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سلايدات

رصفات

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Pavement Materials & Design (110401466/2104011466)

Pavement Types

Instructor:

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Pavement Definition

- In **engineering** terms, a **pavement** means a man-made surface on natural ground that people, vehicles or animals can cross. Any ground surface prepared for transport counts as a **pavement**.

- **Pavement, in civil engineering**, durable surfacing of a road, airstrip, or similar area. The primary function of a **pavement** is to transmit loads to the sub-base and underlying soil. ... Such a **pavement** has enough plasticity to absorb shock.

- **Pavement** is that part of the road or highway which supports the wheel loads imposed on it from traffic moving over it.

- **Pavement** is a multi-layered structure put as horizontal layers one above the other, which distributes the vehicular loads over a larger area

Pavement Types

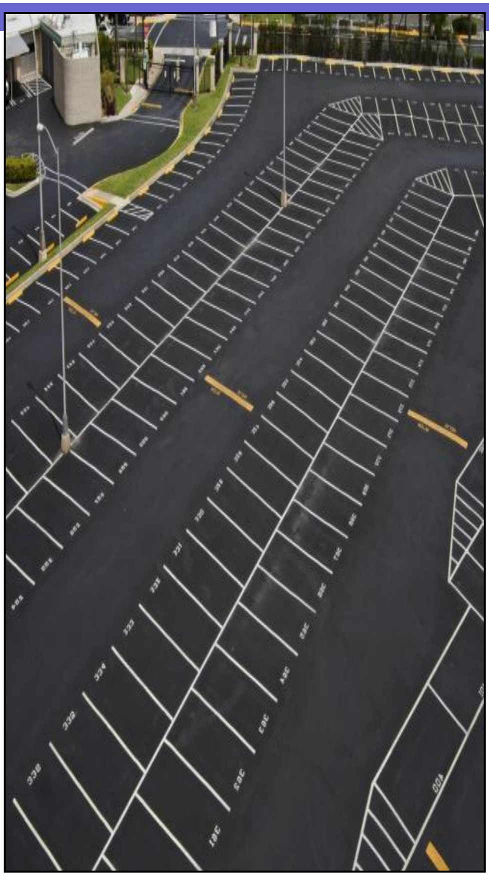
1. Flexible Pavement: Pavement constructed of bituminous and granular materials. It’s called “flexible” since the total **pavement** structure “bends” or “deflects” due to traffic loads.
2. Rigid pavement: Pavement constructed of Portland cement concrete.

Pavement Functions

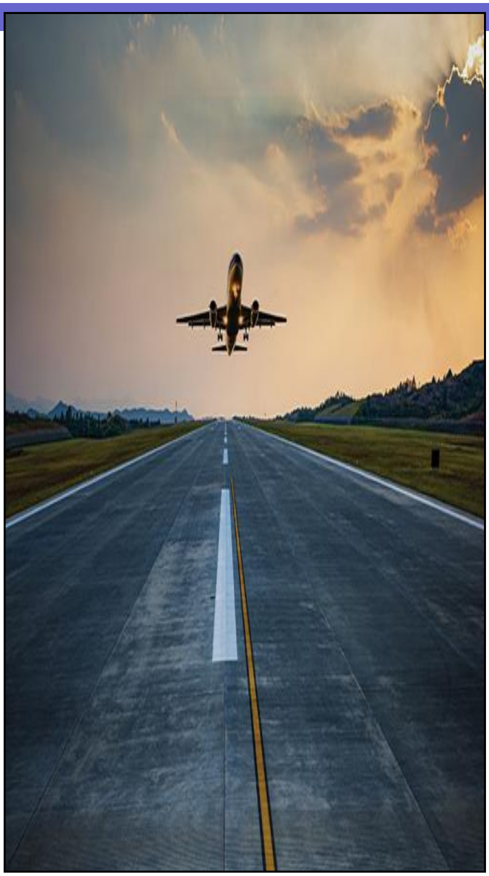
- Reduce and distribute the traffic loading so as not to damage the subgrade (natural soil).
- Provide vehicle access between two points under all-weather conditions.
- Provide safe, smooth and comfortable ride to road users without undue delays and excessive wear & tear.
- Meet environmental and aesthetics requirement.
- Limited noise and air pollution.
- Reasonable economy.

Classification of pavements by Function

Highway pavement



Parking lots pavements



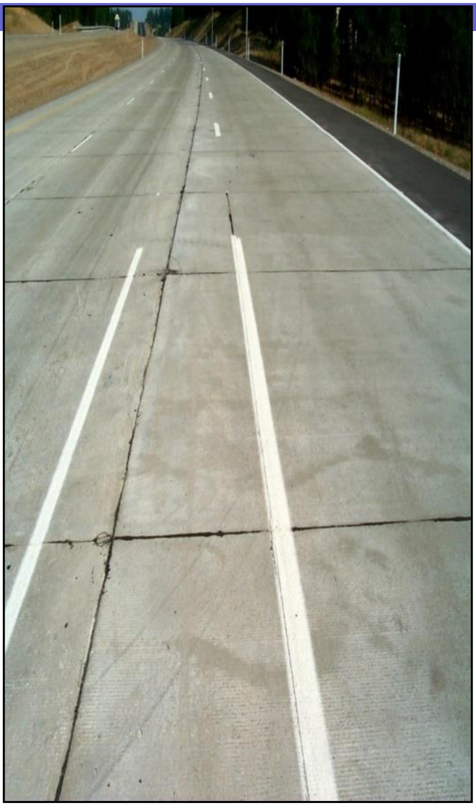
Airport pavements

Ports and Heavy industrial pavements

Classification of Pavements by Structure

Gravel (unpaved) pavements

Flexible pavements (asphalt concrete)



Rigid (concrete) pavement

Composite pavements

Pavement Requirements

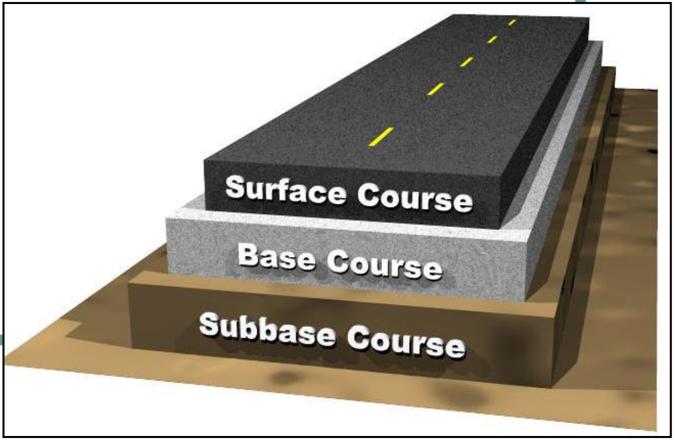
- **Sufficient thickness:** to distribute the wheel load stresses to a safe value on the sub-grade soil.
- **Structurally strong:** to withstand all types of stresses imposed upon it.
- **Adequate coefficient of friction:** to prevent skidding of vehicles.
- **Smooth surface:** to provide comfort to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

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

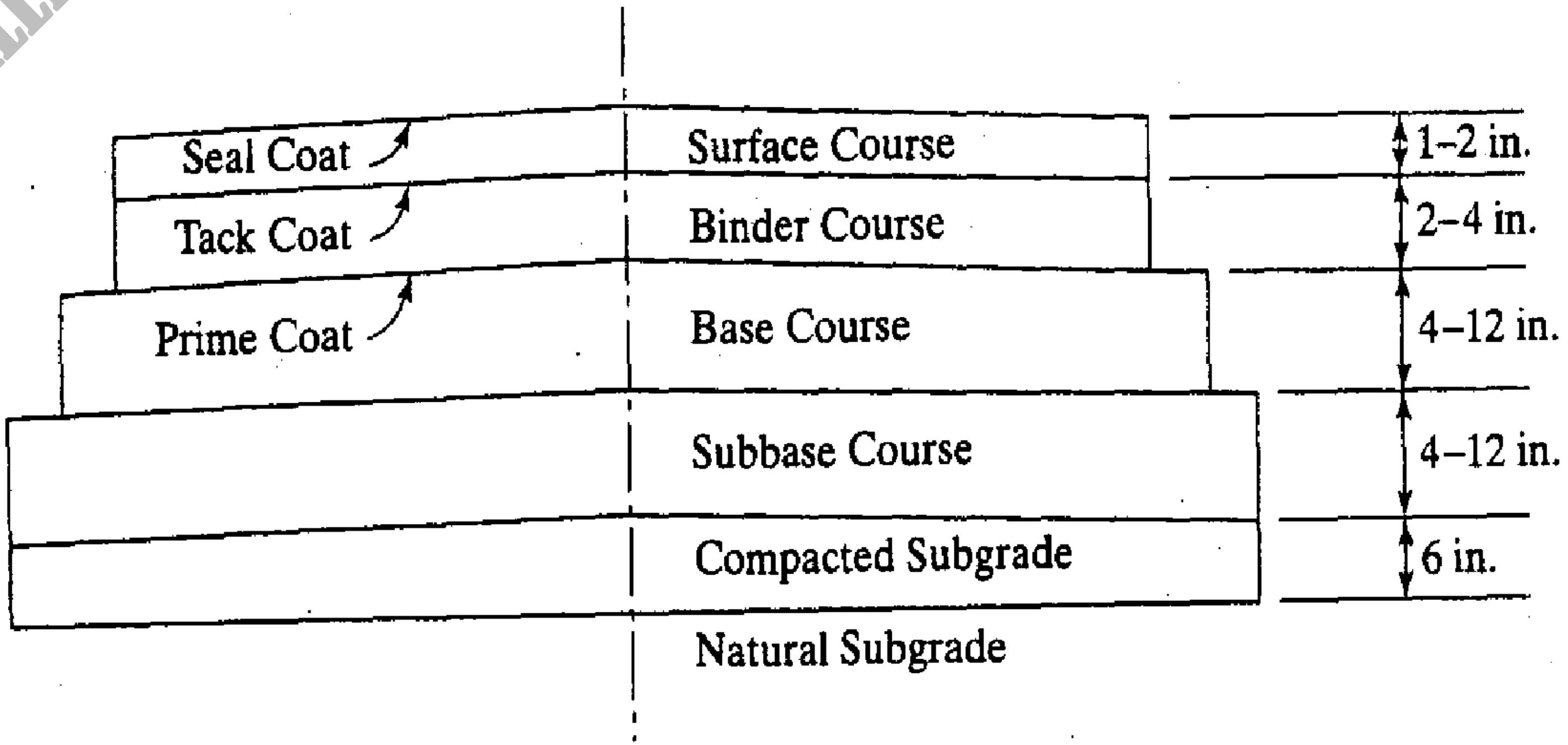
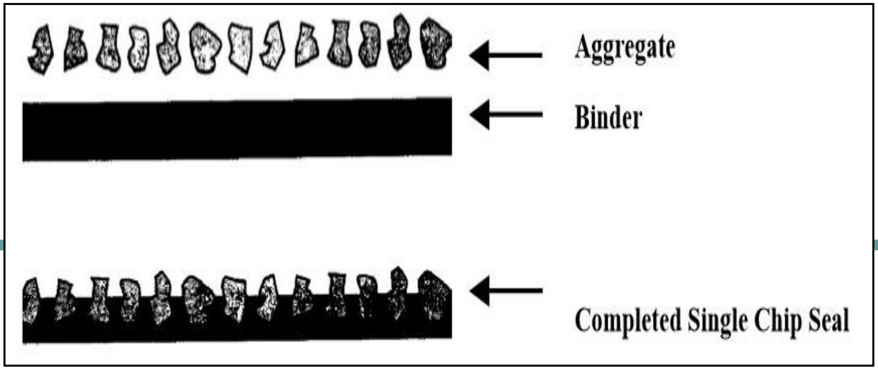


FIGURE 1.2 •

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

Conventional Flexible Pavements Cont./ Seal Coat (Chip seal)

- 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.



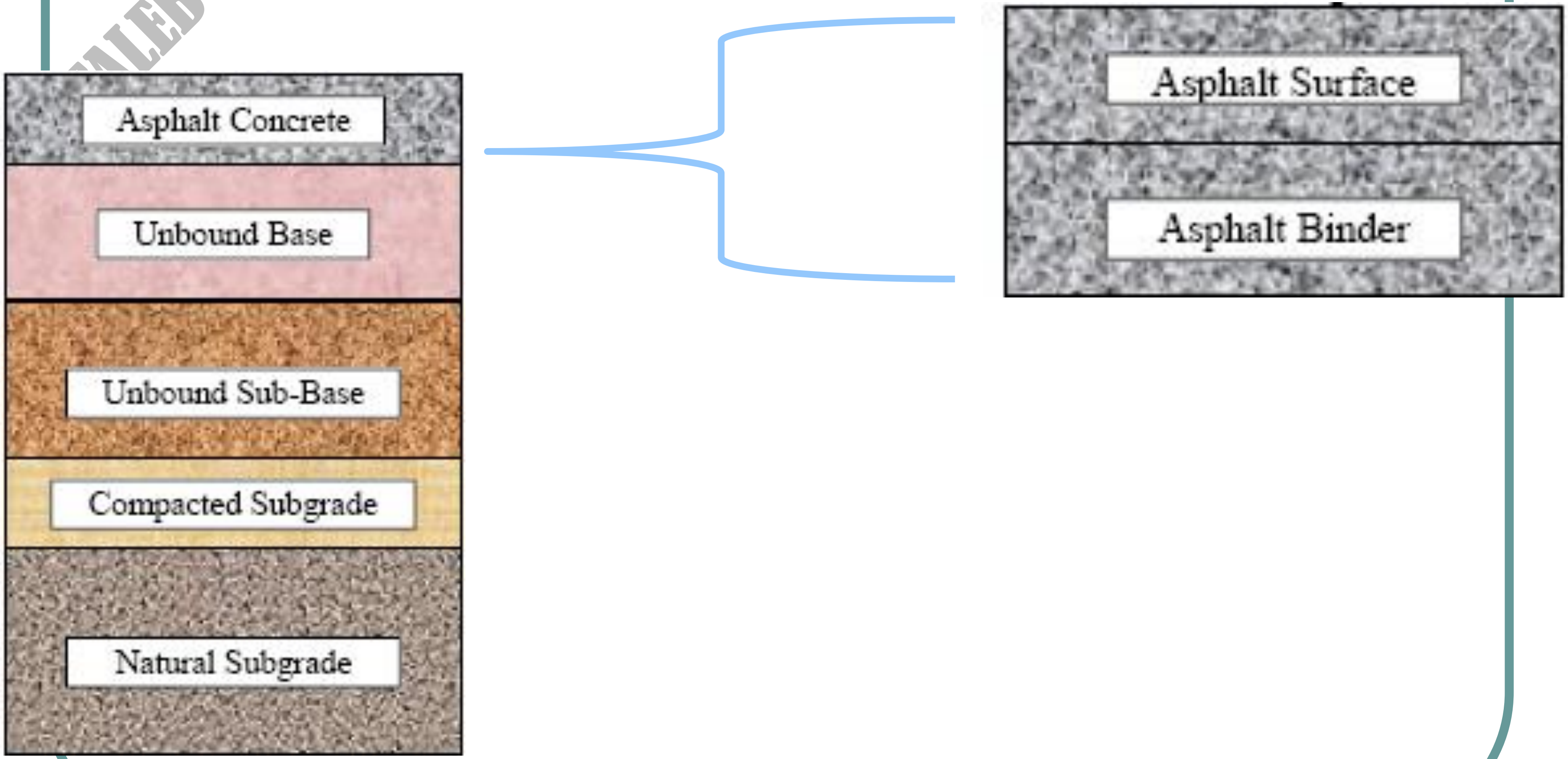
Conventional Flexible Pavements Cont./ Surface Course

- Is the top course of asphalt pavement (Wearing course).
- Constructed of dense graded HMA.
- Must be:
  - Tuff to resist distortion under traffic
  - Provide smooth and skid resistant riding surface.
  - 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 Pavement Layers



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.

Prime Coat

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.

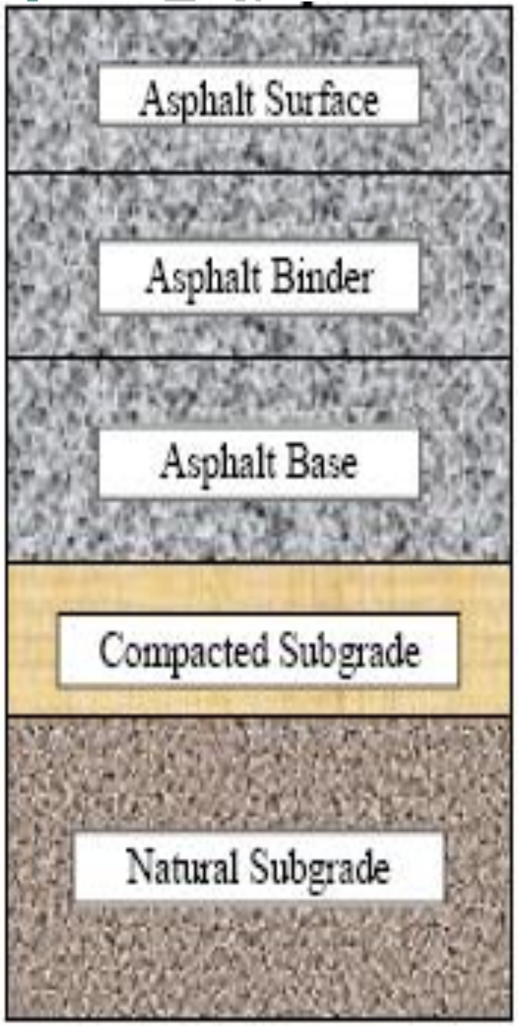
Conventional Flexible Pavements Cont./ Subgrade

- 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.
- Minimize the administration and equipment costs.
- Typical cross section: Asphalt surface, tack coat, asphalt base, and prepared subgrade.

Full-Depth Asphalt Cross Section



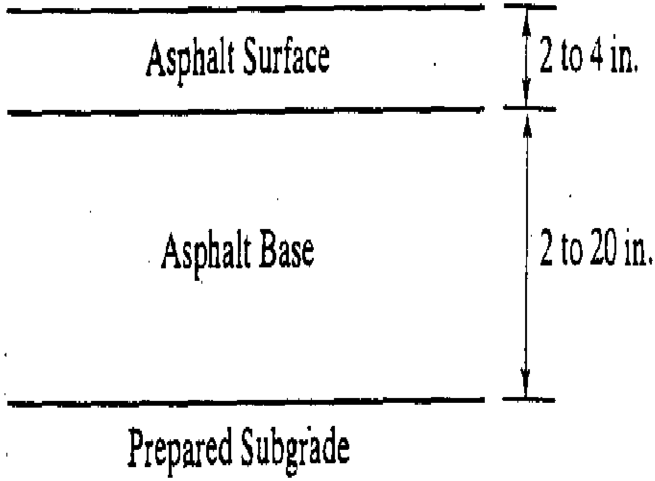


FIGURE 1.3

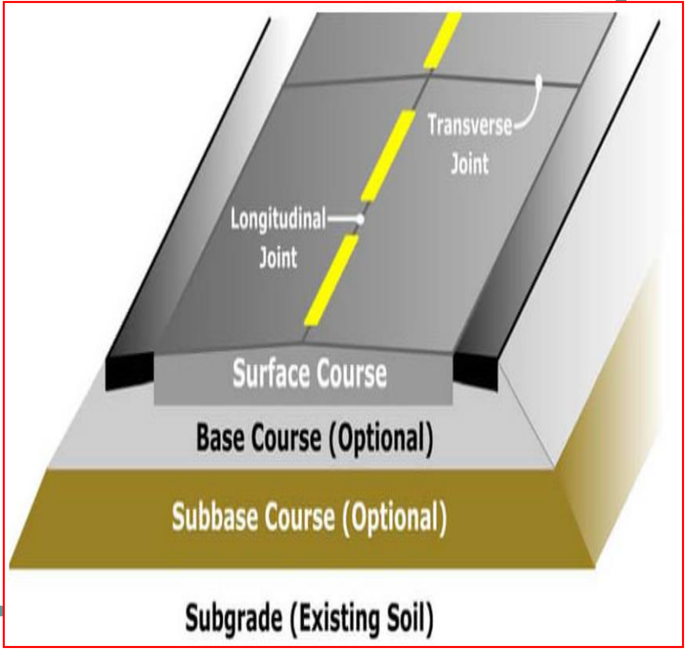
Typical cross-section of a full-depth asphalt pavement (1 in. = 25.4 mm).

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.

Rigid Pavements

- Pavement constructed of Portland cement concrete layer (150 -300 mm) placed over granular base/subbase layers (100-300 mm) supported by the subgrade.



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

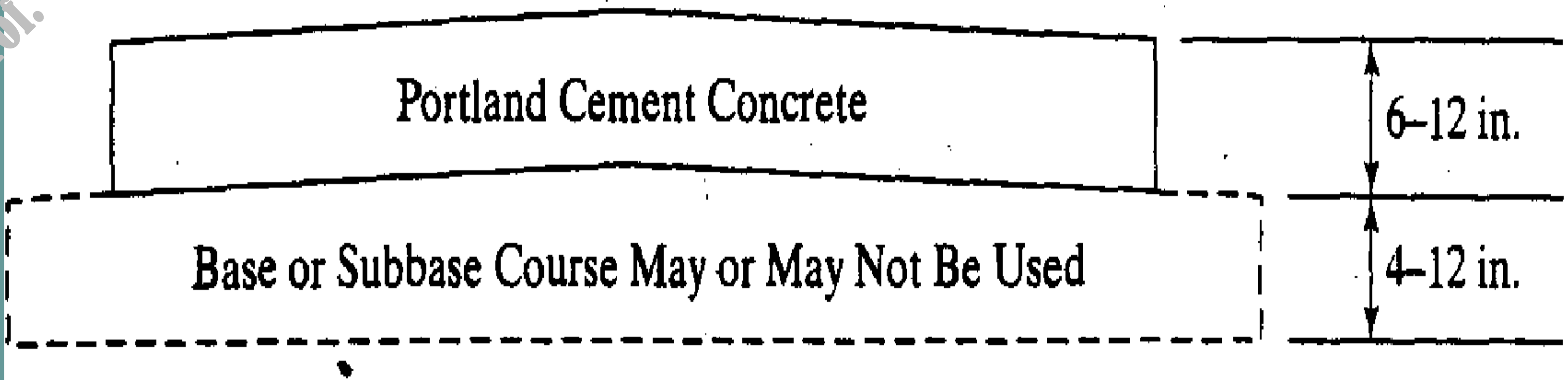


FIGURE 1.4

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

Types of Rigid Pavements

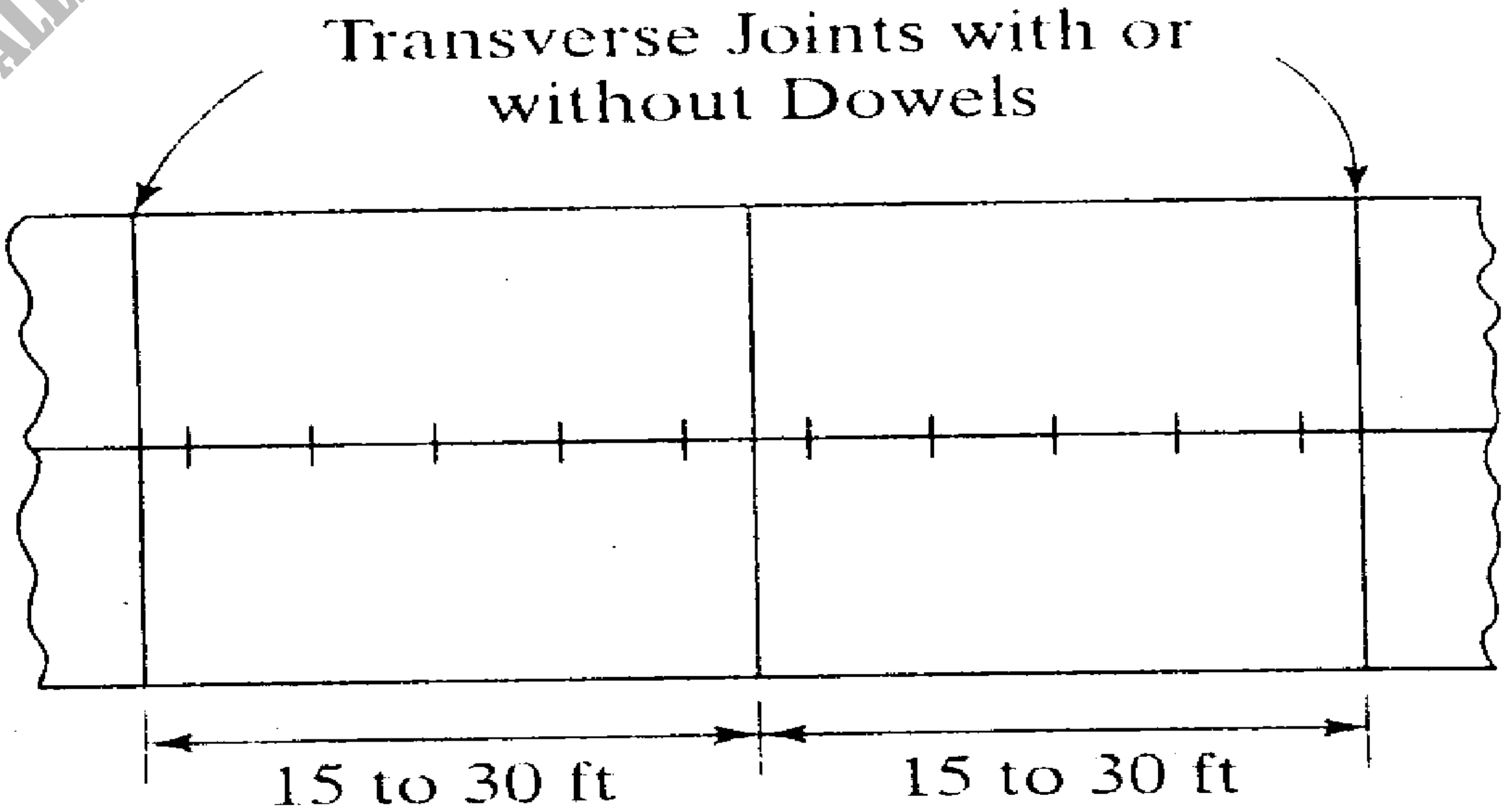
1. Joint Plain Concrete Pavements (JPCP).
2. Jointed Reinforced Concrete Pavements (JRCP).
3. Continuous Reinforced Concrete pavements (CRCP).
4. Prestressed Concrete Pavements (PCP).

