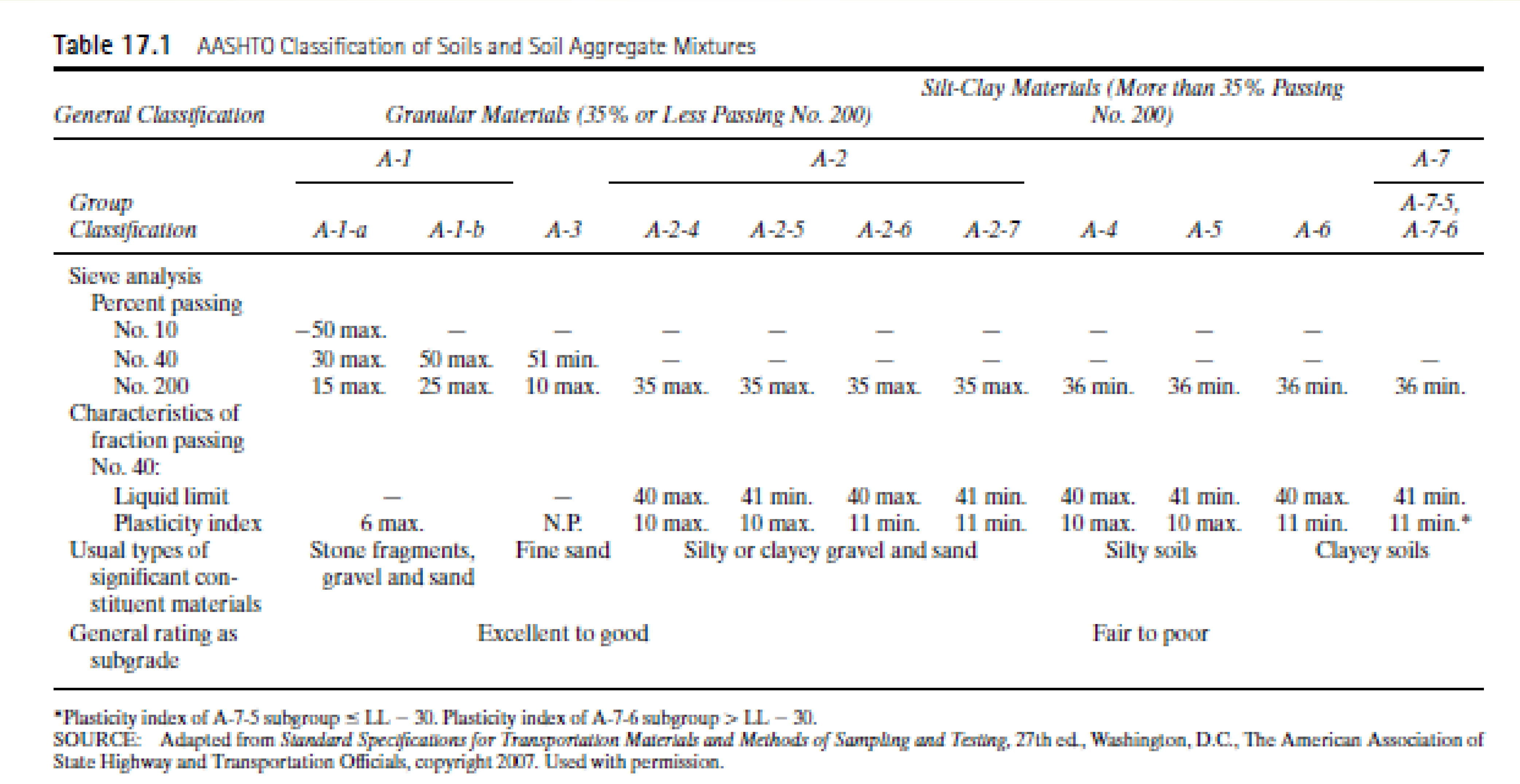


Table 17.1 AASHTO Classification of Soils and Soil Aggregate Mixtures

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

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

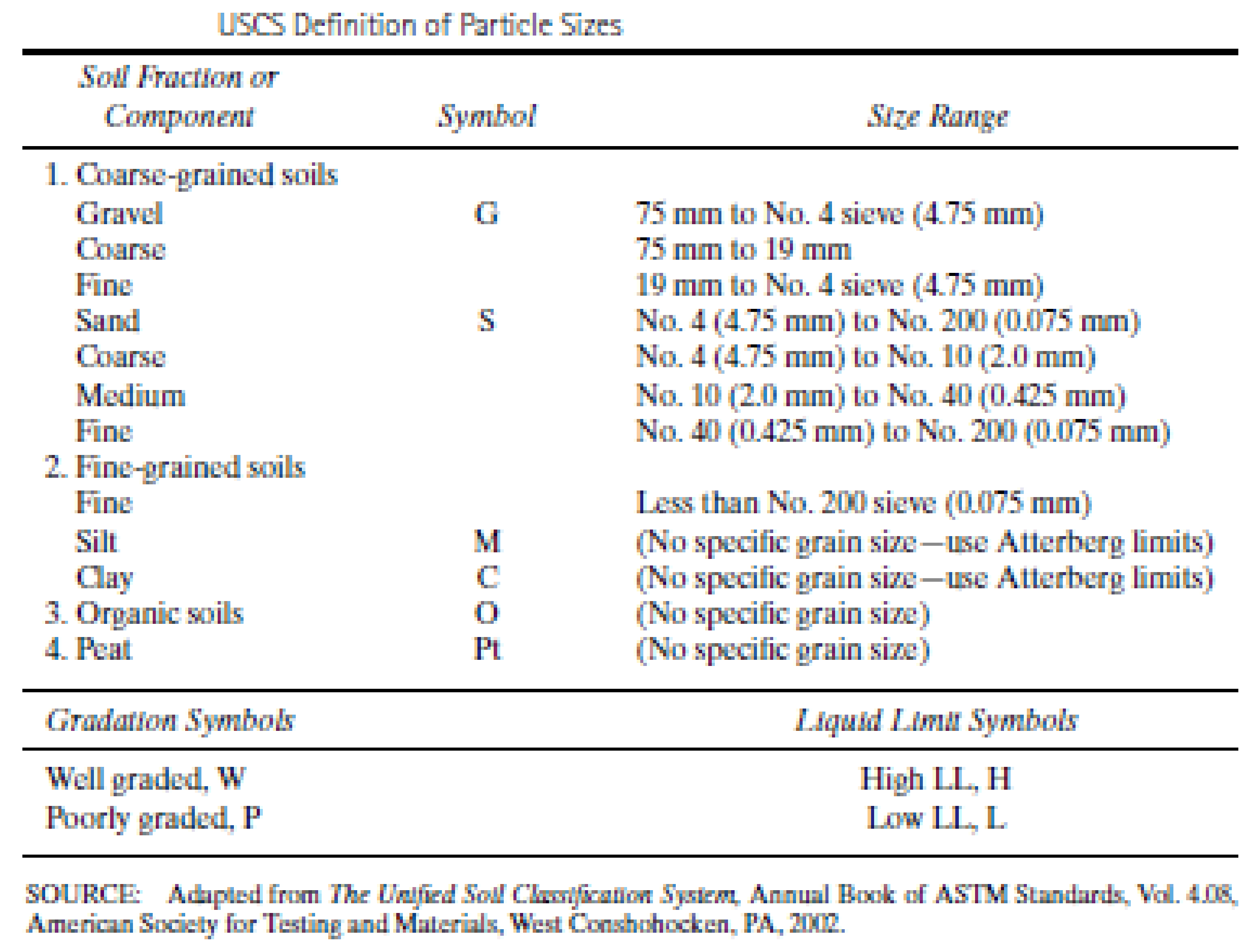
SOURCE: Adapted from *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 27th ed., Washington, D.C., The American Association of State Highway and Transportation Officials, copyright 2007. Used with permission.

Soil Characteristics

Unified Soil Classification System (USCS)

- ❖ Developed originally for airfield construction and can be applied to other types of construction such as dams and foundations
- ❖ Coarse-grained soils are classified based on grain size characteristics
- ❖ Fine-grained soils are classified based on plasticity

Soil Characteristics

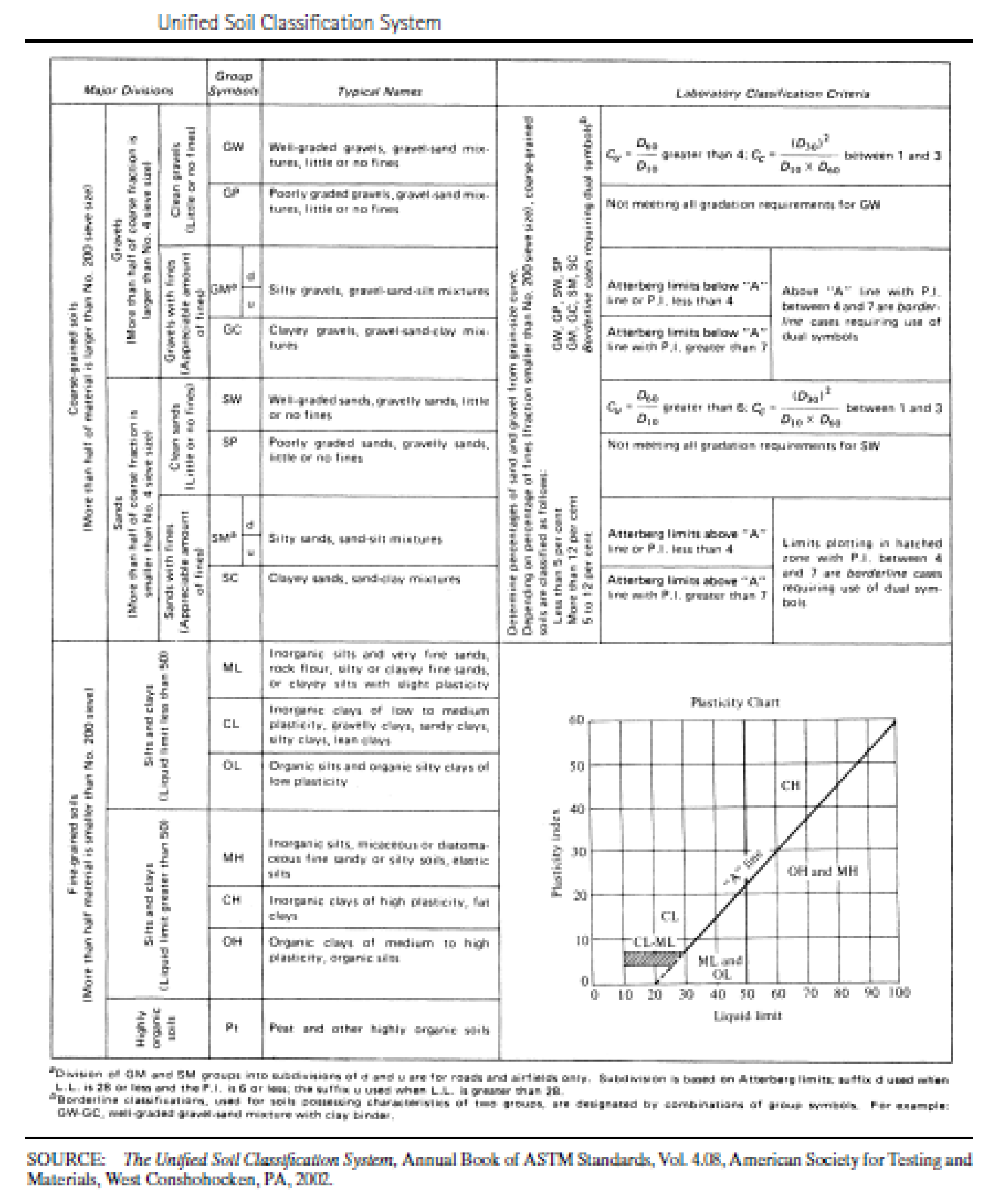


USCS Definition of Particle Sizes

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

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

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



Unified Soil Classification System

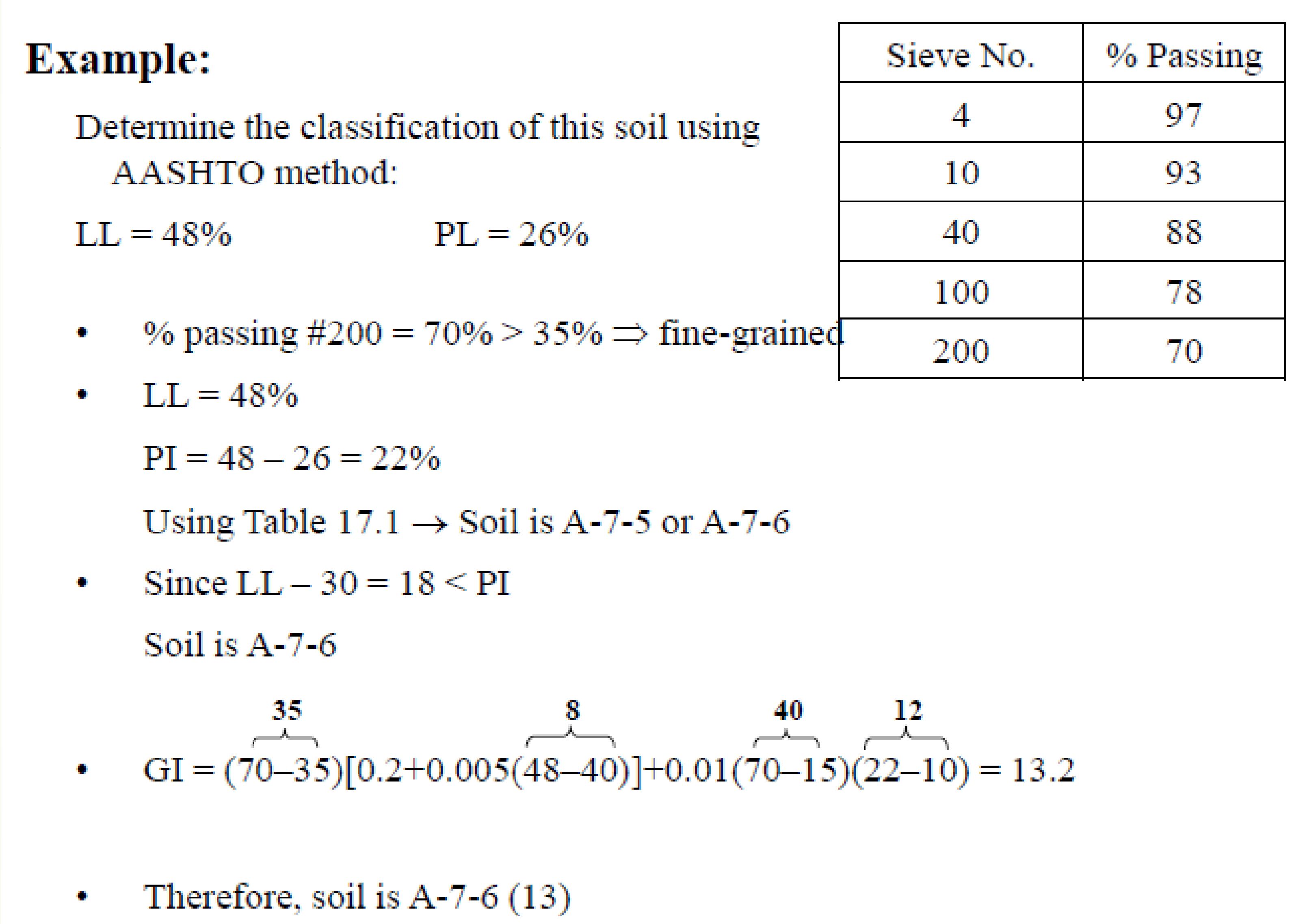
Major Divisions			Group Symbols		Typical Names	Laboratory Classification Criteria		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent GW, GP, SW, SP More than 12 per cent GM, GC, SM, SC 5 to 12 per cent *Borderline cases requiring dual symbols*[b]	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM[a]	d u	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *border-line* cases requiring use of dual symbols
			GC		Clayey gravels, gravel-sand-clay mixtures		Atterberg limits below "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM[a]	d u	Silty sands, sand-silt mixtures		Atterberg limits above "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			SC		Clayey sands, sand-clay mixtures		Atterberg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Plasticity Chart		
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt		Peat and other highly organic soils			

[a] Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterberg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

[b] Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

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

Soil Characteristics



Example:

Determine the classification of this soil using AASHTO method:

LL = 48% PL = 26%

Sieve No.	% Passing
4	97
10	93
40	88
100	78
200	70

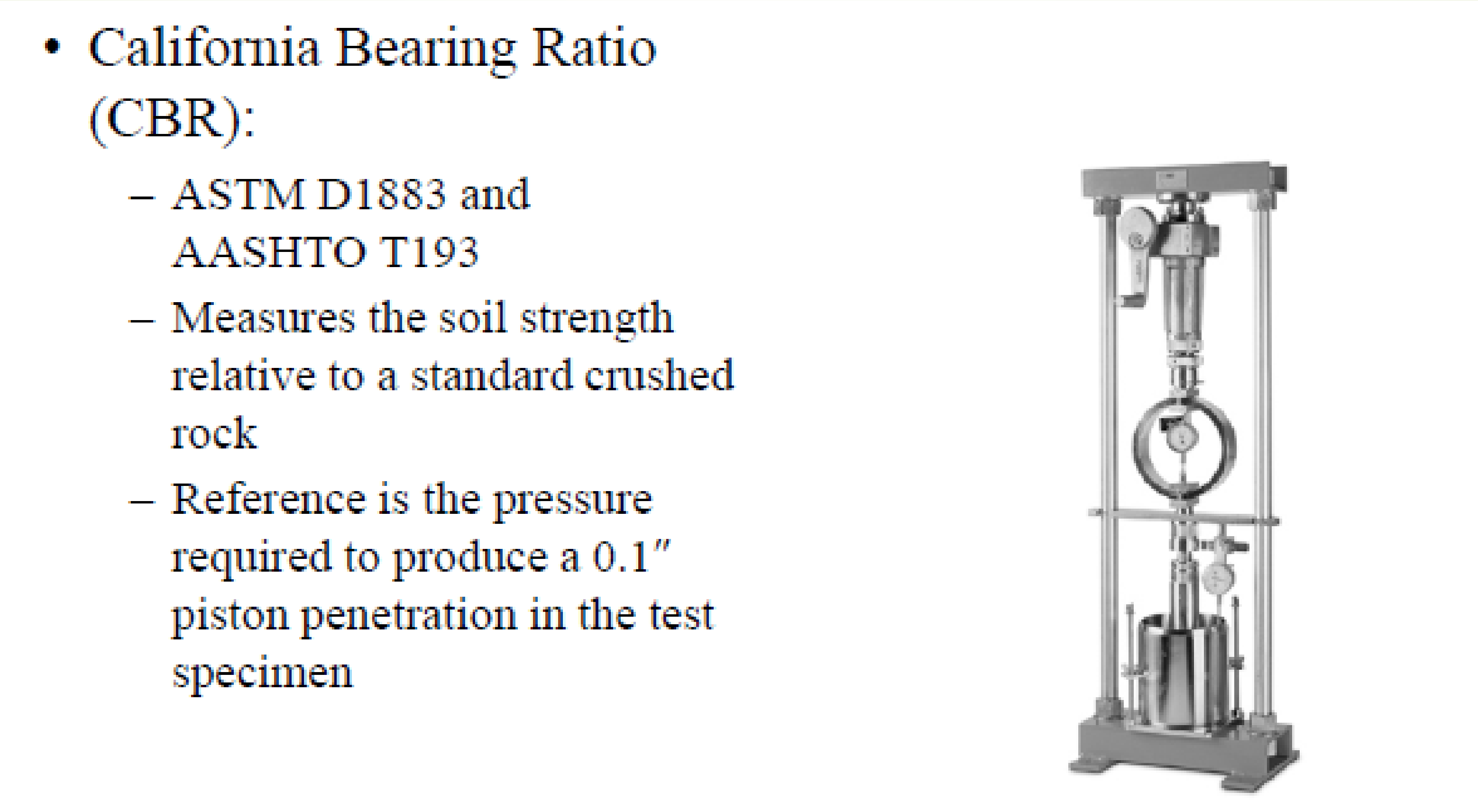
- % passing #200 = 70% > 35% ⇒ fine-grained
- LL = 48%

  PI = 48 – 26 = 22%

  Using Table 17.1 → Soil is A-7-5 or A-7-6
- Since LL – 30 = 18 < PI

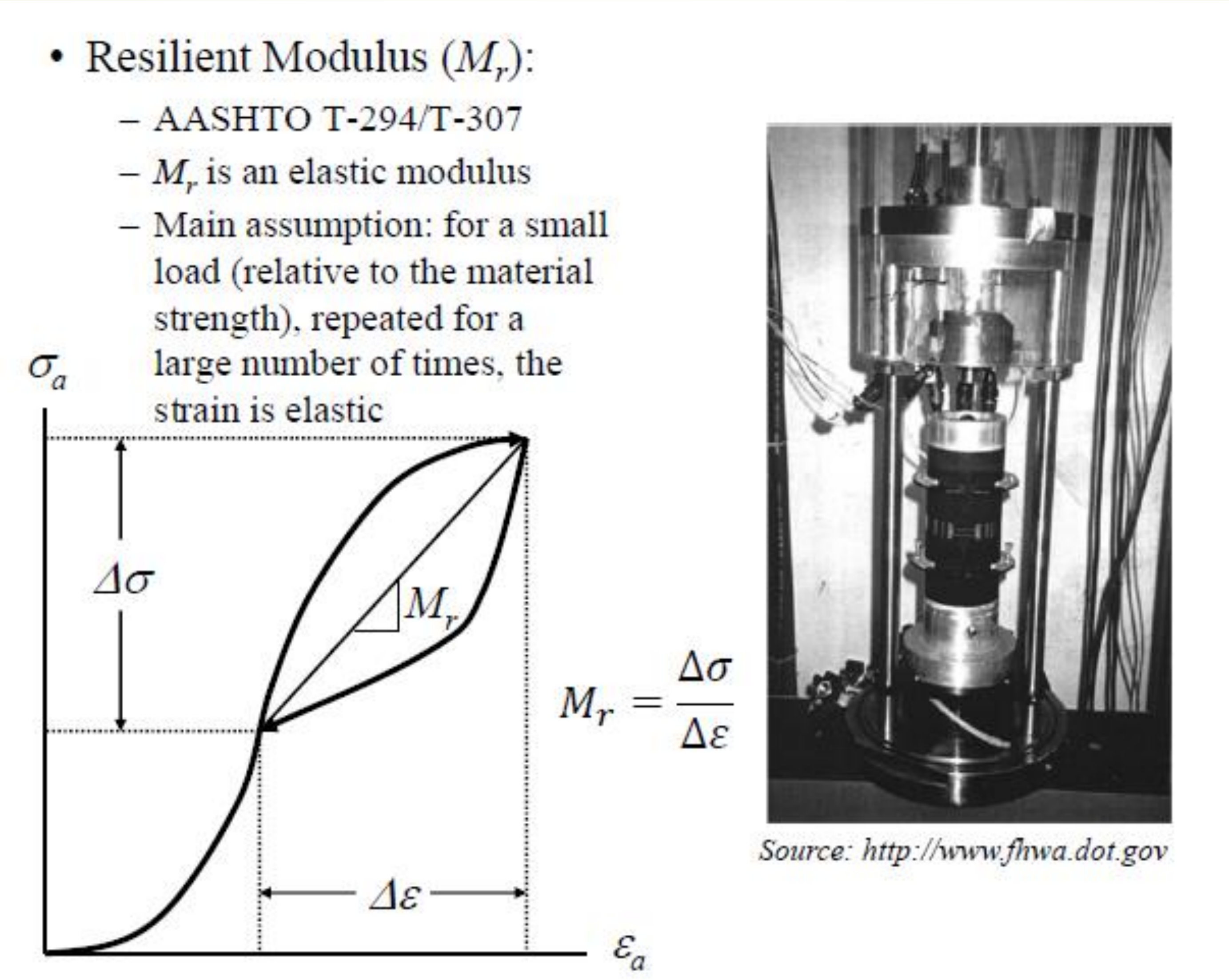
  Soil is A-7-6
- $\text{GI} = \overbrace{(70-35)}^{35}[0.2+0.005\overbrace{(48-40)}^{8}]+0.01\overbrace{(70-15)}^{40}\overbrace{(22-10)}^{12} = 13.2$
- Therefore, soil is A-7-6 (13)

Soil Tests in Pavement Design



- California Bearing Ratio (CBR):
  - ASTM D1883 and AASHTO T193
  - Measures the soil strength relative to a standard crushed rock
  - Reference is the pressure required to produce a 0.1″ piston penetration in the test specimen