- 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

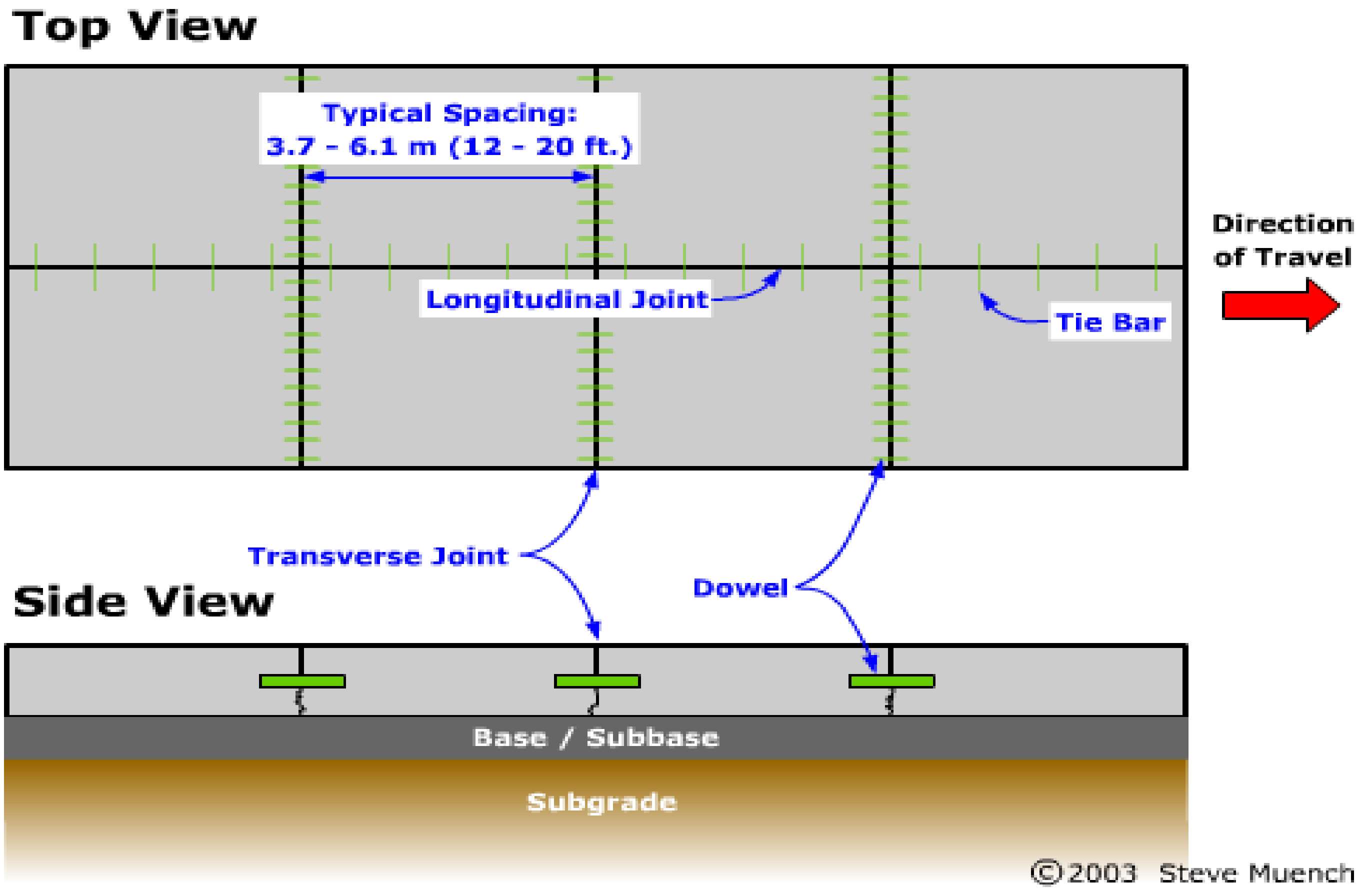


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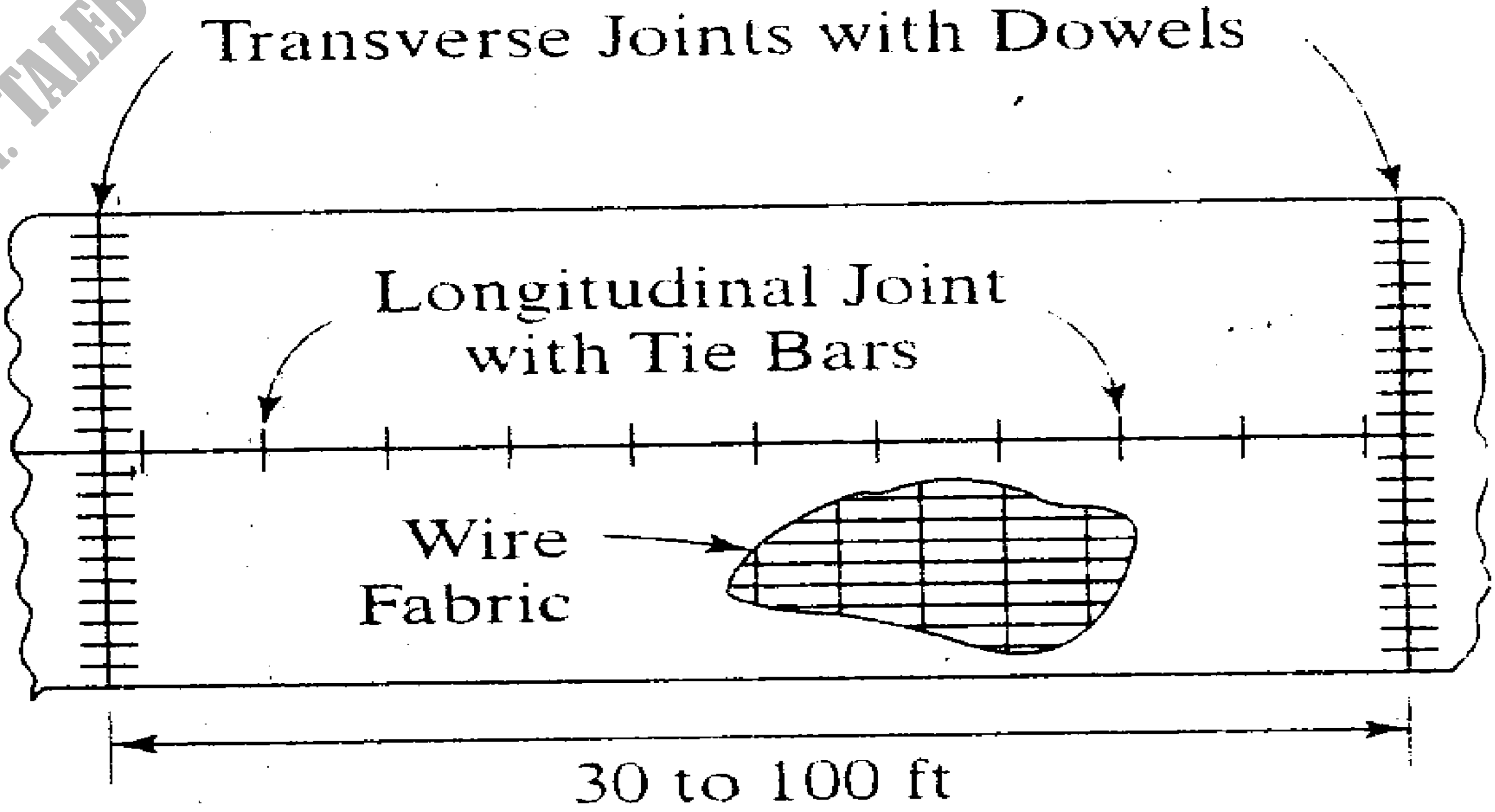
Figure 2.39: Jointed Plain Concrete Pavement (JPCP)

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

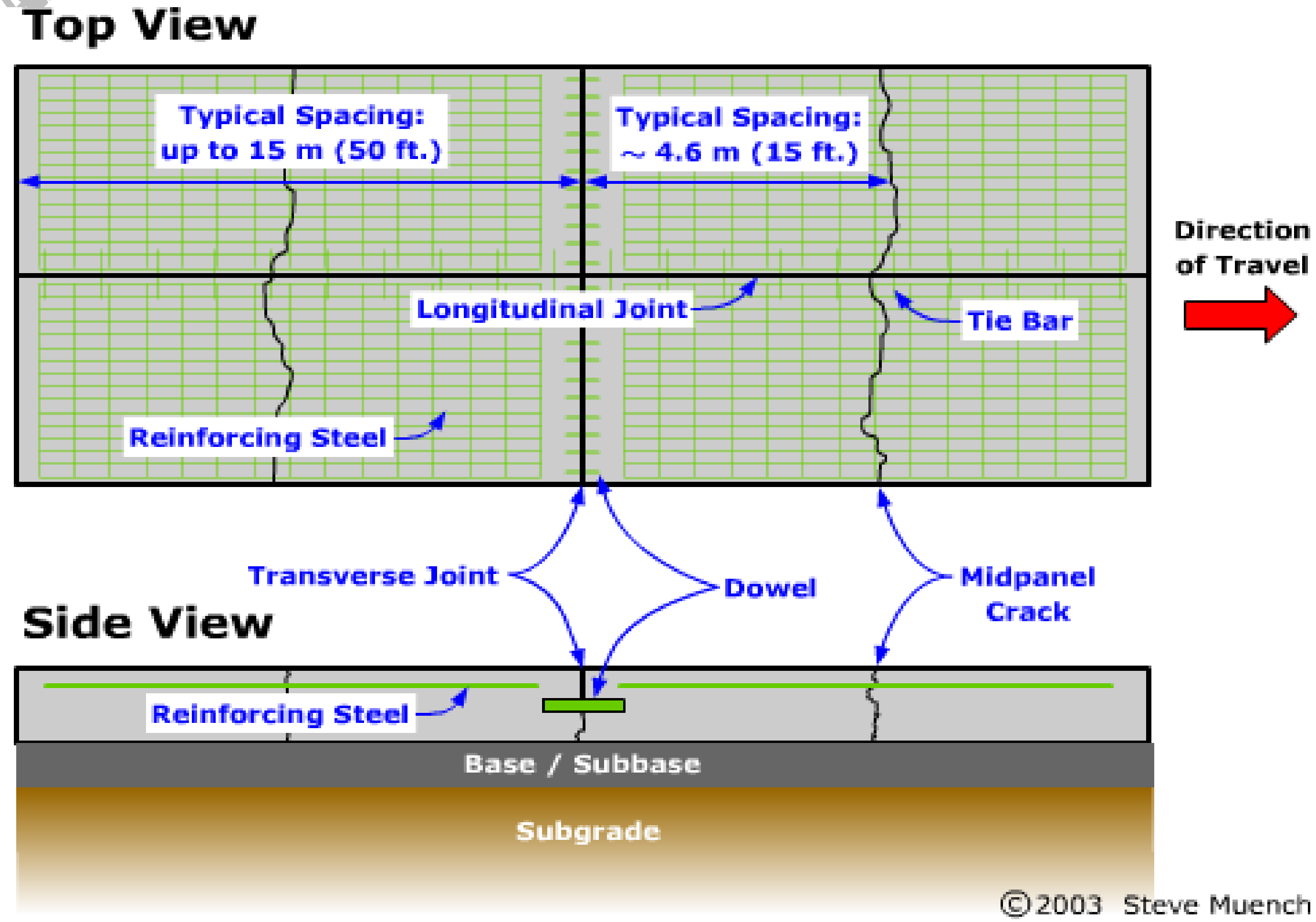


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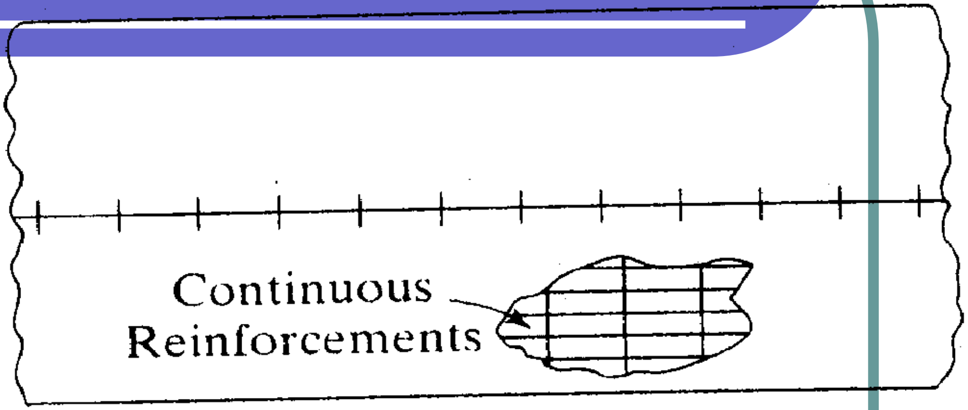
Figure 2.40: Jointed Reinforced Concrete Pavement (JRCP)

Continuous Reinforced Concrete pavements (CRCP).

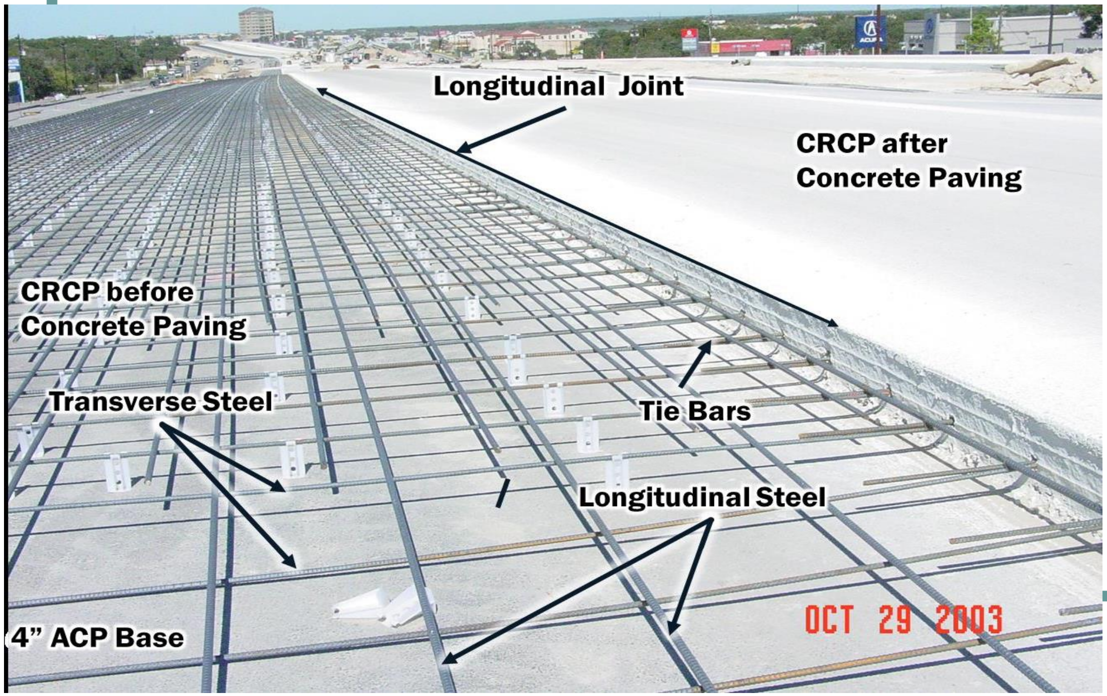
- It has no joints.
- Joints are the weak spots in rigid pavements.
- Eliminating joints reduced thickness of pavement by 1 to 2”.
- Used for heavy traffic.
- Most frequent distress is punchout at the pavement edge.

CRCP



No Joints

(c) CRCP



CRCP

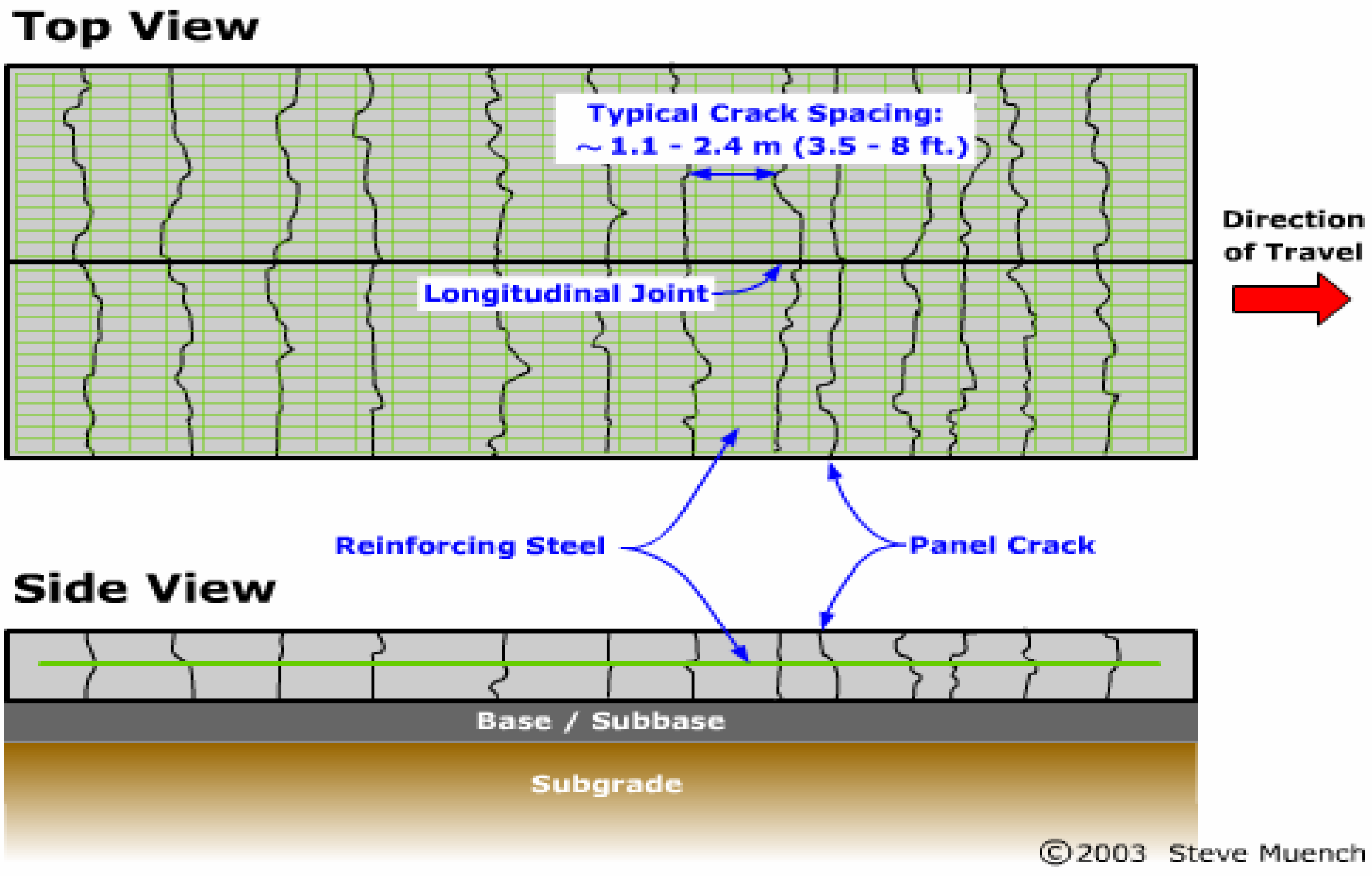


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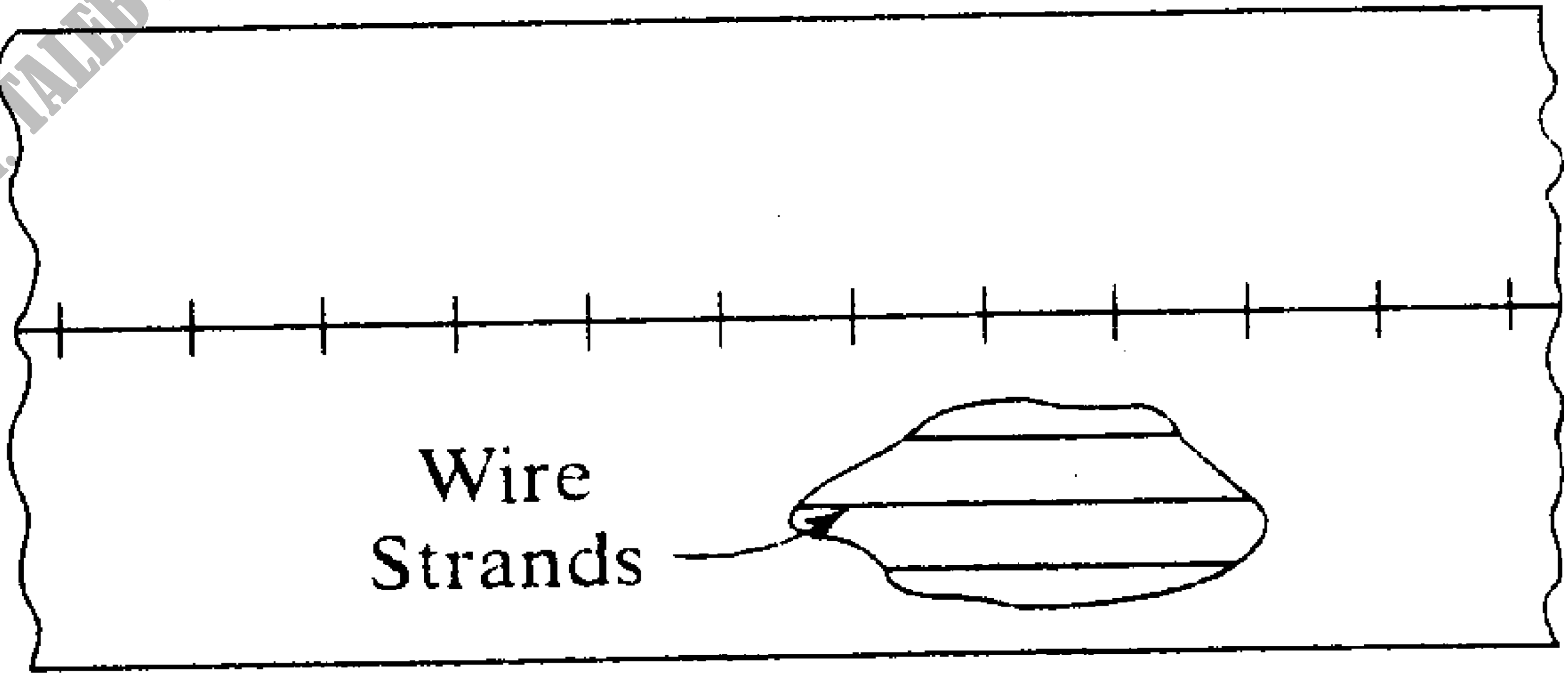
Figure 2.41: Continuously Reinforced Concrete Pavement (CRCP)

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

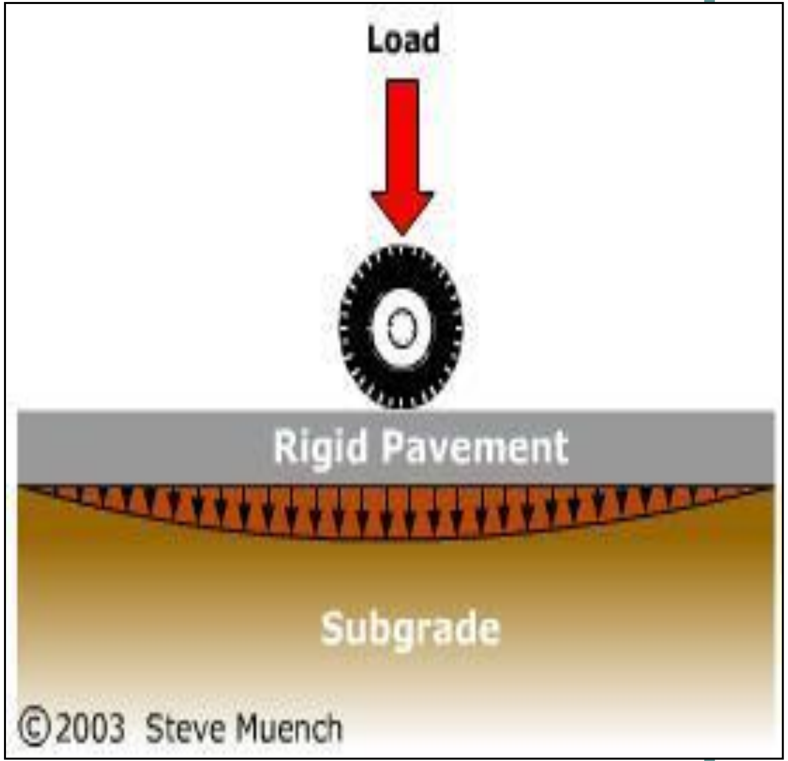
- Composed of both HMA & PCC.
- Using PCC bottom layer & HMA top layer results in an ideal pavement with most desirable characteristics.
- PCC provide strong base.
- HMA provides a smooth non-reflective surface.
- Very expensive and rarely used.
- Most of the available are the rehabilitation of PCC using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

Typical Composite Pavement Sections

Rigid VS. Flexible pavement

Load Distribution over the Subgrade

- The essential difference between the two types of pavements, flexible and rigid, is **the manner in which they distribute the load over the subgrade.**
- Rigid pavement
  - because of PCC's high elastic modulus (stiffness), tends to distribute the load over a relatively wide area of subgrade
  - The concrete slab itself supplies most of a rigid pavement's structural capacity.



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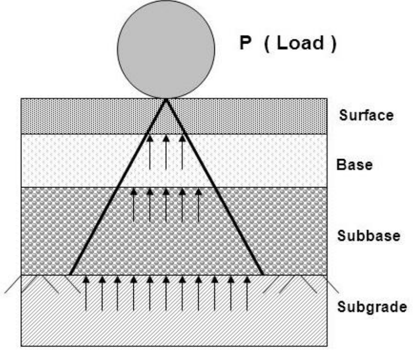
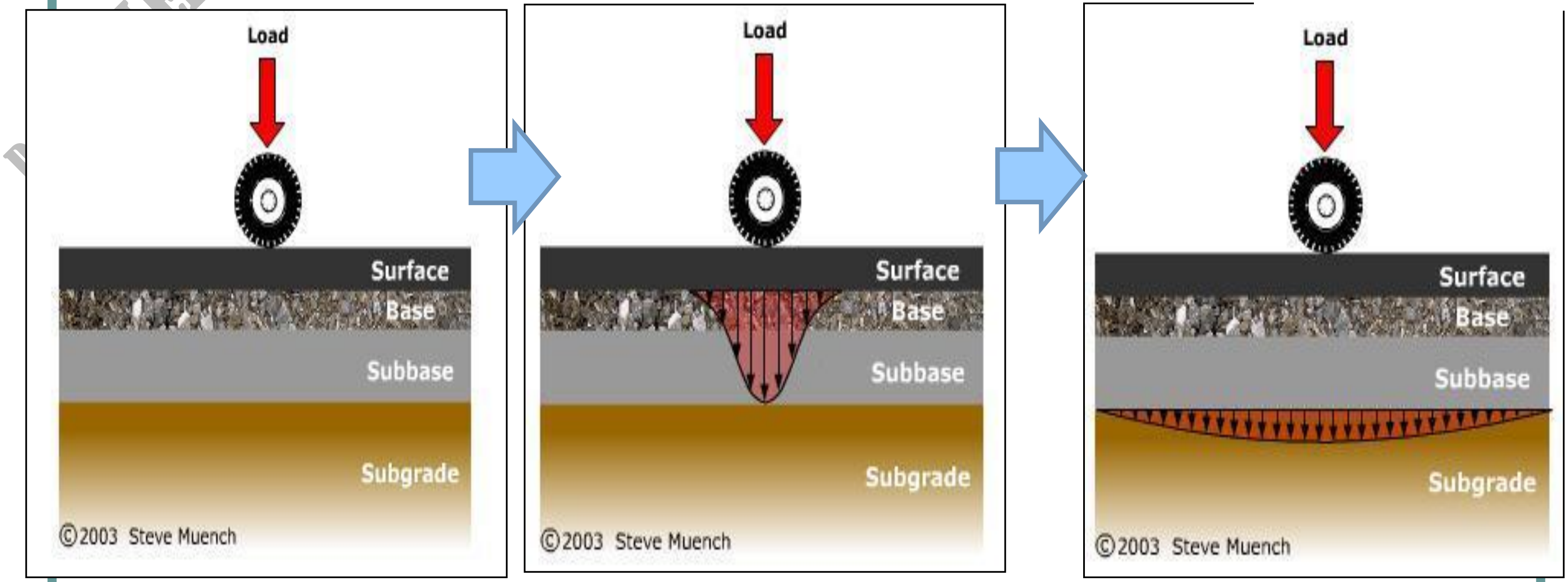
Rigid VS. Flexible pavement

Flexible Pavement Load Distribution

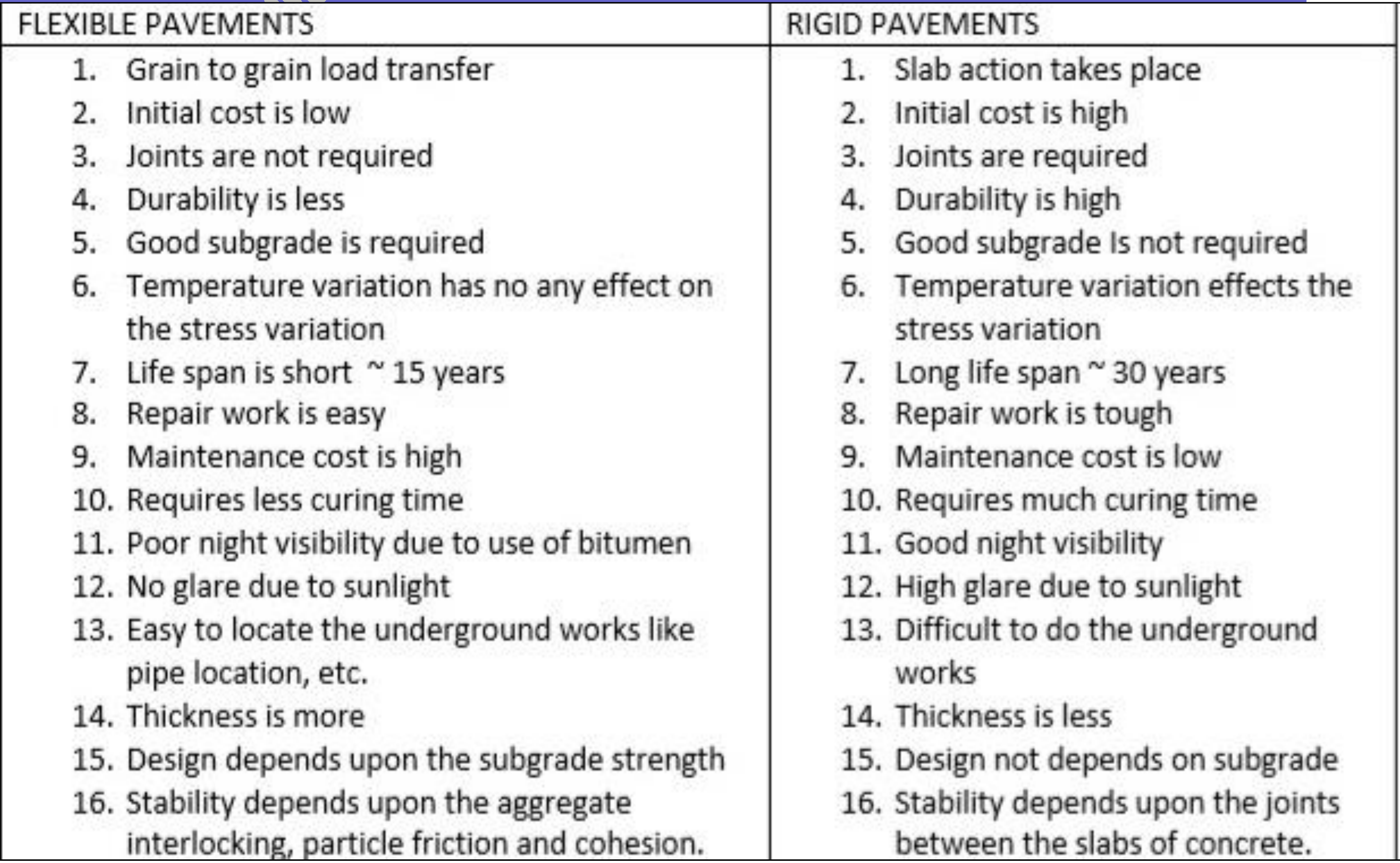




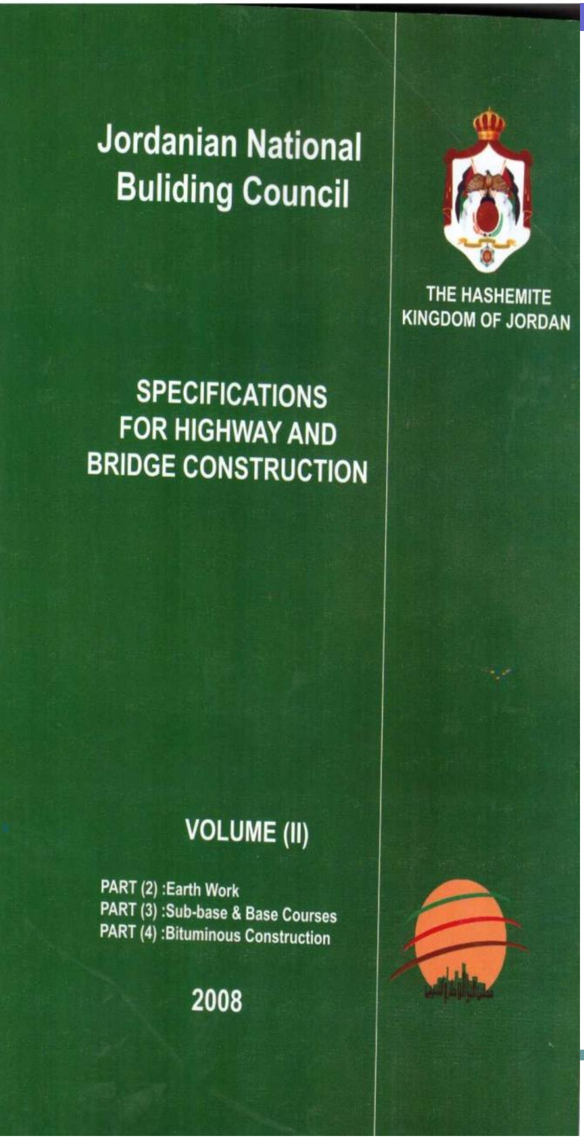
- Flexible pavement uses more flexible surface course and distributes loads over a smaller area.
- It relies on a combination of layers for transmitting load to the subgrade

Image source: http://www.pavementinteractive.org/wpcontent/uploads/2010/12/Flex_layer

Rigid VS. Flexible pavement



FLEXIBLE PAVEMENTS	RIGID PAVEMENTS
1. Grain to grain load transfer	1. Slab action takes place
2. Initial cost is low	2. Initial cost is high
3. Joints are not required	3. Joints are required
4. Durability is less	4. Durability is high
5. Good subgrade is required	5. Good subgrade Is not required
6. Temperature variation has no any effect on the stress variation	6. Temperature variation effects the stress variation
7. Life span is short ~ 15 years	7. Long life span ~ 30 years
8. Repair work is easy	8. Repair work is tough
9. Maintenance cost is high	9. Maintenance cost is low
10. Requires less curing time	10. Requires much curing time
11. Poor night visibility due to use of bitumen	11. Good night visibility
12. No glare due to sunlight	12. High glare due to sunlight
13. Easy to locate the underground works like pipe location, etc.	13. Difficult to do the underground works
14. Thickness is more	14. Thickness is less
15. Design depends upon the subgrade strength	15. Design not depends on subgrade
16. Stability depends upon the aggregate interlocking, particle friction and cohesion.	16. Stability depends upon the joints between the slabs of concrete.