Soil Tests in Pavement Design

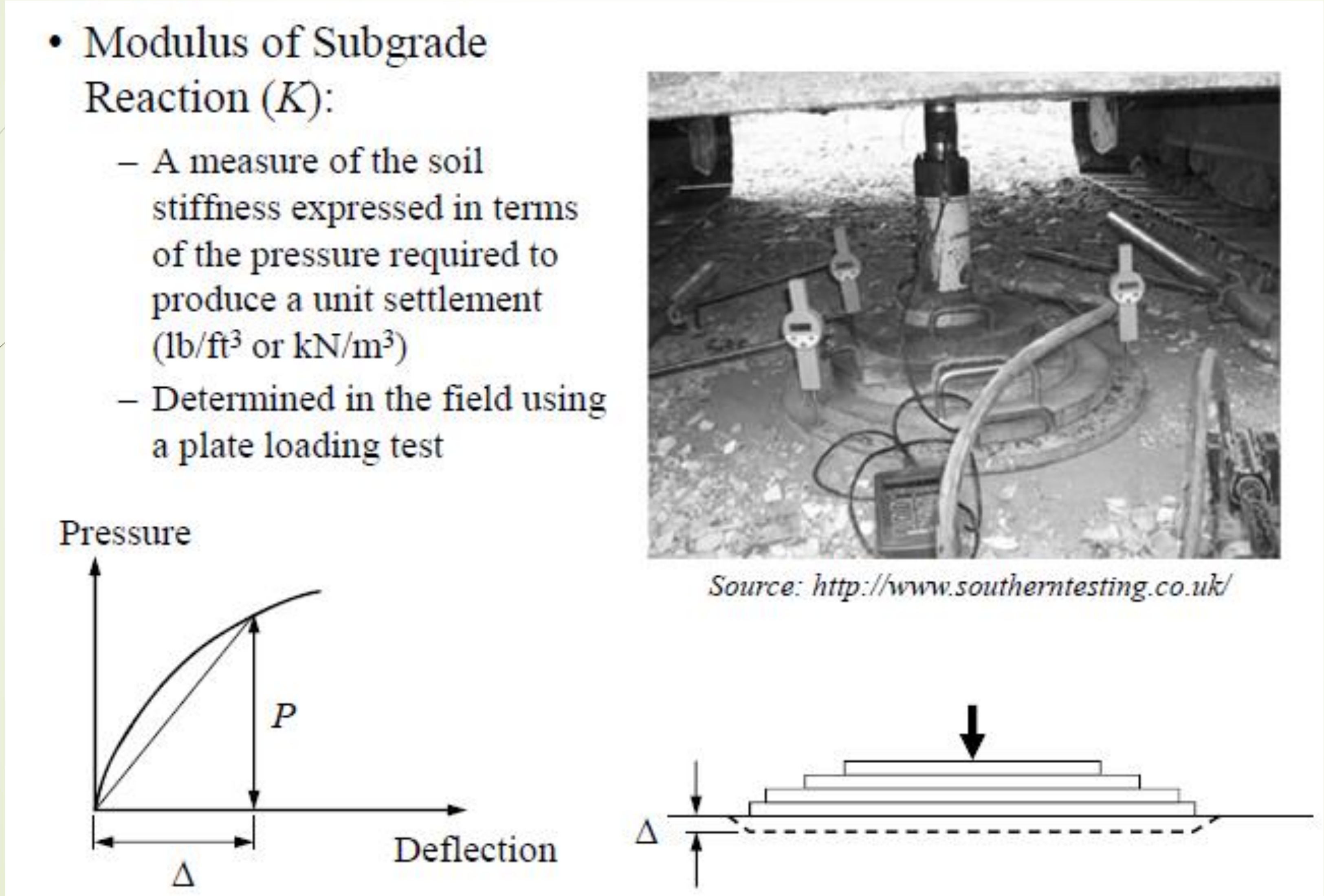


- Resilient Modulus (M_r):
  - AASHTO T-294/T-307
  - M_r is an elastic modulus
  - Main assumption: for a small load (relative to the material strength), repeated for a large number of times, the strain is elastic

$$M_r = \frac{\Delta\sigma}{\Delta\varepsilon}$$

Source: http://www.fhwa.dot.gov

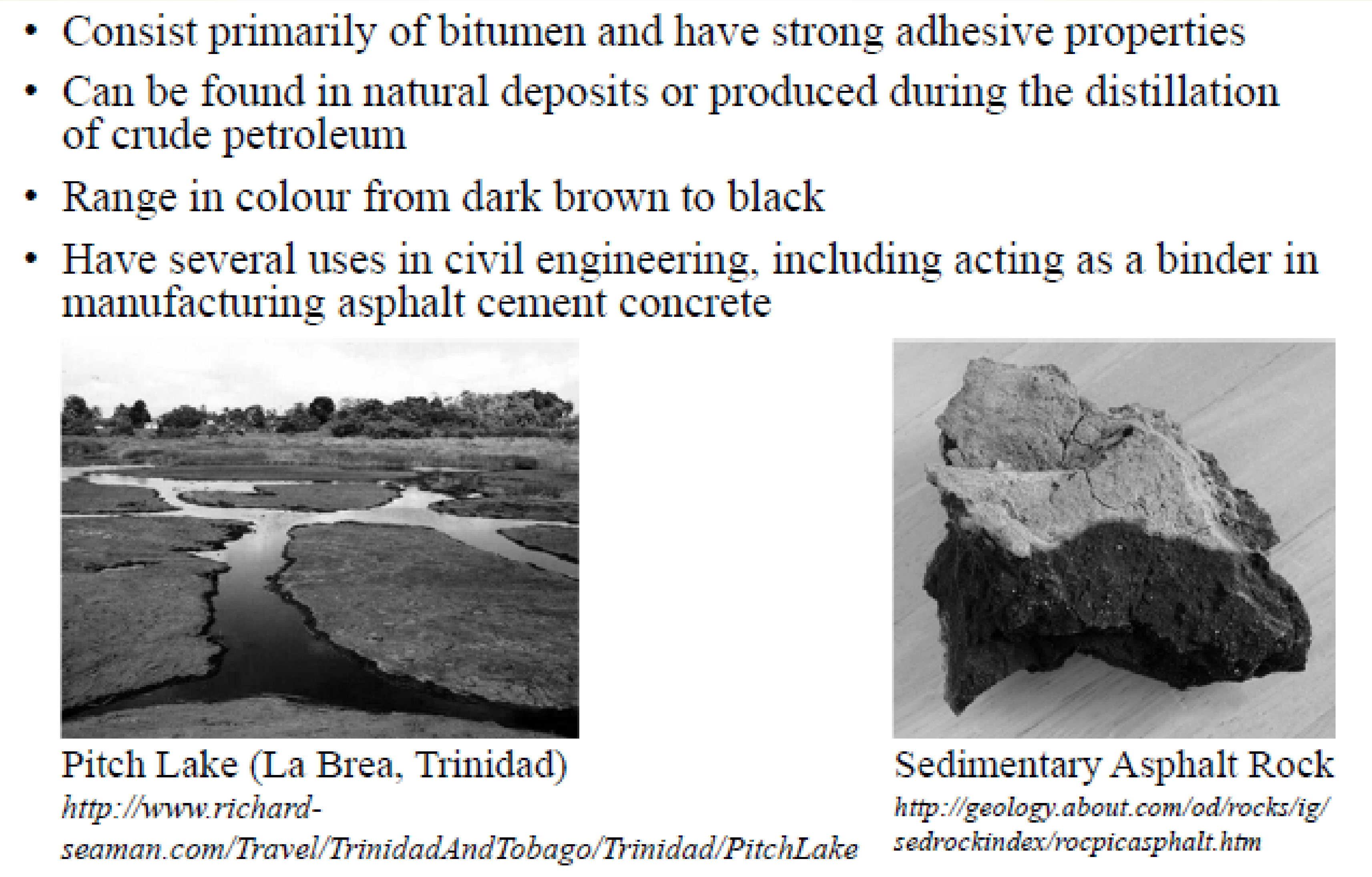
Soil Tests in Pavement Design



- Modulus of Subgrade Reaction (*K*):
  - A measure of the soil stiffness expressed in terms of the pressure required to produce a unit settlement (lb/ft^3 or kN/m^3)
  - Determined in the field using a plate loading test

Source: http://www.southerntesting.co.uk/

Bituminous Materials



- Consist primarily of bitumen and have strong adhesive properties
- Can be found in natural deposits or produced during the distillation of crude petroleum
- Range in colour from dark brown to black
- Have several uses in civil engineering, including acting as a binder in manufacturing asphalt cement concrete

Pitch Lake (La Brea, Trinidad)

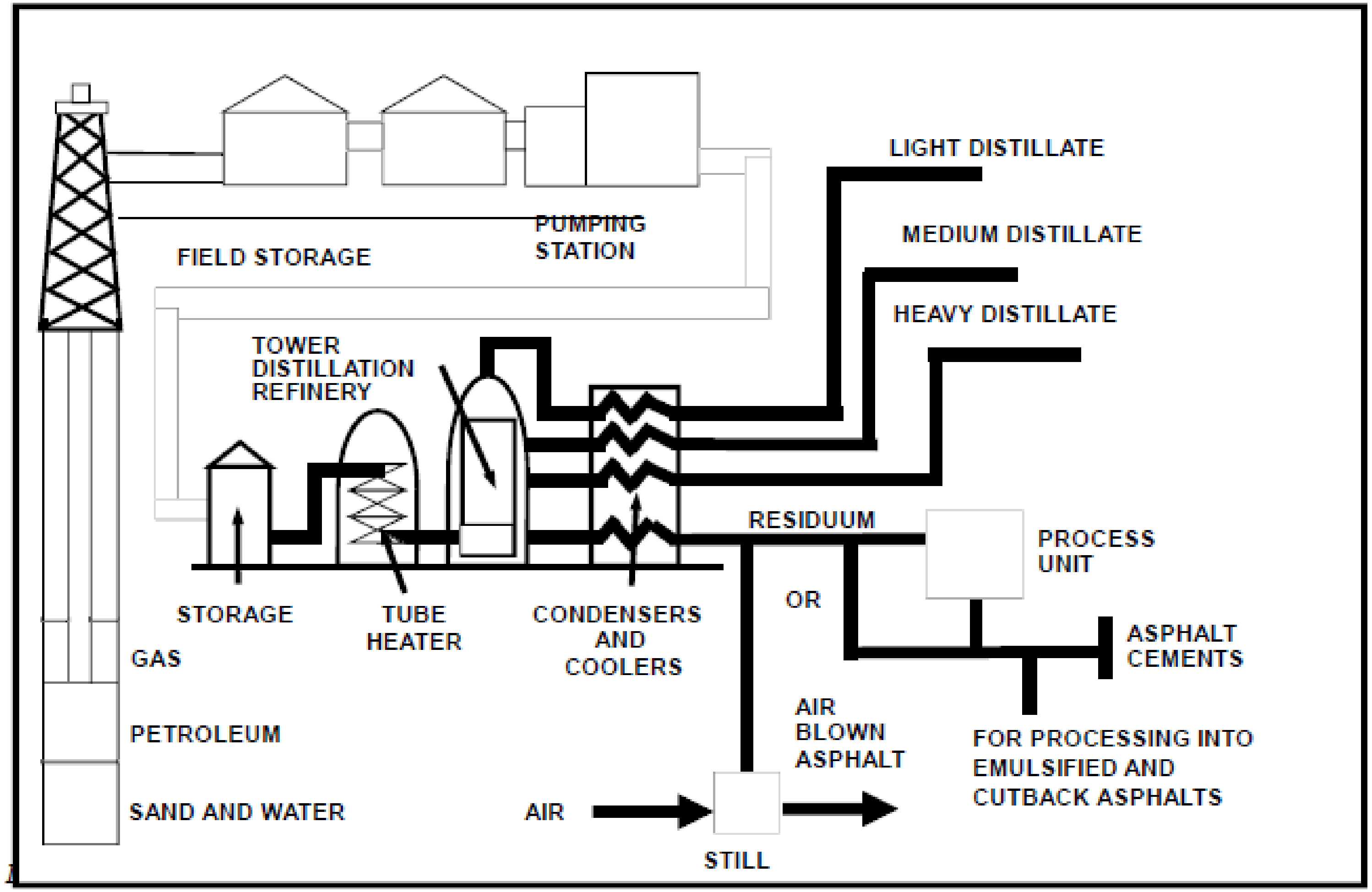
http://www.richard-seaman.com/Travel/TrinidadAndTobago/Trinidad/PitchLake

Sedimentary Asphalt Rock

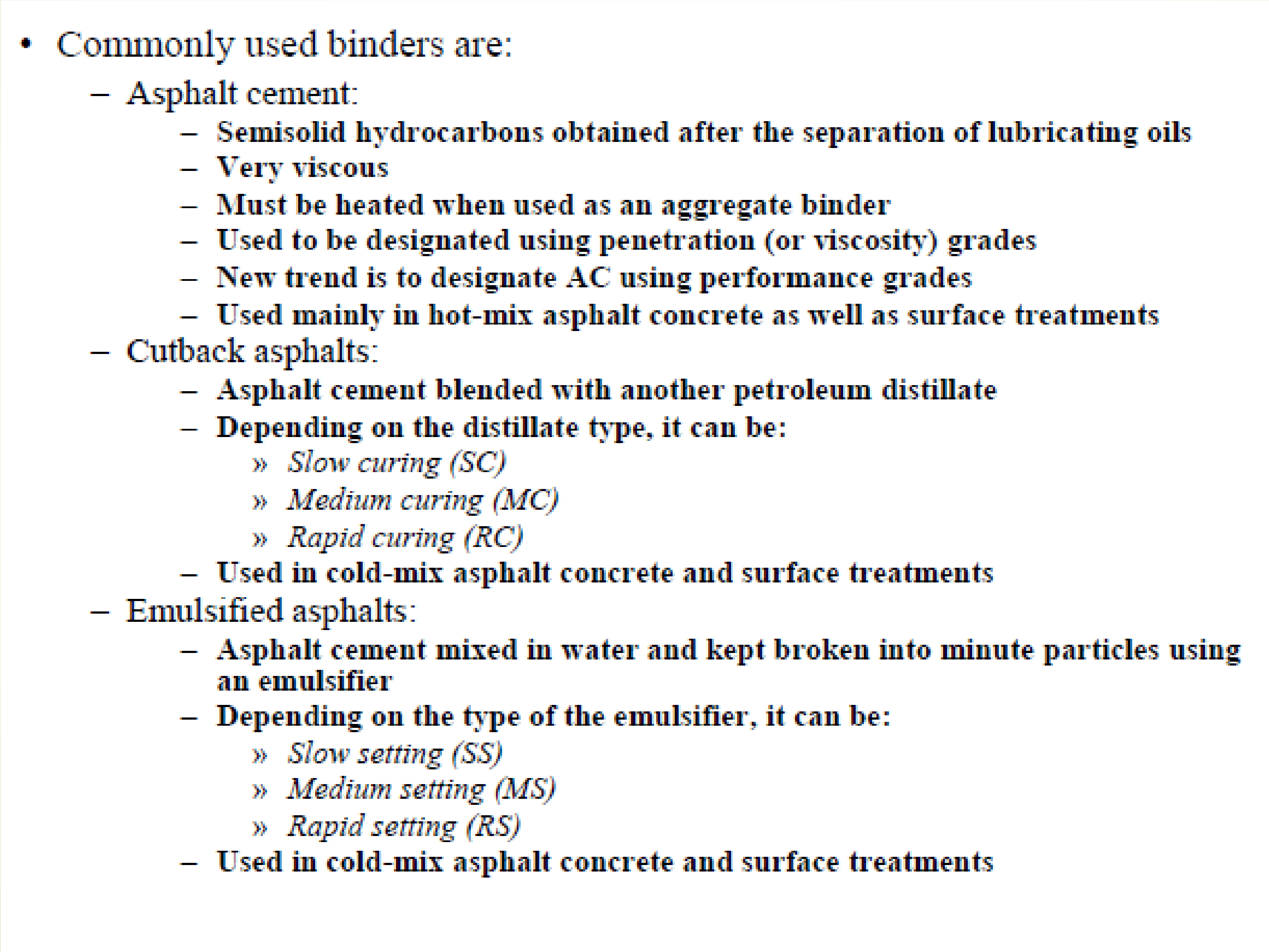
http://geology.about.com/od/rocks/ig/sedrockindex/rocpicasphalt.htm

Bituminous Materials

Refinery Operation

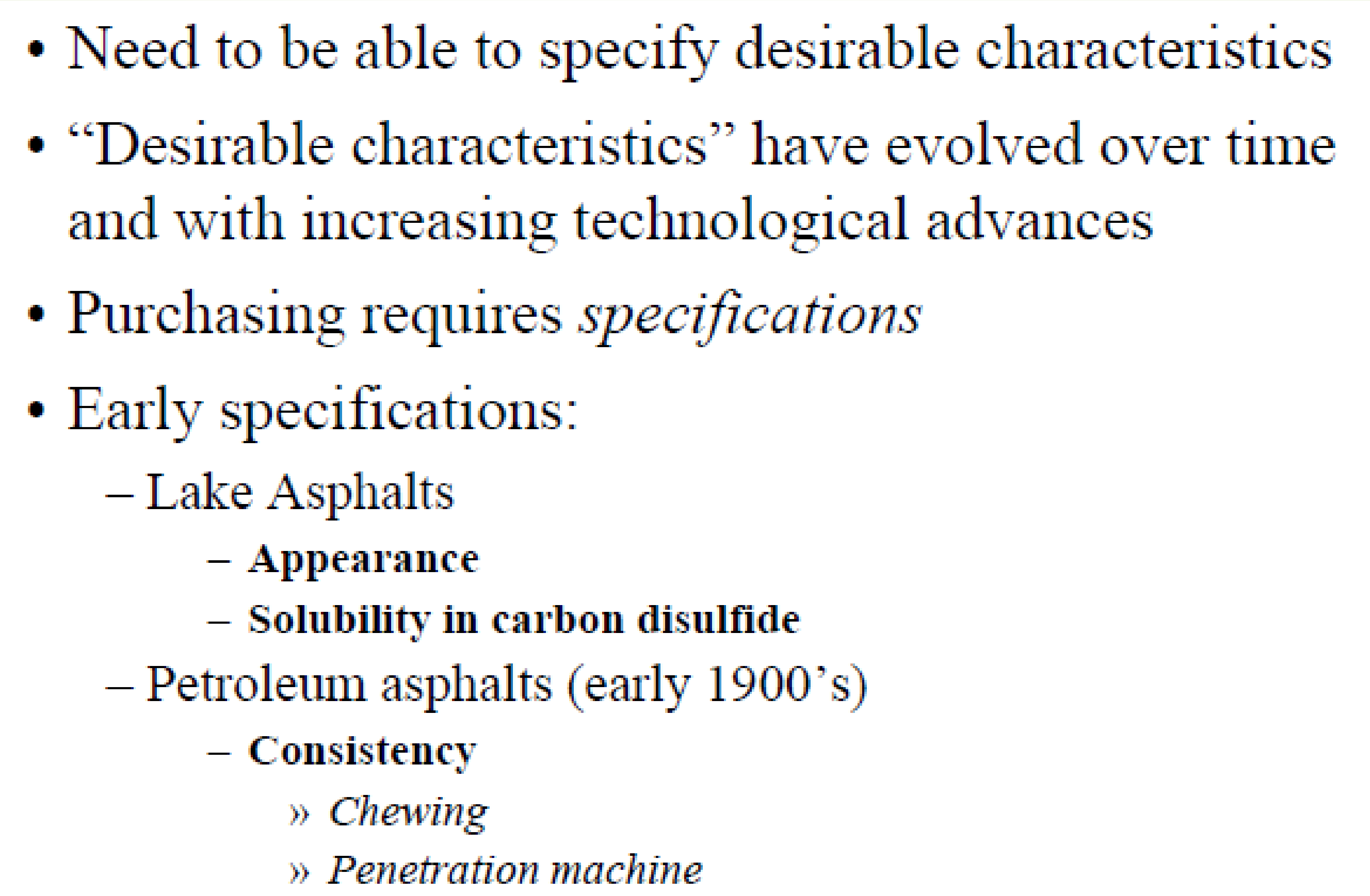


Bituminous Materials



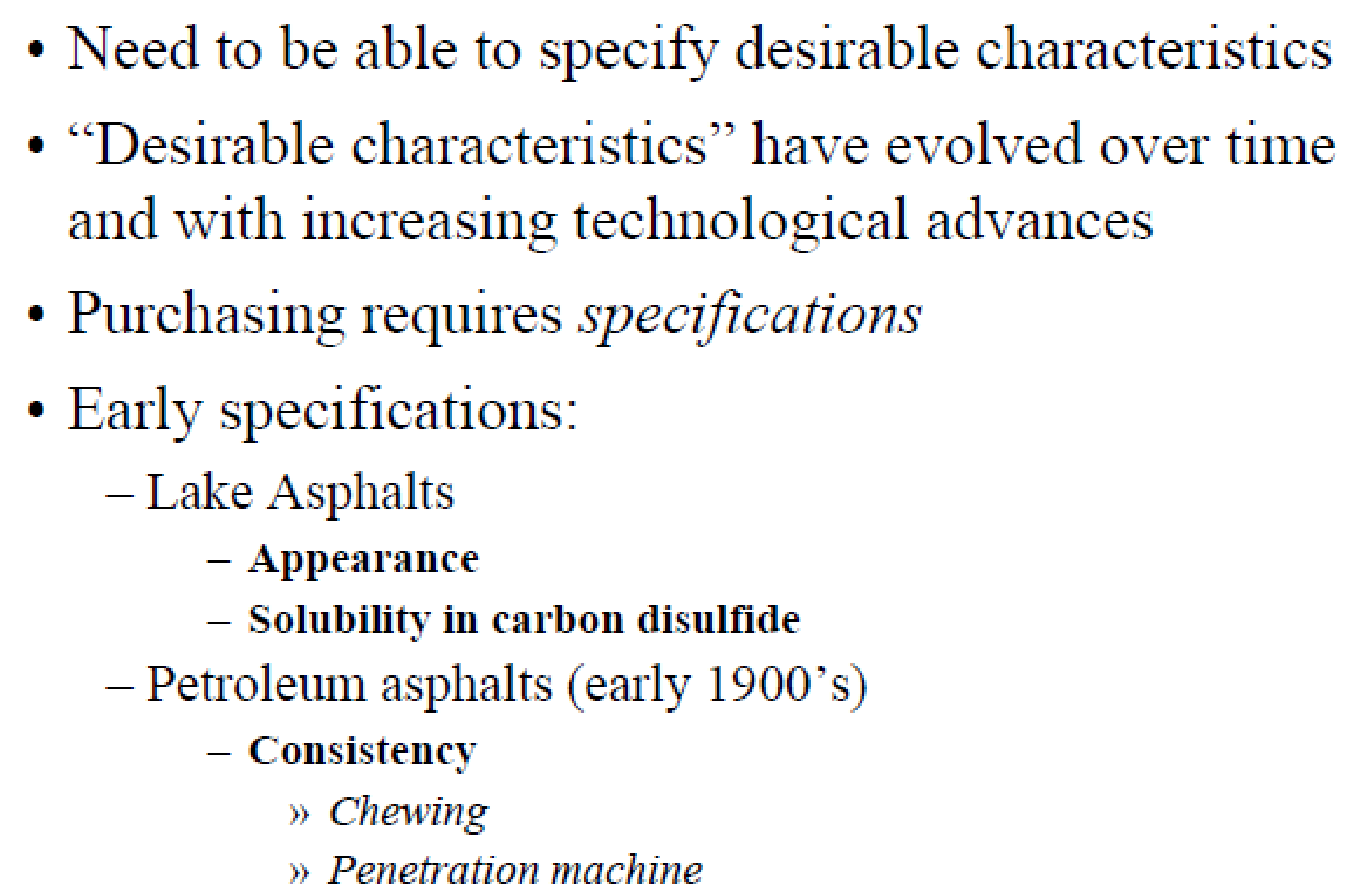
- Commonly used binders are:
  - Asphalt cement:
    - **Semisolid hydrocarbons obtained after the separation of lubricating oils**
    - **Very viscous**
    - **Must be heated when used as an aggregate binder**
    - **Used to be designated using penetration (or viscosity) grades**
    - **New trend is to designate AC using performance grades**
    - **Used mainly in hot-mix asphalt concrete as well as surface treatments**
  - Cutback asphalts:
    - **Asphalt cement blended with another petroleum distillate**
    - **Depending on the distillate type, it can be:**
      - » *Slow curing (SC)*
      - » *Medium curing (MC)*
      - » *Rapid curing (RC)*
    - **Used in cold-mix asphalt concrete and surface treatments**
  - Emulsified asphalts:
    - **Asphalt cement mixed in water and kept broken into minute particles using an emulsifier**
    - **Depending on the type of the emulsifier, it can be:**
      - » *Slow setting (SS)*
      - » *Medium setting (MS)*
      - » *Rapid setting (RS)*
    - **Used in cold-mix asphalt concrete and surface treatments**

Purchasing of Asphalt Cements



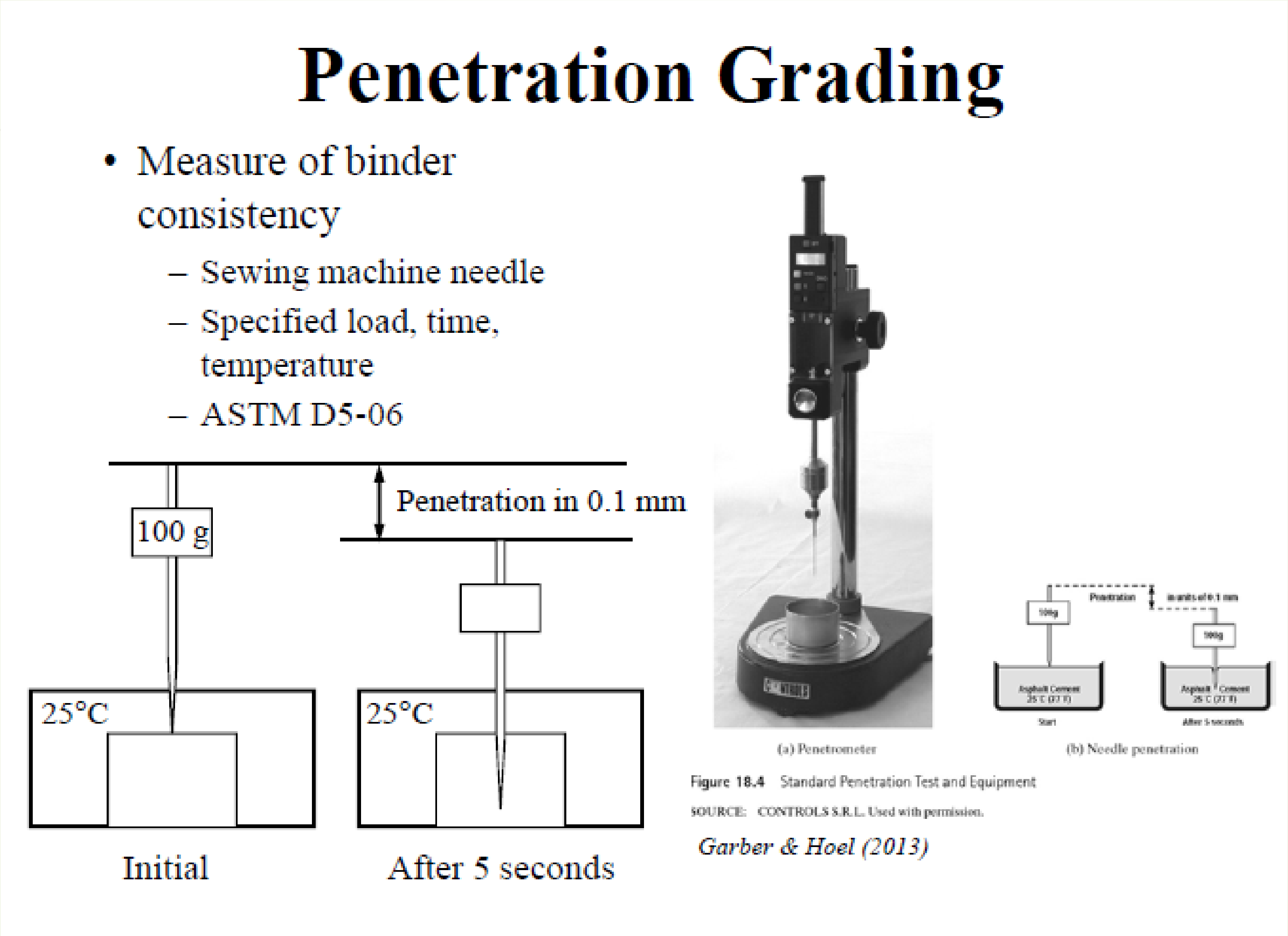
- Need to be able to specify desirable characteristics
- "Desirable characteristics" have evolved over time and with increasing technological advances
- Purchasing requires *specifications*
- Early specifications:
  - Lake Asphalts
    - **Appearance**
    - **Solubility in carbon disulfide**
  - Petroleum asphalts (early 1900's)
    - **Consistency**
      - » *Chewing*
      - » *Penetration machine*

Purchasing of Asphalt Cements



- Need to be able to specify desirable characteristics
- "Desirable characteristics" have evolved over time and with increasing technological advances
- Purchasing requires *specifications*
- Early specifications:
  - Lake Asphalts
    - **Appearance**
    - **Solubility in carbon disulfide**
  - Petroleum asphalts (early 1900's)
    - **Consistency**
      - » *Chewing*
      - » *Penetration machine*

Bituminous Materials



Penetration Grading

- Measure of binder consistency
  - Sewing machine needle
  - Specified load, time, temperature
  - ASTM D5-06

(a) Penetrometer

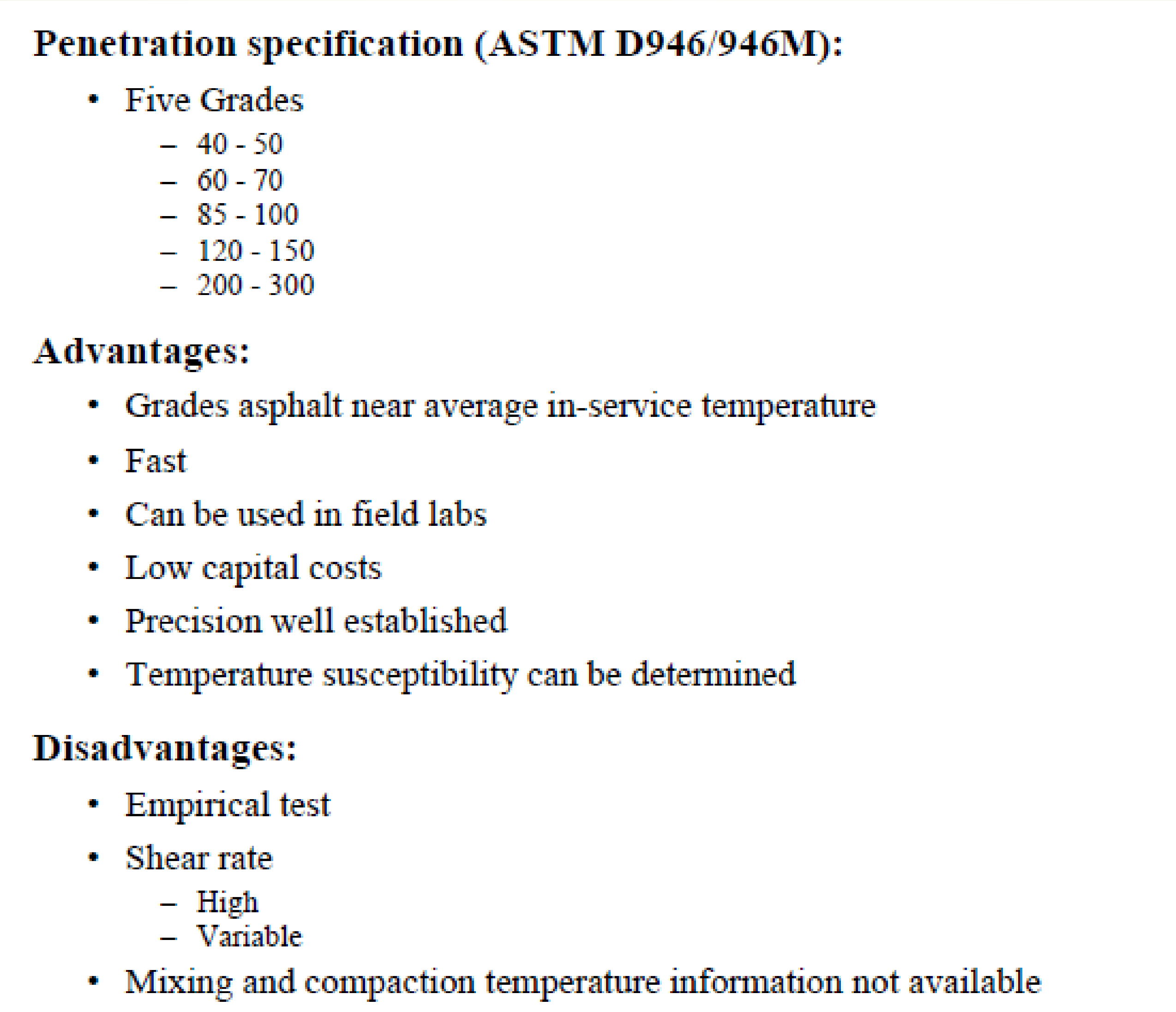
(b) Needle penetration

Figure 18.4 Standard Penetration Test and Equipment

SOURCE: CONTROLS S.R.L. Used with permission.

Garber & Hoel (2013)

Bituminous Materials



Penetration specification (ASTM D946/946M):

- Five Grades
  - 40 - 50
  - 60 - 70
  - 85 - 100
  - 120 - 150
  - 200 - 300

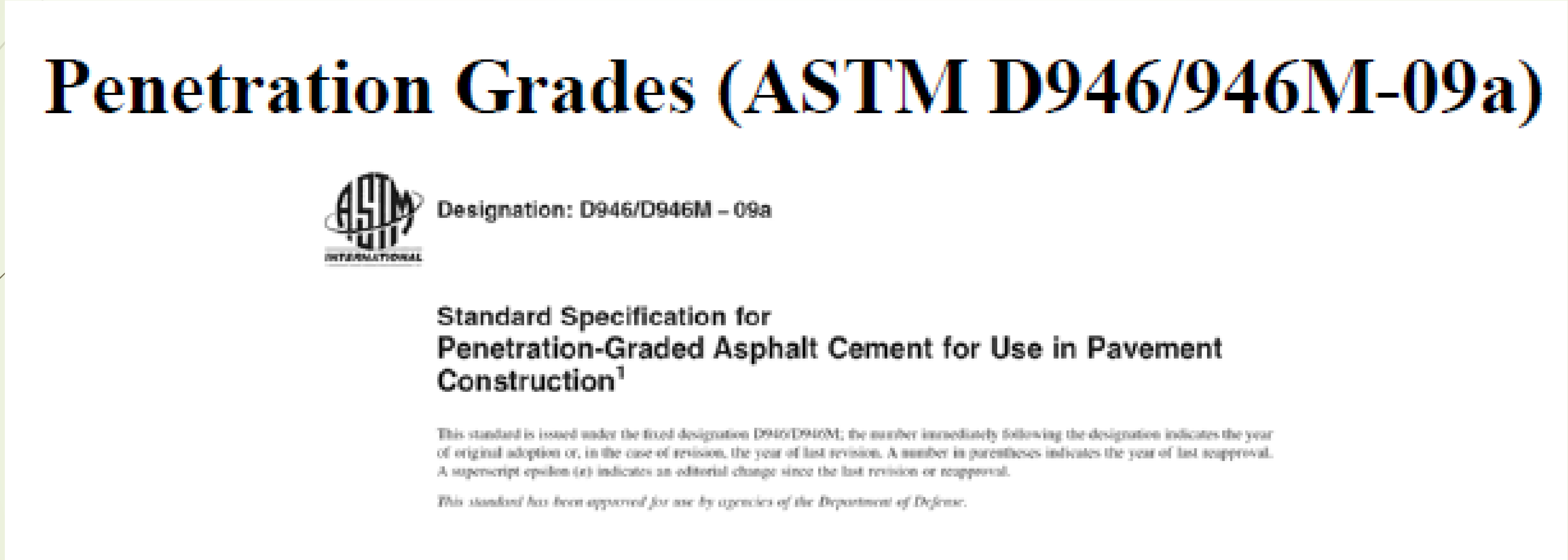
Advantages:

- Grades asphalt near average in-service temperature
- Fast
- Can be used in field labs
- Low capital costs
- Precision well established
- Temperature susceptibility can be determined

Disadvantages:

- Empirical test
- Shear rate
  - High
  - Variable
- Mixing and compaction temperature information not available

Bituminous Materials



Penetration Grades (ASTM D946/946M-09a)

Designation: D946/D946M – 09a

Standard Specification for Penetration-Graded Asphalt Cement for Use in Pavement Construction[1]

This standard is issued under the fixed designation D946/D946M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

Bituminous Materials

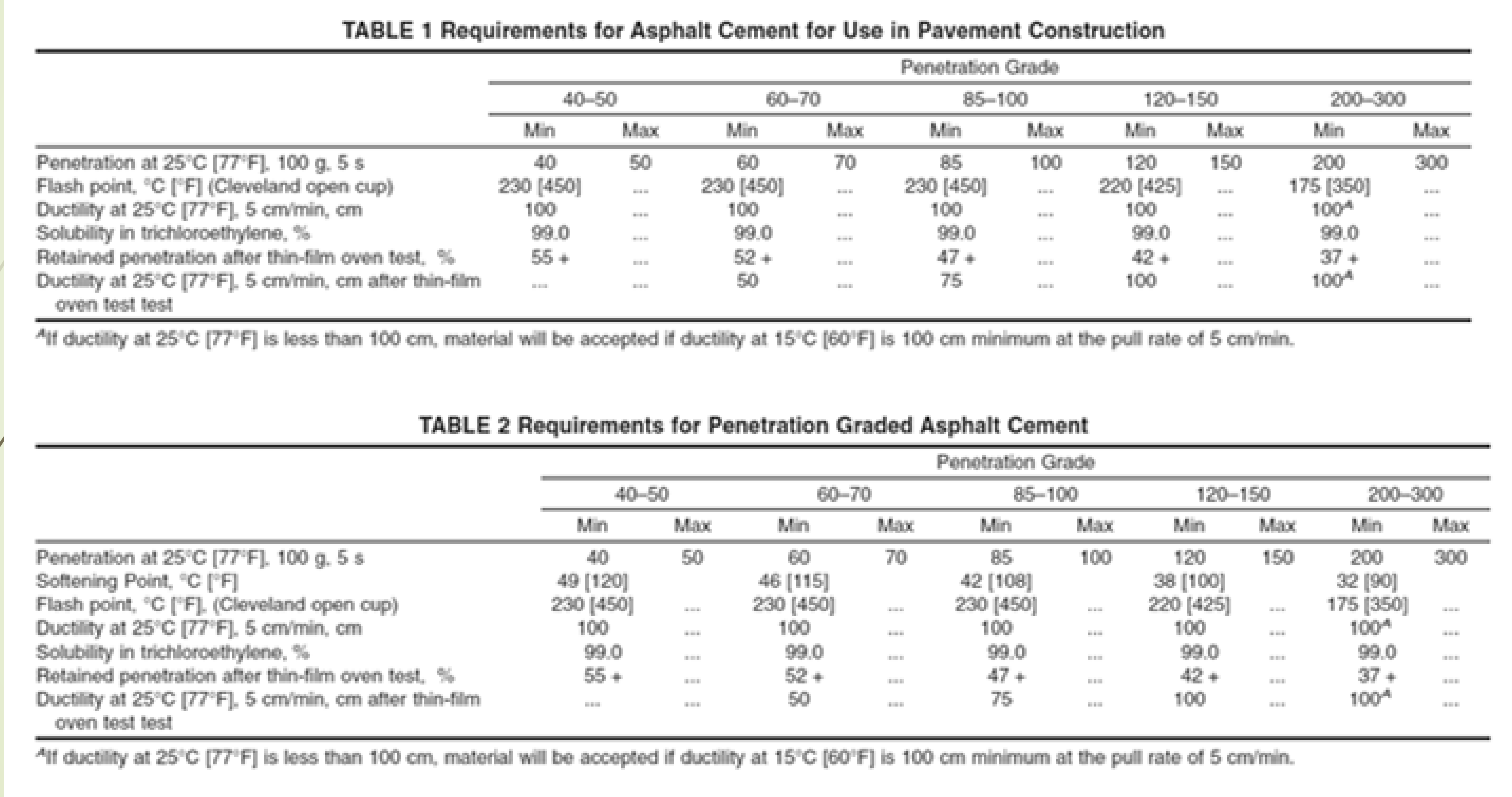


TABLE 1 Requirements for Asphalt Cement for Use in Pavement Construction

	Penetration Grade									
	40–50		60–70		85–100		120–150		200–300	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Penetration at 25°C [77°F], 100 g, 5 s	40	50	60	70	85	100	120	150	200	300
Flash point, °C [°F] (Cleveland open cup)	230 [450]	...	230 [450]	...	230 [450]	...	220 [425]	...	175 [350]	...
Ductility at 25°C [77°F], 5 cm/min, cm	100	...	100	...	100	...	100	...	100^A	...
Solubility in trichloroethylene, %	99.0	...	99.0	...	99.0	...	99.0	...	99.0	...
Retained penetration after thin-film oven test, %	55 +	...	52 +	...	47 +	...	42 +	...	37 +	...
Ductility at 25°C [77°F], 5 cm/min, cm after thin-film oven test test	...	...	50	...	75	...	100	...	100^A	...

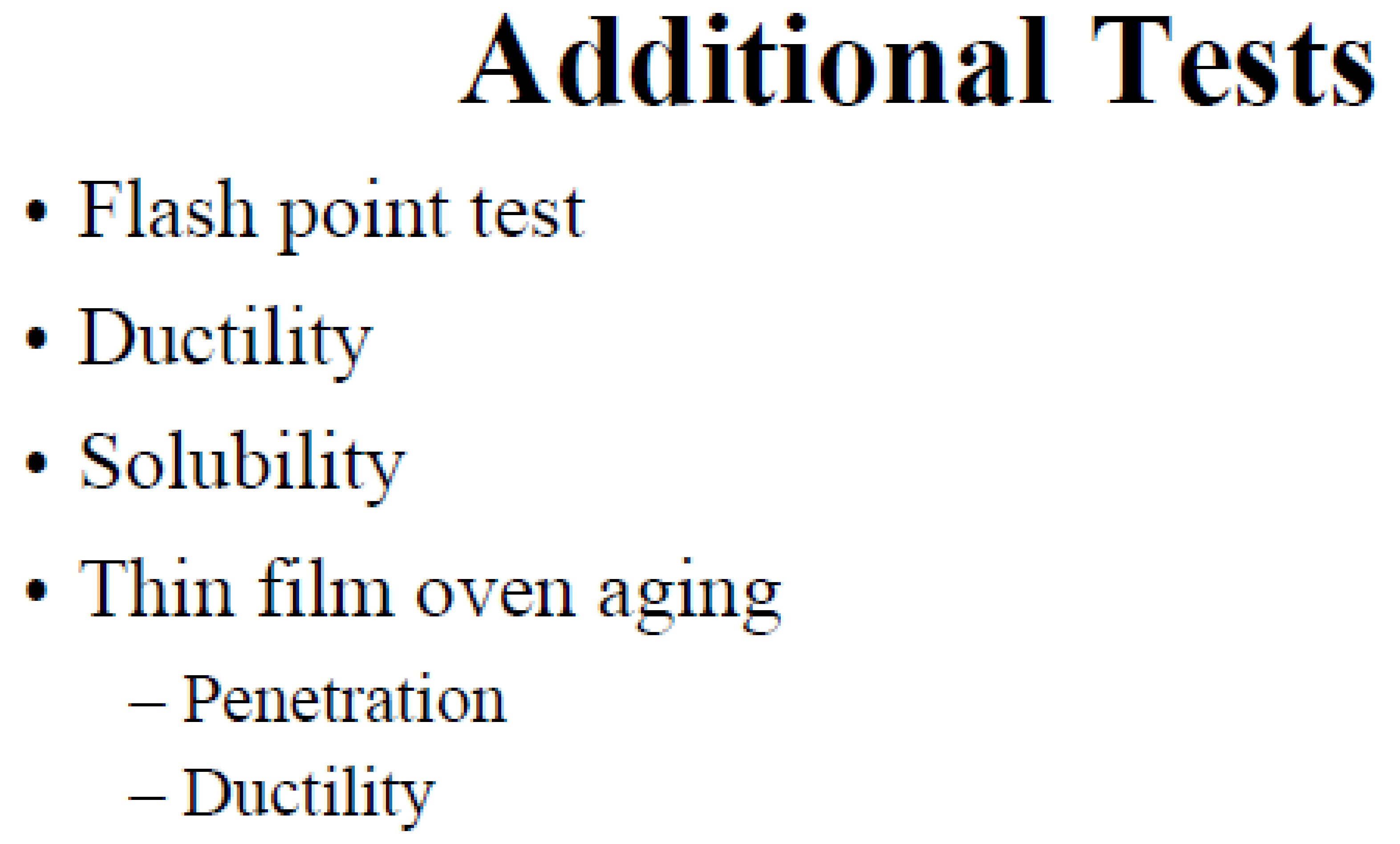
^{A}If ductility at 25°C [77°F] is less than 100 cm, material will be accepted if ductility at 15°C [60°F] is 100 cm minimum at the pull rate of 5 cm/min.

TABLE 2 Requirements for Penetration Graded Asphalt Cement

	Penetration Grade									
	40–50		60–70		85–100		120–150		200–300	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Penetration at 25°C [77°F], 100 g, 5 s	40	50	60	70	85	100	120	150	200	300
Softening Point, °C [°F]	49 [120]		46 [115]		42 [108]		38 [100]		32 [90]	
Flash point, °C [°F], (Cleveland open cup)	230 [450]	...	230 [450]	...	230 [450]	...	220 [425]	...	175 [350]	...
Ductility at 25°C [77°F], 5 cm/min, cm	100	...	100	...	100	...	100	...	100^A	...
Solubility in trichloroethylene, %	99.0	...	99.0	...	99.0	...	99.0	...	99.0	...
Retained penetration after thin-film oven test, %	55 +	...	52 +	...	47 +	...	42 +	...	37 +	...
Ductility at 25°C [77°F], 5 cm/min, cm after thin-film oven test test	...	...	50	...	75	...	100	...	100^A	...

^{A}If ductility at 25°C [77°F] is less than 100 cm, material will be accepted if ductility at 15°C [60°F] is 100 cm minimum at the pull rate of 5 cm/min.

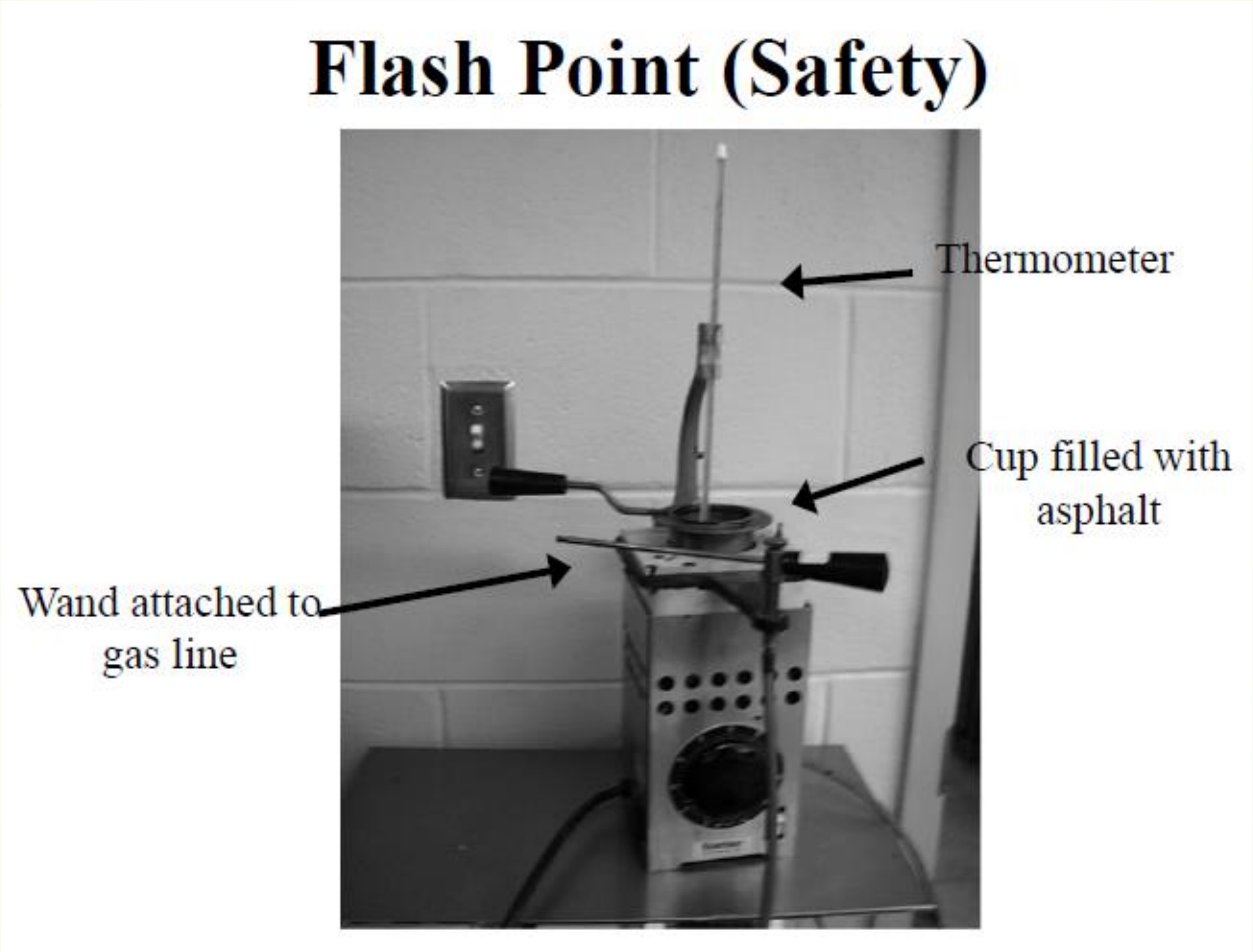
Bituminous Materials



Additional Tests

- Flash point test
- Ductility
- Solubility
- Thin film oven aging
  - Penetration
  - Ductility

Bituminous Materials



Flash Point (Safety)