Jordanian National
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THE HASHEMITE
KINGDOM OF JORDAN

SPECIFICATIONS
FOR HIGHWAY AND
BRIDGE CONSTRUCTION

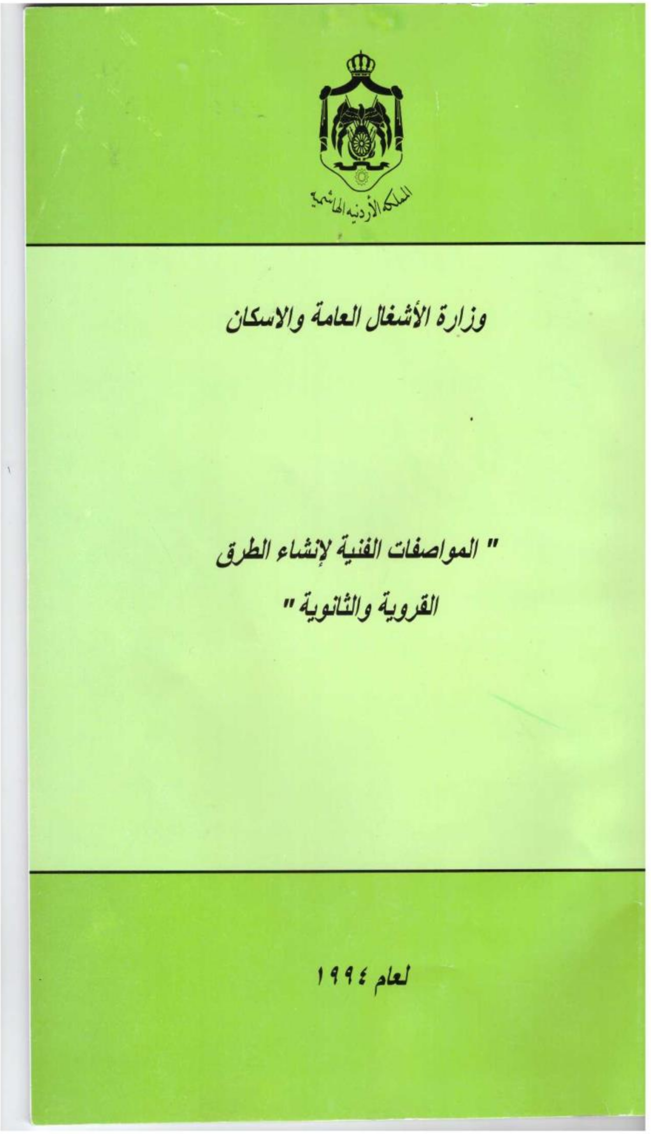
VOLUME (II)

PART (2) :Earth Work
PART (3) :Sub-base & Base Courses
PART (4) :Bituminous Construction

2008

Jordanian National Building council

Specifications for highway and bridge construction



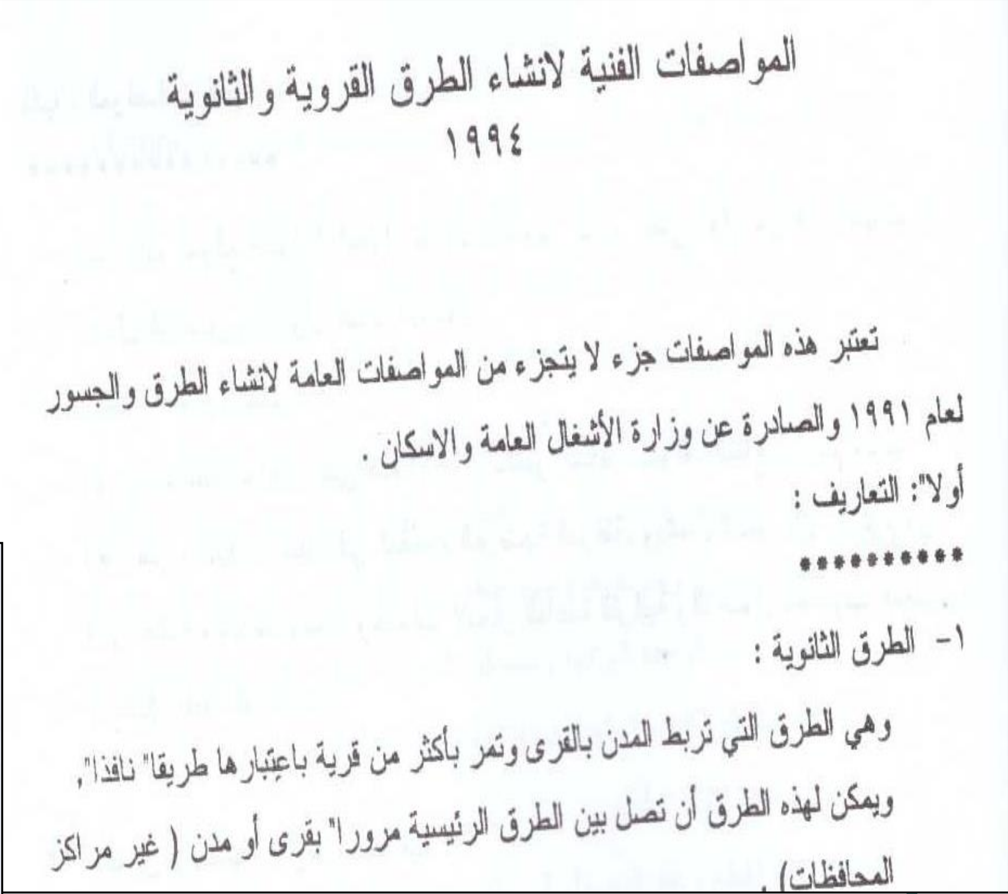
المملكة الأردنيه الهاشميه

وزارة الأشغال العامة والاسكان

" المواصفات الفنية لإنشاء الطرق
القروية والثانوية "

لعام ١٩٩٤

Specifications for highway and bridge construction



المواصفات الفنية لانشاء الطرق القروية والثانوية
١٩٩٤

تعتبر هذه المواصفات جزء لا يتجزء من المواصفات العامة لانشاء الطرق والجسور لعام ١٩٩١ والصادرة عن وزارة الأشغال العامة والاسكان .

أولا": التعاريف :

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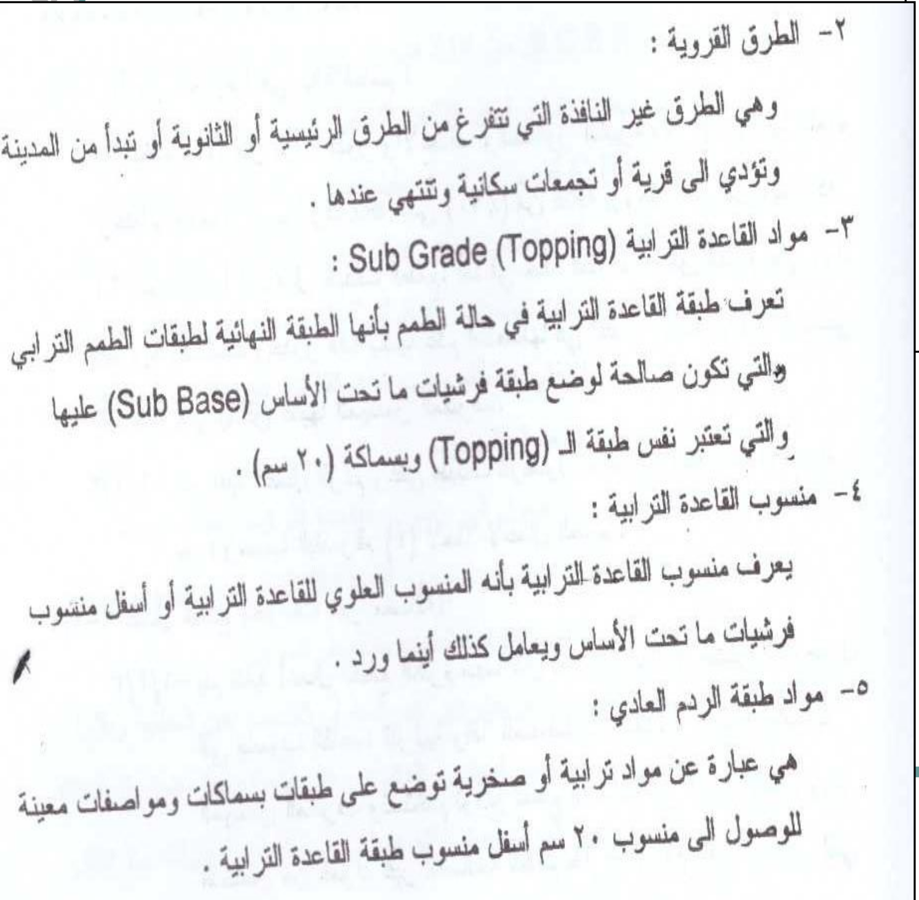
١- الطرق الثانوية :

وهي الطرق التي تربط المدن بالقرى وتمر بأكثر من قرية باعتبارها طريقا" نافذا"، ويمكن لهذه الطرق أن تصل بين الطرق الرئيسية مرورا" بقرى أو مدن (غير مراكز المحافظات) .



٢- الطرق القروية :

وهي الطرق غير النافذة التي تتفرغ من الطرق الرئيسية أو الثانوية أو تبدأ من المدينة وتؤدي الى قرية أو تجمعات سكانية وتنتهي عندها .

٣- مواد القاعدة الترابية (Sub Grade (Topping :

تعرف طبقة القاعدة الترابية في حالة الطمم بأنها الطبقة النهائية لطبقات الطمم الترابي والتي تكون صالحة لوضع طبقة فرشيات ما تحت الأساس (Sub Base) عليها والتي تعتبر نفس طبقة الـ (Topping) وبسماكة (٢٠ سم) .

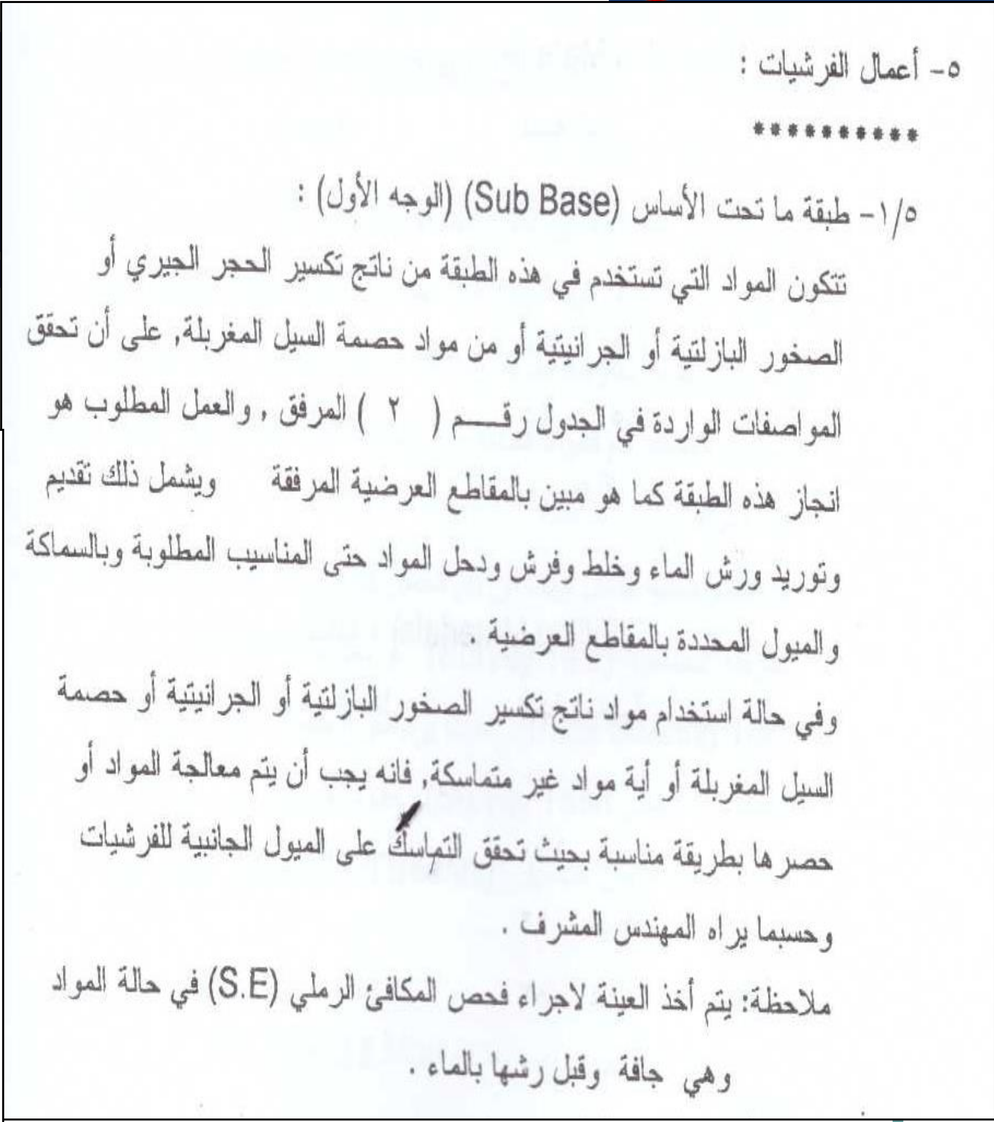
٤- منسوب القاعدة الترابية :

يعرف منسوب القاعدة الترابية بأنه المنسوب العلوي للقاعدة الترابية أو أسفل منسوب فرشيات ما تحت الأساس ويعامل كذلك أينما ورد .

٥- مواد طبقة الردم العادي :

هي عبارة عن مواد ترابية أو صخرية توضع على طبقات بسماكات ومواصفات معينة للوصول الى منسوب ٢٠ سم أسفل منسوب طبقة القاعدة الترابية .

Specifications for highway and bridge construction



٥- أعمال الفرشيات :

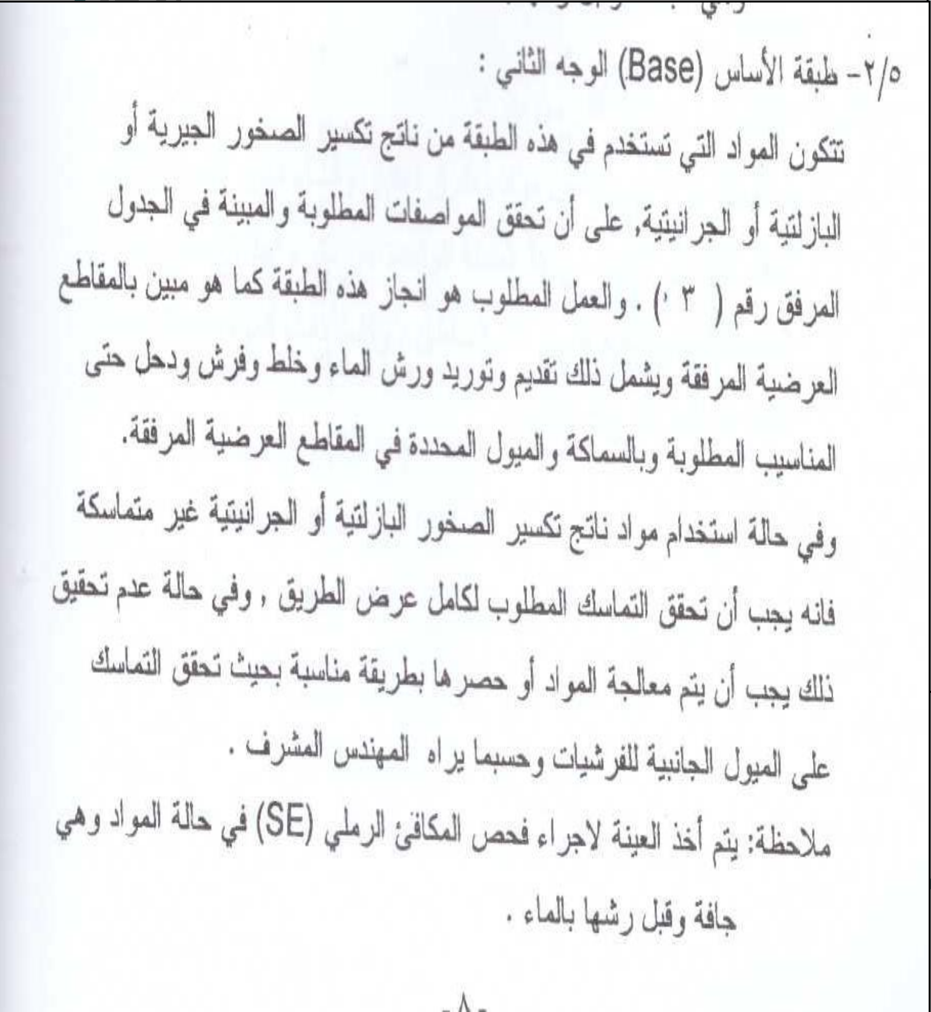
****

١/٥- طبقة ما تحت الأساس (Sub Base) (الوجه الأول) :

تتكون المواد التي تستخدم في هذه الطبقة من ناتج تكسير الحجر الجيري أو الصخور البازلتية أو الجرانيتية أو من مواد حصمة السيل المغربلة, على أن تحقق المواصفات الواردة في الجدول رقــم (٢) المرفق , والعمل المطلوب هو انجاز هذه الطبقة كما هو مبين بالمقاطع العرضية المرفقة ويشمل ذلك تقديم وتوريد ورش الماء وخلط وفرش ودحل المواد حتى المناسيب المطلوبة وبالسماكة والميول المحددة بالمقاطع العرضية .

وفي حالة استخدام مواد ناتج تكسير الصخور البازلتية أو الجرانيتية أو حصمة السيل المغربلة أو أية مواد غير متماسكة, فانه يجب أن يتم معالجة المواد أو حصرها بطريقة مناسبة بحيث تحقق التماسك على الميول الجانبية للفرشيات وحسبما يراه المهندس المشرف .

ملاحظة: يتم أخذ العينة لاجراء فحص المكافئ الرملي (S.E) في حالة المواد وهي جافة وقبل رشها بالماء .



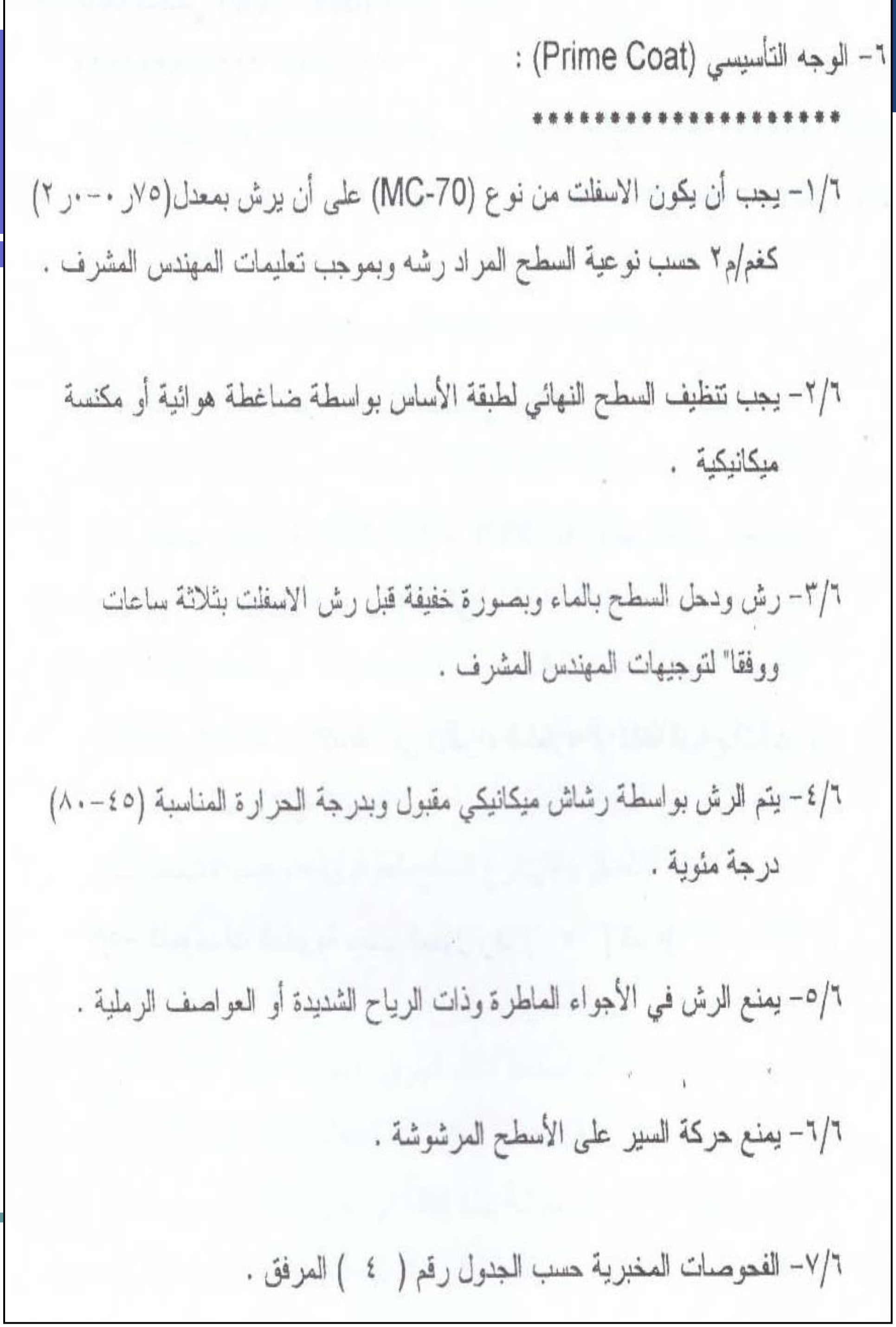
٢/٥- طبقة الأساس (Base) الوجه الثاني :

تتكون المواد التي تستخدم في هذه الطبقة من ناتج تكسير الصخور الجيرية أو البازلتية أو الجرانيتية, على أن تحقق المواصفات المطلوبة والمبينة في الجدول المرفق رقم (٣) . والعمل المطلوب هو انجاز هذه الطبقة كما هو مبين بالمقاطع العرضية المرفقة ويشمل ذلك تقديم وتوريد ورش الماء وخلط وفرش ودحل حتى المناسيب المطلوبة وبالسماكة والميول المحددة في المقاطع العرضية المرفقة.

وفي حالة استخدام مواد ناتج تكسير الصخور البازلتية أو الجرانيتية غير متماسكة فانه يجب أن تحقق التماسك المطلوب لكامل عرض الطريق , وفي حالة عدم تحقيق ذلك يجب أن يتم معالجة المواد أو حصرها بطريقة مناسبة بحيث تحقق التماسك على الميول الجانبية للفرشيات وحسبما يراه المهندس المشرف .

ملاحظة: يتم أخذ العينة لاجراء فحص المكافئ الرملي (SE) في حالة المواد وهي جافة وقبل رشها بالماء .

Specifications for highway and bridge construction



٦- الوجه التأسيسي (Prime Coat) :

****

٦/١- يجب أن يكون الاسفلت من نوع (MC-70) على أن يرش بمعدل(٧٥ر٠--٠ر٢) كغم/م٢ حسب نوعية السطح المراد رشه وبموجب تعليمات المهندس المشرف .

٦/٢- يجب تنظيف السطح النهائي لطبقة الأساس بواسطة ضاغطة هوائية أو مكنسة ميكانيكية .

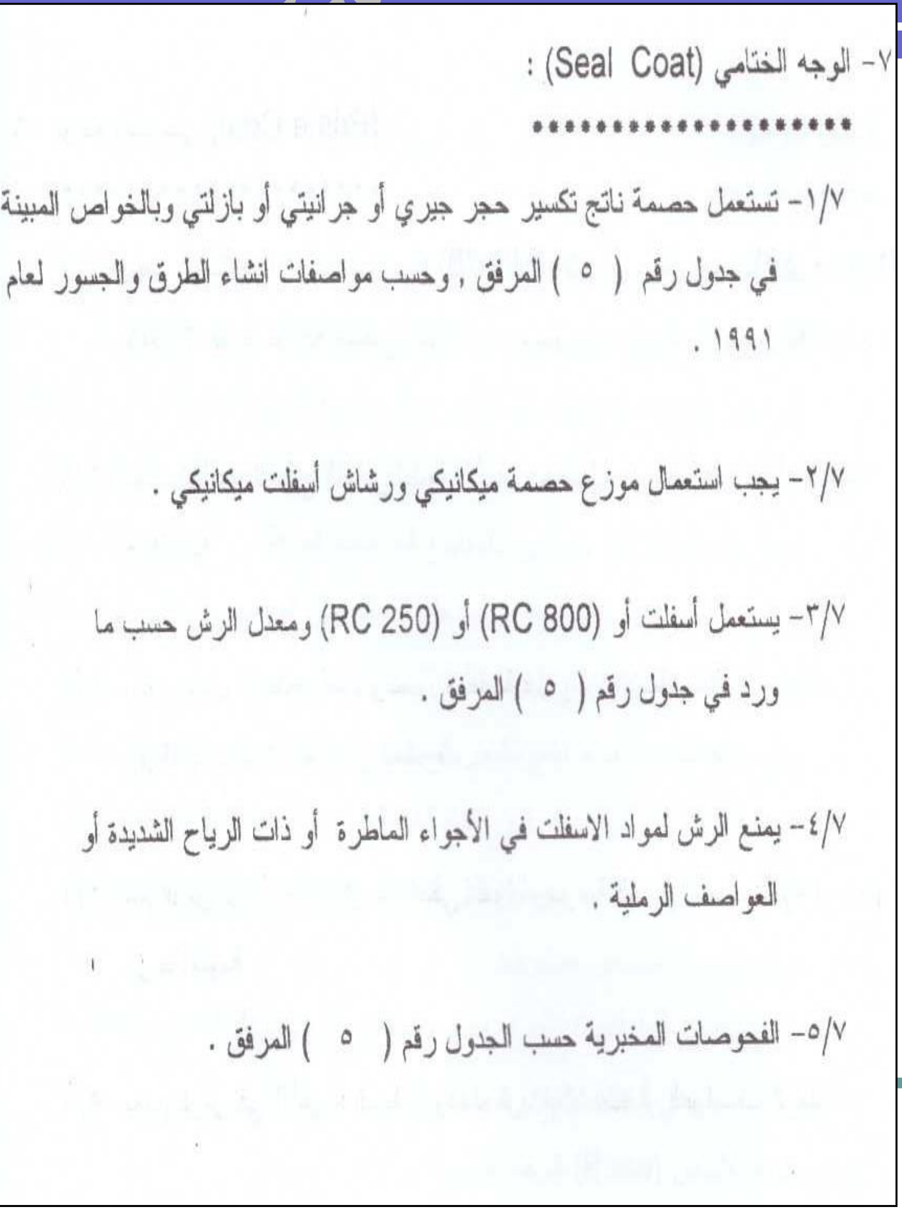
٦/٣- رش ودحل السطح بالماء وبصورة خفيفة قبل رش الاسفلت بثلاثة ساعات ووفقا" لتوجيهات المهندس المشرف .

٦/٤- يتم الرش بواسطة رشاش ميكانيكي مقبول وبدرجة الحرارة المناسبة (٤٥-٨٠) درجة مئوية .

٦/٥- يمنع الرش في الأجواء الماطرة وذات الرياح الشديدة أو العواصف الرملية .

٦/٦- يمنع حركة السير على الأسطح المرشوشة .

٦/٧- الفحوصات المختبرية حسب الجدول رقم (٤) المرفق .



٧- الوجه الختامي (Seal Coat) :

****

٧/١- تستعمل حصمة ناتج تكسير حجر جيري أو جرانيتي أو بازلتي وبالخواص المبينة في جدول رقم (٥) المرفق , وحسب مواصفات انشاء الطرق والجسور لعام ١٩٩١ .

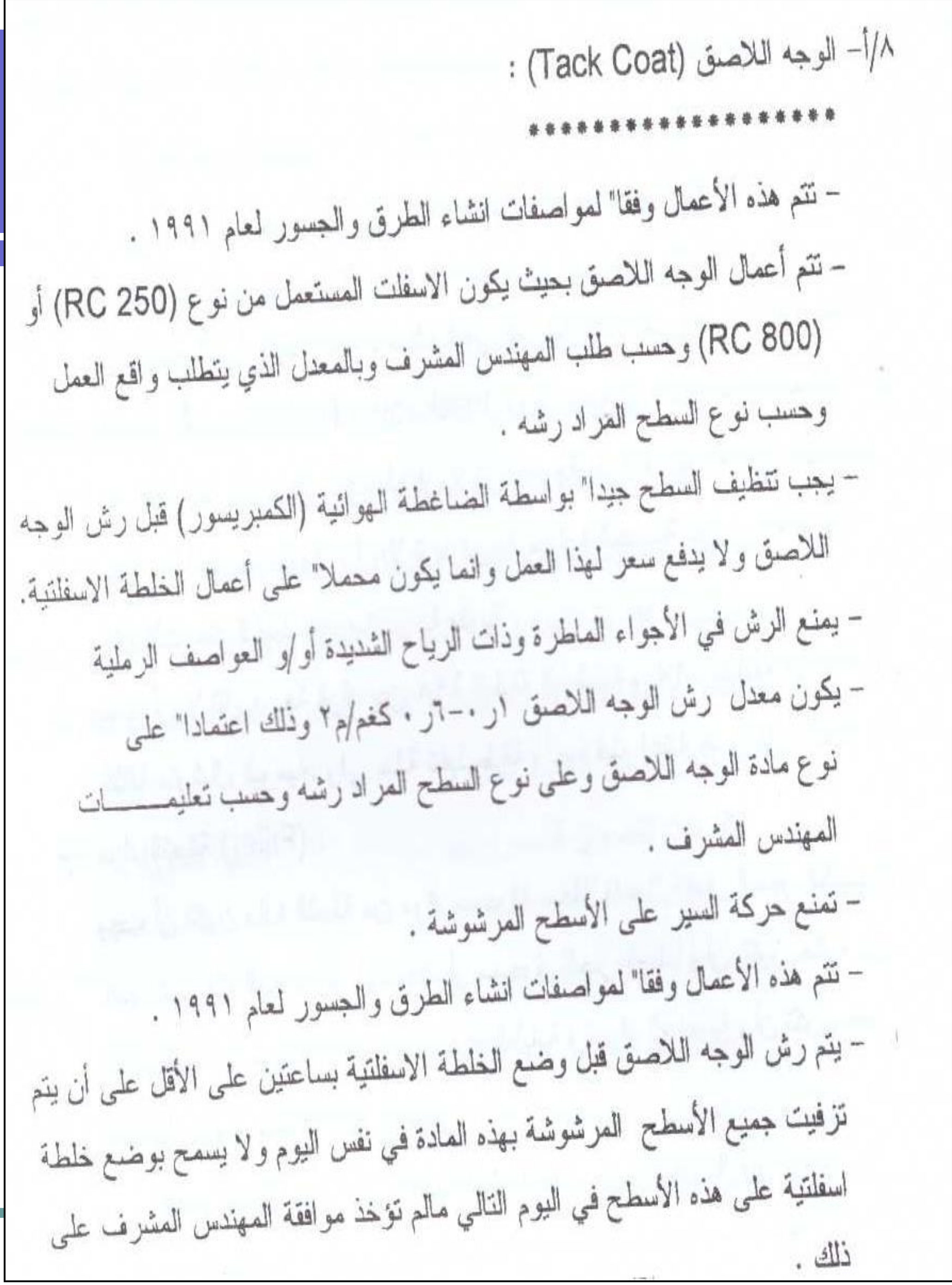
٧/٢- يجب استعمال موزع حصمة ميكانيكي ورشاش أسفلت ميكانيكي .