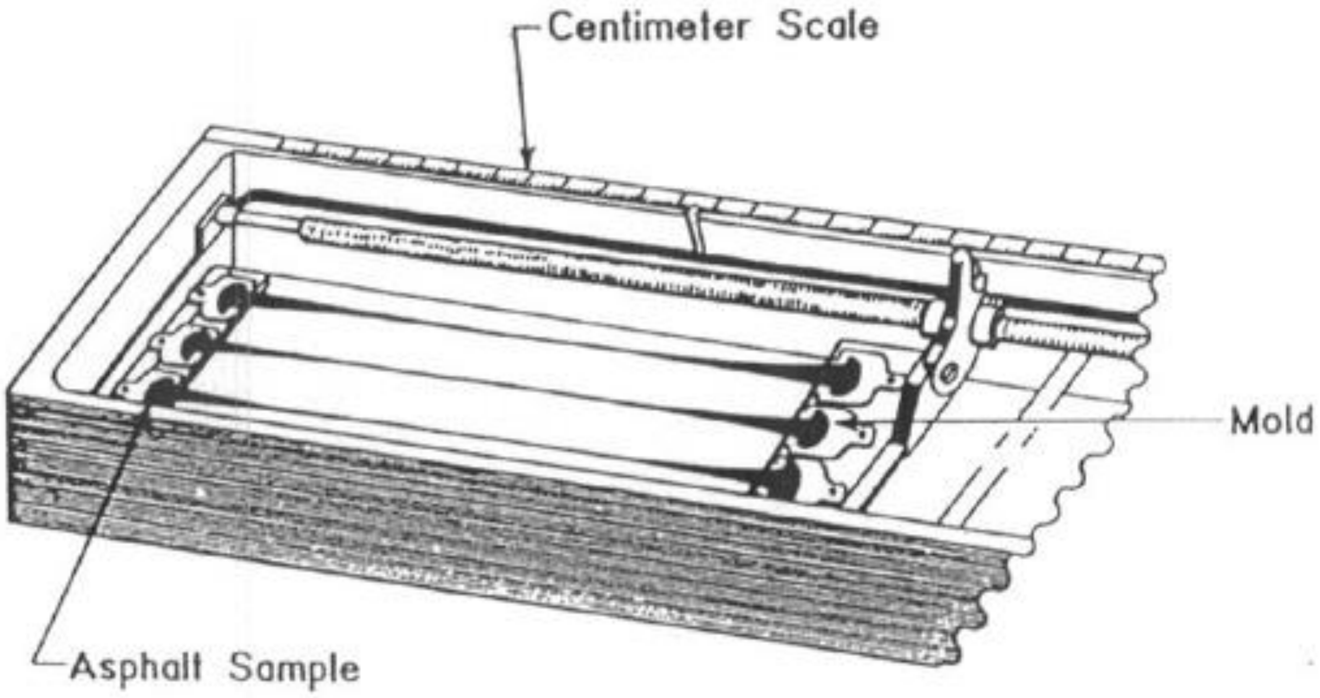
Thermometer

Cup filled with asphalt

Wand attached to gas line

Bituminous Materials

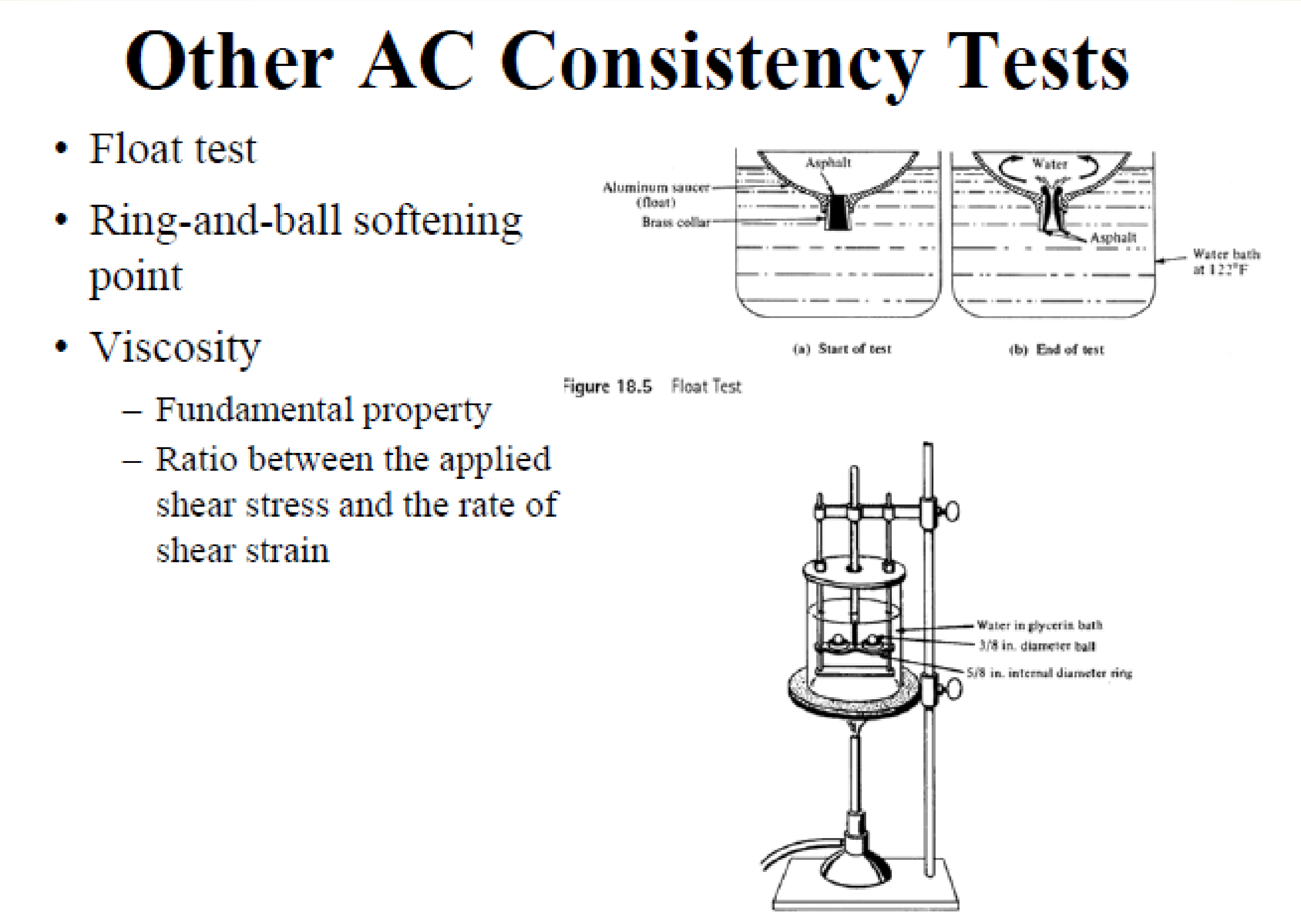
Ductility



Bituminous Materials

Solubility (Purity)

Bituminous Materials

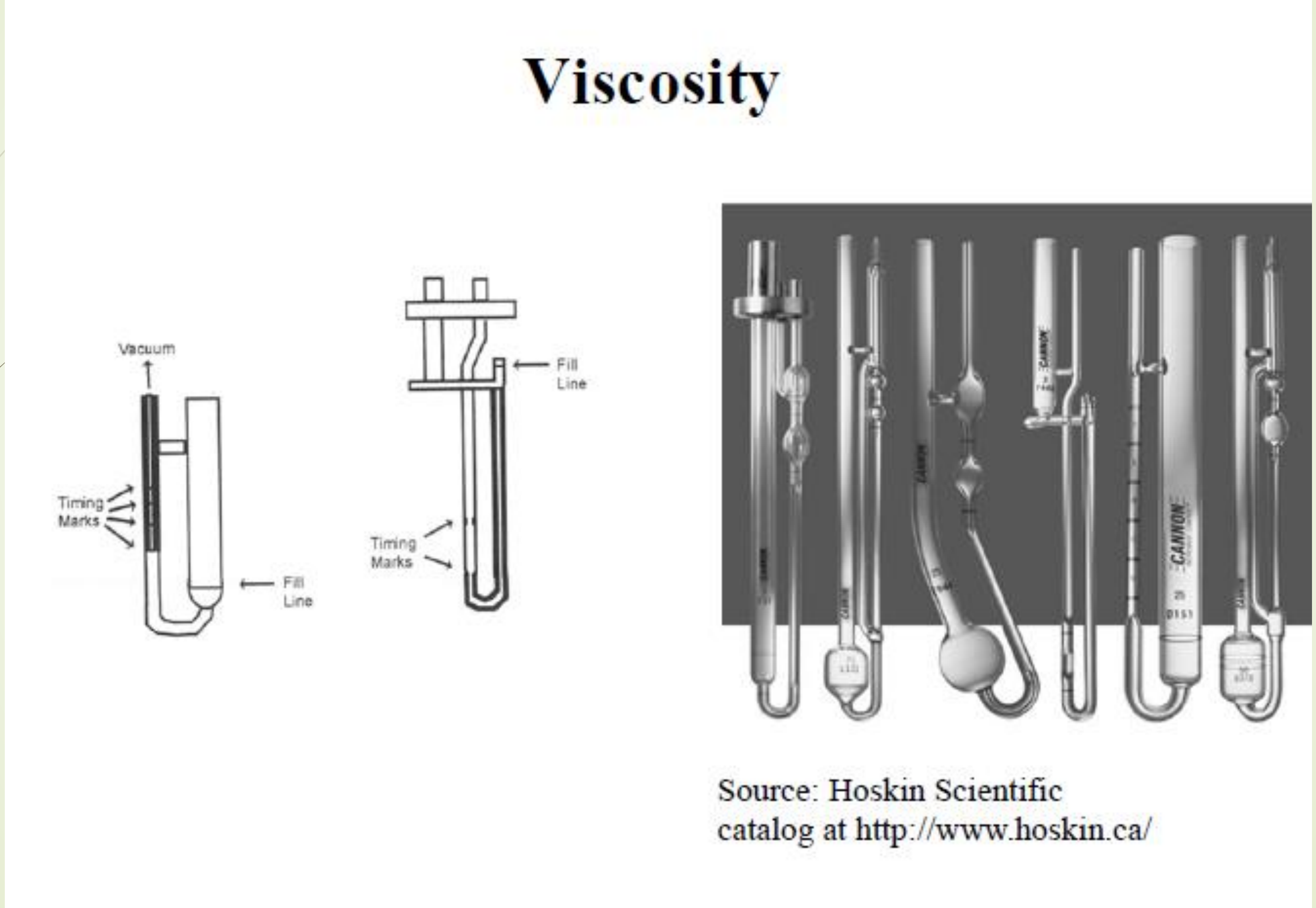


Other AC Consistency Tests

- Float test
- Ring-and-ball softening point
- Viscosity
  - Fundamental property
  - Ratio between the applied shear stress and the rate of shear strain

Figure 18.5 Float Test

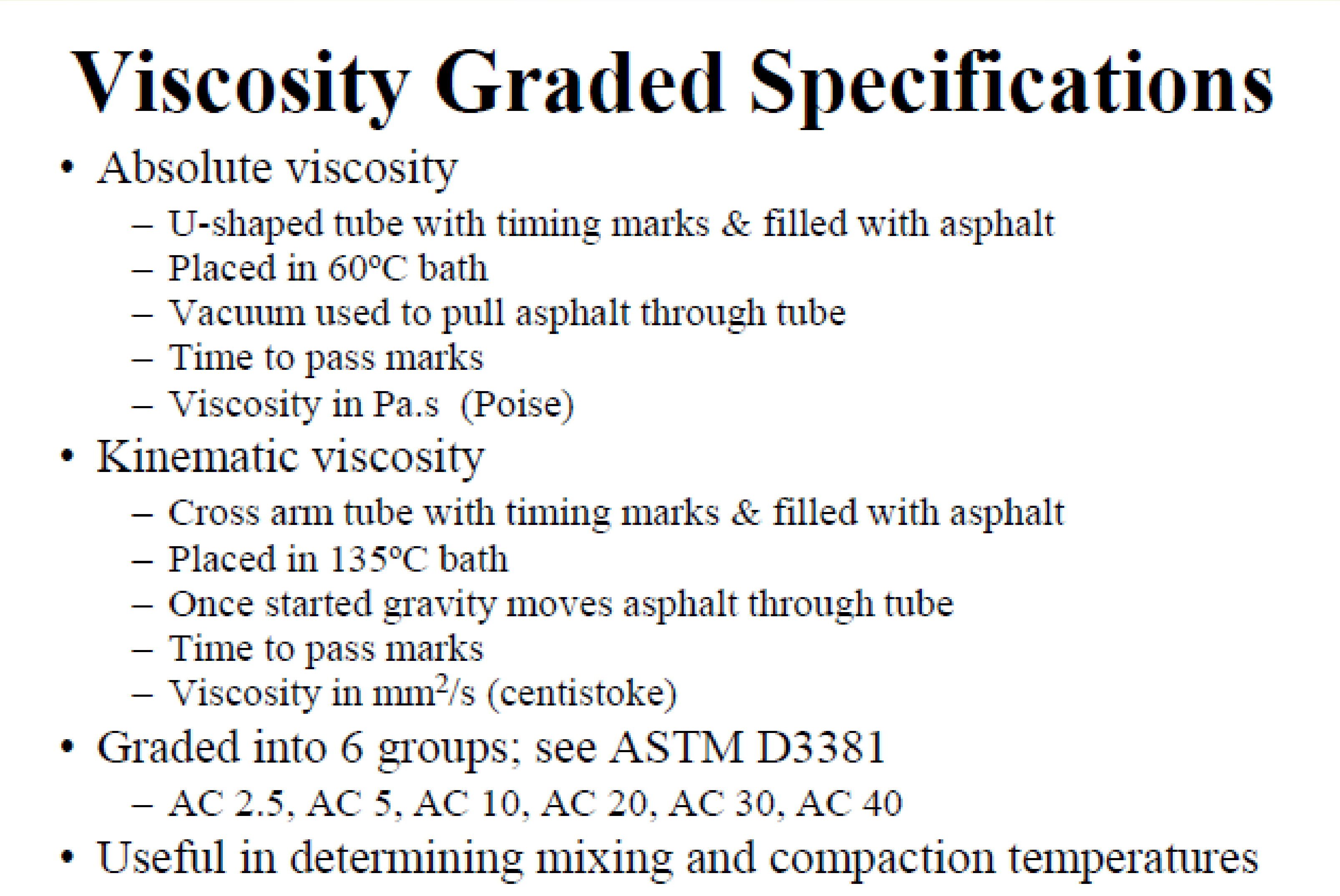
Bituminous Materials



Viscosity

Source: Hoskin Scientific
catalog at http://www.hoskin.ca/

Bituminous Materials

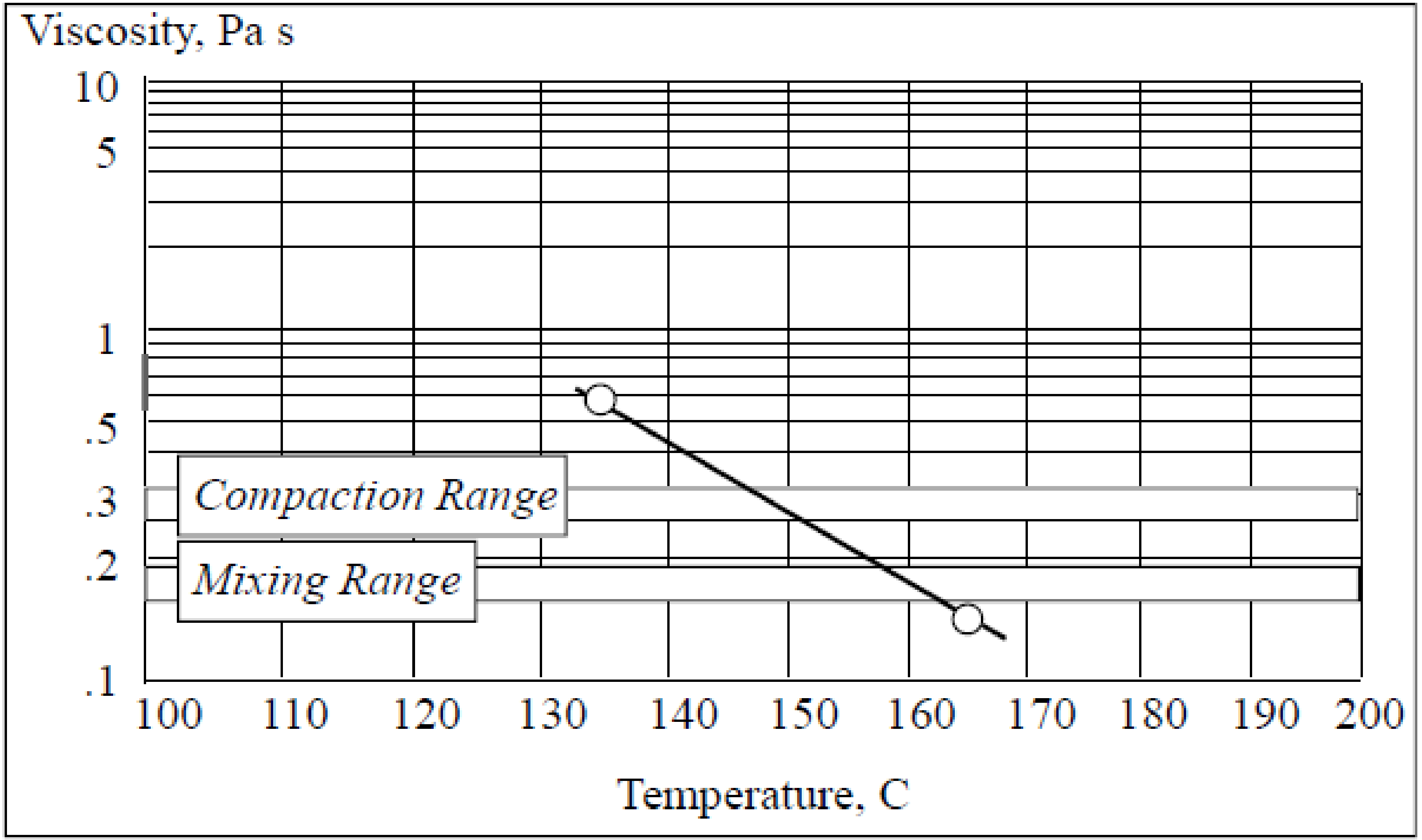


Viscosity Graded Specifications

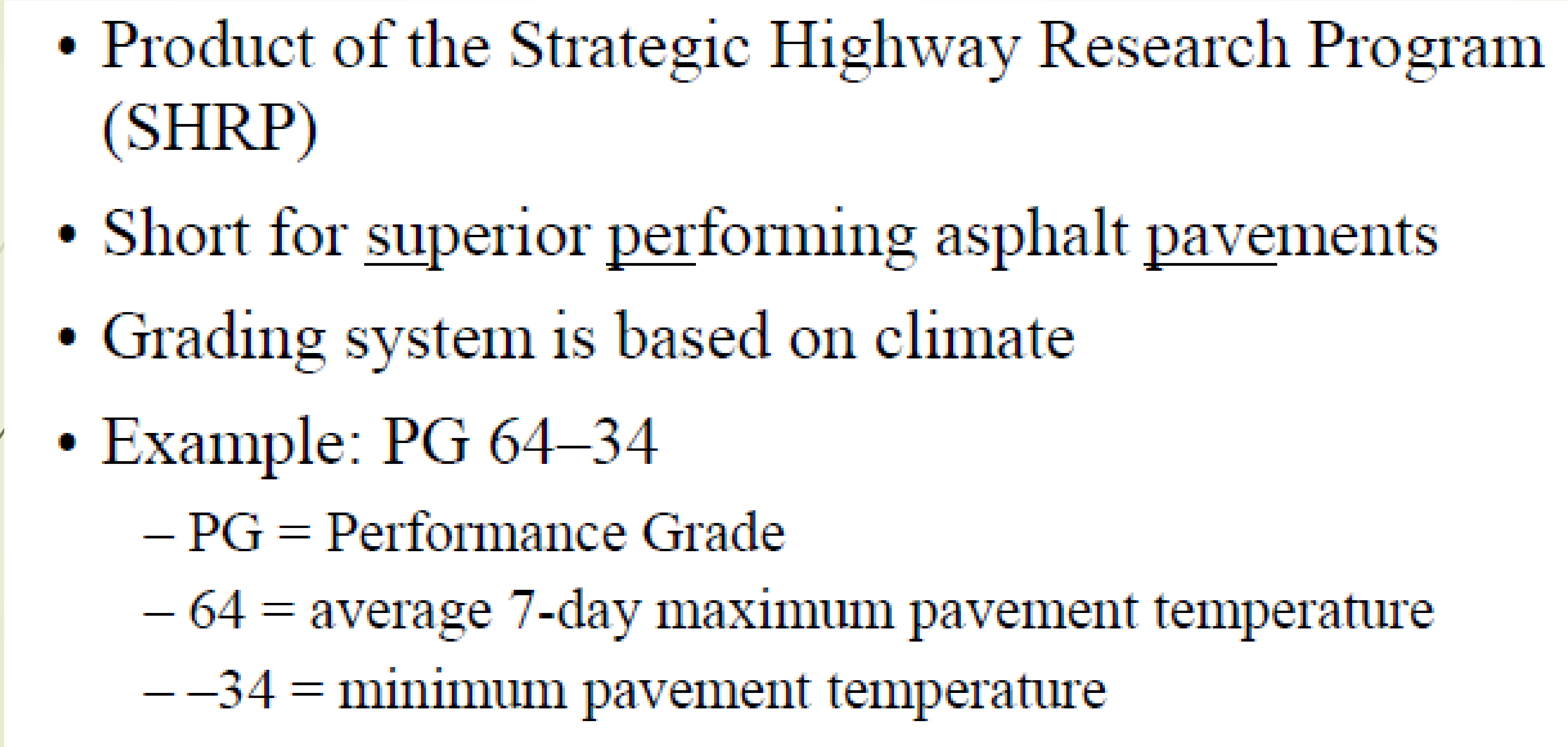
- Absolute viscosity
  - U-shaped tube with timing marks & filled with asphalt
  - Placed in 60°C bath
  - Vacuum used to pull asphalt through tube
  - Time to pass marks
  - Viscosity in Pa.s (Poise)
- Kinematic viscosity
  - Cross arm tube with timing marks & filled with asphalt
  - Placed in 135°C bath
  - Once started gravity moves asphalt through tube
  - Time to pass marks
  - Viscosity in mm^2/s (centistoke)
- Graded into 6 groups; see ASTM D3381
  - AC 2.5, AC 5, AC 10, AC 20, AC 30, AC 40
- Useful in determining mixing and compaction temperatures

Bituminous Materials

Mixing/Compaction Temps

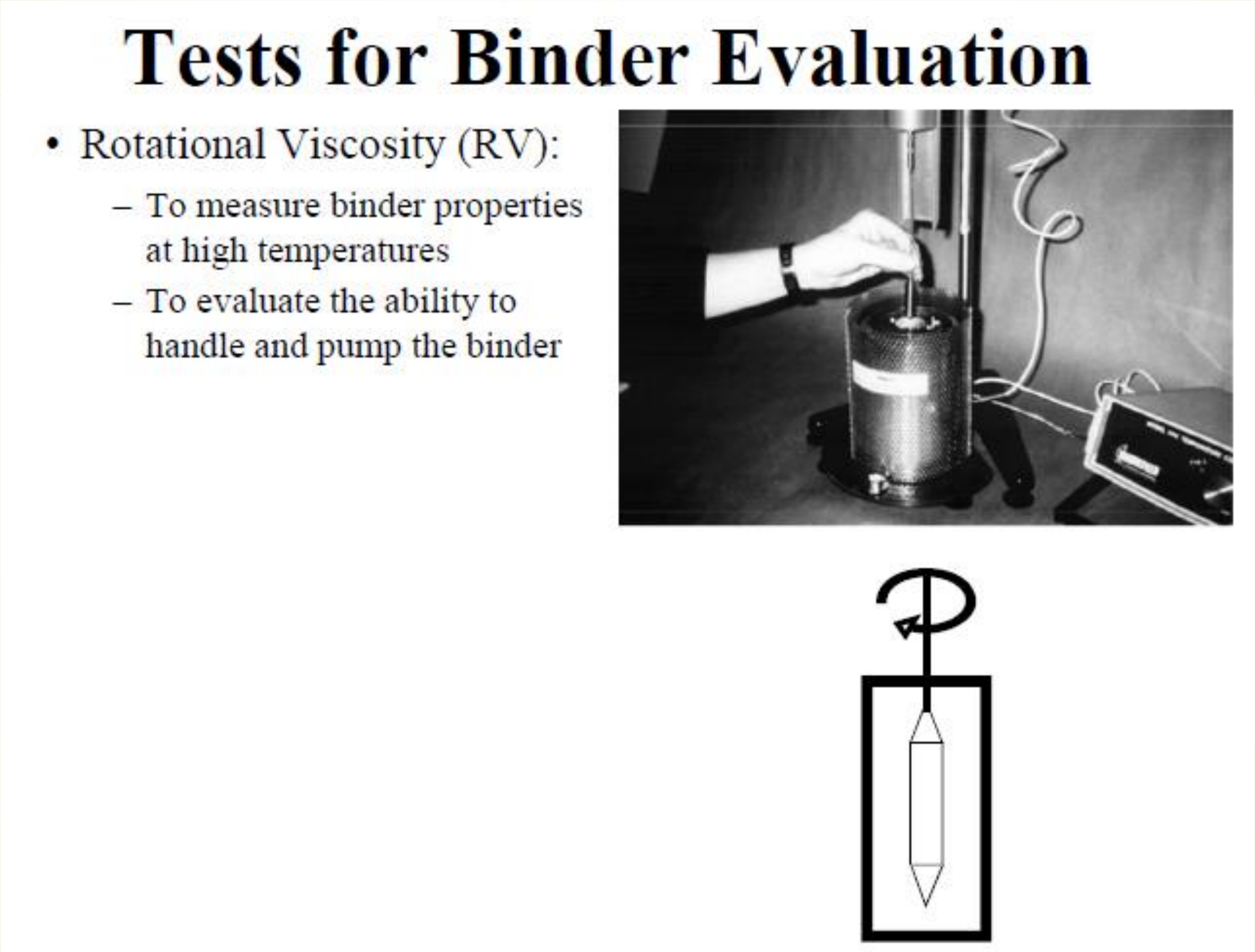


Superpave Asphalt Binder Grading



- Product of the Strategic Highway Research Program (SHRP)
- Short for superior performing asphalt pavements
- Grading system is based on climate
- Example: PG 64–34
  - PG = Performance Grade
  - 64 = average 7-day maximum pavement temperature
  - –34 = minimum pavement temperature