٧/٣- يستعمل أسفلت أو (RC 800) أو (RC 250) ومعدل الرش حسب ما ورد في جدول رقم (٥) المرفق .

٧/٤- يمنع الرش لمواد الاسفلت في الأجواء الماطرة أو ذات الرياح الشديدة أو العواصف الرملية .

٧/٥- الفحوصات المختبرية حسب الجدول رقم (٥) المرفق .

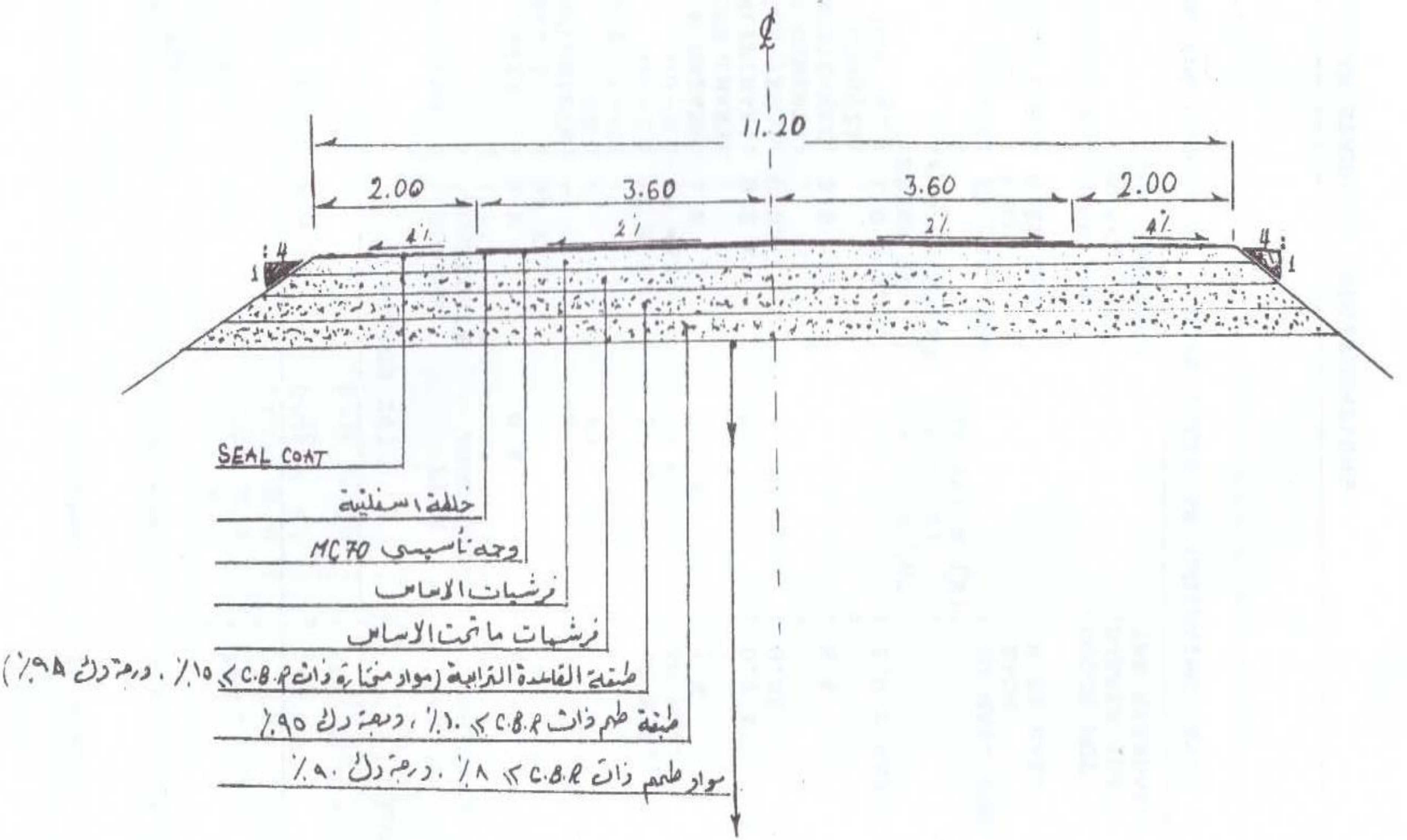
Specifications for highway and bridge construction



٨/أ- الوجه اللاصق (Tack Coat) :

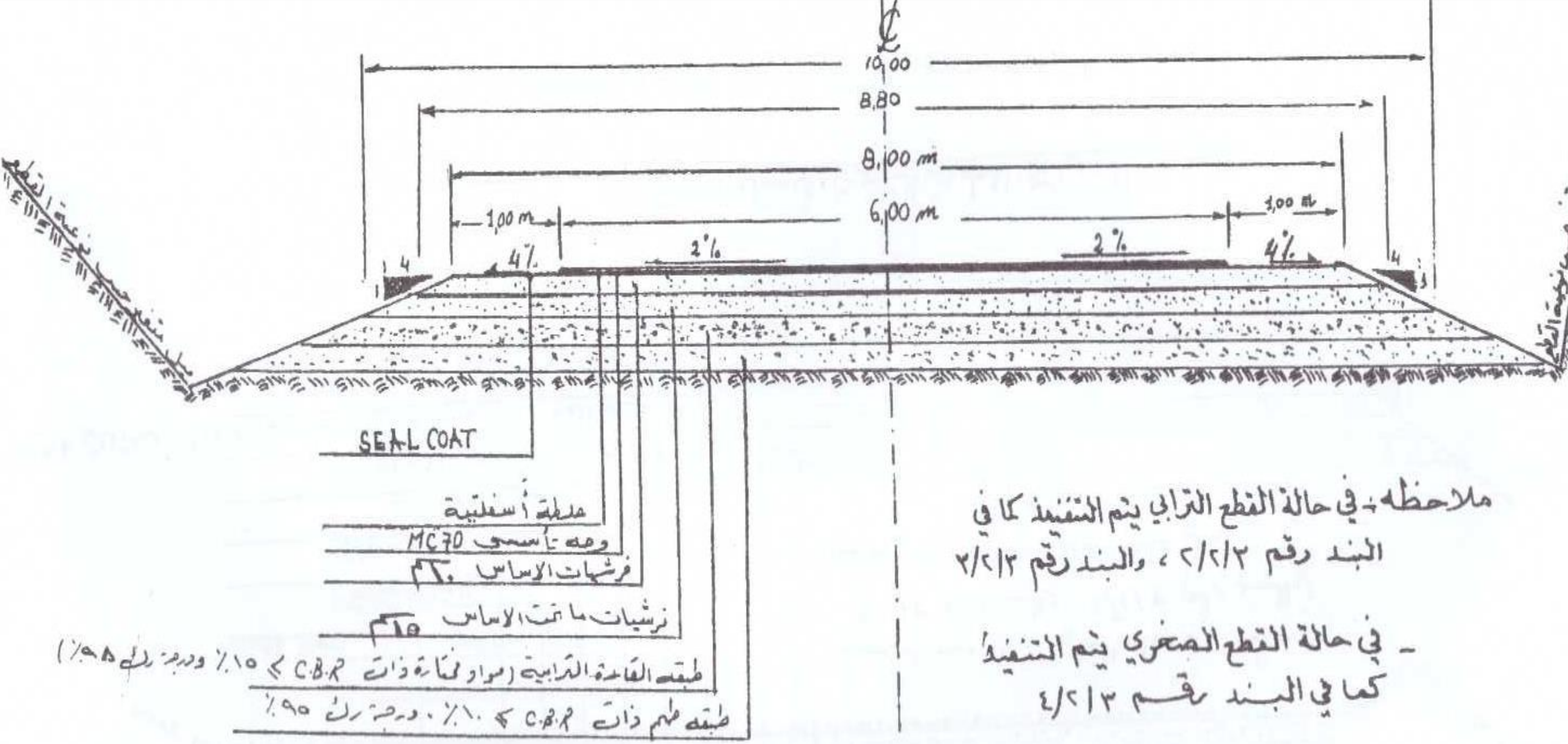
****

- تتم هذه الأعمال وفقا" لمواصفات انشاء الطرق والجسور لعام ١٩٩١ .
- تتم أعمال الوجه اللاصق بحيث يكون الاسفلت المستعمل من نوع (RC 250) أو (RC 800) وحسب طلب المهندس المشرف وبالمعدل الذي يتطلب واقع العمل وحسب نوع السطح المراد رشه .
- يجب تنظيف السطح جيدا" بواسطة الضاغطة الهوائية (الكمبريسور) قبل رش الوجه اللاصق ولا يدفع سعر لهذا العمل وانما يكون محملا" على أعمال الخلطة الاسفلتية.
- يمنع الرش في الأجواء الماطرة وذات الرياح الشديدة أو/و العواصف الرملية
- يكون معدل رش الوجه اللاصق ١ر٠-٦ر٠ كغم/م٢ وذلك اعتمادا" على نوع مادة الوجه اللاصق وعلى نوع السطح المراد رشه وحسب تعليمات المهندس المشرف .
- تمنع حركة السير على الأسطح المرشوشة .
- تتم هذه الأعمال وفقا" لمواصفات انشاء الطرق والجسور لعام ١٩٩١ .
- يتم رش الوجه اللاصق قبل وضع الخلطة الاسفلتية بساعتين على الأقل على أن يتم تزفيت جميع الأسطح المرشوشة بهذه المادة في نفس اليوم ولا يسمح بوضع خلطة اسفلتية على هذه الأسطح في اليوم التالي مالم تؤخذ موافقة المهندس المشرف على ذلك .



المقطع النموذجي للطريق الثانوي، في حالة الطمم

- يتم تحديد العروض النهائية حسب سماكة الفرشيات الواردة في المخططات .



ملاحظه :- في حالة القطع الترابي يتم التنفيذ كما في البند رقم ٣/٢/٢ ، والبند رقم ٣/٢/٣

- في حالة القطع الصخري يتم التنفيذ كما في البند رقم ٣/٢/٤

المقطع النموذجي للطريق القروي في حالة القطع

SCALE : V. 1:50
H.

* يتم تحديد العروض النهائية حسب سماكة الفرشيات الواردة في المخططات .

Pavement Materials & Design (110401466/2104011466)

Bituminous Materials

Instructor:

Prof. TALEB M. AL-ROUSAN

Source:

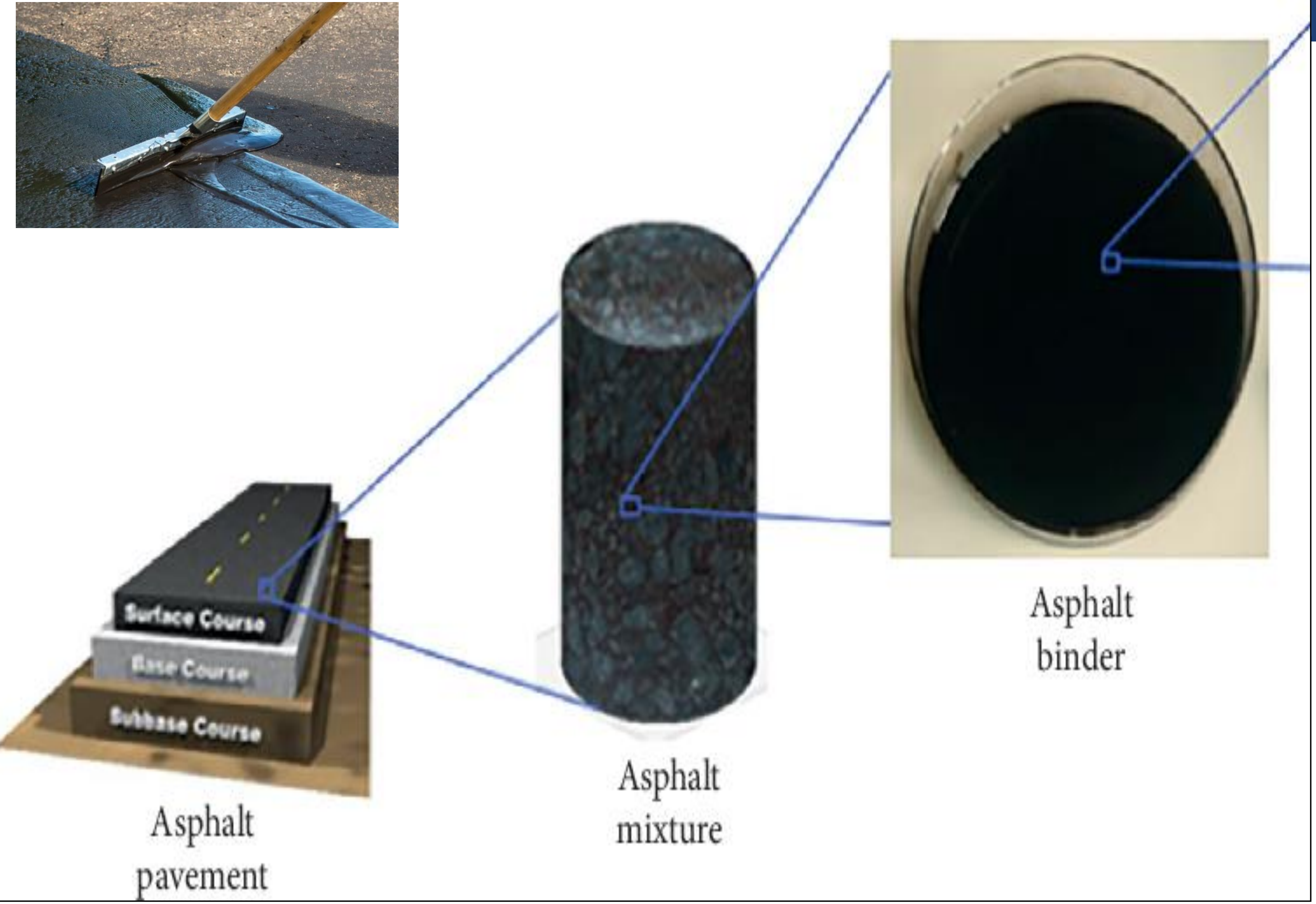
Chapter 18: Traffic & Highway Engineering by Nicholas Garber and Lester Hoel, Fifth Edition, Brooks/Cole.

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

Highway Materials/ Bituminous Materials

- Bitumen: Black or dark colored solid or viscous Cementous substances composed of high molecular weight hydrocarbons.
- Bitumen is soluble in carbon disulfide (CS2).
- Bituminous Materials are used for highway construction because:

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



Qu, X., D. Wang, L. Wang, Y. Huang, Yue Hou and M. Oeser. “TheState-ofthe-ArtReviewonMolecularDynamics Simulationof Asphalt Binder.” (2018).

Image source: http://gilsoniteco.com/2018/02/22/gilsonite-binder-grade/

Image source: http://alliancepavingmaterials.com/hot-mix-asphalt/

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

Trinidad island

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.

Asphalt Paving types

- Asphalt most commonly used in flexible pavement construction can be divided into:

Asphalt cement (binder)

Image source https://vaasphalt.org/liquid-asphalt/

Emulsified asphalt

Images soure https://pavementinteractive.org/sweet-emulsion-how-asphalt-and-water-combine/

Cutback asphalt

https://www.wataniyagroup.com/productsdetail/11

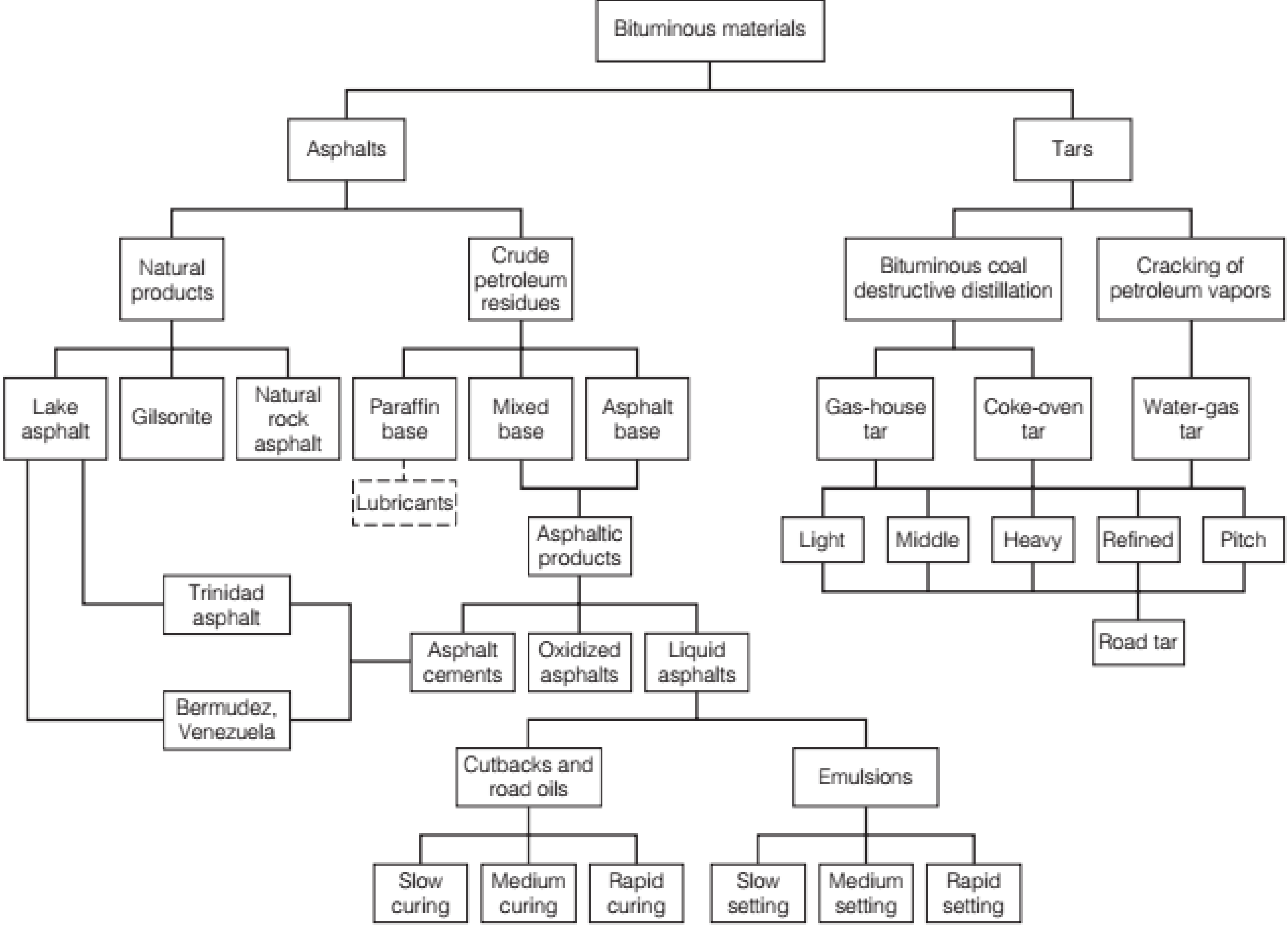


FIGURE 9.1 Classification of bituminous materials (Goetz and Wood, 1960).

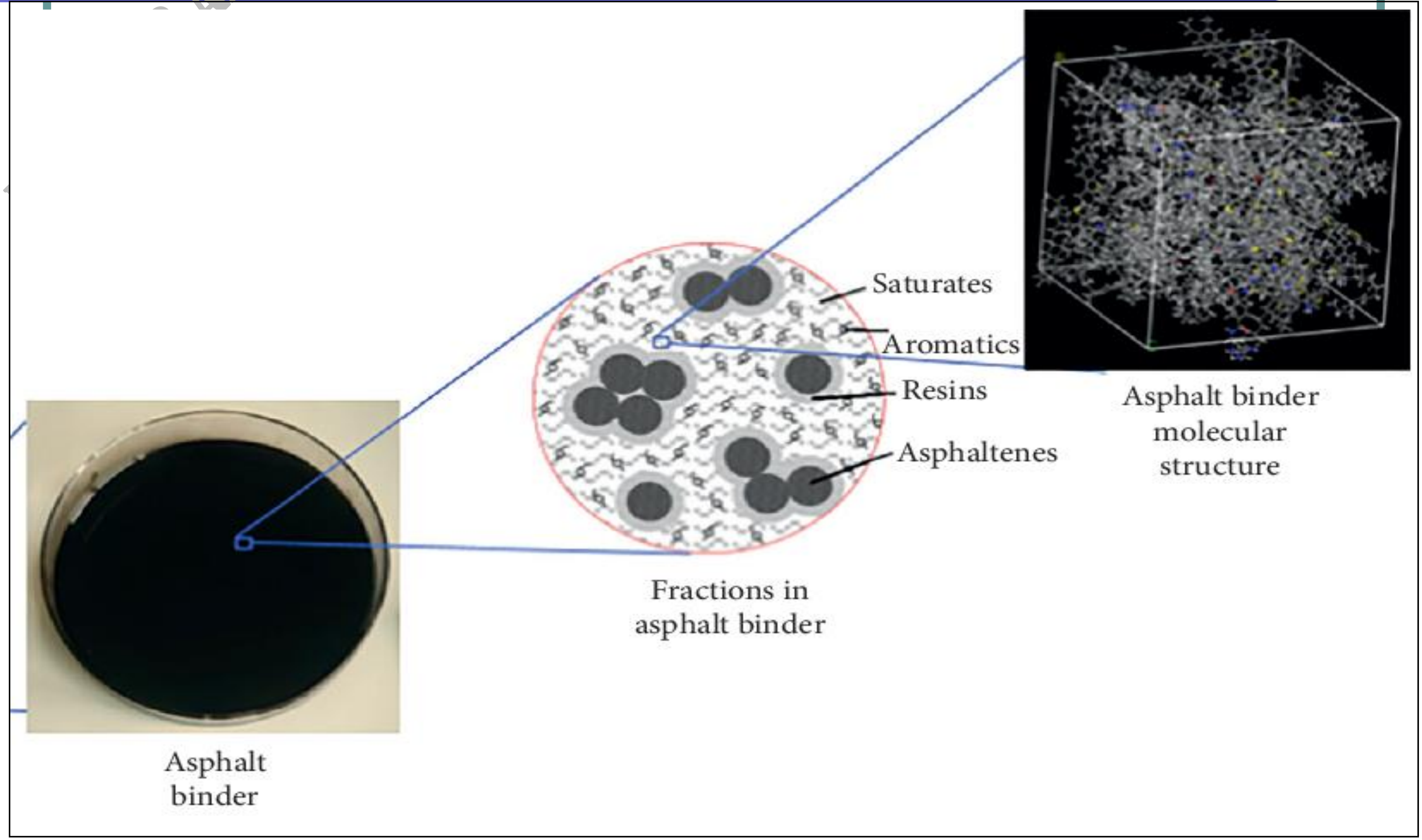
Bituminous Materials Categories

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

Chemical Composition of Asphalt

- Asphalt is a complex chemical compound composed predominately of carbon and hydrogen (hydrocarbon), with a small amount of heterocyclic compounds containing sulfur, nitrogen and oxygen
- Despite the complexity of asphalt's chemical composition, it is possible to be separated into two broad chemical groups:
  - **The asphaltenes**
  - **The maltenes:**
    - Saturated hydrocarbons
    - Aromatic hydrocarbons
    - Resin
- Any fluctuation in the percentage of asphaltenes and maltenes, particularly of resins and saturates, influences the viscosity and the temperature sensitivity of asphalt.
- The fluctuation of the abovementioned substances takes place mainly during production of asphalt

Chemical Composition of Asphalt



Chemical Composition of Asphalt

Asphaltenes:

- The asphaltene content directly affects the rheological properties of the asphalt.
- When asphaltene content increases:
  - The asphalt is harder (low penetration and high softening point)
  - The asphalt is more viscous (high viscosity)
- The percentage of asphaltenes in asphalt usually ranges from 5% to 28%

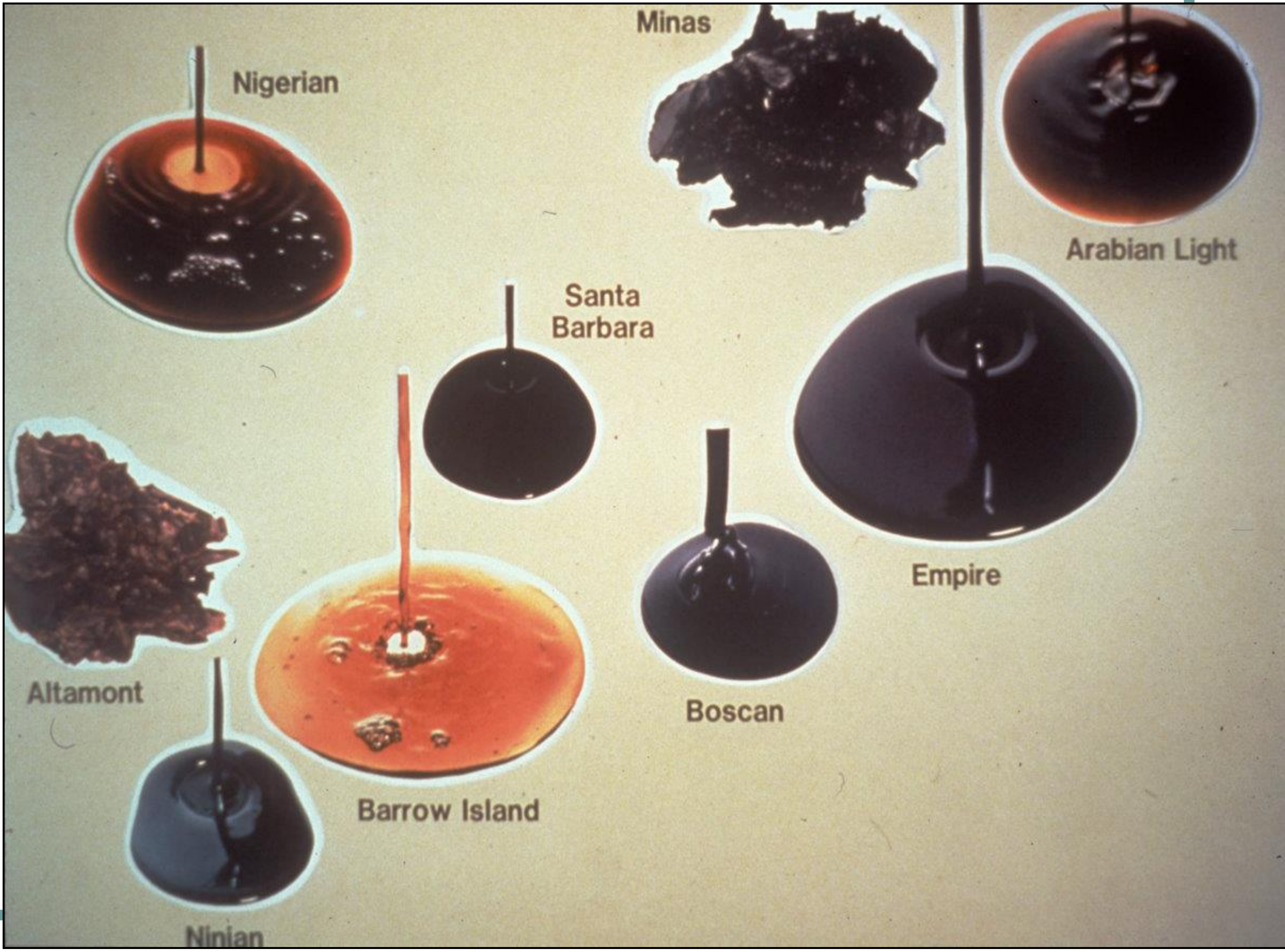
Resins

- They are solid or semi-solid, dark brown in color and strongly adhesive.
- Resins are dispersing agents to asphaltenes and their proportion to asphaltenes control the gel/sol type of character of asphalt.

Chemical Composition of Asphalt

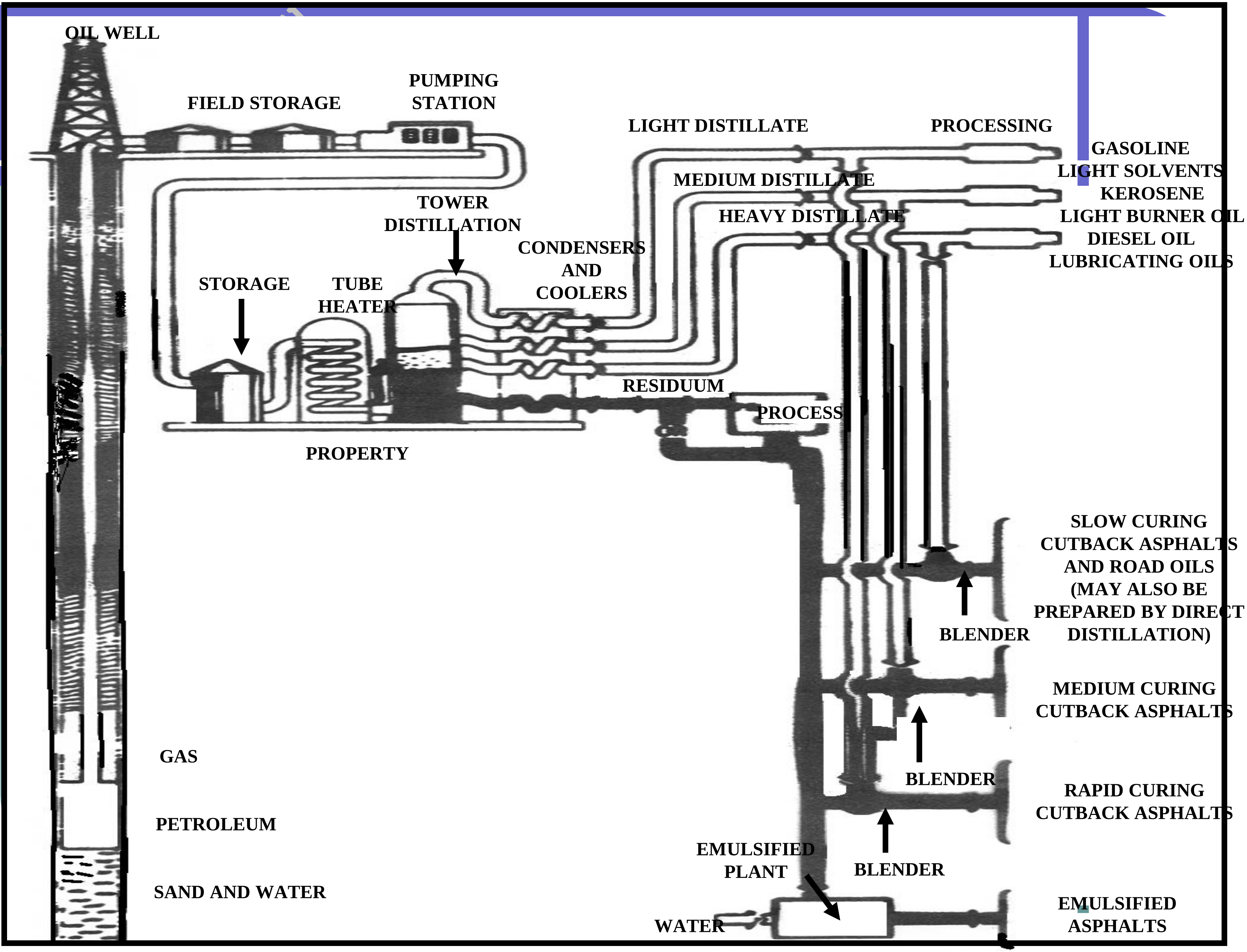
The exact composition of asphalt differs, and it depends on:

- The source of the crude oil
- The modification during its fractional distillation
- The oncoming ageing in service.