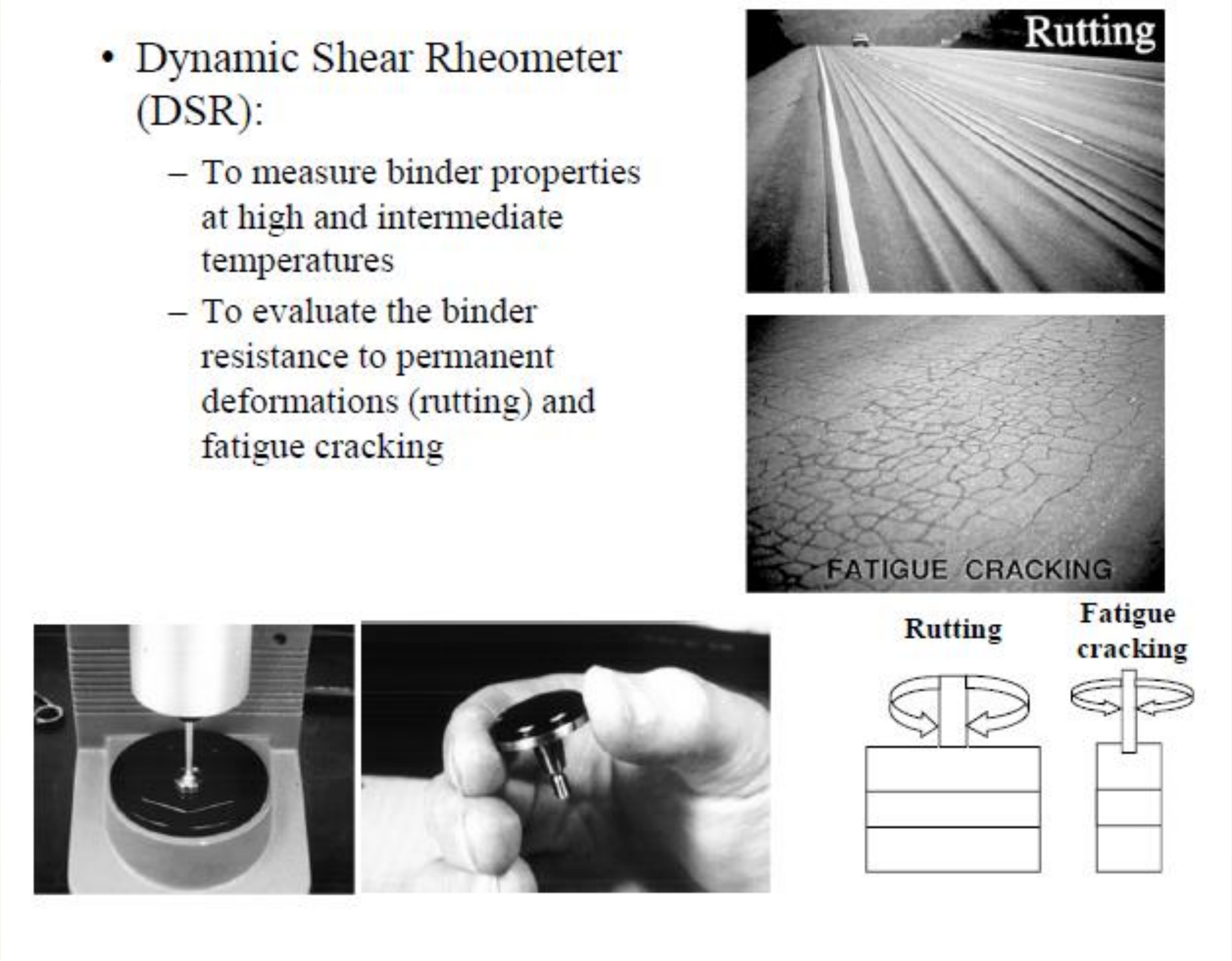
Superpave Asphalt Binder Grading



Tests for Binder Evaluation

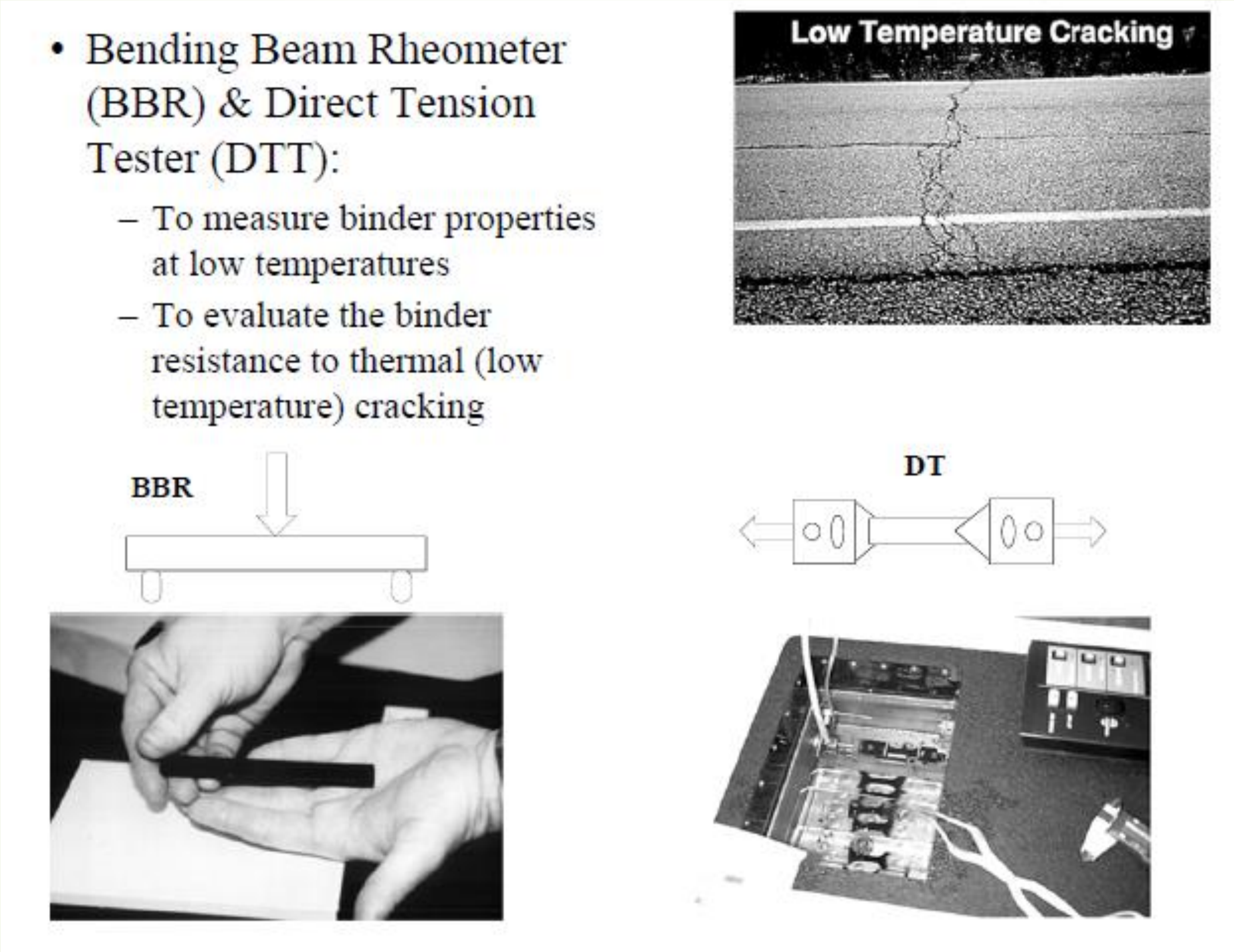
- Rotational Viscosity (RV):
  - To measure binder properties at high temperatures
  - To evaluate the ability to handle and pump the binder

Superpave Asphalt Binder Grading



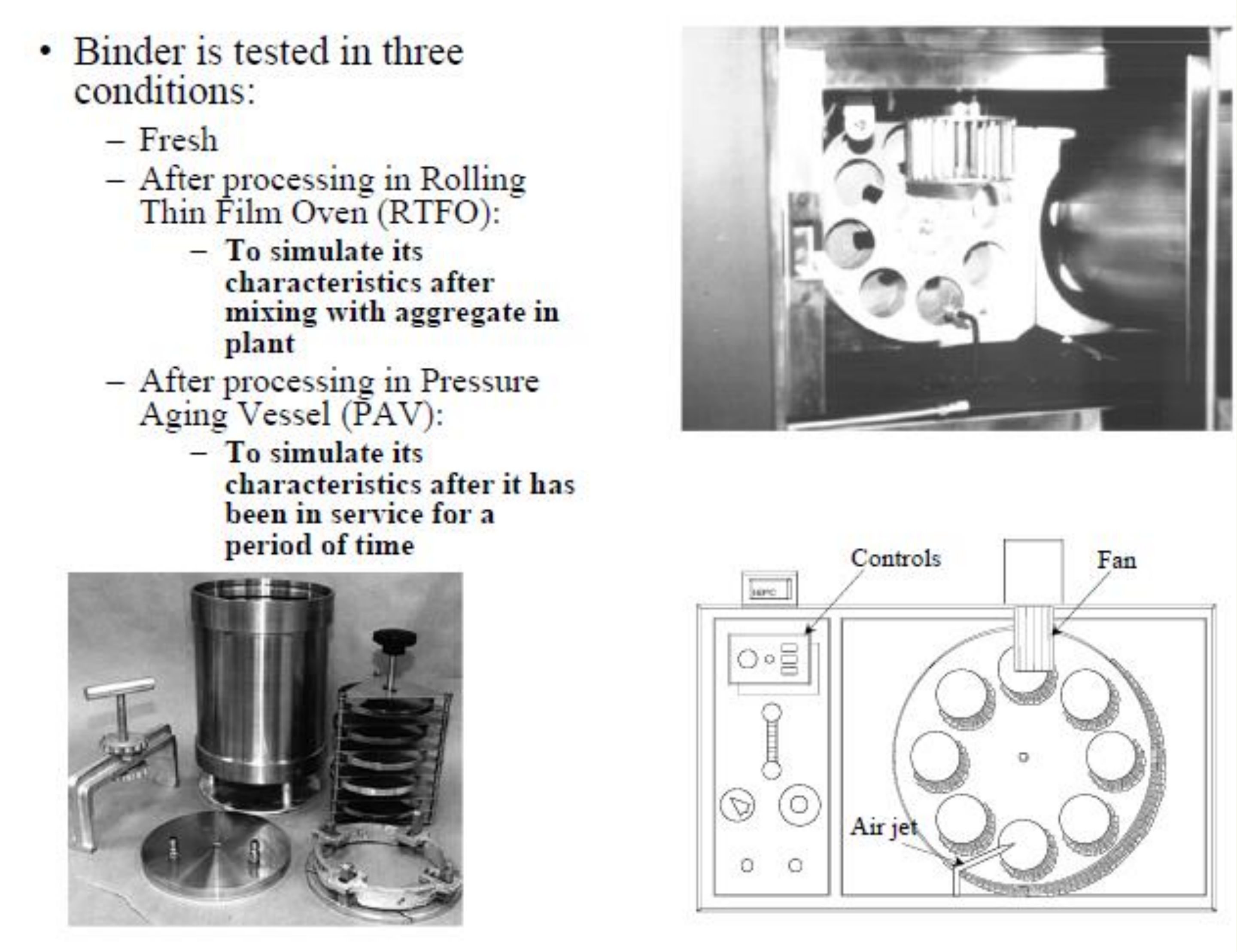
- Dynamic Shear Rheometer (DSR):
  - To measure binder properties at high and intermediate temperatures
  - To evaluate the binder resistance to permanent deformations (rutting) and fatigue cracking

Superpave Asphalt Binder Grading



- Bending Beam Rheometer (BBR) & Direct Tension Tester (DTT):
  - To measure binder properties at low temperatures
  - To evaluate the binder resistance to thermal (low temperature) cracking

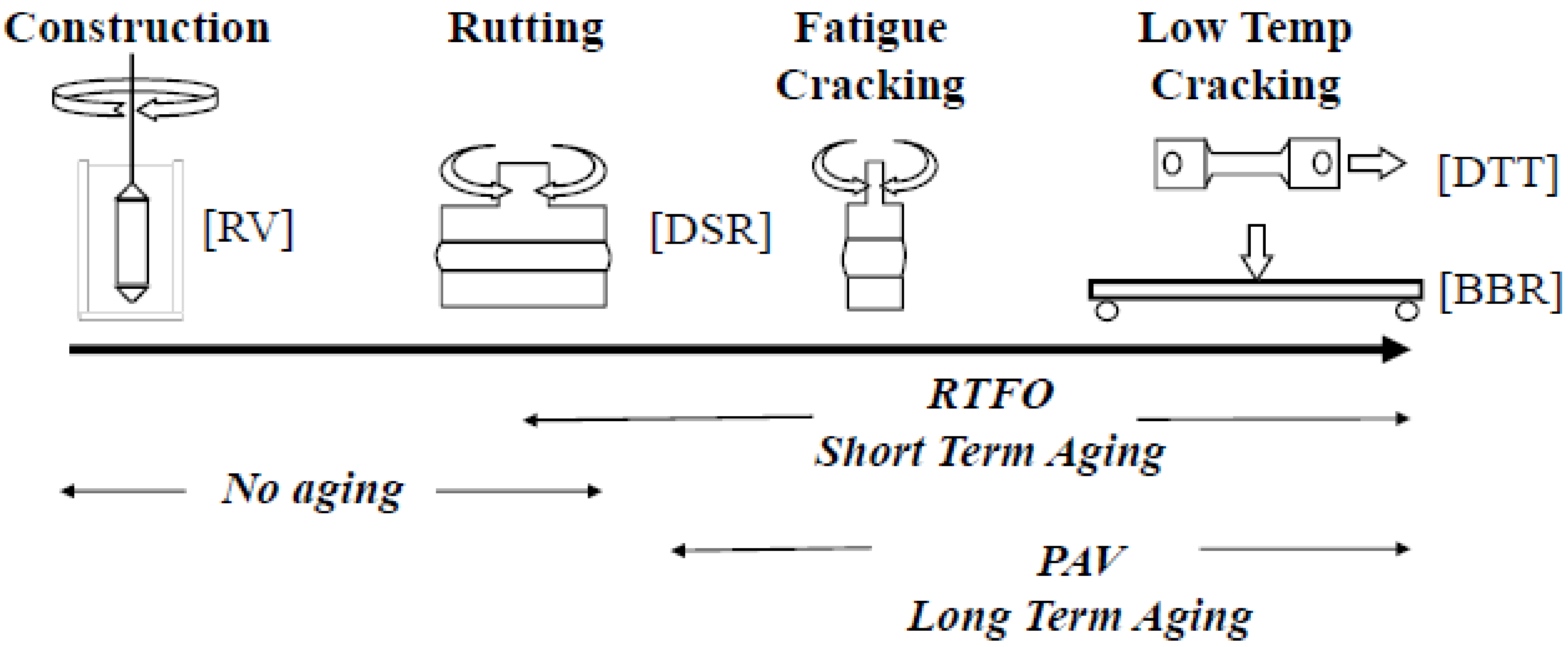
Superpave Asphalt Binder Grading



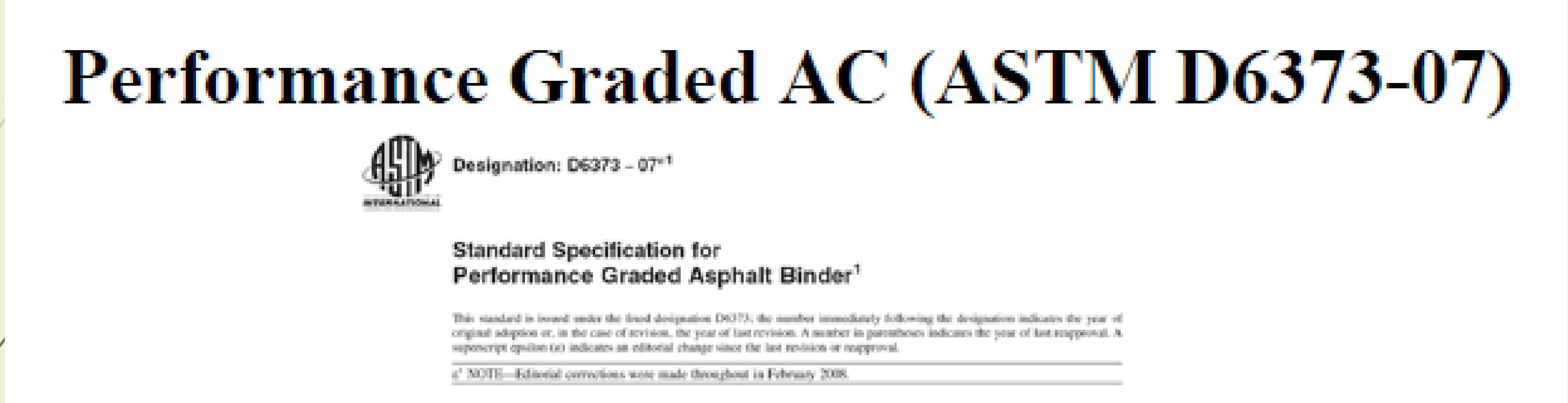
- Binder is tested in three conditions:
  - Fresh
  - After processing in Rolling Thin Film Oven (RTFO):
    - **To simulate its characteristics after mixing with aggregate in plant**
  - After processing in Pressure Aging Vessel (PAV):
    - **To simulate its characteristics after it has been in service for a period of time**

Superpave Asphalt Binder Grading

- All test specifications remain constant but testing temperature changes depending on the binder PG
  - See ASTM D6373



Superpave Asphalt Binder Grading



Performance Graded AC (ASTM D6373-07)

Designation: D6373 – 07$^{\varepsilon 1}$

Standard Specification for
Performance Graded Asphalt Binder[1]

This standard is issued under the fixed designation D6373; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε^1 NOTE—Editorial corrections were made throughout in February 2008.

Superpave Asphalt Binder Grading

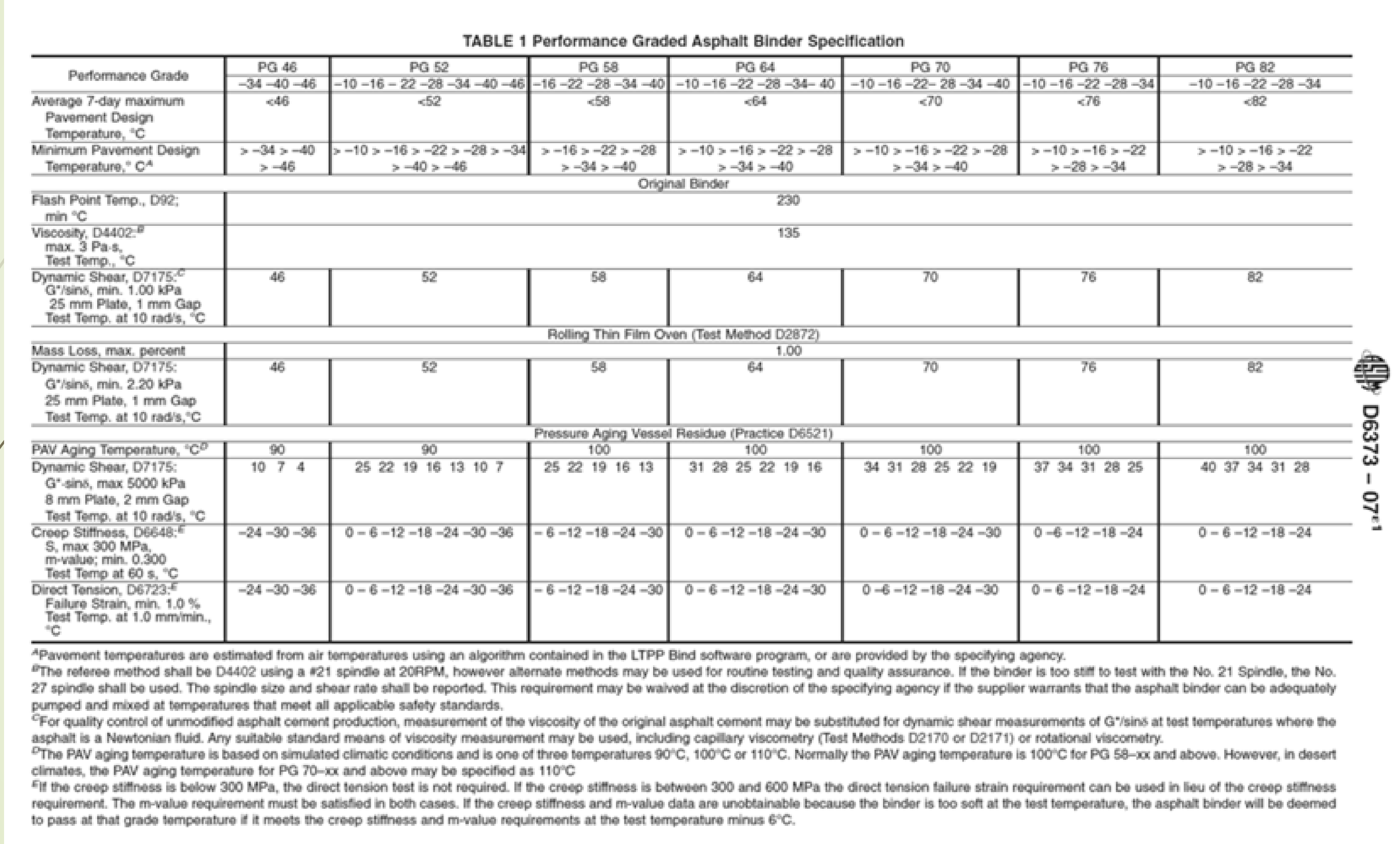


TABLE 1 Performance Graded Asphalt Binder Specification

Performance Grade	PG 46	PG 52	PG 58	PG 64	PG 70	PG 76	PG 82
	−34 −40 −46	−10 −16 − 22 −28 −34 −40 −46	−16 −22 −28 −34 −40	−10 −16 −22 −28 −34− 40	−10 −16 −22− 28 −34 −40	−10 −16 −22 −28 −34	−10 −16 −22 −28 −34
Average 7-day maximum Pavement Design Temperature, °C	<46	<52	<58	<64	<70	<76	<82
Minimum Pavement Design Temperature,° C[A]	> −34 > −40 > −46	> −10 > −16 > −22 > −28 > −34 > −40 > −46	> −16 > −22 > −28 > −34 > −40	> −10 > −16 > −22 > −28 > −34 > −40	> −10 > −16 > −22 > −28 > −34 > −40	> −10 > −16 > −22 > −28 > −34	> −10 > −16 > −22 > −28 > −34
Original Binder							
Flash Point Temp., D92; min °C	230						
Viscosity, D4402:[B] max. 3 Pa·s, Test Temp., °C	135						
Dynamic Shear, D7175:[C] G*/sinδ, min. 1.00 kPa 25 mm Plate, 1 mm Gap Test Temp. at 10 rad/s, °C	46	52	58	64	70	76	82
Rolling Thin Film Oven (Test Method D2872)							
Mass Loss, max. percent	1.00						
Dynamic Shear, D7175: G*/sinδ, min. 2.20 kPa 25 mm Plate, 1 mm Gap Test Temp. at 10 rad/s,°C	46	52	58	64	70	76	82
Pressure Aging Vessel Residue (Practice D6521)							
PAV Aging Temperature, °C[D]	90	90	100	100	100	100	100
Dynamic Shear, D7175: G*·sinδ, max 5000 kPa 8 mm Plate, 2 mm Gap Test Temp. at 10 rad/s, °C	10 7 4	25 22 19 16 13 10 7	25 22 19 16 13	31 28 25 22 19 16	34 31 28 25 22 19	37 34 31 28 25	40 37 34 31 28
Creep Stiffness, D6648:[E] S, max 300 MPa, m-value; min. 0.300 Test Temp at 60 s, °C	−24 −30 −36	0 − 6 −12 −18 −24 −30 −36	− 6 −12 −18 −24 −30	0 − 6 −12 −18 −24 −30	0 − 6 −12 −18 −24 −30	0 −6 −12 −18 −24	0 − 6 −12 −18 −24
Direct Tension, D6723:[E] Failure Strain, min. 1.0 % Test Temp. at 1.0 mm/min., °C	−24 −30 −36	0 − 6 −12 −18 −24 −30 −36	− 6 −12 −18 −24 −30	0 − 6 −12 −18 −24 −30	0 −6 −12 −18 −24 −30	0 − 6 −12 −18 −24	0 − 6 −12 −18 −24

[A] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind software program, or are provided by the specifying agency.

[B] The referee method shall be D4402 using a #21 spindle at 20RPM, however alternate methods may be used for routine testing and quality assurance. If the binder is too stiff to test with the No. 21 Spindle, the No. 27 spindle shall be used. The spindle size and shear rate shall be reported. This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

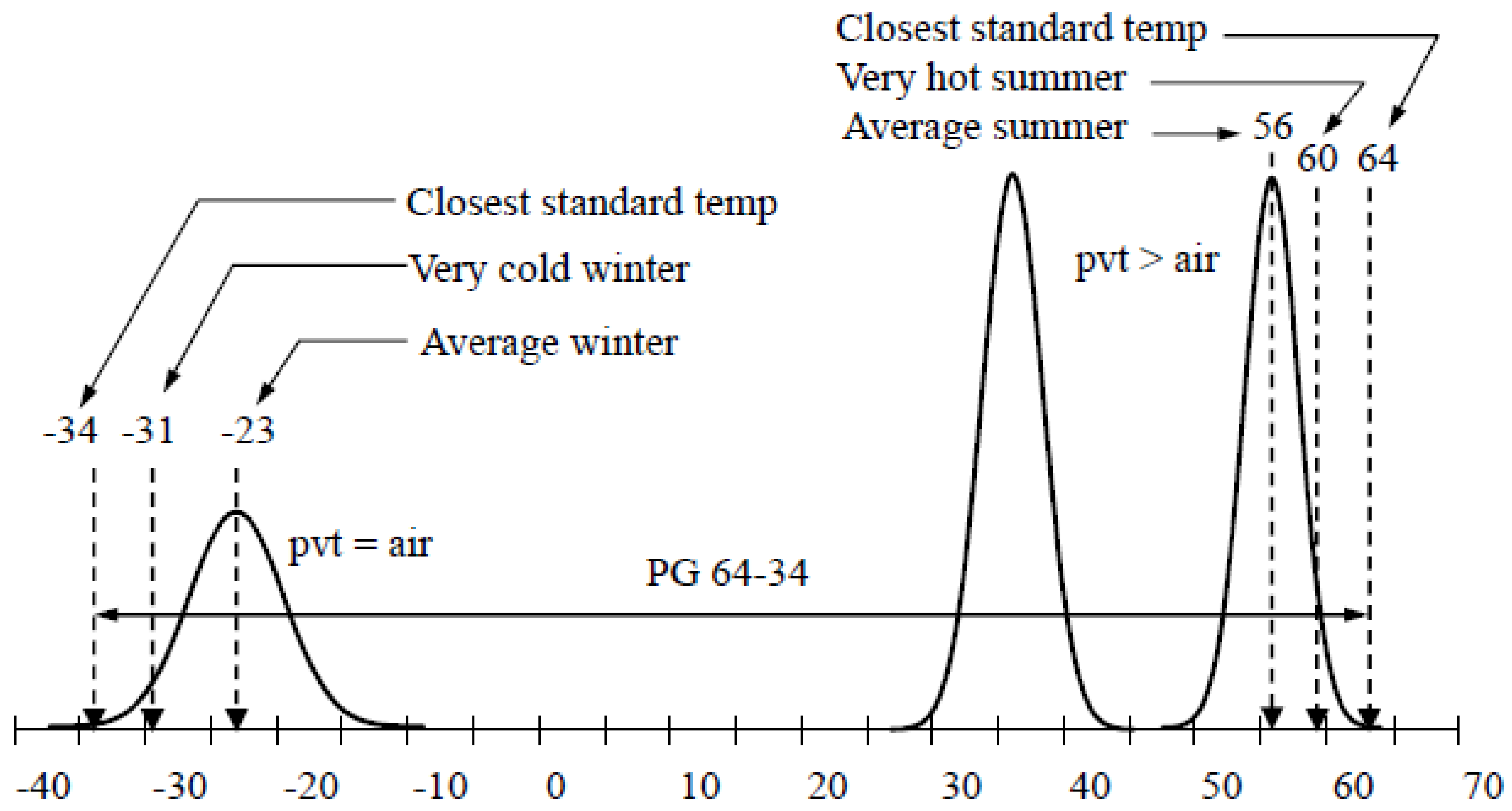
[C] For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary viscometry (Test Methods D2170 or D2171) or rotational viscometry.

[D] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90°C, 100°C or 110°C. Normally the PAV aging temperature is 100°C for PG 58–xx and above. However, in desert climates, the PAV aging temperature for PG 70–xx and above may be specified as 110°C

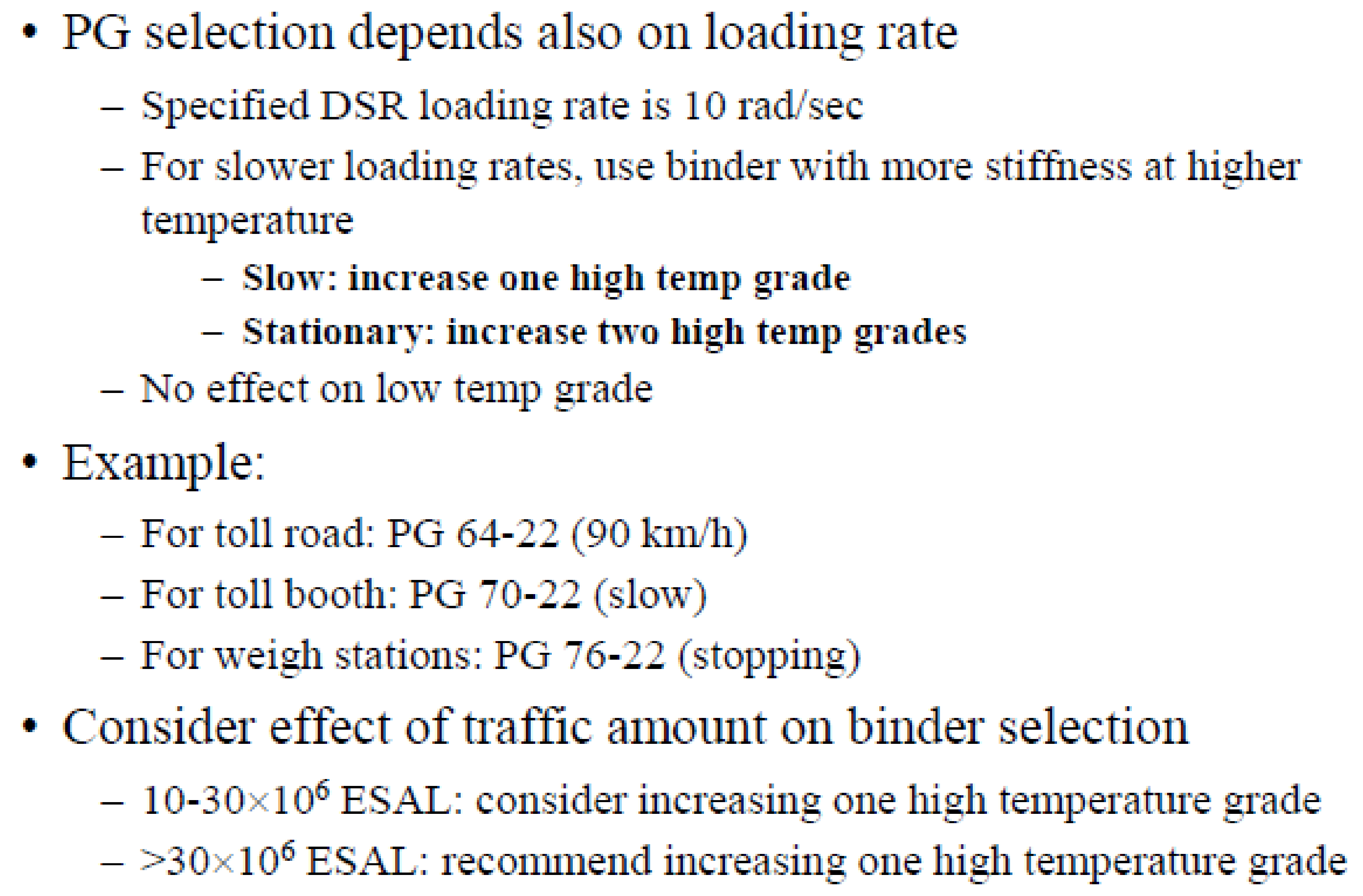
[E] If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases. If the creep stiffness and m-value data are unobtainable because the binder is too soft at the test temperature, the asphalt binder will be deemed to pass at that grade temperature if it meets the creep stiffness and m-value requirements at the test temperature minus 6°C.

D6373 – 07ε1

PG Binder Selection



PG Binder Selection



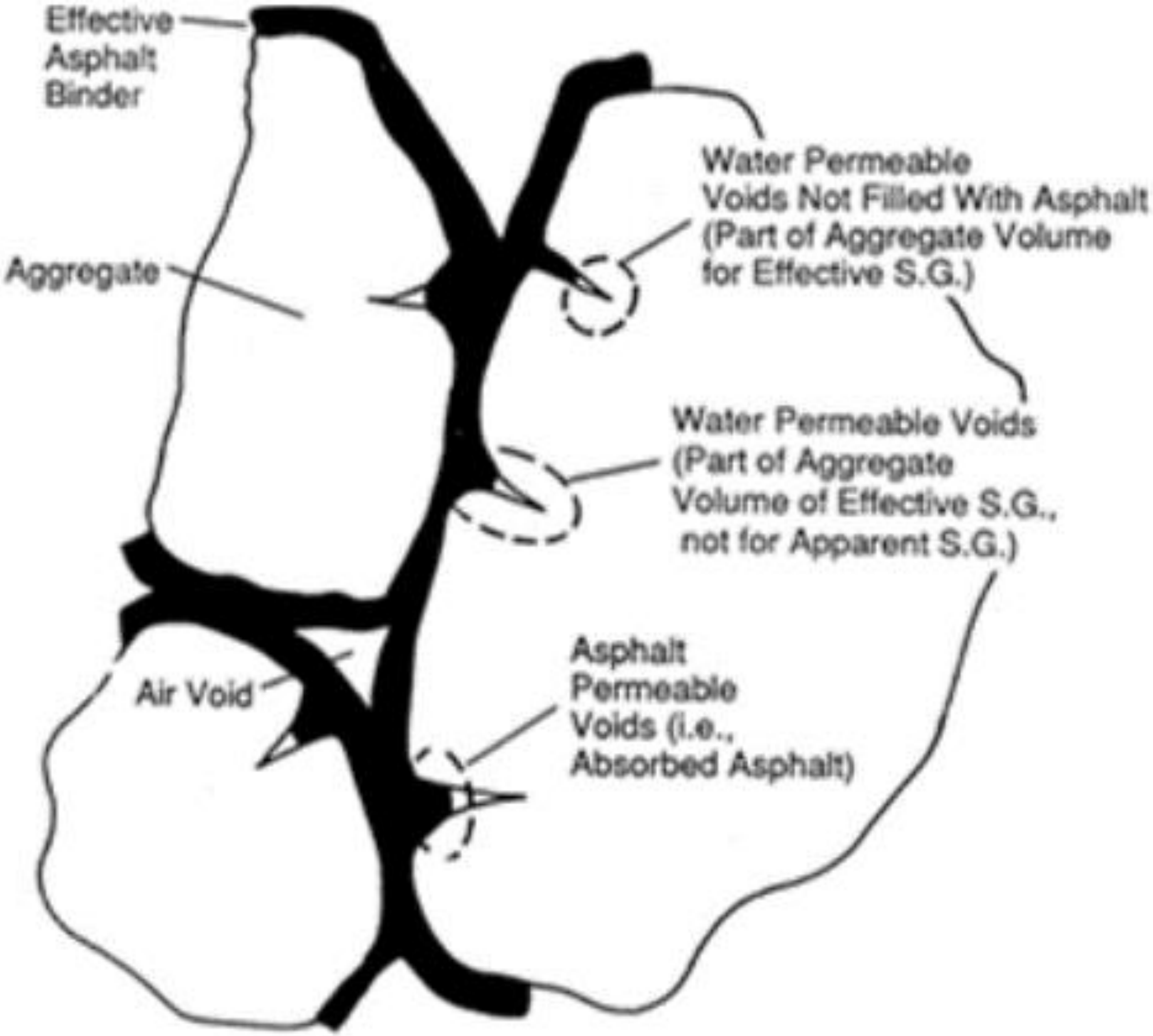
- PG selection depends also on loading rate
  - Specified DSR loading rate is 10 rad/sec
  - For slower loading rates, use binder with more stiffness at higher temperature
    - **Slow: increase one high temp grade**
    - **Stationary: increase two high temp grades**
  - No effect on low temp grade
- Example:
  - For toll road: PG 64-22 (90 km/h)
  - For toll booth: PG 70-22 (slow)
  - For weigh stations: PG 76-22 (stopping)
- Consider effect of traffic amount on binder selection
  - $10\text{-}30\times10^6$ ESAL: consider increasing one high temperature grade
  - $>30\times10^6$ ESAL: recommend increasing one high temperature grade

Asphalt Concrete

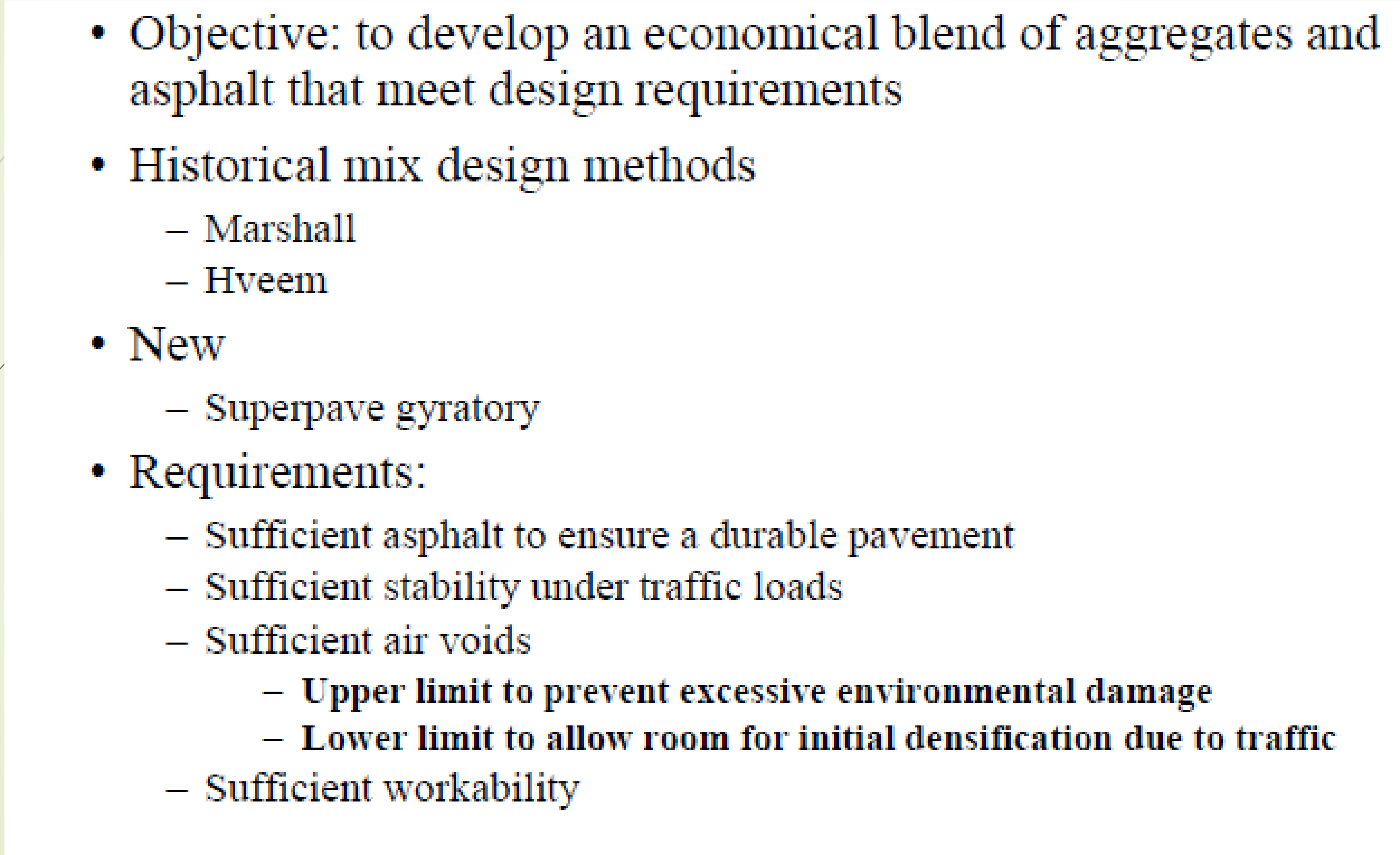
- A uniformly mixed combination of bituminous material, coarse aggregate, fine aggregate, and mineral filler (dust)
- Different types of asphalt concrete:

1. Hot-mix, hot-laid
   - Used normally for high-type pavement construction
   - Aggregate gradation can be dense graded, open-graded, coarse graded, or fine-graded
   - Resistance to load is produced by the interlock friction between the aggregate particles
   - To increase the mix resistance to loading, angular and rough textured aggregates are usually used
   - Therefore, coarse aggregate used in the mix is usually crushed stones
2. Cold-mix, cold-laid
3. Recycled

Asphalt Concrete

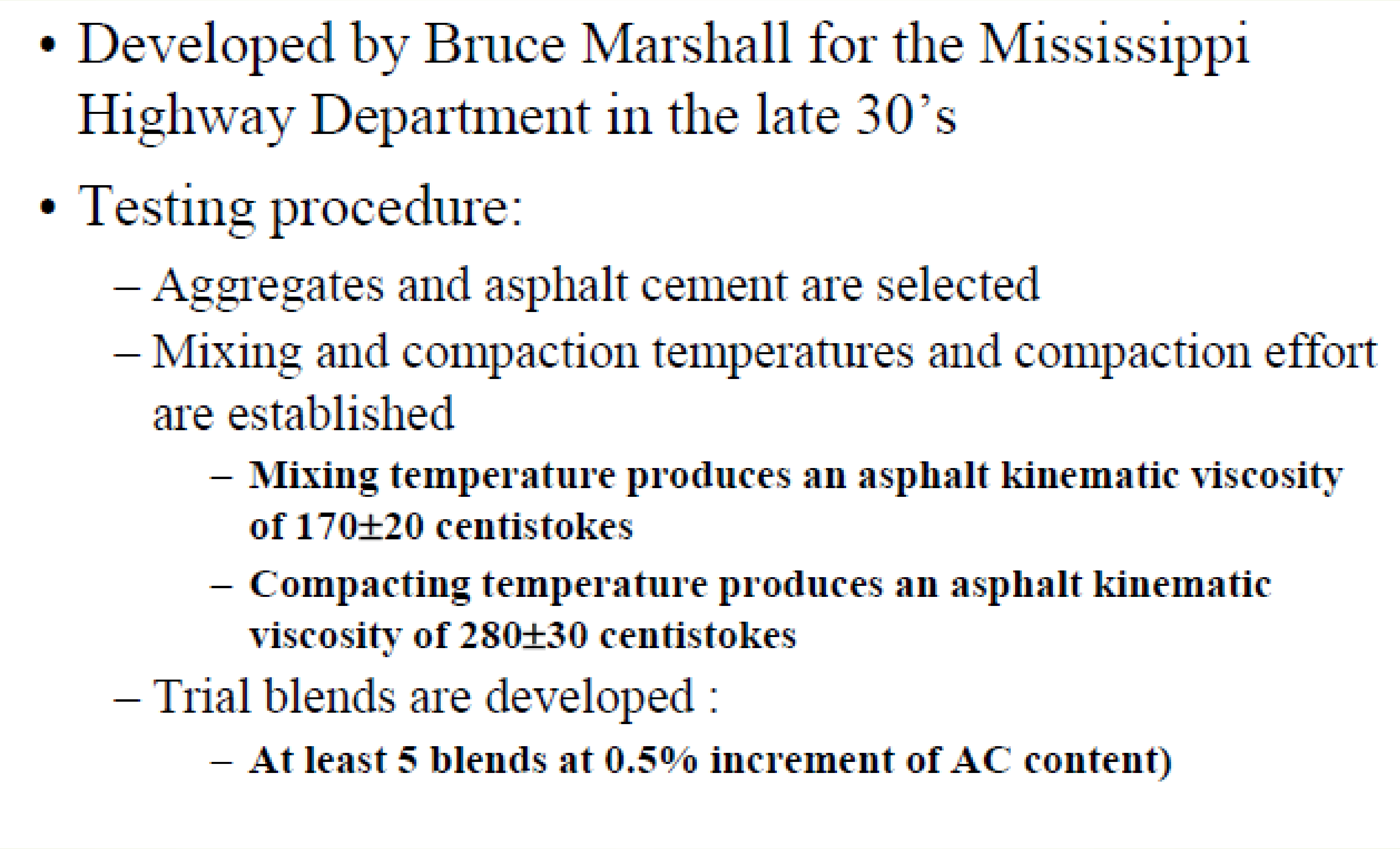


Asphalt Concrete Mix Design



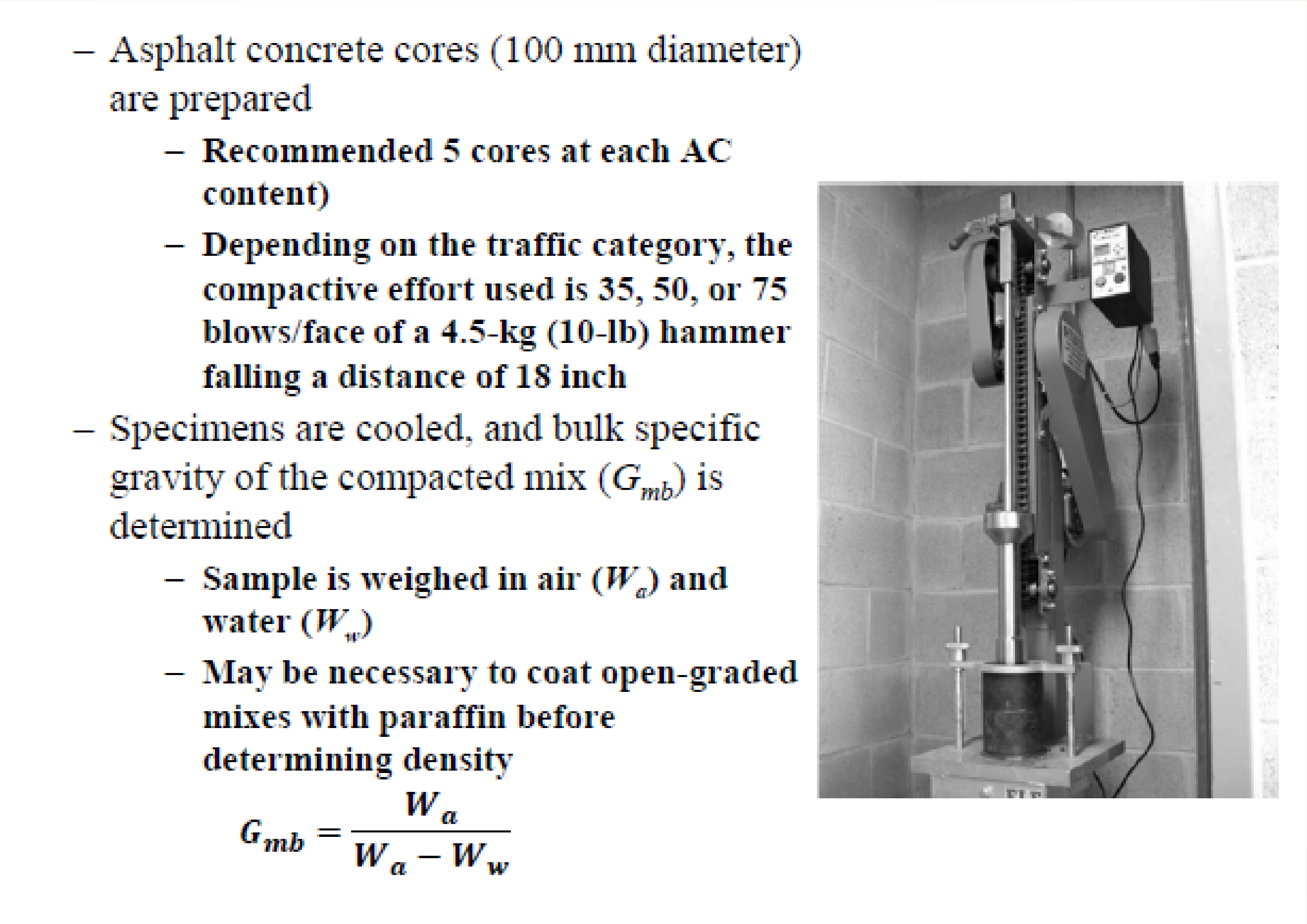
- Objective: to develop an economical blend of aggregates and asphalt that meet design requirements
- Historical mix design methods
  - Marshall
  - Hveem
- New
  - Superpave gyratory
- Requirements:
  - Sufficient asphalt to ensure a durable pavement
  - Sufficient stability under traffic loads
  - Sufficient air voids
    - **Upper limit to prevent excessive environmental damage**
    - **Lower limit to allow room for initial densification due to traffic**
  - Sufficient workability

Marshall Mix Design



- Developed by Bruce Marshall for the Mississippi Highway Department in the late 30's
- Testing procedure:
  - Aggregates and asphalt cement are selected
  - Mixing and compaction temperatures and compaction effort are established
    - **Mixing temperature produces an asphalt kinematic viscosity of 170±20 centistokes**
    - **Compacting temperature produces an asphalt kinematic viscosity of 280±30 centistokes**
  - Trial blends are developed :
    - **At least 5 blends at 0.5% increment of AC content)**