Production of Petroleum 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

GAS

PETROLEUM

SAND AND WATER

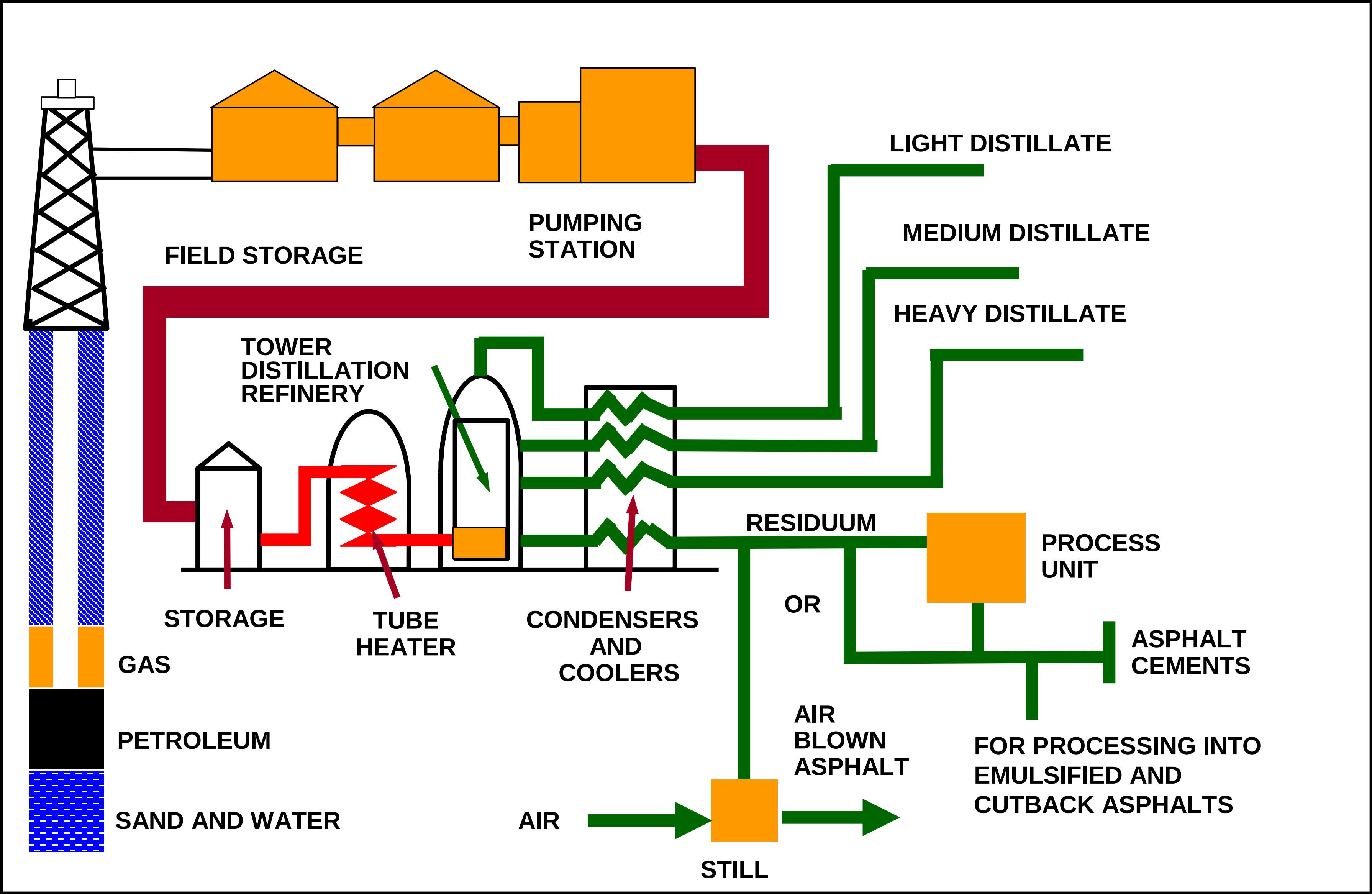
EMULSIFIED
PLANT

BLENDER

WATER

EMULSIFIED
ASPHALTS

Refinery Operation



FIELD STORAGE

PUMPING STATION

LIGHT DISTILLATE

MEDIUM DISTILLATE

HEAVY DISTILLATE

TOWER DISTILLATION REFINERY

RESIDUUM

PROCESS UNIT

OR

STORAGE

TUBE HEATER

CONDENSERS AND COOLERS

ASPHALT CEMENTS

GAS

PETROLEUM

AIR BLOWN ASPHALT

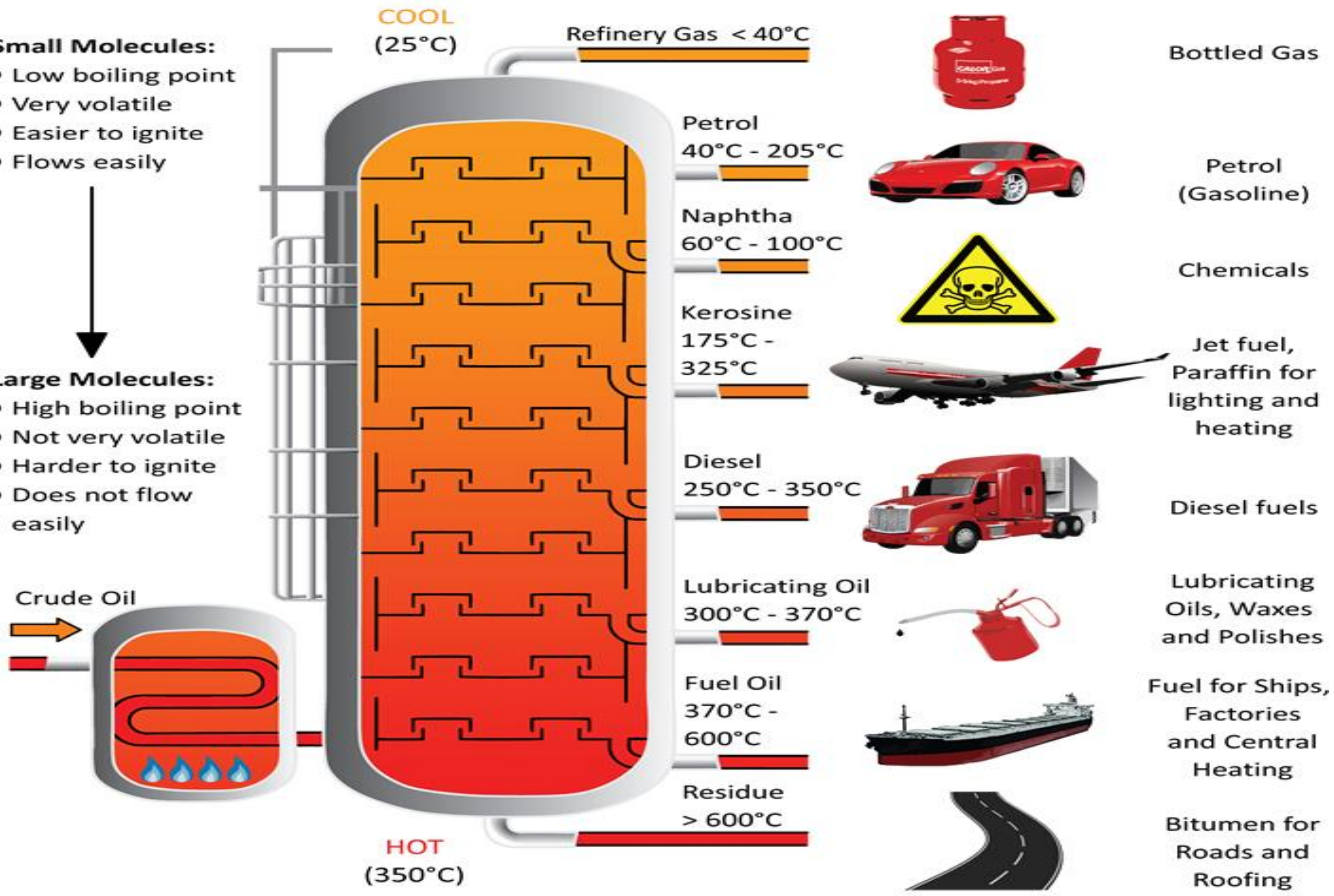
FOR PROCESSING INTO EMULSIFIED AND CUTBACK ASPHALTS

SAND AND WATER

AIR

STILL

Fractional Distillation of Crude Oil



Small Molecules:

- Low boiling point
- Very volatile
- Easier to ignite
- Flows easily

Large Molecules:

- High boiling point
- Not very volatile
- Harder to ignite
- Does not flow easily

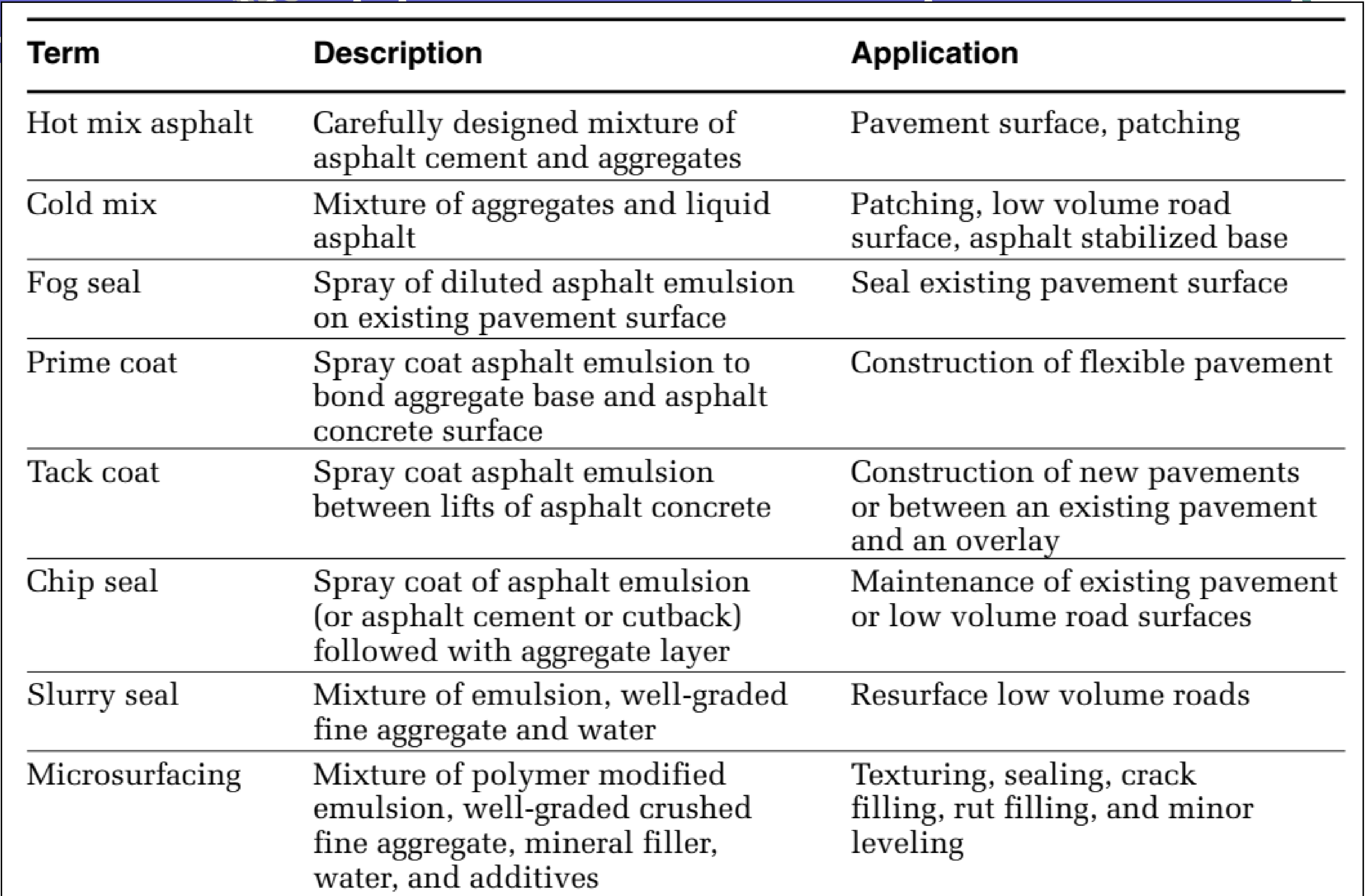
Refinery Gas < 40°C	Bottled Gas
Petrol 40°C - 205°C	Petrol (Gasoline)
Naphtha 60°C - 100°C	Chemicals
Kerosine 175°C - 325°C	Jet fuel, Paraffin for lighting and heating
Diesel 250°C - 350°C	Diesel fuels
Lubricating Oil 300°C - 370°C	Lubricating Oils, Waxes and Polishes
Fuel Oil 370°C - 600°C	Fuel for Ships, Factories and Central Heating
Residue > 600°C	Bitumen for Roads and Roofing

Fractionating column

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.

Paving Applications of Asphalt



Term	Description	Application
Hot mix asphalt	Carefully designed mixture of asphalt cement and aggregates	Pavement surface, patching
Cold mix	Mixture of aggregates and liquid asphalt	Patching, low volume road surface, asphalt stabilized base
Fog seal	Spray of diluted asphalt emulsion on existing pavement surface	Seal existing pavement surface
Prime coat	Spray coat asphalt emulsion to bond aggregate base and asphalt concrete surface	Construction of flexible pavement
Tack coat	Spray coat asphalt emulsion between lifts of asphalt concrete	Construction of new pavements or between an existing pavement and an overlay
Chip seal	Spray coat of asphalt emulsion (or asphalt cement or cutback) followed with aggregate layer	Maintenance of existing pavement or low volume road surfaces
Slurry seal	Mixture of emulsion, well-graded fine aggregate and water	Resurface low volume roads
Microsurfacing	Mixture of polymer modified emulsion, well-graded crushed fine aggregate, mineral filler, water, and additives	Texturing, sealing, crack filling, rut filling, and minor leveling

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): Diesel /Road Oil

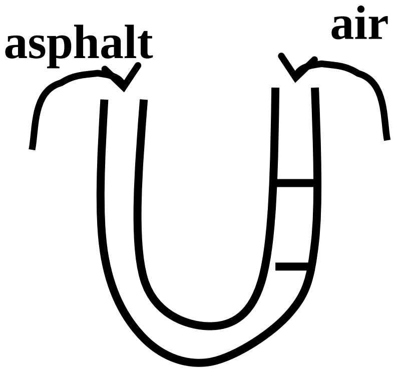
Cutback Asphalts

RAPID CURING (RC)	MEDIUM CURING (MC)	SLOW CURING (SC)
85-100 pent. Asphalt + Gasoline or Naphtha	120-150 pent. Asphalt + Kerosene	200-300 pent. Asphalt + Diesel Oil
Surface treatment + Road mixing	Stockpile patch + Road mixing	Prime Coat + 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

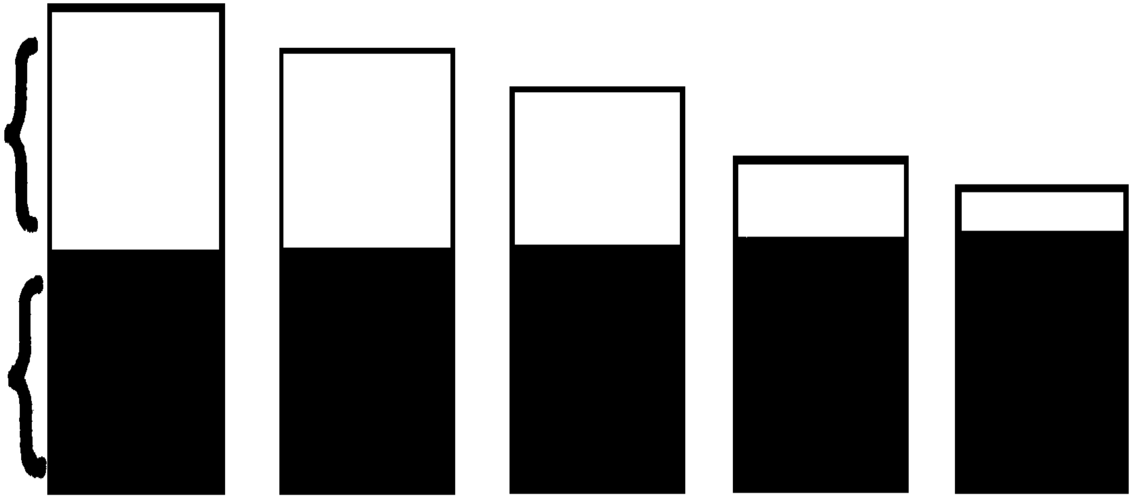
Grades based on min. Kinematic Viscosity @ 60C (cSt)

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

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



Composition of Cutback Asphalts



NAPTHA FOR RC
KEROSENE FOR MC
LIGHT OIL FOR SC

SOLVENT

ASPHALT CEMENT

GRADE	30	70	250	800	3000
APPRX. FUROL VIS., 140°F, SEC.	15-30	35-70	125-250	400-800	1500-3000
APPROX. KINEMATIC VIS. 140°F, CS	30-60	70-140	250-500	800-1600	3000-6000

30% solvent

10% solvent

Uses of Cutback Asphalts

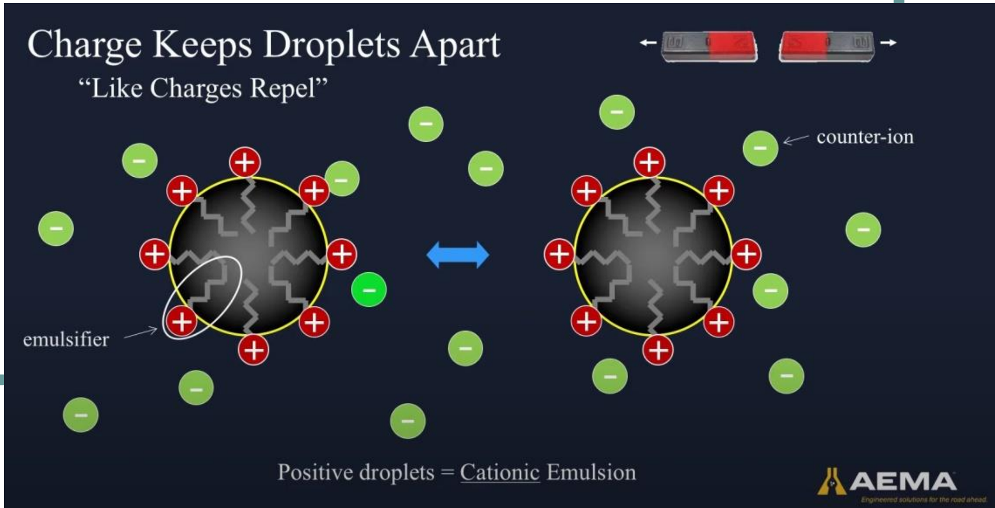
Cutback Asphalts used less frequently now and the use of emulsions becoming more common.

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**

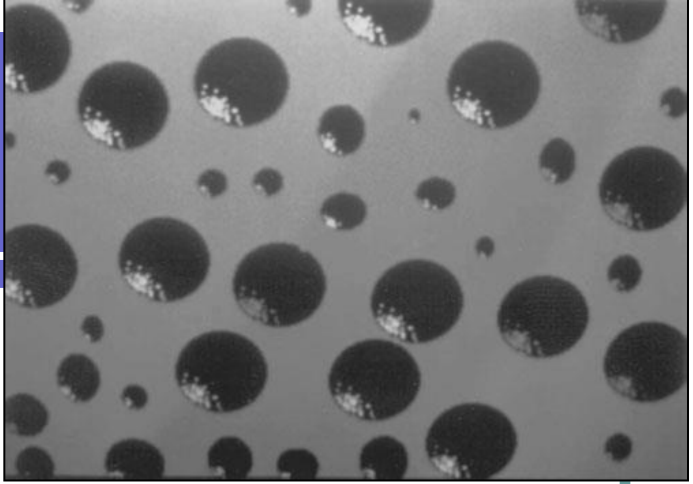
Emulsified Asphalts

- 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.



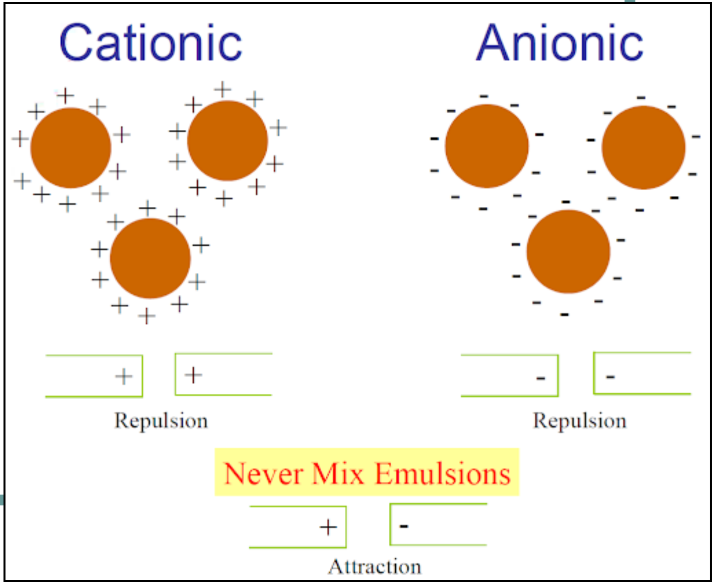
Emulsions



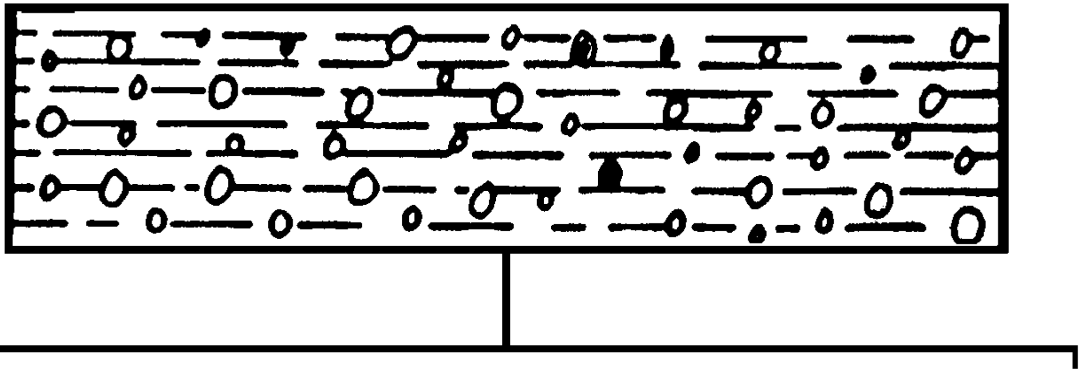
- When used (i.e. exposed to air), it sets or breaks.
- Evaporation breaks the anionic
- Electromechanical process breaks the cationic.
- Emulsions are graded based on the rate of setting:

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

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



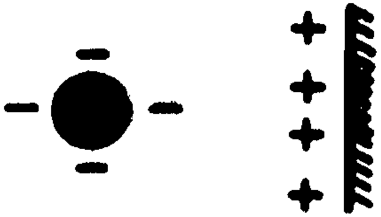
EMULSIONS



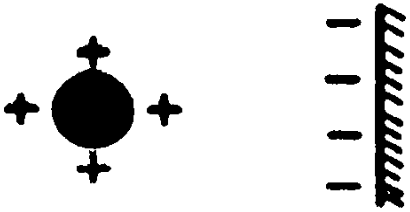
ASPHALT
+
WATER
+
EMULSIFIER

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

Emulsion Grades

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

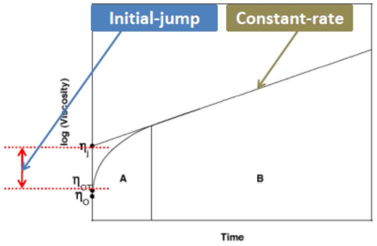
- When asphalt is exposed to environment, natural deterioration (***weathering***) gradually takes place, and the materials lose their plasticity and become brittle.
- For better performance weathering must be minimized.
- **Durability** :The ability of asphalt to resist weathering.
- Factors influencing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

Durability/ Factors Influencing Weathering

Bitumen Oxidation Kinetics

At a given temperature and pressure, the asphalt oxidizes in **two stages**:

(1) a rapid-rate period followed by
(2) a long period with constant oxidation rate.



- 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).

Aging Behavior

- Oxidation affects the mechanical behavior of the asphalt and usually reduces the pavement’s service life
  - Reduction of penetration
  - Increase of softening point
  - Reduction of elasticity and adhesion ability
  - Increase of friability

- **Oxidation** is the loss of electrons. ... In terms of oxygen transfer, **oxidation** may be defined as the chemical process in which a substance gains oxygen or loses electrons and hydrogen. When one of the reactants is oxygen, then **oxidation** is the gain of oxygen

What is Ageing

Ageing (British and Australian English) or **aging** (American and Canadian English) is the accumulation of changes in an organism or object over time.

Asphalt/bitumen properties change over time on exposure to high temperature and the atmosphere. This process is referred to as **ageing**.

ageing is an effect of asphalt hardening with time caused by **oxidation, heat, UV light**.

Over the lifetime of the road, an asphalt binder oxidizes and subsequently hardens eventually causing failure of the road.

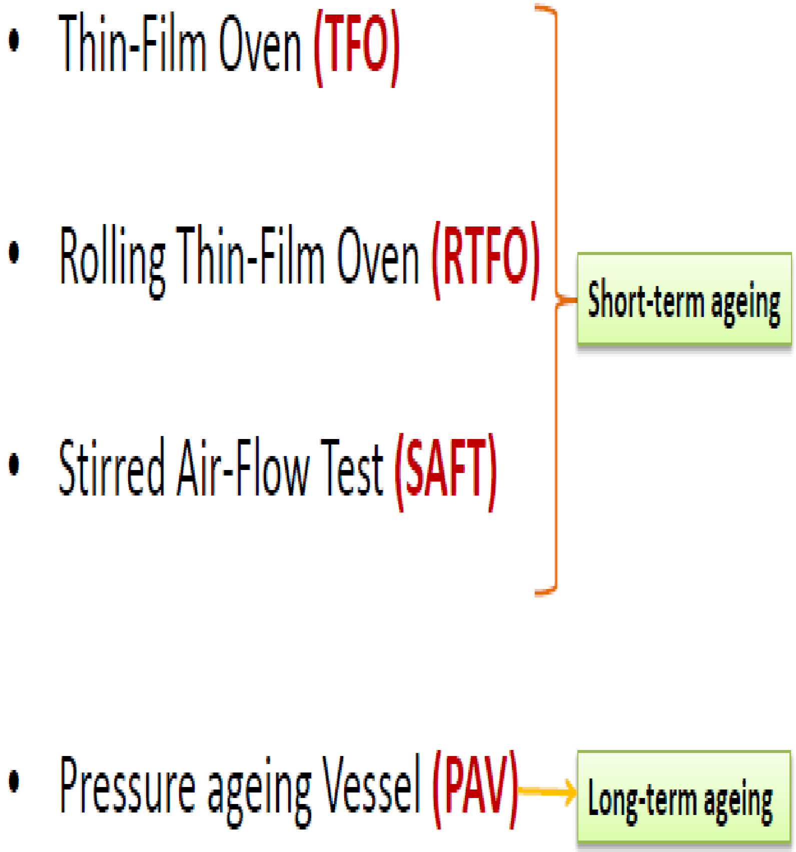
Ageing of Bitumen

Asphalt binder ageing is usually split up into two categories:

- ***Short-term ageing***: This occurs when bitumen is mixed with hot aggregates i.e., ***during production and construction***
- ***Long-term ageing***: This occurs after HMA pavement construction and is generally due to environmental exposure and loading i.e., ***during the life of the pavement***

Laboratory Ageing Procedure

Typical ageing simulation tests are:



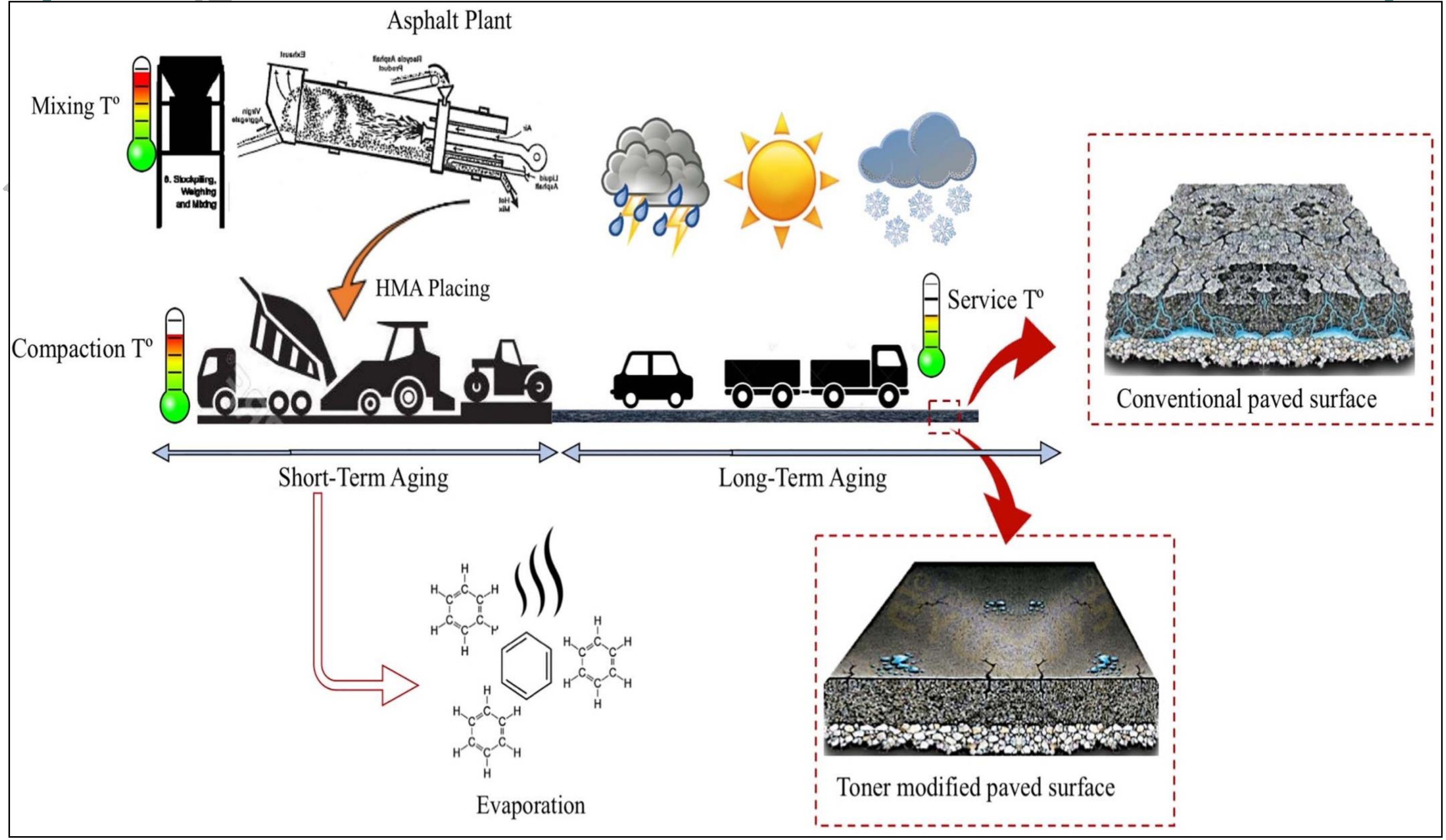
- Thin-Film Oven **(TFO)**
- Rolling Thin-Film Oven **(RTFO)**
- Stirred Air-Flow Test **(SAFT)**