Marshall Mix Design



- Asphalt concrete cores (100 mm diameter) are prepared
  - **Recommended 5 cores at each AC content)**
  - **Depending on the traffic category, the compactive effort used is 35, 50, or 75 blows/face of a 4.5-kg (10-lb) hammer falling a distance of 18 inch**
- Specimens are cooled, and bulk specific gravity of the compacted mix (G_{mb}) is determined
  - **Sample is weighed in air (W_a) and water (W_w)**
  - **May be necessary to coat open-graded mixes with paraffin before determining density**

$$G_{mb} = \frac{W_a}{W_a - W_w}$$

Marshall Mix Design

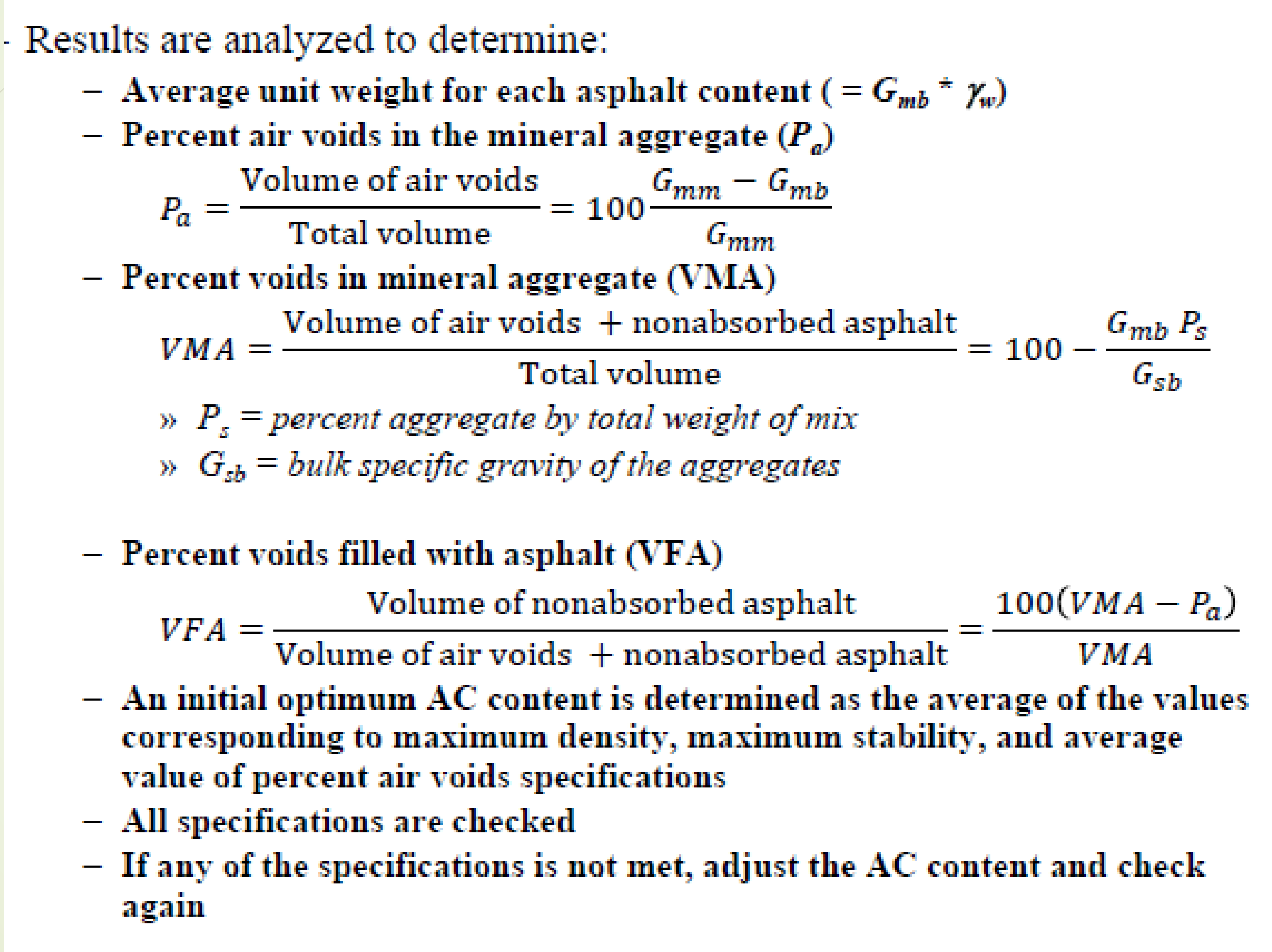
- Maximum specific gravity of the mix corresponding to no voids (G_{mm}) is determined for each asphalt cement content according to the ASTM D2041 test
- Specimens are immersed in a water bath at temperature of 60±1°C for 30-40 minutes, then tested for stability and flow
  - **Stability is defined as the maximum load resistance in pounds (or Newtons) that the specimen will achieve at 60°C (140°F) under specified conditions**
  - **Flow is the total movement of the specimen in units of 0.25 mm (0.01 inch)**

Marshall Stability Equipment

SOURCE: CONTROLS S.R.L. Used with permission.

Garber & Hoel (2013)

Marshall Mix Design



Results are analyzed to determine:

- **Average unit weight for each asphalt content (= $G_{mb} * \gamma_w$)**
- **Percent air voids in the mineral aggregate (P_a)**

$$P_a = \frac{\text{Volume of air voids}}{\text{Total volume}} = 100\frac{G_{mm} - G_{mb}}{G_{mm}}$$

- **Percent voids in mineral aggregate (VMA)**

$$VMA = \frac{\text{Volume of air voids } + \text{nonabsorbed asphalt}}{\text{Total volume}} = 100 - \frac{G_{mb}\,P_s}{G_{sb}}$$

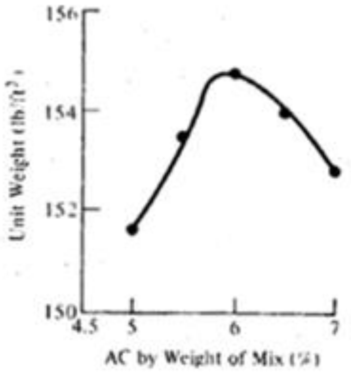
  - » P_s = *percent aggregate by total weight of mix*
  - » G_{sb} = *bulk specific gravity of the aggregates*

- **Percent voids filled with asphalt (VFA)**

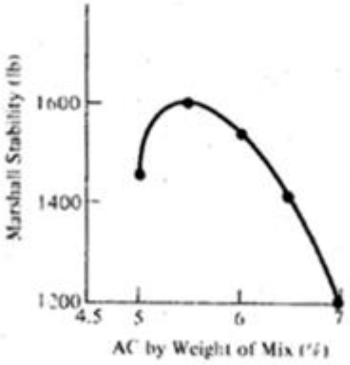
$$VFA = \frac{\text{Volume of nonabsorbed asphalt}}{\text{Volume of air voids } + \text{nonabsorbed asphalt}} = \frac{100(VMA - P_a)}{VMA}$$

- **An initial optimum AC content is determined as the average of the values corresponding to maximum density, maximum stability, and average value of percent air voids specifications**
- **All specifications are checked**
- **If any of the specifications is not met, adjust the AC content and check again**

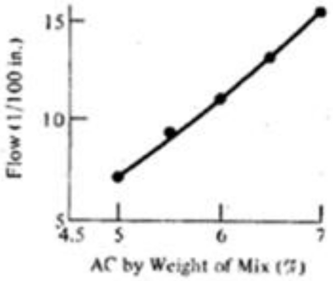
Marshall Mix Design



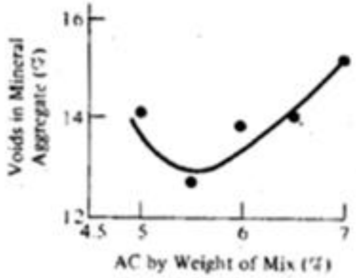
(a) Unit of weight versus asphalt content



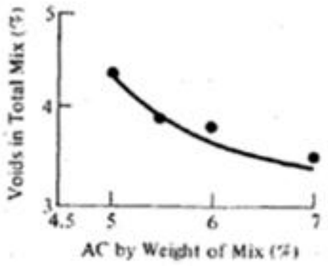
(b) Marshall stability versus asphalt content



(c) Flow versus asphalt content

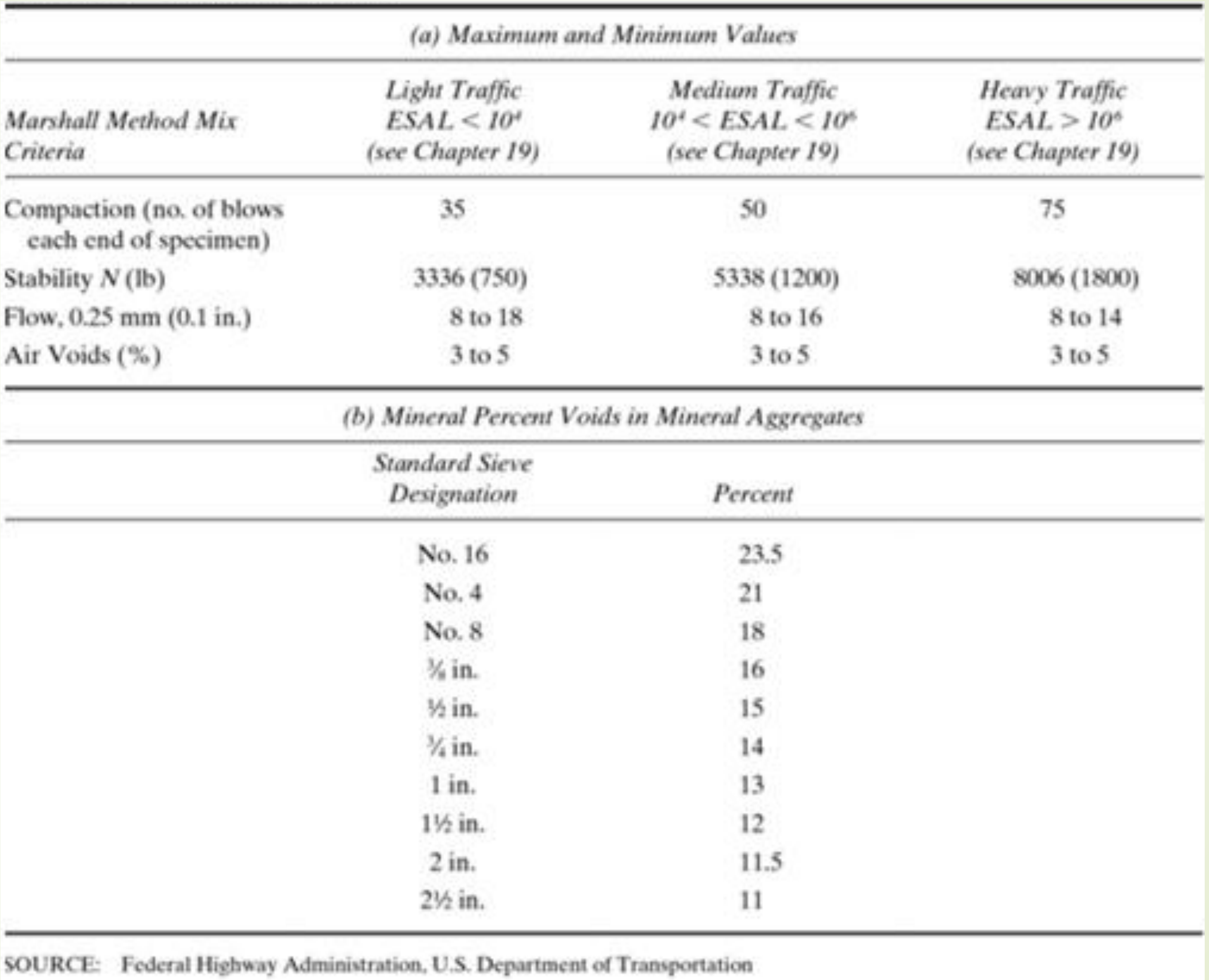


(d) VMA versus asphalt content



(e) Voids in total mix versus asphalt content

Marshall Mix Design



(a) Maximum and Minimum Values

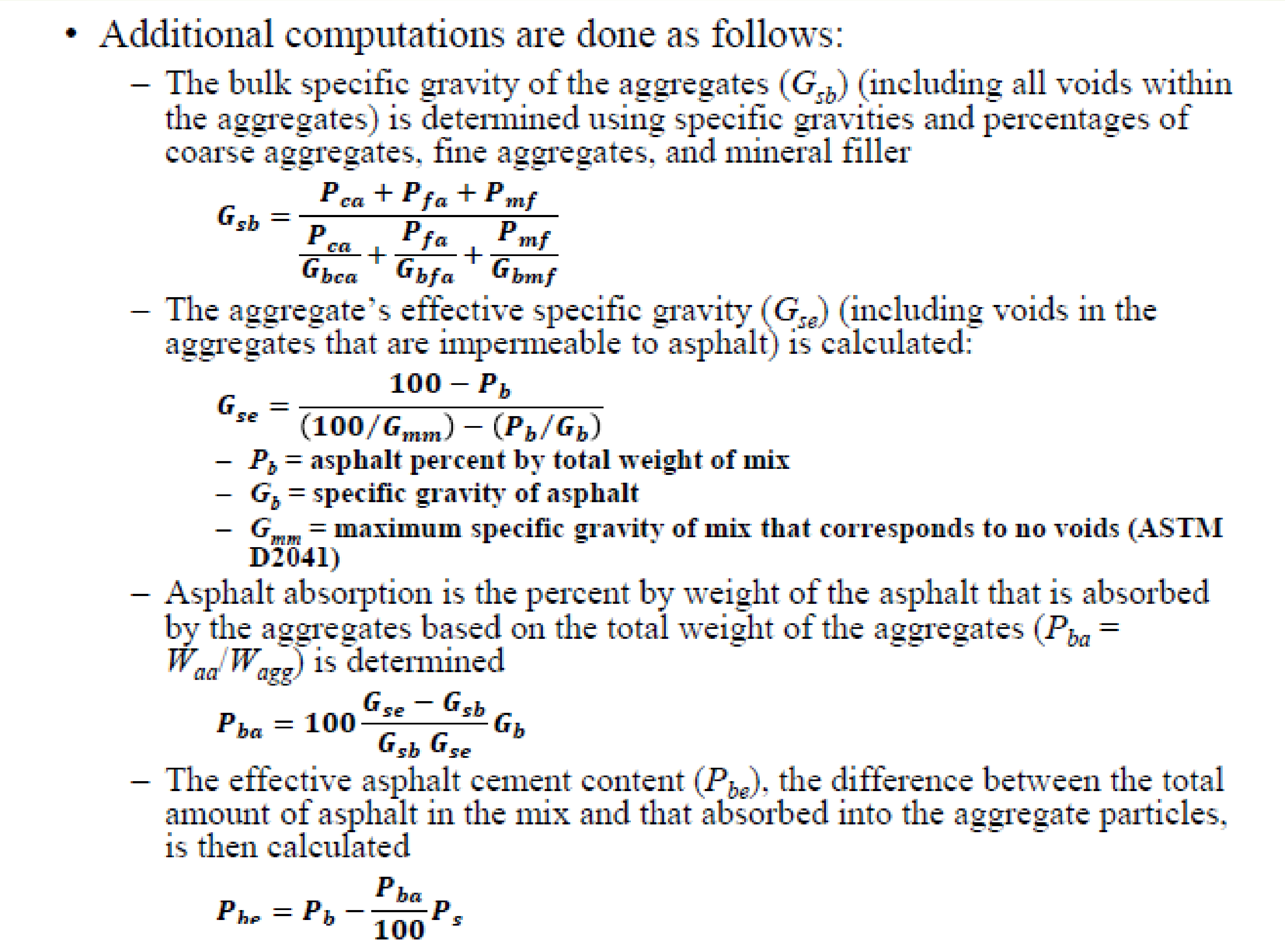
Marshall Method Mix Criteria	*Light Traffic ESAL $< 10^4$ (see Chapter 19)*	*Medium Traffic $10^4 <$ ESAL $< 10^6$ (see Chapter 19)*	*Heavy Traffic ESAL $> 10^6$ (see Chapter 19)*
Compaction (no. of blows each end of specimen)	35	50	75
Stability *N* (lb)	3336 (750)	5338 (1200)	8006 (1800)
Flow, 0.25 mm (0.1 in.)	8 to 18	8 to 16	8 to 14
Air Voids (%)	3 to 5	3 to 5	3 to 5

(b) Mineral Percent Voids in Mineral Aggregates

Standard Sieve Designation	*Percent*
No. 16	23.5
No. 4	21
No. 8	18
⅜ in.	16
½ in.	15
¾ in.	14
1 in.	13
1½ in.	12
2 in.	11.5
2½ in.	11

SOURCE: Federal Highway Administration, U.S. Department of Transportation

Marshall Mix Design



- Additional computations are done as follows:
  - The bulk specific gravity of the aggregates (G_{sb}) (including all voids within the aggregates) is determined using specific gravities and percentages of coarse aggregates, fine aggregates, and mineral filler

$$G_{sb} = \frac{P_{ca} + P_{fa} + P_{mf}}{\frac{P_{ca}}{G_{bca}} + \frac{P_{fa}}{G_{bfa}} + \frac{P_{mf}}{G_{bmf}}}$$

  - The aggregate's effective specific gravity (G_{se}) (including voids in the aggregates that are impermeable to asphalt) is calculated:

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

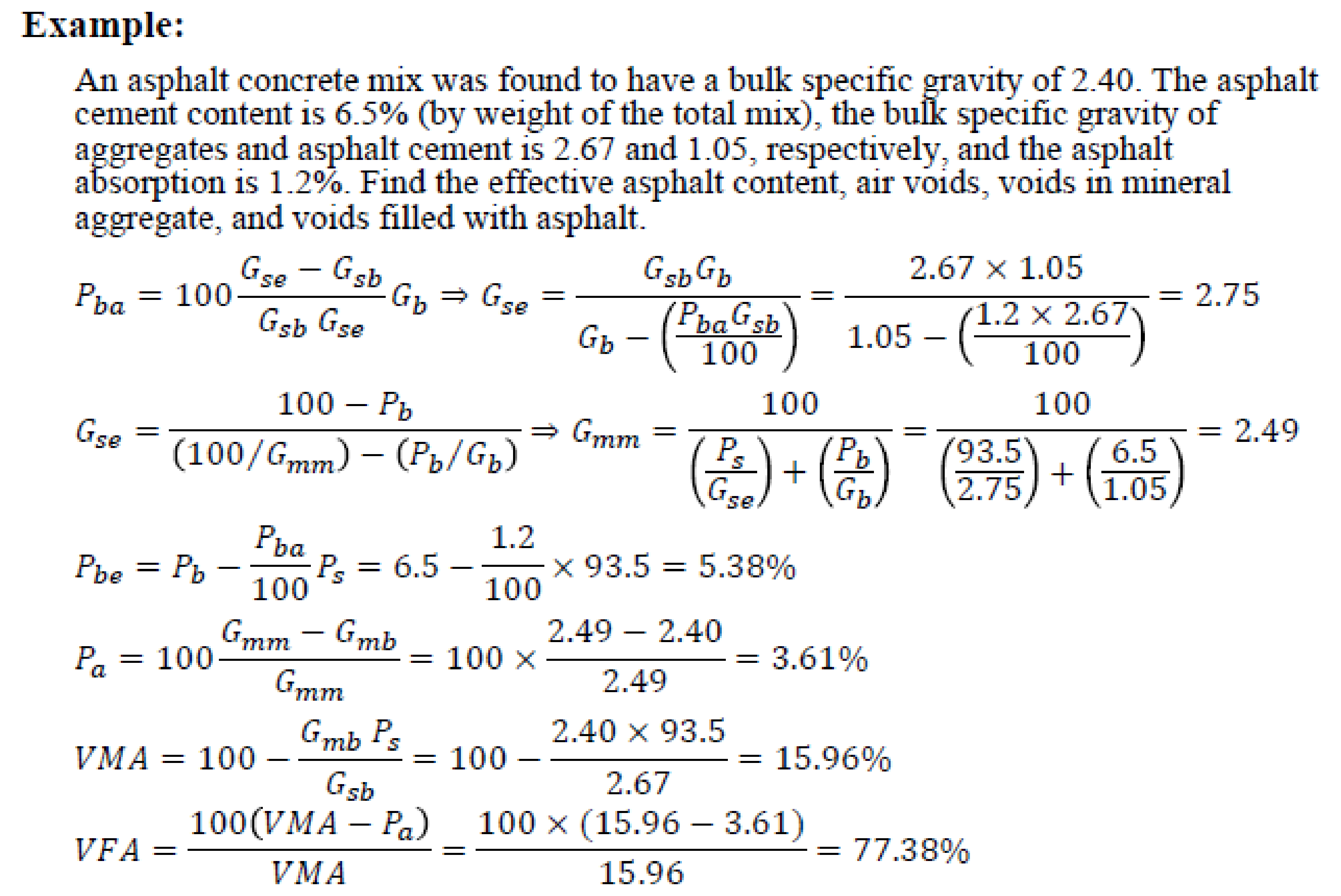
    - P_b = asphalt percent by total weight of mix
    - G_b = specific gravity of asphalt
    - G_{mm} = maximum specific gravity of mix that corresponds to no voids (ASTM D2041)
  - Asphalt absorption is the percent by weight of the asphalt that is absorbed by the aggregates based on the total weight of the aggregates ($P_{ba} = W_{aa}/W_{agg}$) is determined

$$P_{ba} = 100 \frac{G_{se} - G_{sb}}{G_{sb}\, G_{se}} G_b$$

  - The effective asphalt cement content (P_{be}), the difference between the total amount of asphalt in the mix and that absorbed into the aggregate particles, is then calculated

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

Marshall Mix Design



Example:

An asphalt concrete mix was found to have a bulk specific gravity of 2.40. The asphalt cement content is 6.5% (by weight of the total mix), the bulk specific gravity of aggregates and asphalt cement is 2.67 and 1.05, respectively, and the asphalt absorption is 1.2%. Find the effective asphalt content, air voids, voids in mineral aggregate, and voids filled with asphalt.

$$P_{ba} = 100\frac{G_{se} - G_{sb}}{G_{sb}\,G_{se}}G_b \Rightarrow G_{se} = \frac{G_{sb}G_b}{G_b - \left(\frac{P_{ba}G_{sb}}{100}\right)} = \frac{2.67 \times 1.05}{1.05 - \left(\frac{1.2 \times 2.67}{100}\right)} = 2.75$$

$$G_{se} = \frac{100 - P_b}{(100/G_{mm}) - (P_b/G_b)} \Rightarrow G_{mm} = \frac{100}{\left(\frac{P_s}{G_{se}}\right) + \left(\frac{P_b}{G_b}\right)} = \frac{100}{\left(\frac{93.5}{2.75}\right) + \left(\frac{6.5}{1.05}\right)} = 2.49$$

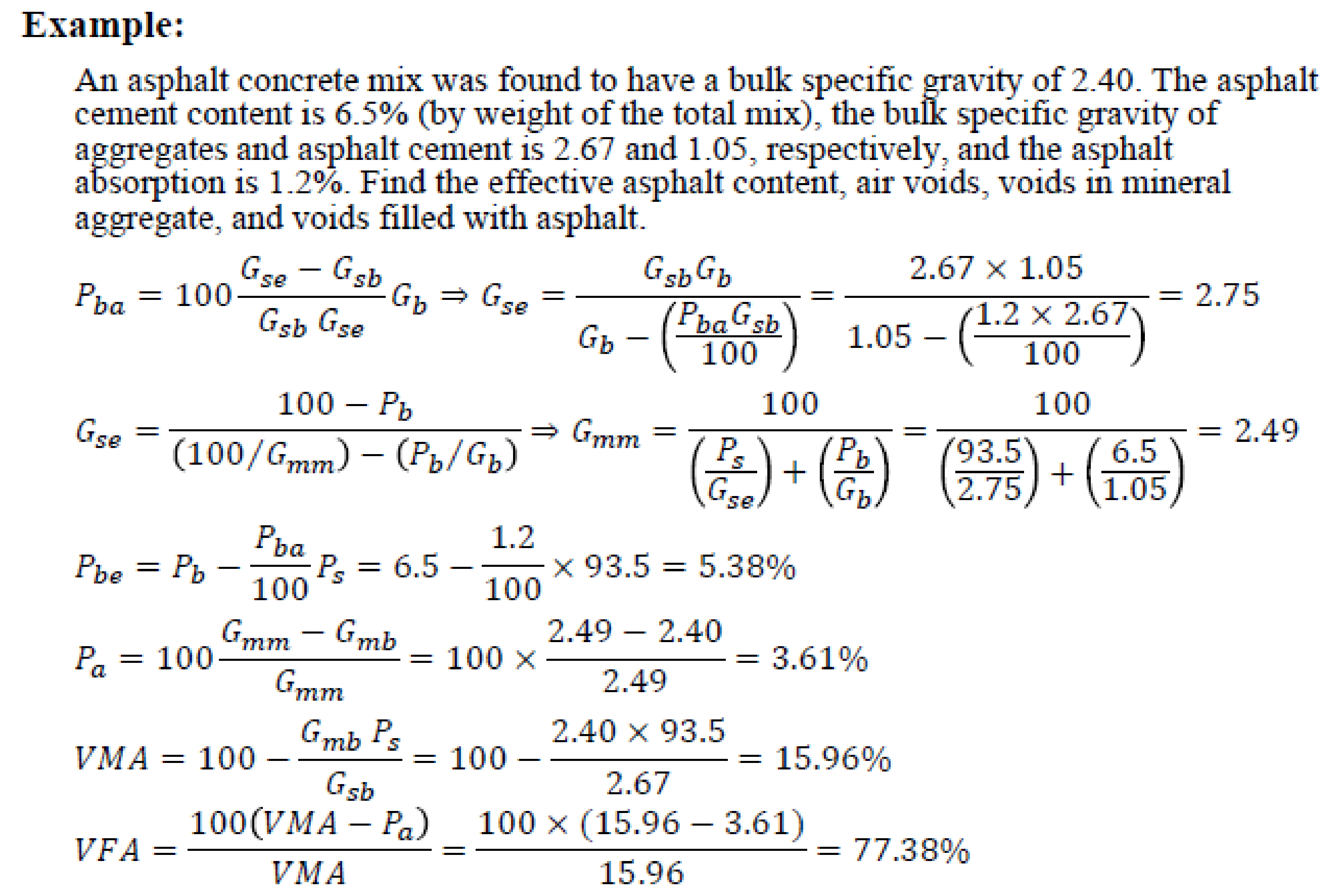
$$P_{be} = P_b - \frac{P_{ba}}{100}P_s = 6.5 - \frac{1.2}{100} \times 93.5 = 5.38\%$$

$$P_a = 100\frac{G_{mm} - G_{mb}}{G_{mm}} = 100 \times \frac{2.49 - 2.40}{2.49} = 3.61\%$$

$$VMA = 100 - \frac{G_{mb}\,P_s}{G_{sb}} = 100 - \frac{2.40 \times 93.5}{2.67} = 15.96\%$$

$$VFA = \frac{100(VMA - P_a)}{VMA} = \frac{100 \times (15.96 - 3.61)}{15.96} = 77.38\%$$