Short-term ageing

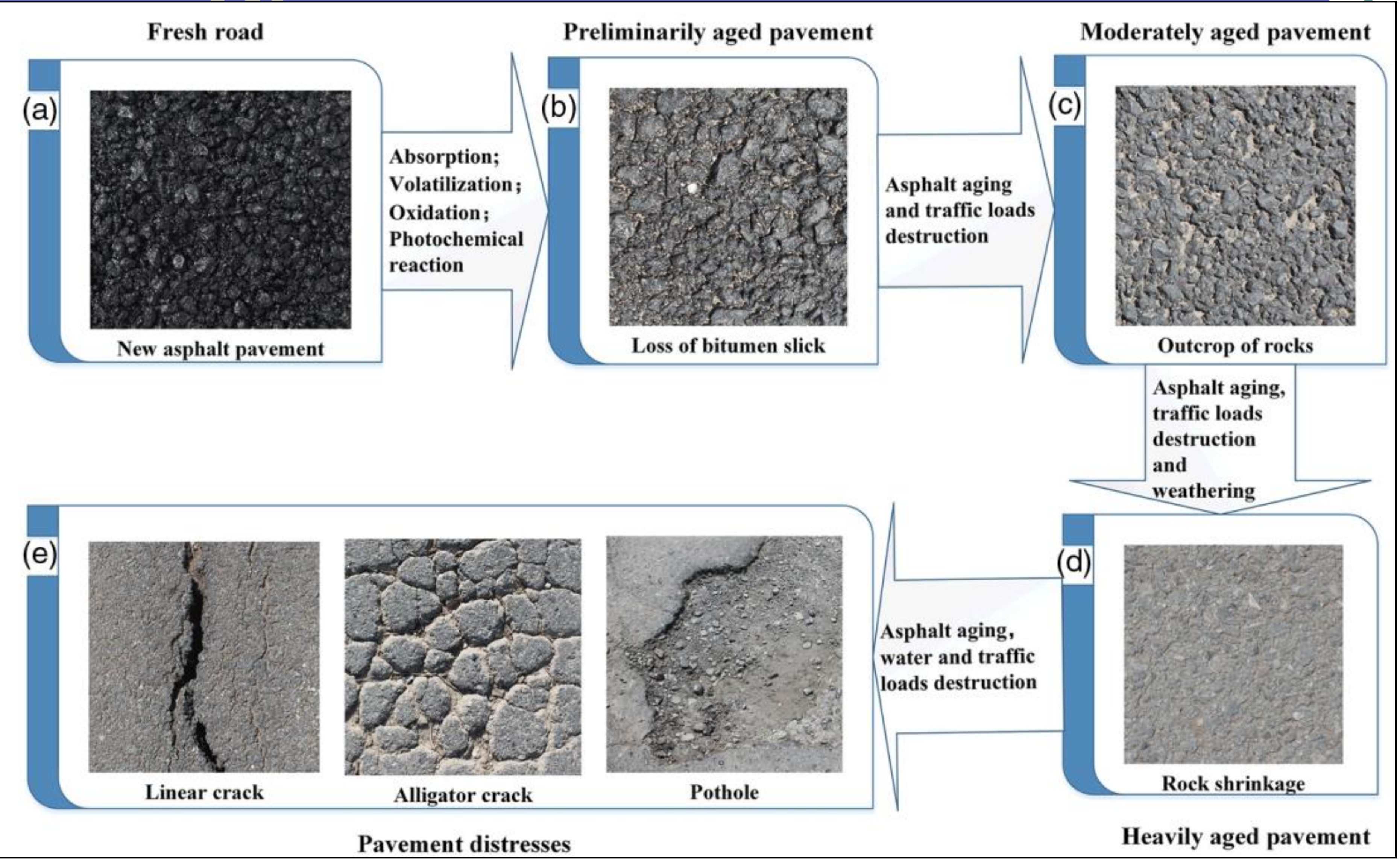
- Pressure ageing Vessel **(PAV)**

Long-term ageing

Aging Behavior



Aging Behavior



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 in Trichloroethylene (ASTM D2042)
- Presence of water (ASTM D95)

Consistency Tests:

- Absolute (dynamic) viscosity (ASTM D2171, D4402)
- Kinematic viscosity (ASTM D445 and D2170)
- Penetration test (ASTM D5)
- Softening point (ASTM D36)
- Ductility test (ASTM D113)

Durability (Volatility & Aging) Tests:

- Thin Film Oven test (ASTM D 1754)
- Rolling Thin Film Oven Test (ASTM D 2872)
- Distillation of Cutback Asphalt (ASTM D402)
- Loss on heating (ASTM D6)

Safety tests:

Flash and fire point test (ASTM D1310)

Other tests:

Specific Gravity (S.G) (ASTM D70)

Testing Standards:
ASTM : Stands for the American Society for Testing and Materials
AASHTO : Stands for American Association of State Highway and Transportation Officials

Purity Tests/ Solubility in Trichloroethylene (ASTM D2042)

- 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.

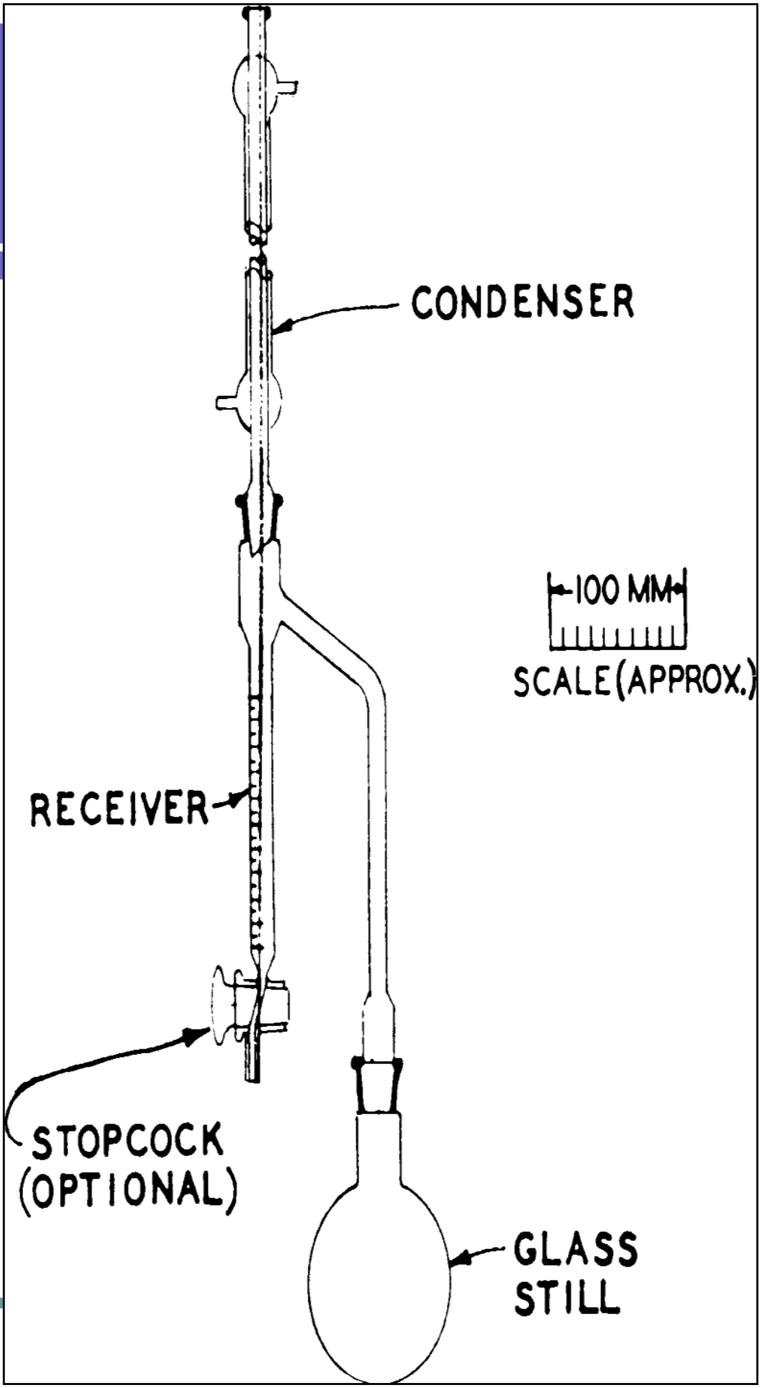
Solubility in Trichloroethylene (ASTM D2042)

Purity Tests/ Presence of Water ASTM D95

- ASTM D95: Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation
- **Scope:** This test method covers the determination of water in the range from 0% to 25 % volume in petroleum products, tars, and other bituminous materials by the distillation method
- **Significance and Use:**
  - knowledge of the water content of petroleum products is important in the refining, purchase, sale, and transfer of products.
  - Water present in asphalt cause asphalt to foam when heated above 100 C.
  - The amount of water as determined by this test method (to the nearest 0.05 volume %) may be used to correct the volume involved in the custody transfer of petroleum products and bituminous materials.
  - The allowable amount of water may be specified in contracts.

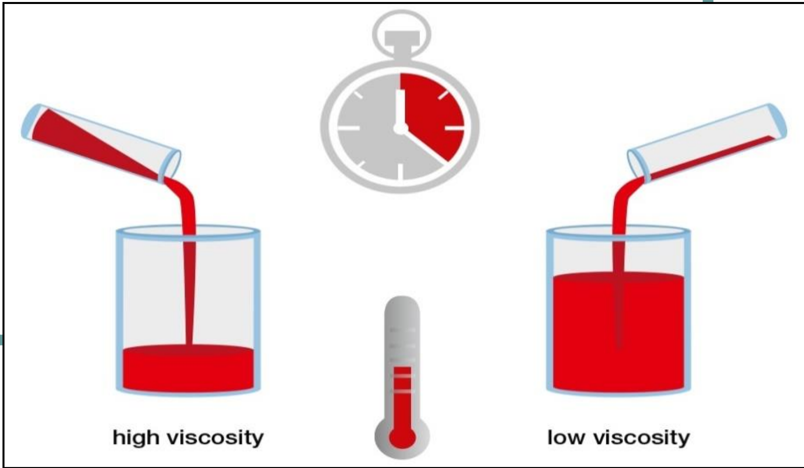
Presence of Water

- Water content :
  - 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.
- Measure of its resistance to gradual deformation by shear stress or tensile stress.
- The shear resistance in a fluid is caused by inter-molecular friction exerted when layers of fluid attempt to slide by one another.
- ***Viscosity is the measure of a fluid's resistance to flow***
  - golden syrup is highly viscous
  - water is medium viscous
  - gas is low viscous



Consistency Tests/ Viscosity

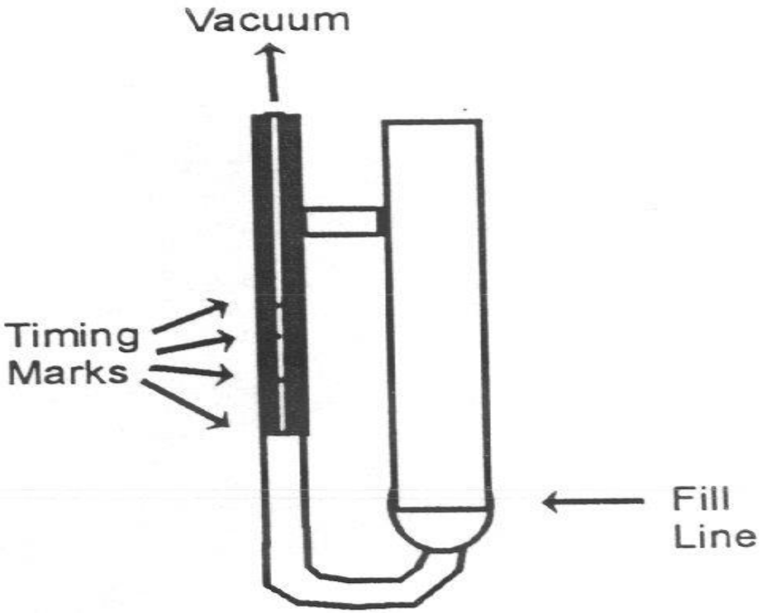
- Asphalt viscosity is important to Asphalt Processing:
  - Storage and Handling
  - Mixing
  - Compaction
  - Application (for liquid asphalt)

- Two related measures of fluid viscosity
  - dynamic (or absolute)
  - kinematic

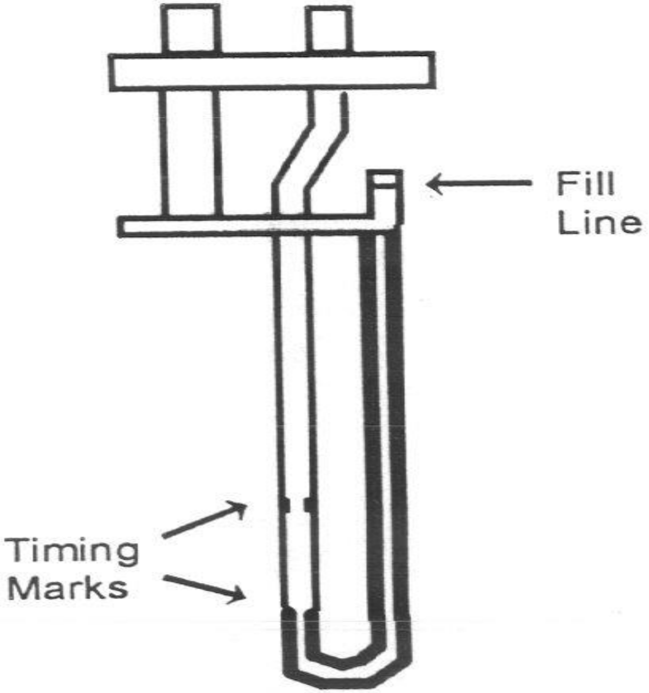
Consistency Tests/ Viscosity

Absolute (Dynamic) ASTM D2171/ ASTM D4402	Kinematic ASTM D2170/ ASTM D445
is a measure of internal resistance. Dynamic (absolute) viscosity is the tangential force per unit area required to move one horizontal plane with respect to an other plane - at a unit velocity It gives you information on the force needed to make the fluid flow at a certain rate	is the ratio of - *absolute (or dynamic) viscosity to density* - a quantity in which no force is involved It tells how fast the fluid is moving when a certain force is applied
- U-shaped tube with timing marks & filled with asphalt - Placed in 60^{o}C bath - Vacuum used to pull asphalt through tube - Time to pass marks Visc. in Pa s (Poise =Ps) = $1\ Pa\ s = 1\ N\ s/m^2 = 1\ kg/(m\ s)$ • 1 Pa.s = 10 Ps = 1000 cPs	- Cross arm tube with timing marks & filled with asphalt - Placed in 135 ^{o}C bath - Once started gravity moves asphalt through tube - Time to pass marks • $1\ St\ (Stokes) = 1\ cm^2/s$ • mm^2 / s = centistoke • = Absolute/ density • Pa.S = 1000 cst

Viscosity Tubes



Asphalt Institute Tube



Zietfuchs Cross-Arm Tube

Absolute (dynamic) viscosity test/ ASTM D2171

Calculation:

$$Dynamic\ viscosity(Pa.s) = K \times t$$

K = Selected calibration factor, (Pa · s/s)

t = flow time (s)

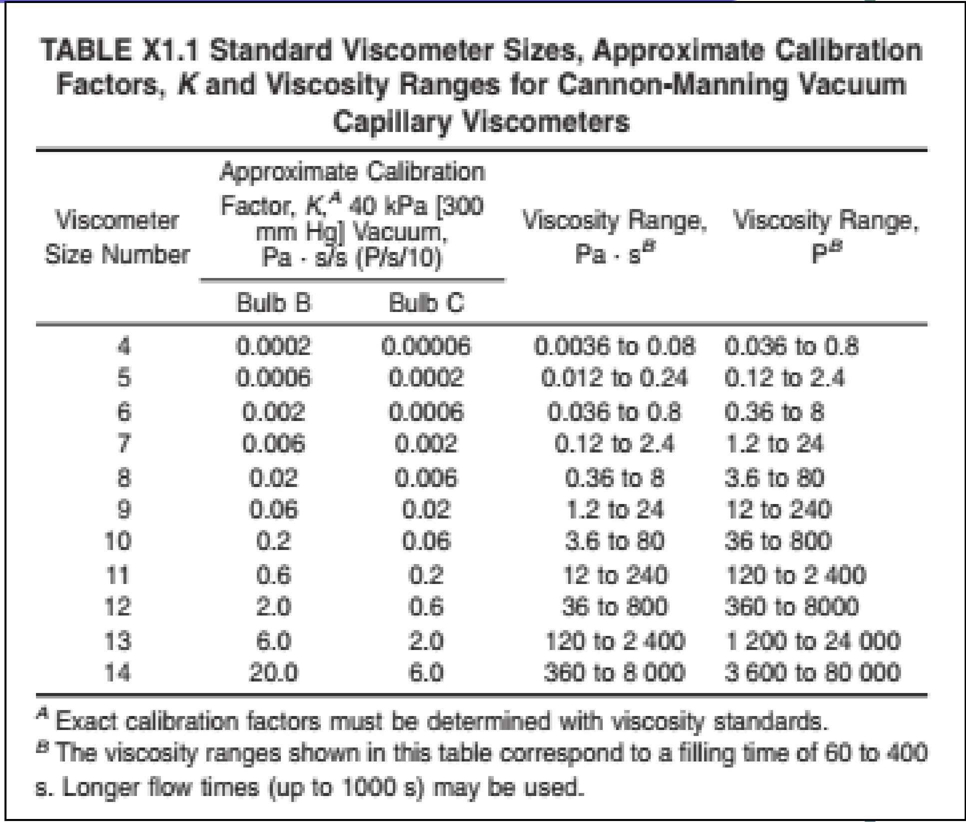


TABLE X1.1 Standard Viscometer Sizes, Approximate Calibration Factors, *K* and Viscosity Ranges for Cannon-Manning Vacuum Capillary Viscometers

Viscometer Size Number	Approximate Calibration Factor, *K*,[A] 40 kPa [300 mm Hg] Vacuum, Pa · s/s (P/s/10)		Viscosity Range, Pa · s[B]	Viscosity Range, P[B]
	Bulb B	Bulb C		
4	0.0002	0.00006	0.0036 to 0.08	0.036 to 0.8
5	0.0006	0.0002	0.012 to 0.24	0.12 to 2.4
6	0.002	0.0006	0.036 to 0.8	0.36 to 8
7	0.006	0.002	0.12 to 2.4	1.2 to 24
8	0.02	0.006	0.36 to 8	3.6 to 80
9	0.06	0.02	1.2 to 24	12 to 240
10	0.2	0.06	3.6 to 80	36 to 800
11	0.6	0.2	12 to 240	120 to 2 400
12	2.0	0.6	36 to 800	360 to 8000
13	6.0	2.0	120 to 2 400	1 200 to 24 000
14	20.0	6.0	360 to 8 000	3 600 to 80 000

[A] Exact calibration factors must be determined with viscosity standards.

[B] The viscosity ranges shown in this table correspond to a filling time of 60 to 400 s. Longer flow times (up to 1000 s) may be used.

Viscosity Grades for AC

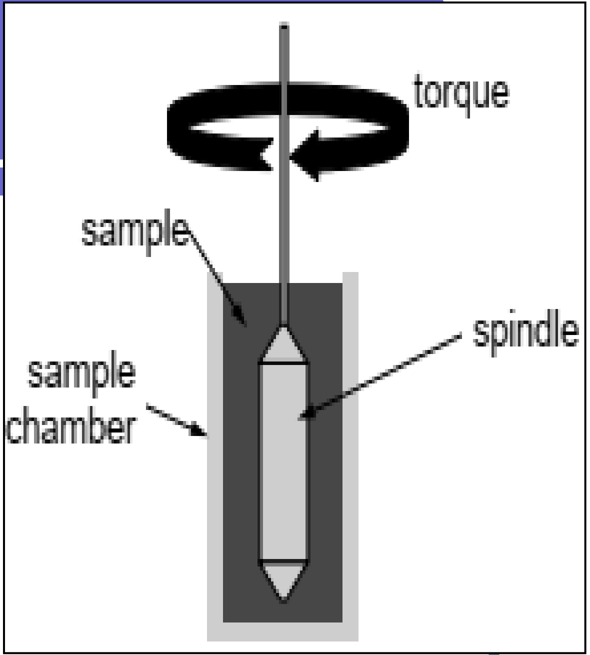
- Viscosity of normal AC based on 60 ^{o} C in poises

AC 2.5	250+- 50
AC 5	500 +- 100
AC 10	1000 +- 200
AC 20	2000 +- 400
AC 30	3000 +- 600
AC 40	4000 +- 800

Absolute (dynamic) viscosity test/ ASTM D4402 (Rotational Viscometer)

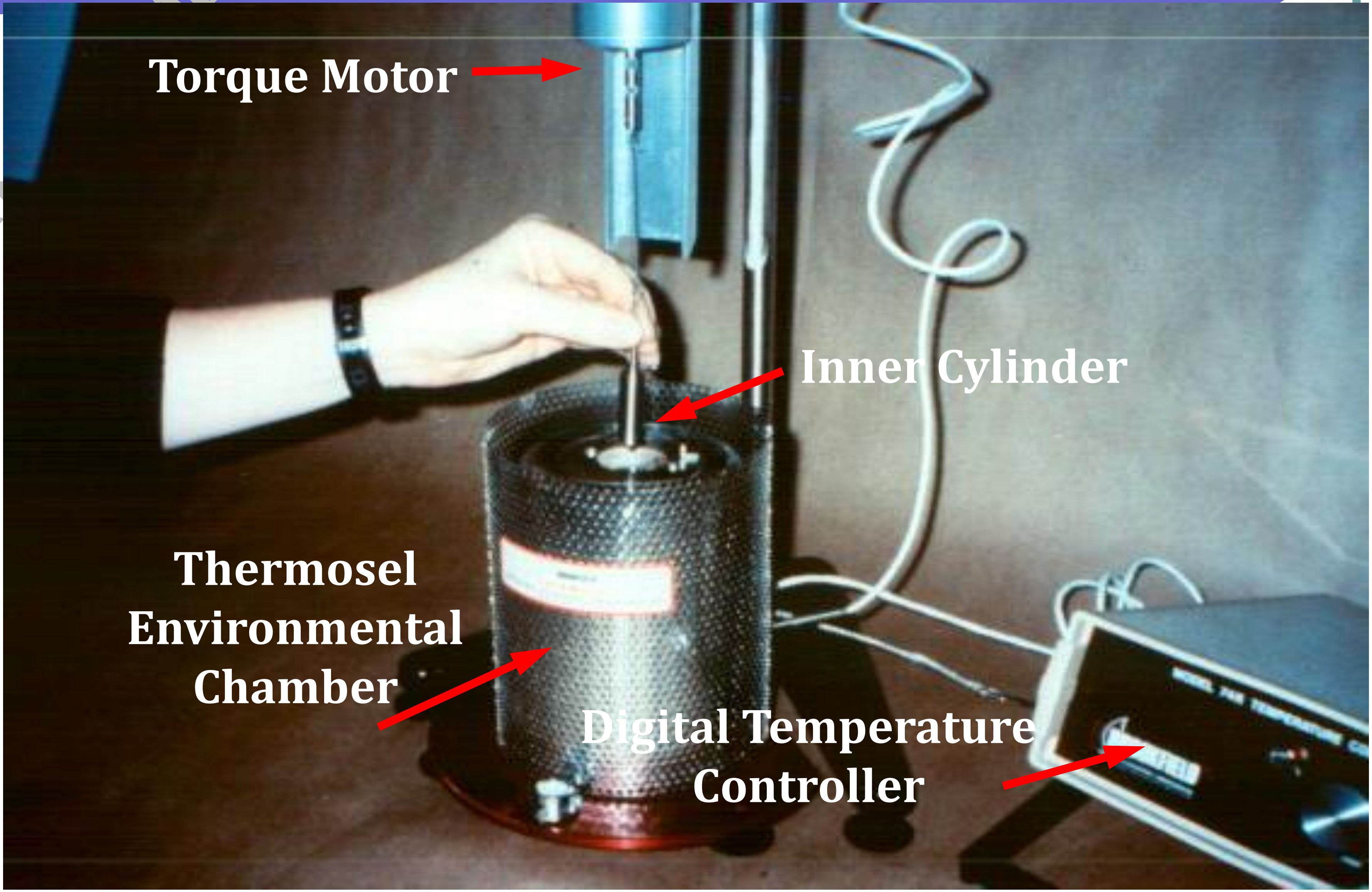
- ASTM D4402: Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer
- Scope:
  - This test method outlines a procedure for measuring the apparent viscosity of asphalt from 38 to 260°C (100 to 500°F) using a rotational viscometer and a temperature-controlled thermal chamber for maintaining the test temperature.
- Significance and Use:
  - This test method is used to **measure the apparent viscosity of asphalts at handling, mixing, or application temperatures**.
  - High temperature (between 38 to 260 C) binder viscosity is measured to ensure that the asphalt is fluid enough when pumping and mixing

Absolute (dynamic) viscosity test/ ASTM D4402



- **Rotational viscosity is determined by measuring the torque required to maintain a constant rotational speed of a cylindrical spindle while submerged in a sample at a constant temperature**
- **The torque required to rotate the spindle at a constant speed is directly related to the viscosity of the binder sample, which is determined automatically by the viscometer.**
- The typical test temperatures for
  - Unmodified asphalt binder are 90°C, 105 °C and 135 °C,
  - Polymer-modified asphalt binder are 135 °C, 150 °C and 165 °C
  - Asphalt emulsions is 40° C,
  - Cut-back and fluxed Asphalt binders is 60 °C

Rotational Viscometer (Brookfield)



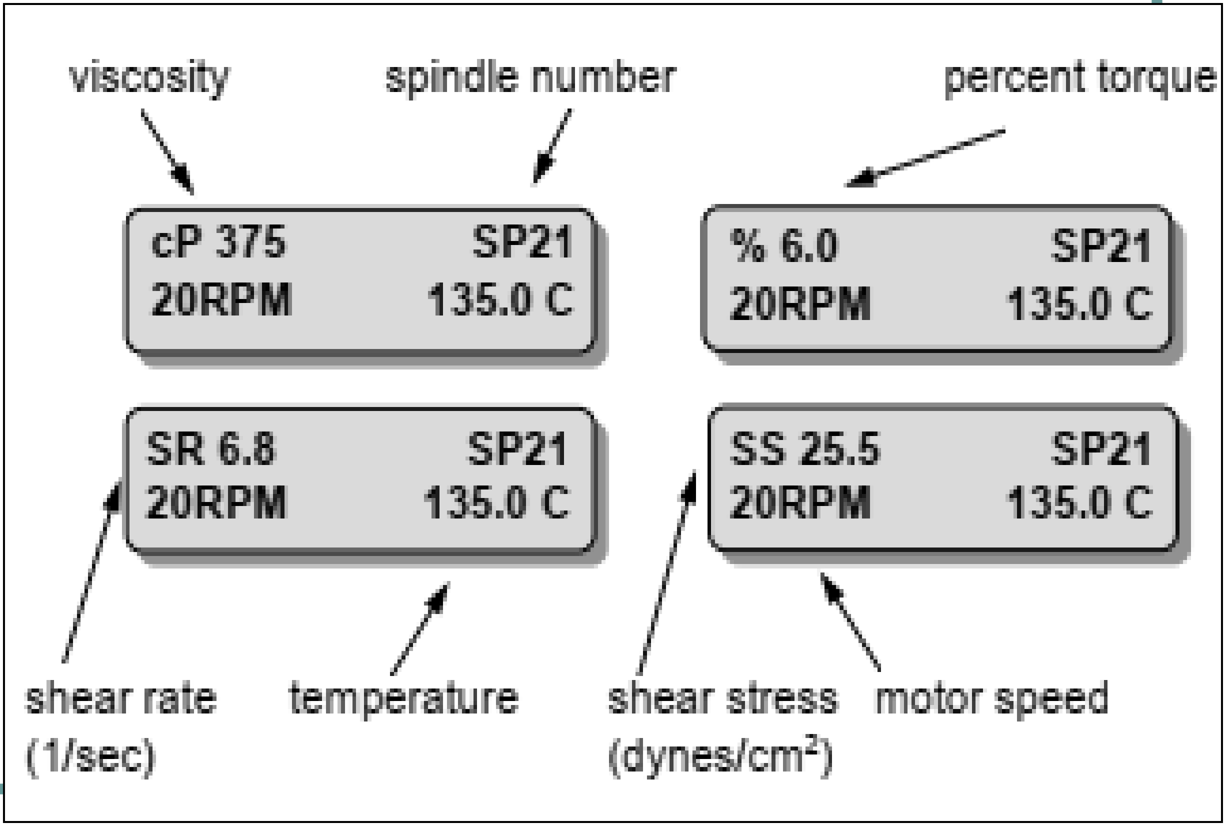
Absolute (dynamic) viscosity test/ ASTM D4402/ Procedure

- Small volume of heated sample (specified for the spindle to be used) is placed in the sample cylindrical container, which is then placed in the temperature-controlled device (environmental chamber).
- The sample together with the appropriate size spindle is left for a certain period to reach uniform testing temperature.
- Upon reaching the required test temperature, the spindle starts to rotate at a speed such that the desired shear rate is achieved with a precision of ±10%.
- Readings of torque, viscosity and shear rate are taken after the shear rate is stabilized for a period of 60 ± 5 s
- The dynamic viscosity is expressed in Pa·s or in millipascal-seconds (mPa·s) and is the mean of the two independent measurements, provided that the values do not differ by more than 10%.

Absolute (dynamic) viscosity test/ ASTM D4402/ Procedure

The viscosity at 135°C is reported.

The digital output of the rotational viscosity test is viscosity in units of centipoise (cP) ………………1000 cP = 1 Pa.s



Standard Viscosity-Temperature Chart for Asphalts

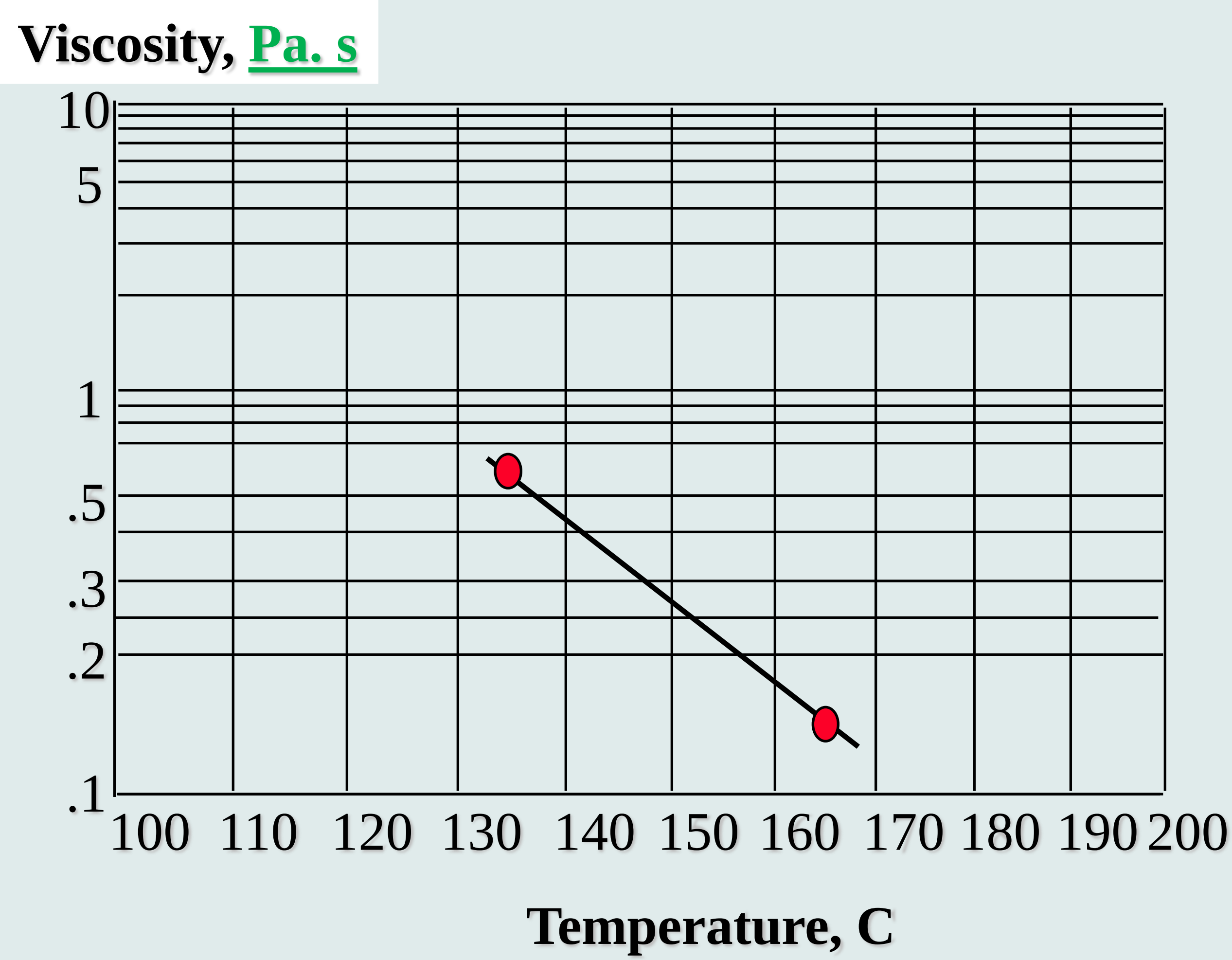
- The Viscosity-Temperature Chart is used to determine laboratory mixing and compaction temperatures
- **The laboratory mixing temperatures**

  Is the temperature where the viscosity-temperature line crosses the viscosity ranges of 0.17 ± 0.02 Pa-s
- **The laboratory Compaction temperatures**

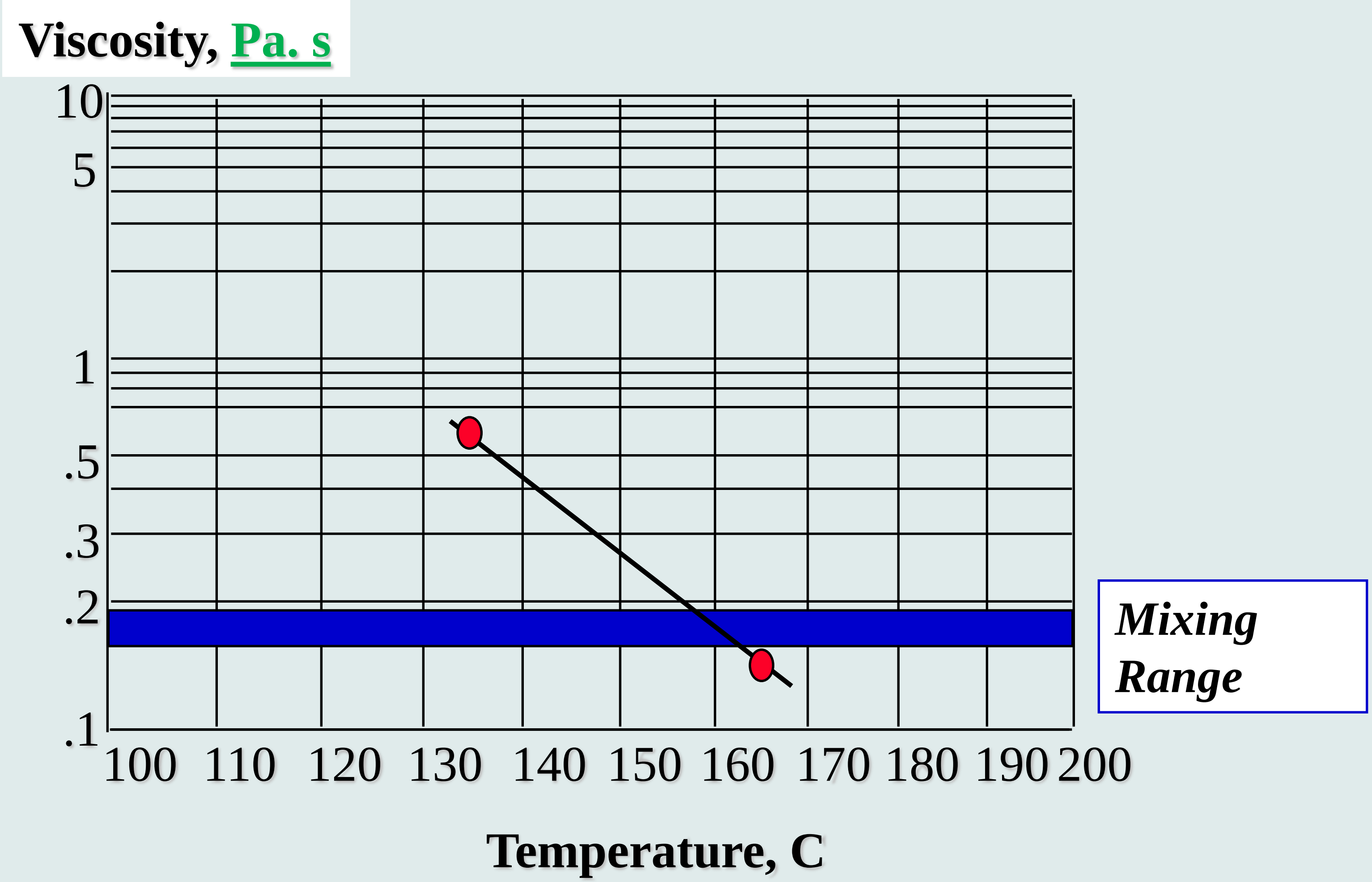
  Is the temperature where the viscosity-temperature line crosses the viscosity ranges of 0.28 ± 0.03 Pa-s
- The corresponding temperatures may be reported as

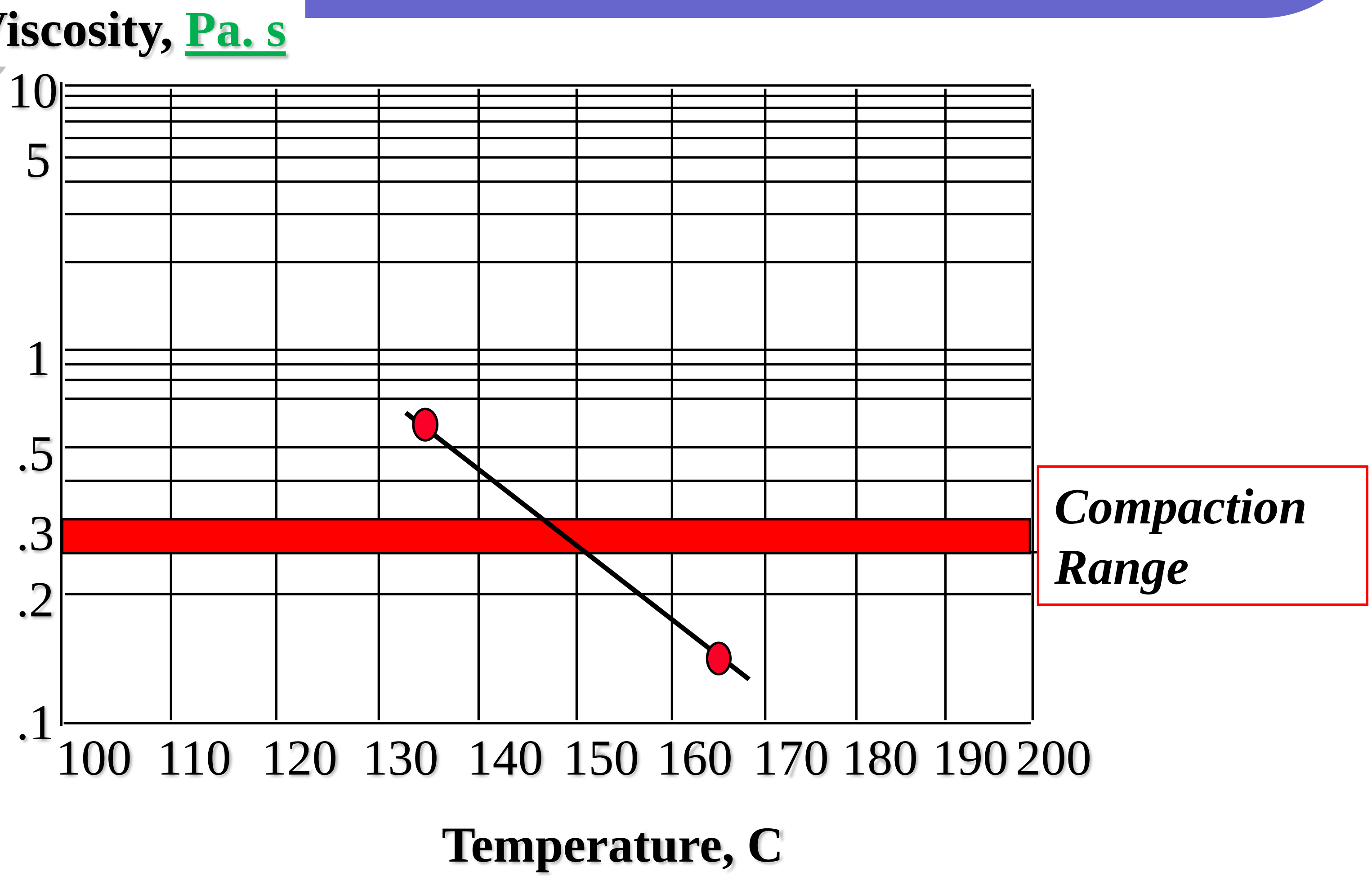
  A range of values (e.g., 155 - 163 °C)

  A single point representing the mid-point of the range (e.g., 159 °C).


Viscosity, Pa. s
10
5
1
.5
.3
.2
.1
100
110
120
130
140
150
160
170
180
190
200
Temperature, C

Mixing viscosity range (0.17 ± 0.02 Pa.s) or (170 +- 20 CSt)
Compaction viscosity range (0.280 ± 0.03 Pa·s) or (280 +- 30 Cst)

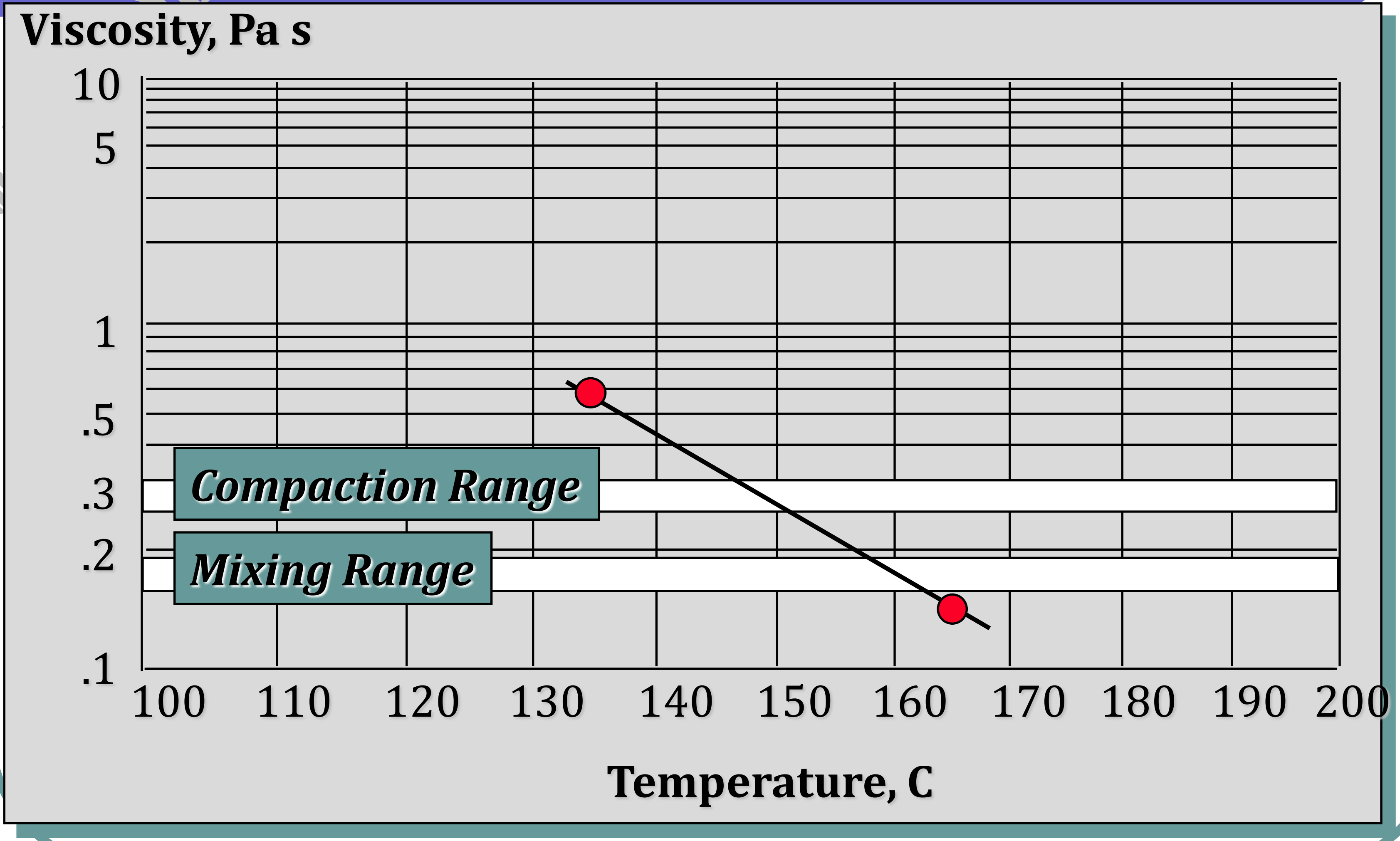




Mixing viscosity range (0.17 ± 0.02 Pa-s) or (170 +- 20 CSt)

Compaction viscosity range (0.280 ± 0.03 Pa·s) or (280 +- 30 Cst)

Mixing / Compaction Temps



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

Kinematic viscosity test/ASTM D2170

ASTM D2170: Standard Test Method for Kinematic Viscosity of Asphalts

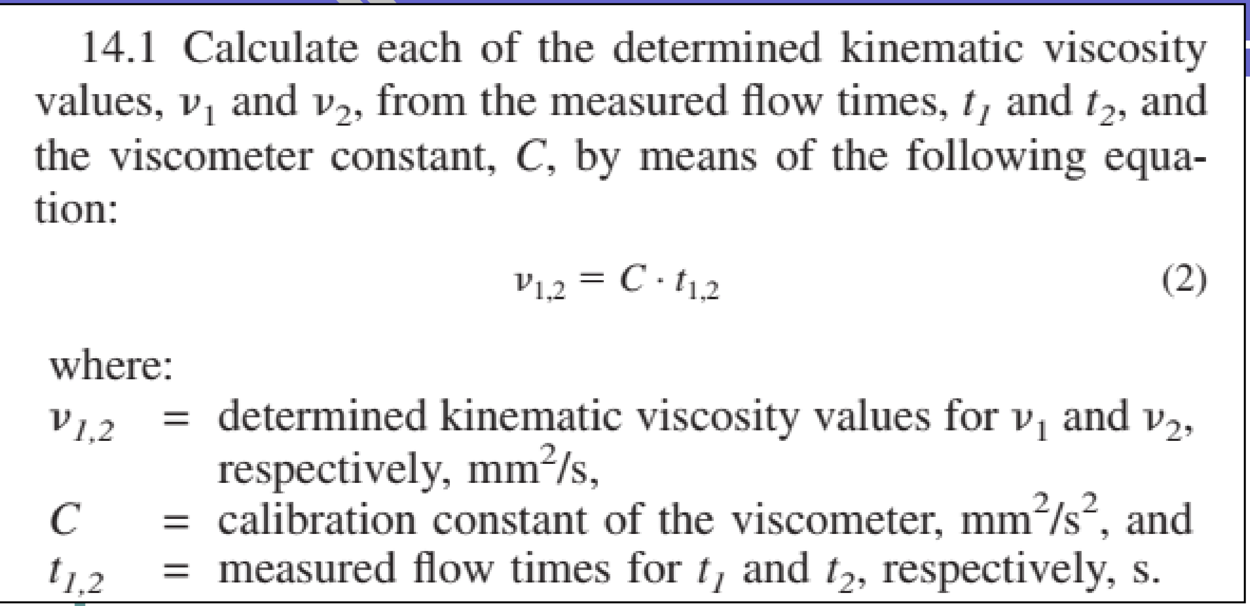
Scope: This test method covers procedures for the determination of kinematic viscosity of liquid asphalts (asphalt's), road oils and distillation residues of liquid asphalts (asphalt's) all at 60 °C [140 °F] and of asphalt cements at 135 °C [275 °F] (

- Results of this test method can be used to calculate viscosity when the density of the test material at the test temperature is known or can be determined.

Kinematic viscosity test/ASTM D2170

- The specifications are usually at temperatures of 60 and 135 °C
  - The 60°C temperature represents the maximum Hot Mix Asphalt (HMA) pavement surface temperature during the summer in the United states
  - The 135°C temperature approximates the mixing and laydown temperature used in the construction of HMA pavements
- Summary of Test Method
  - The time is measured for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer under a reproducible driving head and at a closely controlled and known temperature.
  - The kinematic viscosity (determined value) is the product of the measured flow time and the calibration constant of the viscometer.

Kinematic viscosity test/ASTM D2170



14.1 Calculate each of the determined kinematic viscosity values, ν_1 and ν_2, from the measured flow times, t_1 and t_2, and the viscometer constant, C, by means of the following equation:

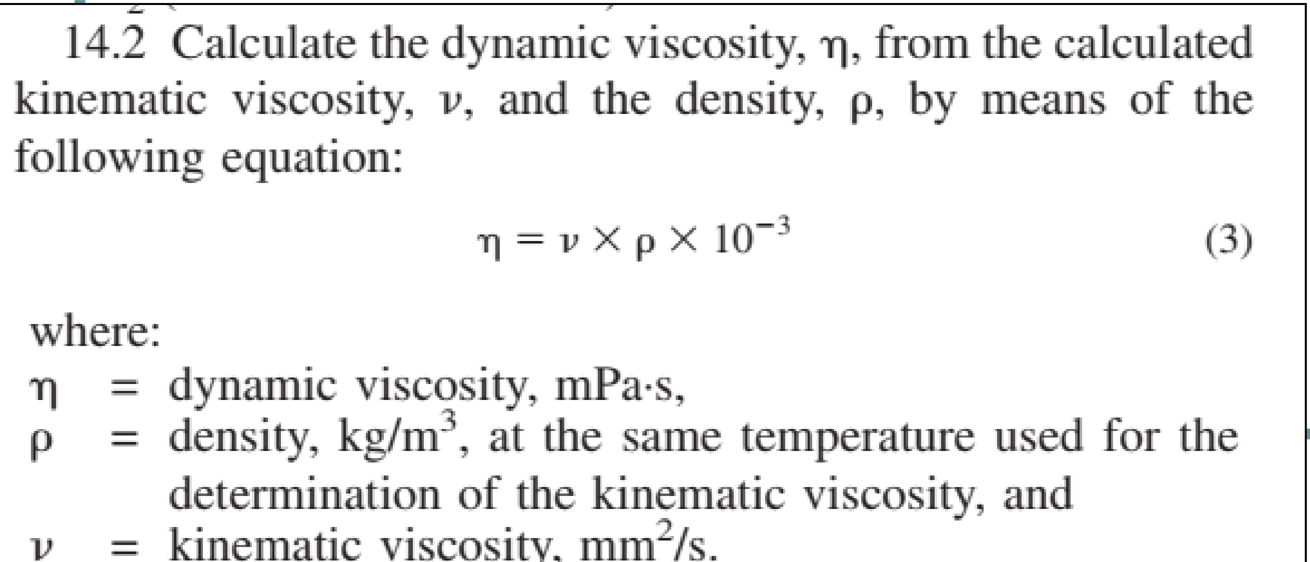
$$\nu_{1,2} = C \cdot t_{1,2} \qquad (2)$$

where:

$\nu_{1,2}$ = determined kinematic viscosity values for ν_1 and ν_2, respectively, mm²/s,

C = calibration constant of the viscometer, mm²/s², and

$t_{1,2}$ = measured flow times for t_1 and t_2, respectively, s.



14.2 Calculate the dynamic viscosity, η, from the calculated kinematic viscosity, ν, and the density, ρ, by means of the following equation:

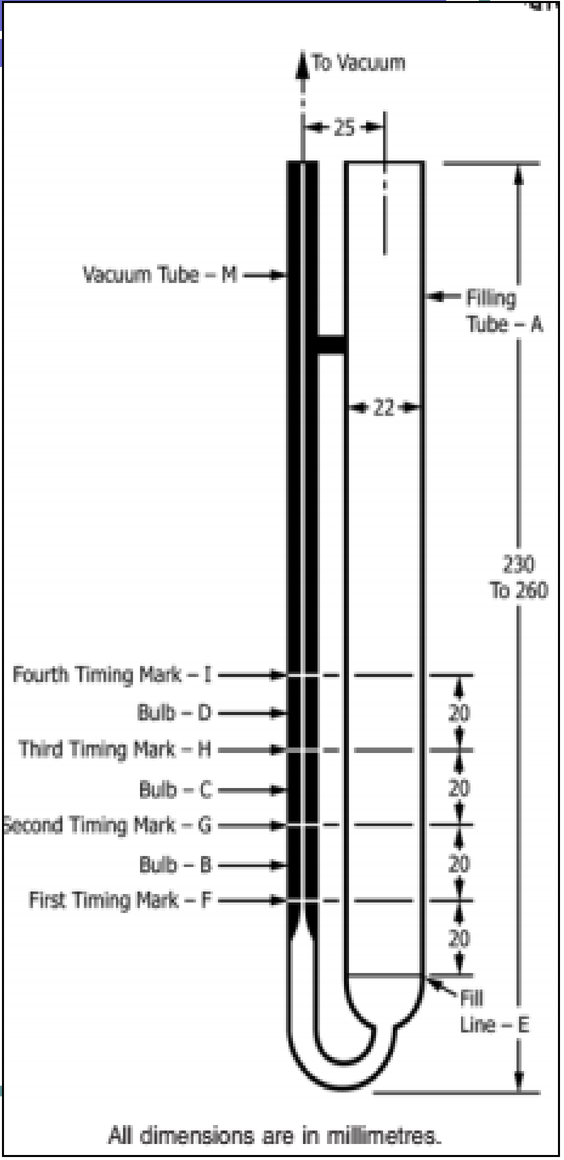
$$\eta = \nu \times \rho \times 10^{-3} \qquad (3)$$

where:

η = dynamic viscosity, mPa·s,

ρ = density, kg/m³, at the same temperature used for the determination of the kinematic viscosity, and

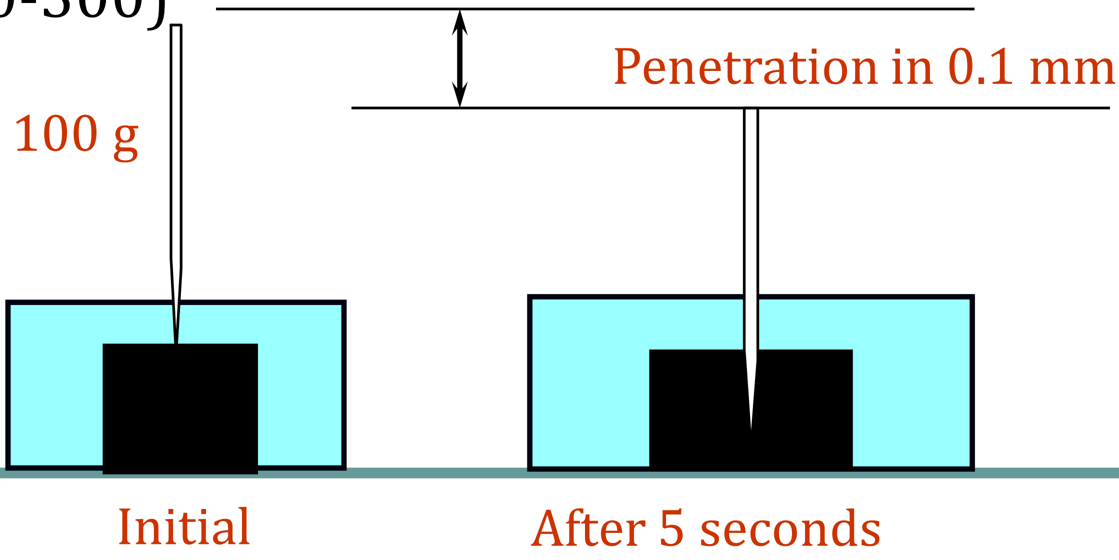
ν = kinematic viscosity, mm²/s.



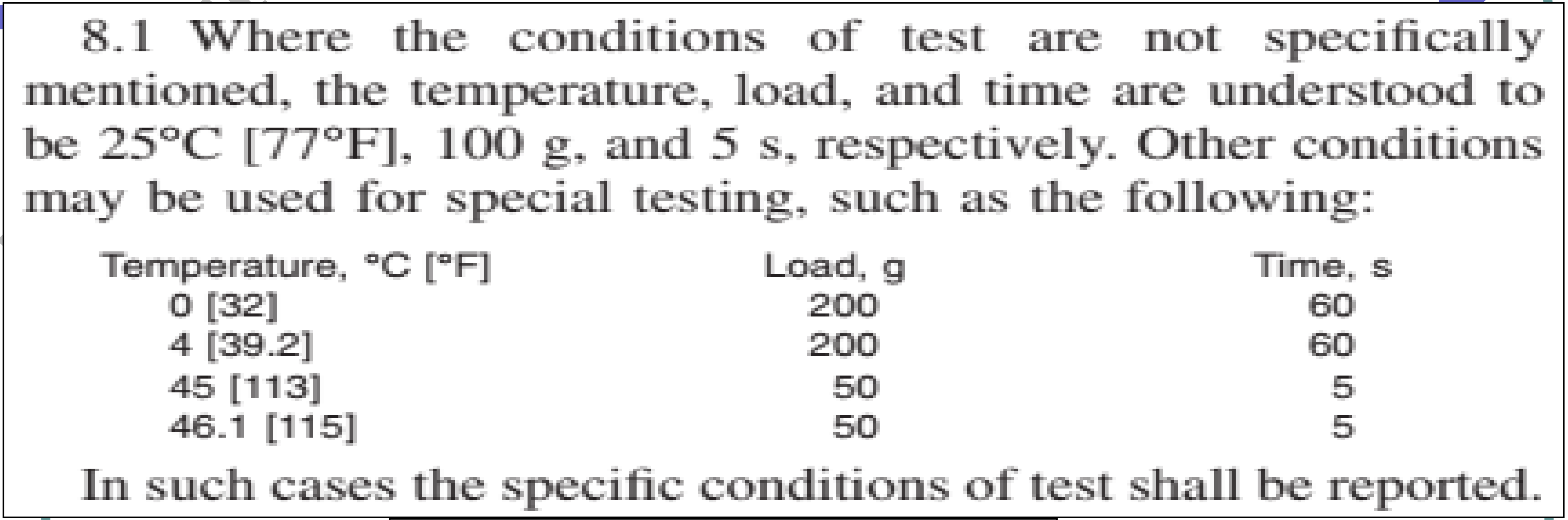
All dimensions are in millimetres.