Superpave Volumetric Mix Design



Example:

An asphalt concrete mix was found to have a bulk specific gravity of 2.40. The asphalt cement content is 6.5% (by weight of the total mix), the bulk specific gravity of aggregates and asphalt cement is 2.67 and 1.05, respectively, and the asphalt absorption is 1.2%. Find the effective asphalt content, air voids, voids in mineral aggregate, and voids filled with asphalt.

$$P_{ba} = 100\frac{G_{se} - G_{sb}}{G_{sb}\, G_{se}} G_b \Rightarrow G_{se} = \frac{G_{sb} G_b}{G_b - \left(\frac{P_{ba} G_{sb}}{100}\right)} = \frac{2.67 \times 1.05}{1.05 - \left(\frac{1.2 \times 2.67}{100}\right)} = 2.75$$

$$G_{se} = \frac{100 - P_b}{(100/G_{mm}) - (P_b/G_b)} \Rightarrow G_{mm} = \frac{100}{\left(\frac{P_s}{G_{se}}\right) + \left(\frac{P_b}{G_b}\right)} = \frac{100}{\left(\frac{93.5}{2.75}\right) + \left(\frac{6.5}{1.05}\right)} = 2.49$$

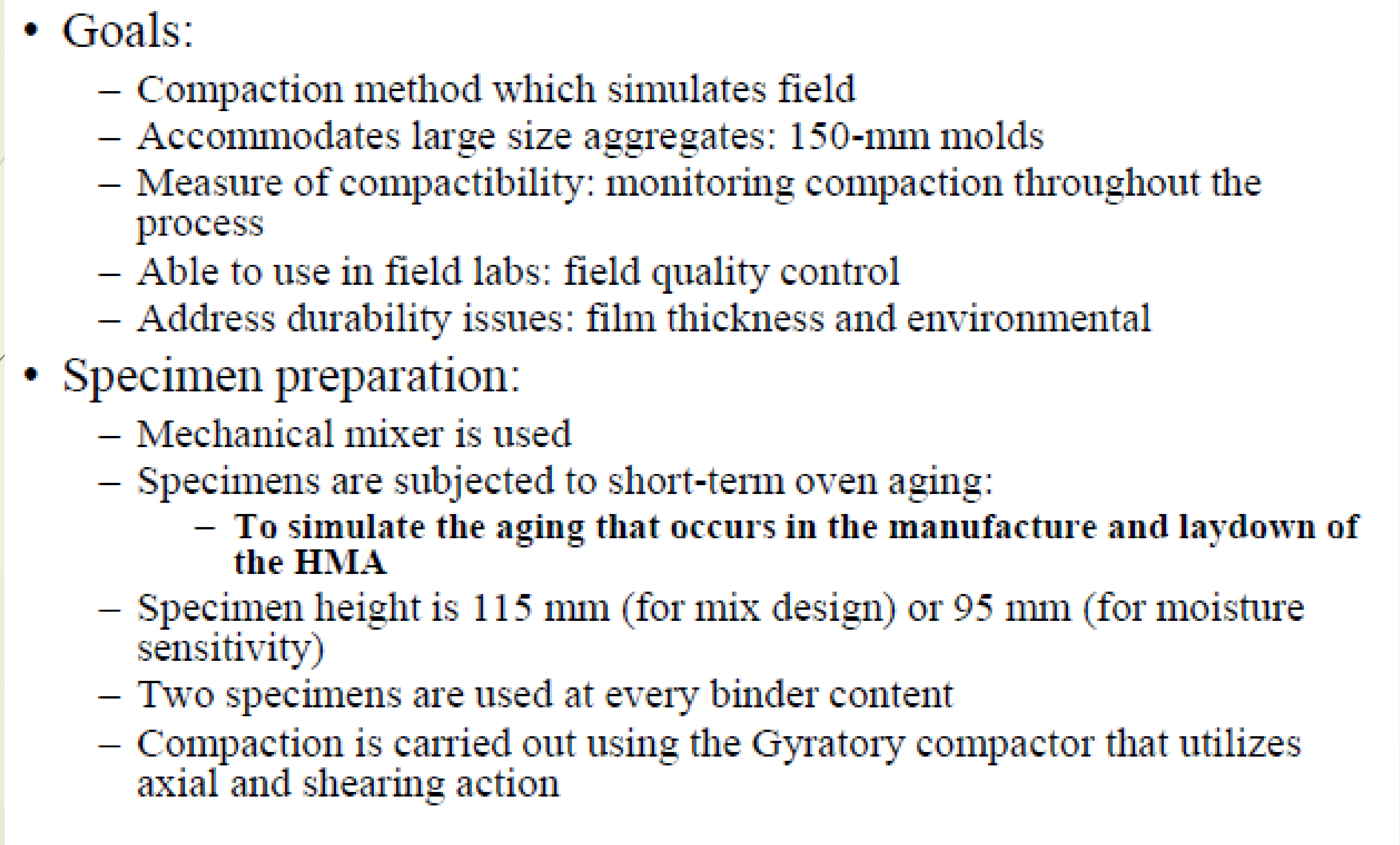
$$P_{be} = P_b - \frac{P_{ba}}{100} P_s = 6.5 - \frac{1.2}{100} \times 93.5 = 5.38\%$$

$$P_a = 100\frac{G_{mm} - G_{mb}}{G_{mm}} = 100 \times \frac{2.49 - 2.40}{2.49} = 3.61\%$$

$$VMA = 100 - \frac{G_{mb}\, P_s}{G_{sb}} = 100 - \frac{2.40 \times 93.5}{2.67} = 15.96\%$$

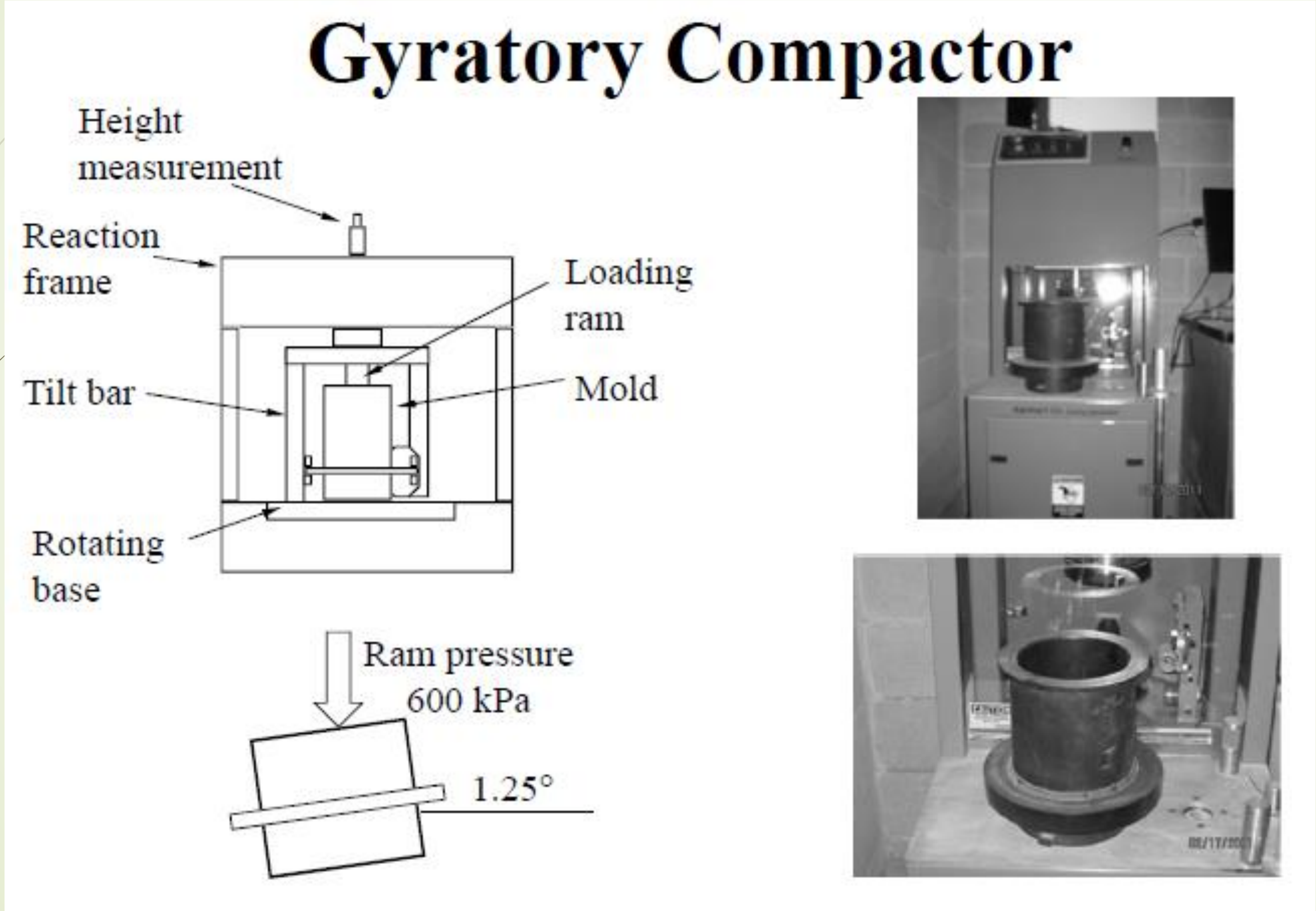
$$VFA = \frac{100(VMA - P_a)}{VMA} = \frac{100 \times (15.96 - 3.61)}{15.96} = 77.38\%$$

Superpave Volumetric Mix Design



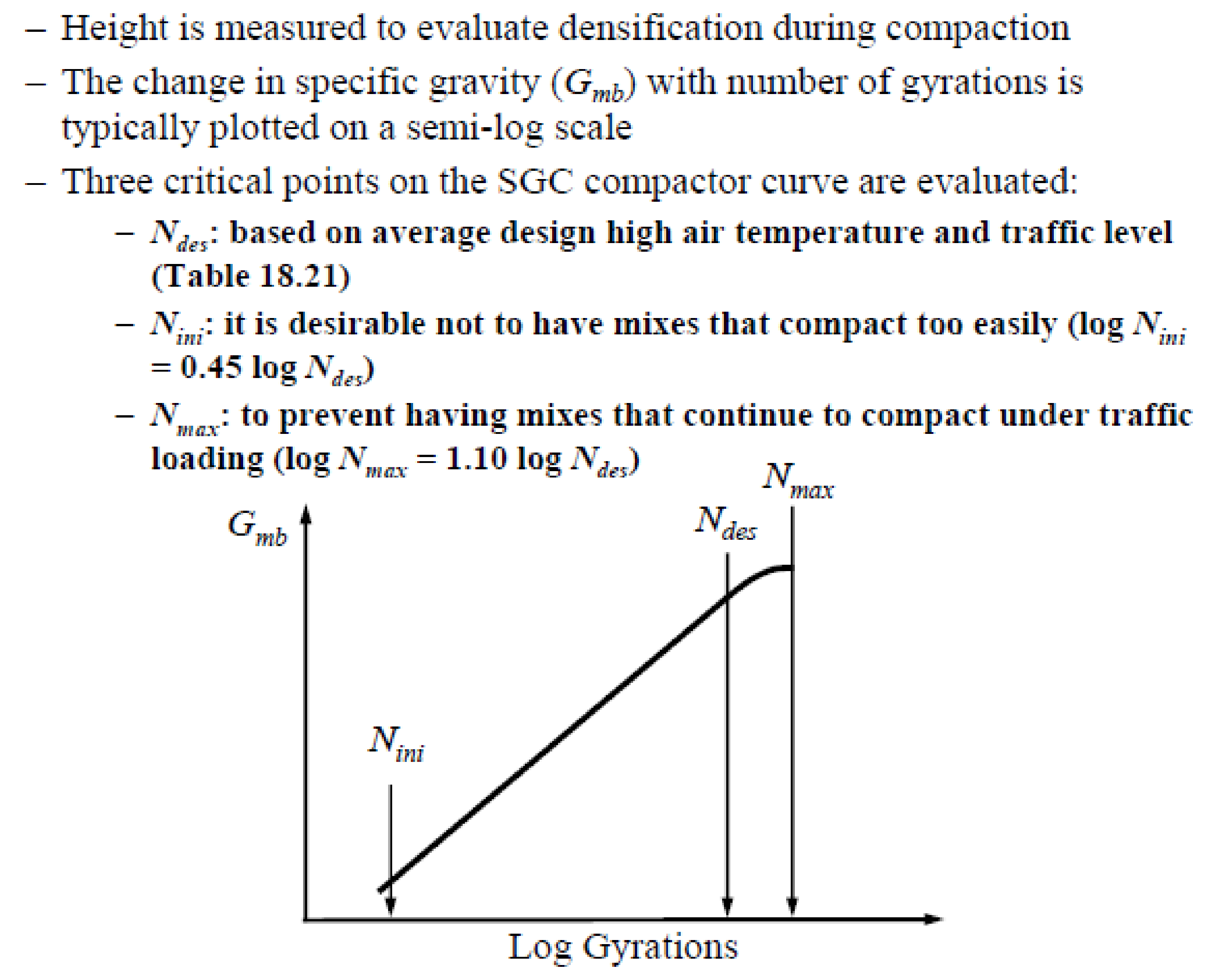
- Goals:
  - Compaction method which simulates field
  - Accommodates large size aggregates: 150-mm molds
  - Measure of compactibility: monitoring compaction throughout the process
  - Able to use in field labs: field quality control
  - Address durability issues: film thickness and environmental
- Specimen preparation:
  - Mechanical mixer is used
  - Specimens are subjected to short-term oven aging:
    - **To simulate the aging that occurs in the manufacture and laydown of the HMA**
  - Specimen height is 115 mm (for mix design) or 95 mm (for moisture sensitivity)
  - Two specimens are used at every binder content
  - Compaction is carried out using the Gyratory compactor that utilizes axial and shearing action

Superpave Volumetric Mix Design



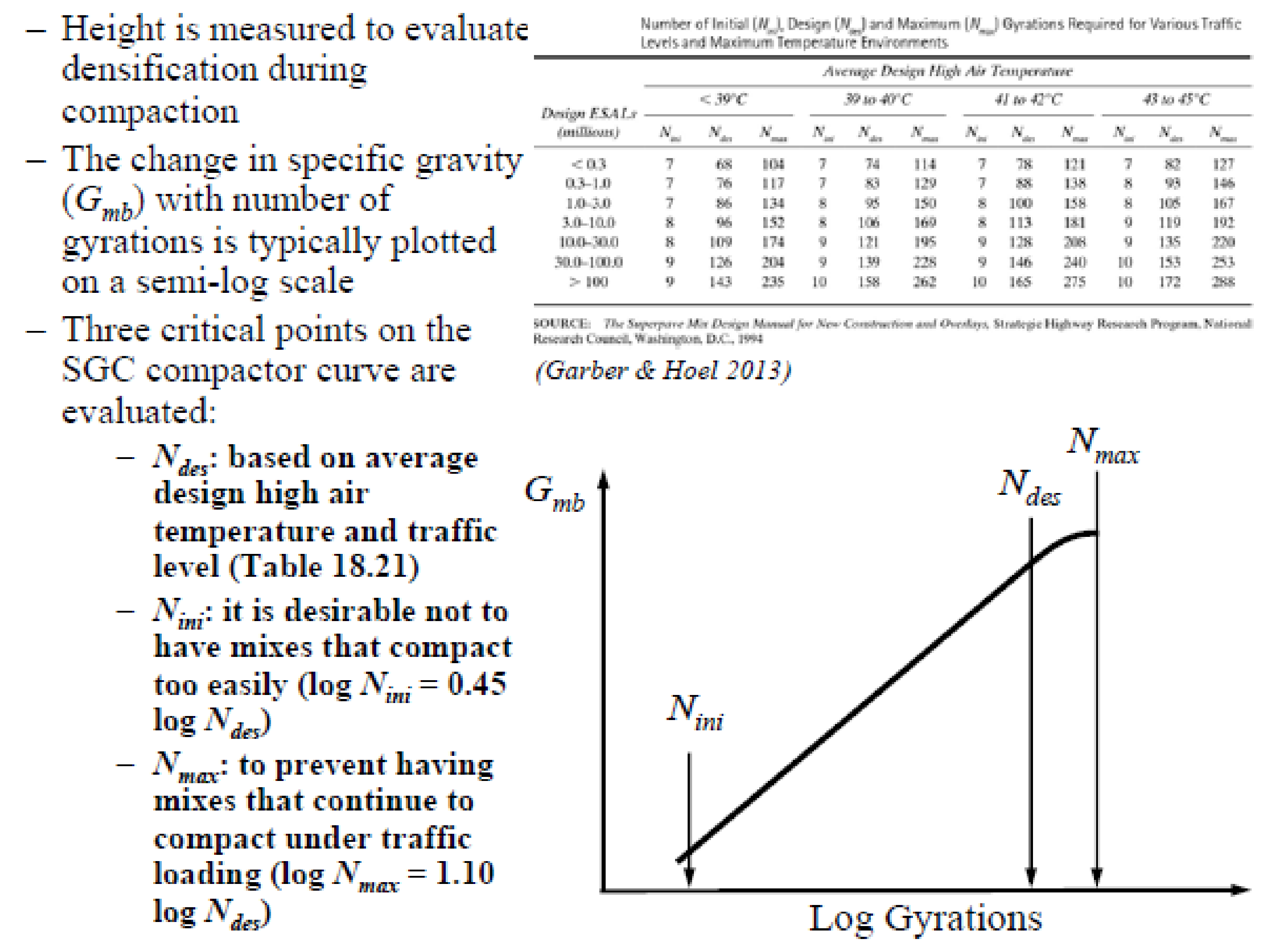
Gyratory Compactor

Superpave Volumetric Mix Design



- Height is measured to evaluate densification during compaction
- The change in specific gravity (G_{mb}) with number of gyrations is typically plotted on a semi-log scale
- Three critical points on the SGC compactor curve are evaluated:
  - **N_{des}: based on average design high air temperature and traffic level (Table 18.21)**
  - **N_{ini}: it is desirable not to have mixes that compact too easily ($\log N_{ini} = 0.45 \log N_{des}$)**
  - **N_{max}: to prevent having mixes that continue to compact under traffic loading ($\log N_{max} = 1.10 \log N_{des}$)**

Superpave Volumetric Mix Design



- Height is measured to evaluate densification during compaction
- The change in specific gravity (G_{mb}) with number of gyrations is typically plotted on a semi-log scale
- Three critical points on the SGC compactor curve are evaluated:
  - **N_{des}: based on average design high air temperature and traffic level (Table 18.21)**
  - **N_{ini}: it is desirable not to have mixes that compact too easily ($\log N_{ini} = 0.45 \log N_{des}$)**
  - **N_{max}: to prevent having mixes that continue to compact under traffic loading ($\log N_{max} = 1.10 \log N_{des}$)**

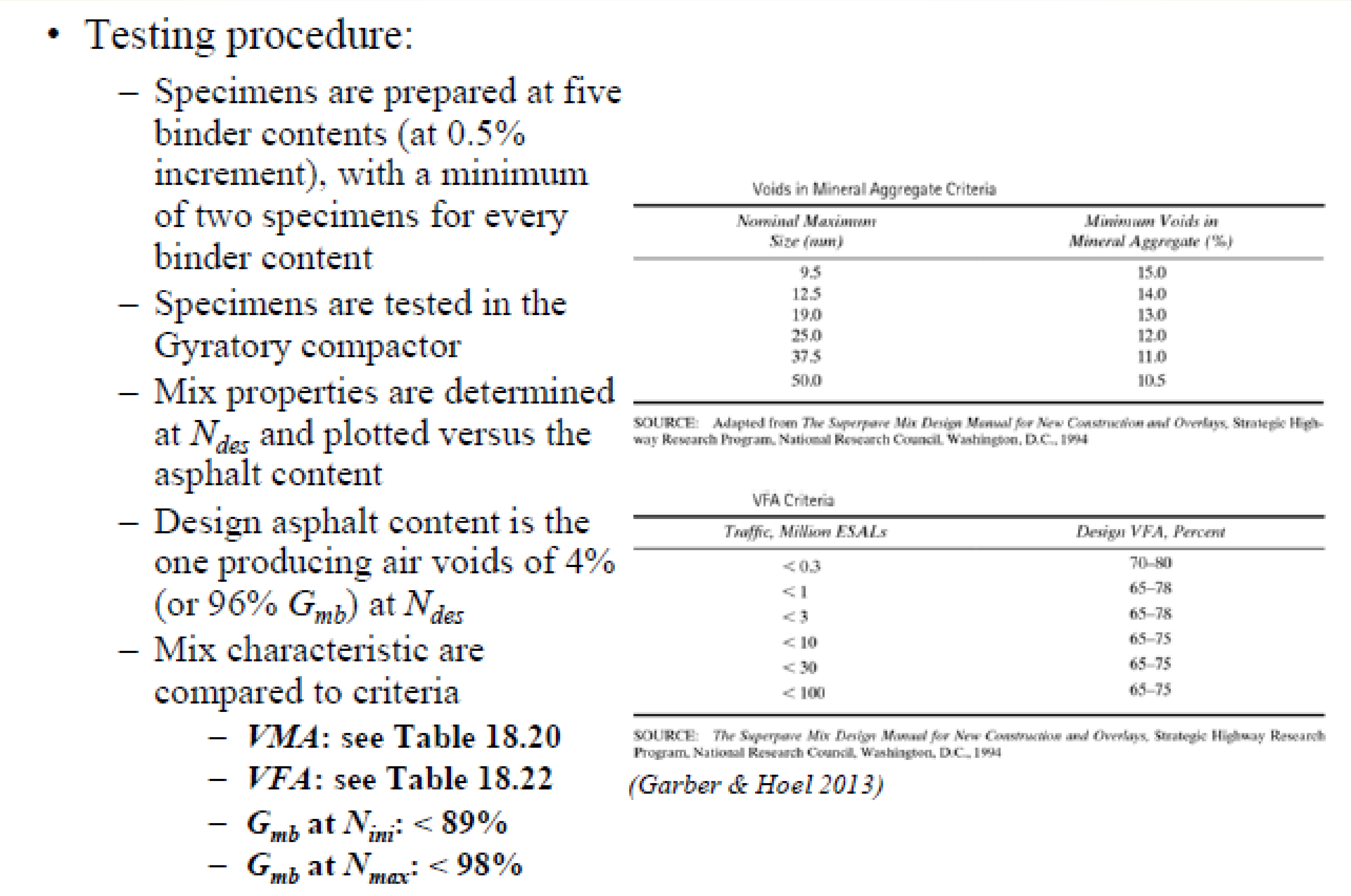
Number of Initial (N_{ini}), Design (N_{des}) and Maximum (N_{max}) Gyrations Required for Various Traffic Levels and Maximum Temperature Environments

	Average Design High Air Temperature											
Design ESALs (millions)	*< 39°C*			*39 to 40°C*			*41 to 42°C*			*43 to 45°C*		
	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}
< 0.3	7	68	104	7	74	114	7	78	121	7	82	127
0.3–1.0	7	76	117	7	83	129	7	88	138	8	93	146
1.0–3.0	7	86	134	8	95	150	8	100	158	8	105	167
3.0–10.0	8	96	152	8	106	169	8	113	181	9	119	192
10.0–30.0	8	109	174	9	121	195	9	128	208	9	135	220
30.0–100.0	9	126	204	9	139	228	9	146	240	10	153	253
> 100	9	143	235	10	158	262	10	165	275	10	172	288

SOURCE: *The Superpave Mix Design Manual for New Construction and Overlays*, Strategic Highway Research Program, National Research Council, Washington, D.C., 1994

(Garber & Hoel 2013)

Superpave Volumetric Mix Design



- Testing procedure:
  - Specimens are prepared at five binder contents (at 0.5% increment), with a minimum of two specimens for every binder content
  - Specimens are tested in the Gyratory compactor
  - Mix properties are determined at N_{des} and plotted versus the asphalt content
  - Design asphalt content is the one producing air voids of 4% (or 96% G_{mb}) at N_{des}
  - Mix characteristic are compared to criteria
    - ***VMA*: see Table 18.20**
    - ***VFA*: see Table 18.22**
    - **G_{mb} at N_{ini}: < 89%**
    - **G_{mb} at N_{max}: < 98%**

Voids in Mineral Aggregate Criteria

Nominal Maximum Size (mm)	*Minimum Voids in Mineral Aggregate (%)*
9.5	15.0
12.5	14.0
19.0	13.0
25.0	12.0
37.5	11.0
50.0	10.5

SOURCE: Adapted from *The Superpave Mix Design Manual for New Construction and Overlays*, Strategic Highway Research Program, National Research Council, Washington, D.C., 1994

VFA Criteria

Traffic, Million ESALs	*Design VFA, Percent*
< 0.3	70–80
< 1	65–78
< 3	65–78
< 10	65–75
< 30	65–75
< 100	65–75

SOURCE: *The Superpave Mix Design Manual for New Construction and Overlays*, Strategic Highway Research Program, National Research Council, Washington, D.C., 1994

(Garber & Hoel 2013)

Thank You!!!