Consistency Tests/ Penetration Test /ASTM D5

- ASTM D5: Standard Test Method for Penetration of Bituminous Materials
- The distance in tenths of millimeters 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)



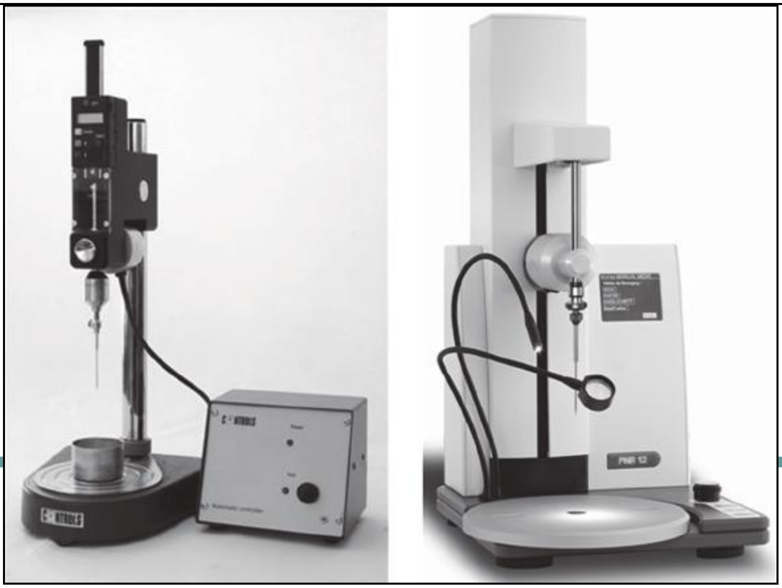
Penetration Test /ASTM D5



8.1 Where the conditions of test are not specifically mentioned, the temperature, load, and time are understood to be 25°C [77°F], 100 g, and 5 s, respectively. Other conditions may be used for special testing, such as the following:

Temperature, °C [°F]	Load, g	Time, s
0 [32]	200	60
4 [39.2]	200	60
45 [113]	50	5
46.1 [115]	50	5

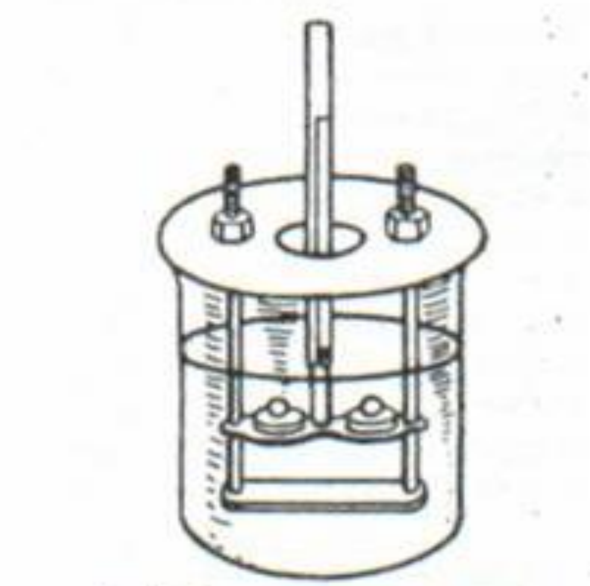
In such cases the specific conditions of test shall be reported.



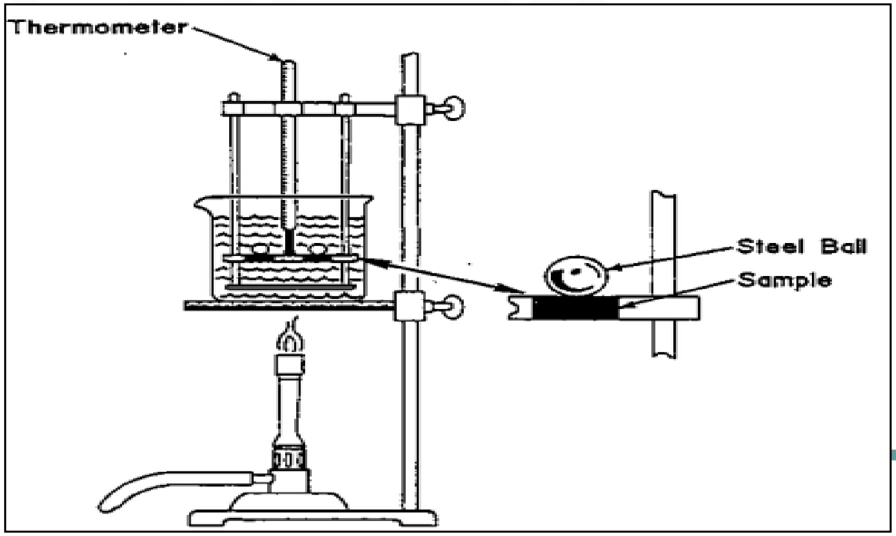
Consistency/ Softening Point

- ASTM D36: Standard Test Method for Softening Point of asphalt (Ring-and-Ball Apparatus)
- This test method covers the determination of the softening point of asphalt in the range from 30 to 157 °C (86 to 315 °F) using the ring-and-ball apparatus immersed in Distilled water (30 to 80°C); USP glycerin (above 80 to 157 °C), Ethylene glycol (30 to 110 °C)
- 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



It is the temperature at which an asphalt cement **cannot** support the weight of a steel ball and starts flowing

Relation between penetration and softening point tests

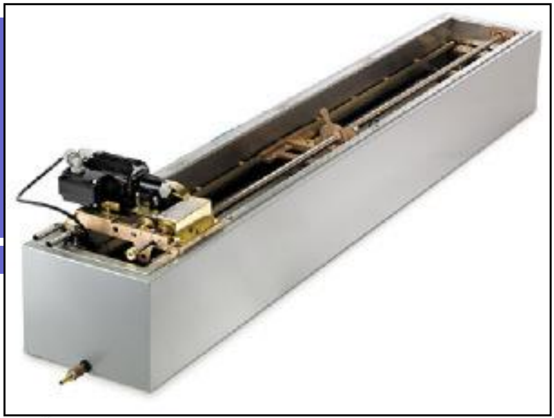
The softening point may be estimated from the penetration value for paving grade asphalt with penetration ranging from 40 to 100 dmm,

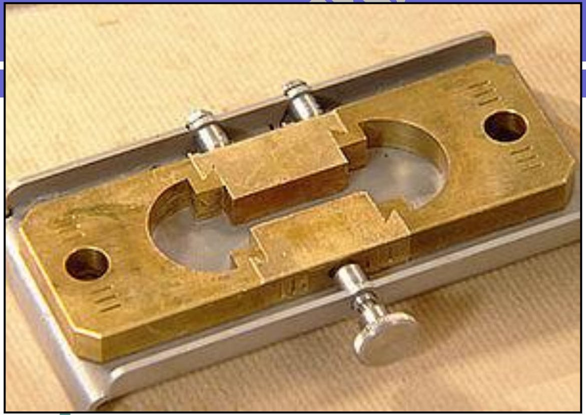
- $t_{R\&B} = 87.3 - 22.5 \times \text{Log}(P)$
- Where
  - $t_{R\&B}$ is the softening point (°C)
  - Log (P) is the logarithm (base 10) of penetration at 25°C

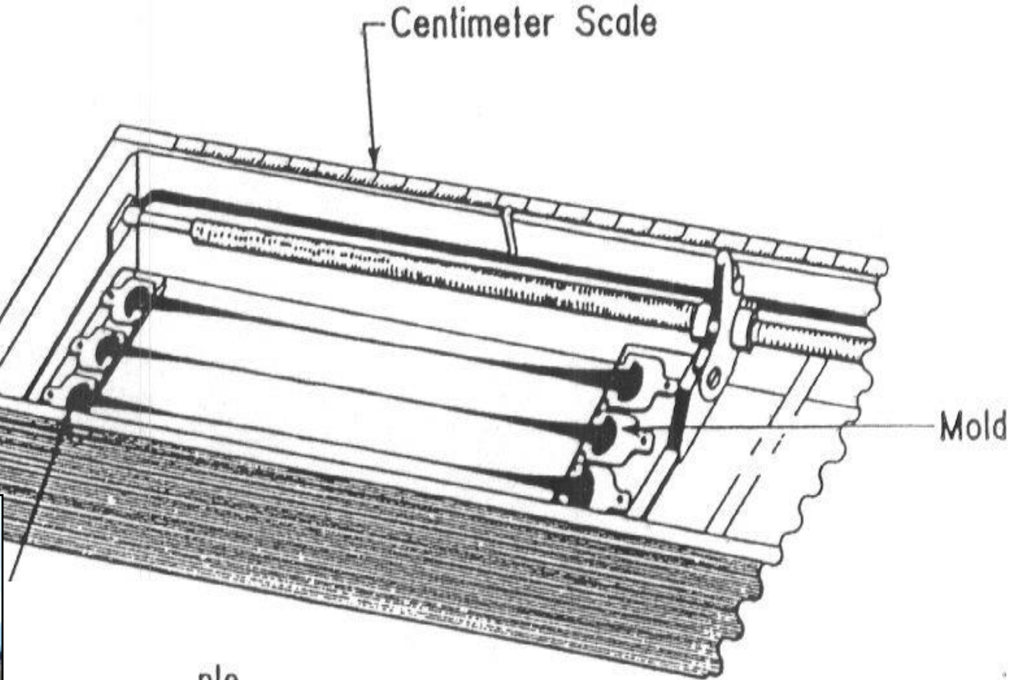
Consistency Tests/ Ductility

- ASTM D113: Standard Test Method for Ductility of Bituminous Materials
- 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 ^{o} C, 5 cm/min,
- Spec. +100 cm

Ductelometer







-19. Ductility Test

Durability Tests/ Thin Film Oven Test (TFO)/ ASTM D1754

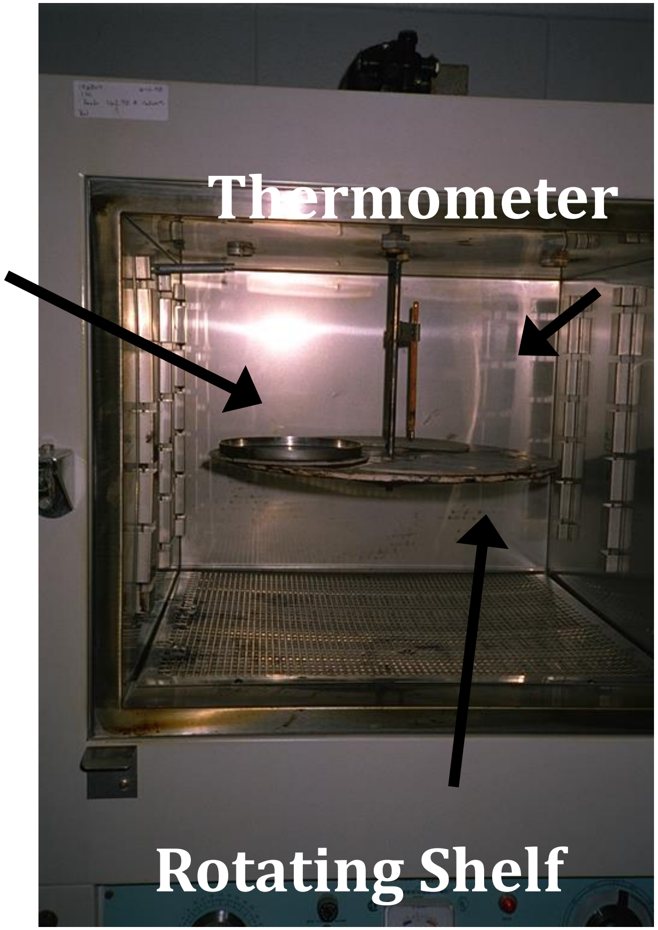
- ASTM D1754 : Standard Test Method for Effects of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)
- **TFO test measures the combined effects of heat and air on a film of asphalt or bituminous binder**
- **It simulates hardening (durability) characteristic of asphalt binder during mix production and construction (Short-term ageing)**
- **The consistency of the material is determined before and after the TFO procedure using either the penetration test or a viscosity test to estimate the amount of hardening that will take place in the material when used to produce plant hot-mix asphalt.**
- The specimen shall have a minimum percentage retained penetration or maximum viscosity

Durability Tests/ Thin Film Oven Test (TFO)/ ASTM D1754

- Procedures
  - The **quantity of asphalt, 50 ± 0.5 g,** is placed on a stainless steel or aluminum cylindrical pan of 140 mm diameter and 9.5 mm wall height, thus, forming a film of approximately 3.2 mm thickness.
  - The oven is ventilated and possesses a rotating metallic tray (of minimum 250 mm diameter) on the vertical axis, on which the asphalt specimens are positioned.
  - **After 5 hrs**, during which the specimens are constantly rotating **at 163 °C ± 1 °C,**
  - **The weight loss, the penetration, softening point and viscosity values of the hardened asphalt are measured**
  - **The penetration, softening point and viscosity values after the TFOT test are compared to the initial values (before hardening)**

Thin Film Oven

Outside of Oven



Rolling Thin Film Oven test RTFO

ASTM D2872: Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test.

- Scope: It has the same purpose as the TFO, but the test setup was modified to achieve several advantages over the TFO including :
    - Less testing time
    - Ability to test large number of samples
- The **differences between the TFOT and the RTFOT** methods are: *Type of oven used; The quantity of the asphalt sample; The type of containers; The duration of rotation and the absence of applying airflow on the samples*.

Rolling film oven test RTFO

Ageing Simulation Tests

Rolling Thin-Film Oven (RTFO): SUPERPAVE Specification

Simulates **short-term ageing** by heating a moving film of bitumen in an oven for **85 minutes** at 163 ^{0}C (325 ^{0}F)

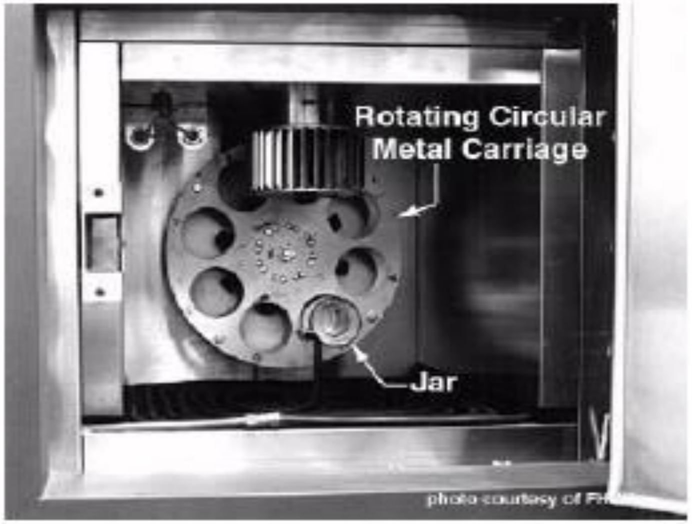


Figure : Rolling Thin-Film Oven Test

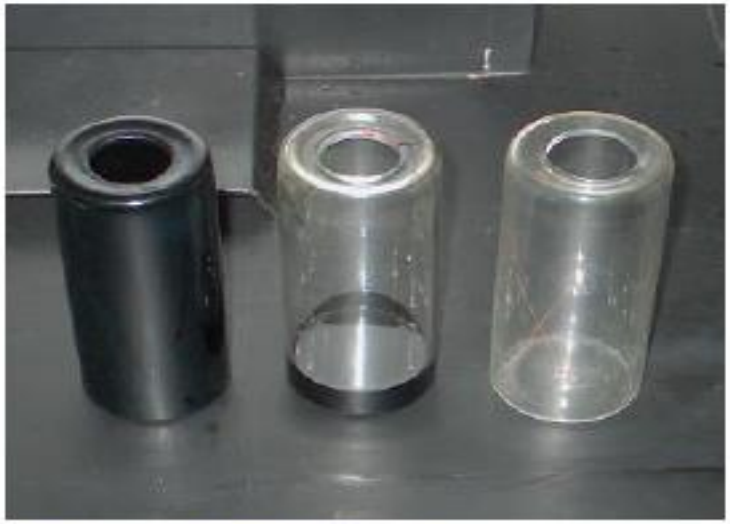


Figure : RTFO Samples
(left - after aging in the RTFO,
center - before aging in the RTFO,
right - empty sample jar)

Rolling Thin Film Oven test RTFO

ASTM D2872:Test procedures

- The small **quantity of asphalt, 35 ± 0.5 g,** is poured in each special glass container, and when the oven attains the test temperature, **163°C ± 0.5°C**, the samples are positioned in the vertical circular carriage.
- The carriage assembly starts to **rotate at a rate of 15 revolutions per minute (rpm)** by applying airflow at a rate of 4 l/min.
- **After rotating for 75 min**, two samples are taken out, allowed to cool and weighed, in order to **determine the change in mass**.
- The rest of the samples are immediately poured in the same collecting vessel for **penetration and softening testing and, if required, for determining dynamic viscosity (η).**
- The penetration, softening point and viscosity values after the RTFO (hardened asphalt) are compared to the corresponding values before RTFO.

Ageing Simulation Tests

Pressure Ageing Vessel (PAV) : SUPERPAVE Specification

simulate the effects of long-term bitumen ageing that occurs as a result of 5 to 10 years HMA pavement service

Figure : Pressure Ageing Vessel

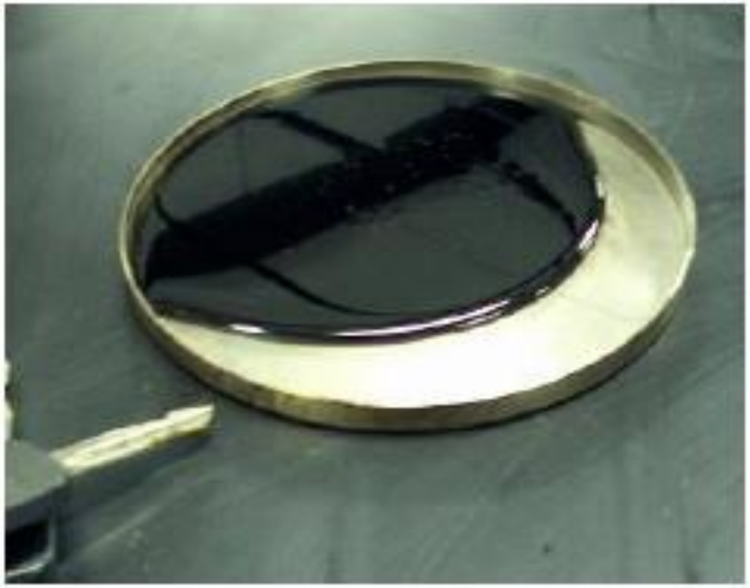
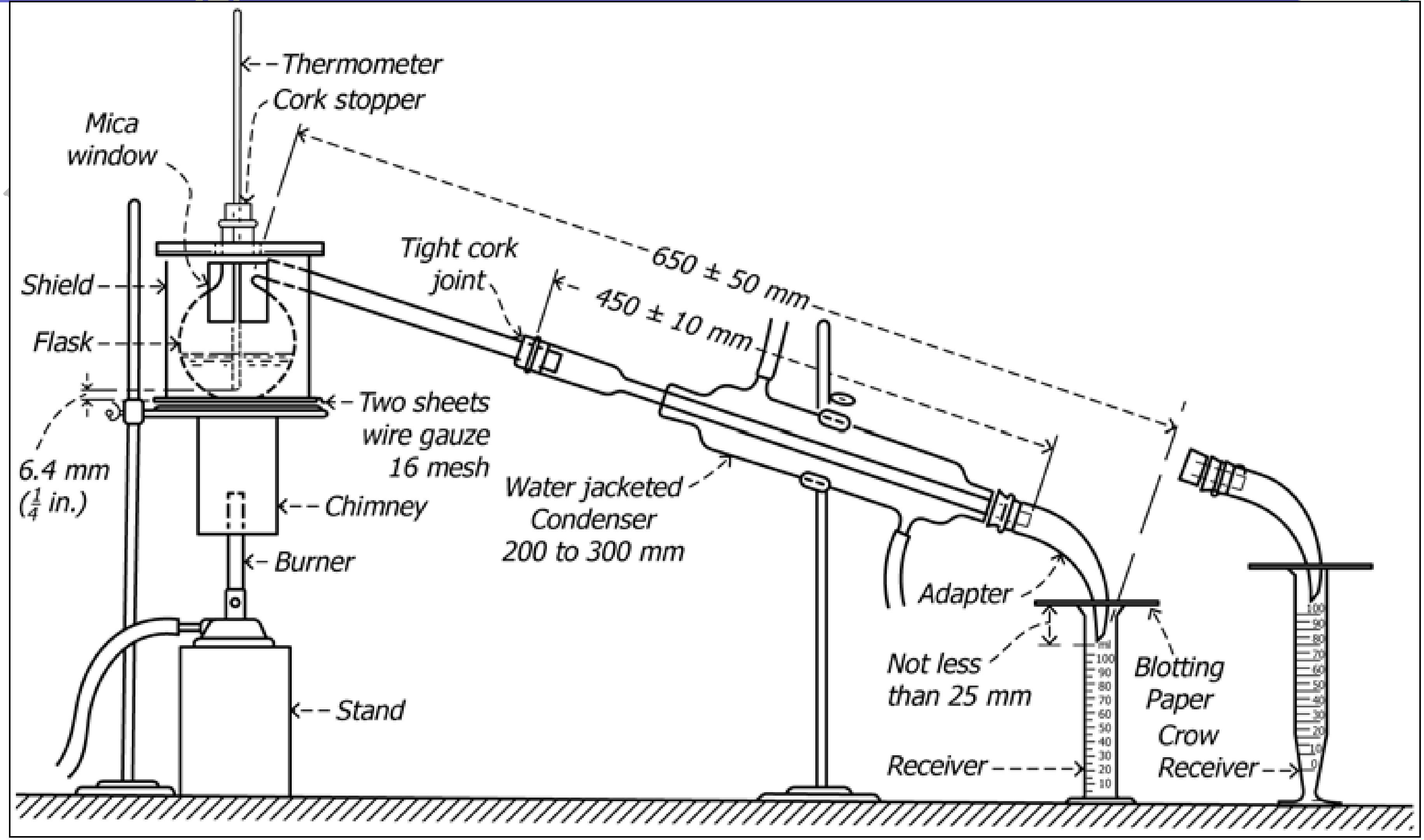


Figure: PAV Sample

Durability Tests/ Distillation of CutBack Asphalt ASTM D402

- ASTM D402
  - Standard Test Method for Distillation of Cutback Asphalt
- Scope
  - This test method covers a distillation test for cutback asphalts
- Significance and Use
  - **This procedure measures the amount of the more volatile constituents in cutback asphalt.**
    - **Used to separate volatile from nonvolatile substances.**
- Summary of Method
  - Two hundred milliliters of the sample are distilled in a 500-mL flask, at a controlled rate, to a temperature in the liquid of 360°C [680°F],
  - The volumes of distillate obtained at specified temperatures are measured.

Distillation of Cutback Asphalt



Durability Tests/ Loss on Heating ASTM D6

- Scope: This test method covers the determination of the loss in mass (exclusive of water) of oil and asphaltic compounds when heated as hereinafter prescribed
  - Determine % of volatile material.
- Significance and Use
  - This test method is **useful in characterizing certain petroleum products by the determination of their loss of mass upon heating under standardized conditions**
- Summary of Test Method
  - 50 g of material, spread out in a dish 55 mm in diameter, is heated in moving air (i.e., RTFO) for 5 h at 163°C (325°F)
  - The percent loss of mass determined along with a comparison, before and after, of any other desired characteristics.
  - This test method provides only a relative measurement of the volatility of a material under test conditions.

Safety Tests / Flash & Fire Points ASTM 1310

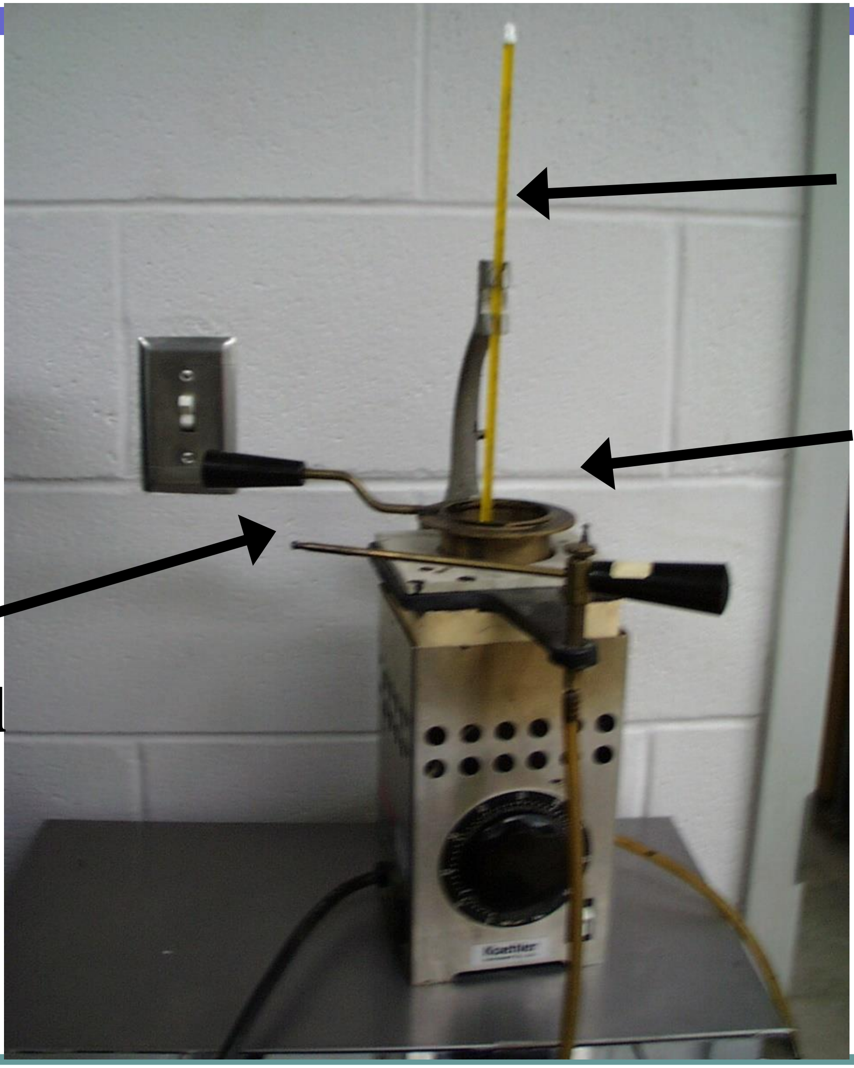
- Known as safety test.
- Cleveland Open cup.
- AC heated at specified rate.
- Flames pass across the surface.
- Min temp. at which sparks appear on the AC surface is reported as flash point.
- For any type of asphalt grade
  - Minimum Flash point value should be = 175 °C
  - Minimum Fire point value should be = 175 °C + 5 °C.

Safety Tests / Flash & Fire Points
ASTM 1310

ASTM D1310 : Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester

- Scope: This test method describes the determination of the flash point and fire point of petroleum products by a manual Cleveland open cup apparatus or an automated Cleveland open cup apparatus.
- **Flash point is defined as : The lowest temperature corrected to a barometric pressure of 101.3 kPa ,at which application of an ignition source causes the vapors of a specimen of the sample to ignite under specified conditions of test**
- **Fire point is defined as: The lowest temperature corrected to a barometric pressure of 101.3 kPa at which application of an ignition source causes the vapors of a test specimen of the sample to ignite and sustain burning for a minimum of 5 s under specified conditions of test.**

Flash & Fire Point Test Appartus



Thermometer

Cup filled with asphalt

Wand attached to gas line

Flash & Fire Points/ Significance and Use

- The flash and fire points are **useful for safety and security reasons for the avoidance of accidents in case of overheating the asphalt.**
- **The flash point is one measure of the tendency of the test specimen to form a flammable mixture** with air under controlled laboratory conditions.
- Flash point **can indicate the possible presence of highly volatile and flammable materials** in a relatively nonvolatile or nonflammable material. For example, an abnormally low flash point on a test specimen of engine oil can indicate gasoline contamination
- The fire point is one measure of the **tendency of the test specimen to support combustion**

Specific Gravity of Asphalt ASTM D70)

- *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 equation:

$$S.G = (C-A) / [(B-A) – (D-C)]$$

where:

A = mass of pycnometer (plus stopper),
B = mass of pycnometer filled with water,
C = mass of pycnometer partially filled with asphalt,
D = mass of pycnometer plus asphalt plus water.

- Calculate density to the nearest 0.001 as follows:

$$\text{Density} = \text{specific gravity} * \gamma_w$$

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

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.

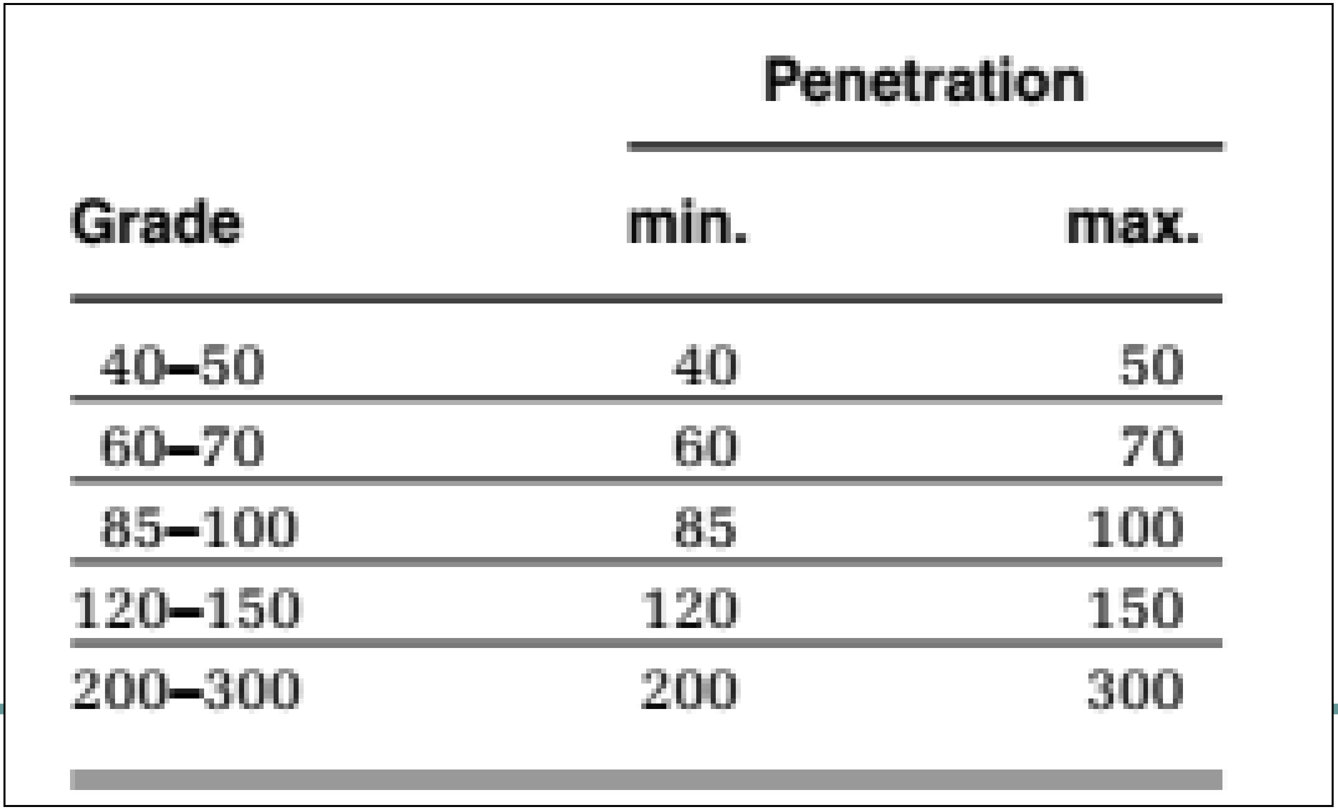
Asphalt binder grading systems

Available systems :

- Grading By Chewing
- Penetration Grading system (ASTM D946)
- Viscosity Grading system based on original asphalt cement (AC system)
- Viscosity Grading system based on aged asphalt cement (AR system)
- Superpave Performance Grade (PG) system

Penetration Grading system

- Binders are classified based on penetration test results
- Five penetration grades are specified

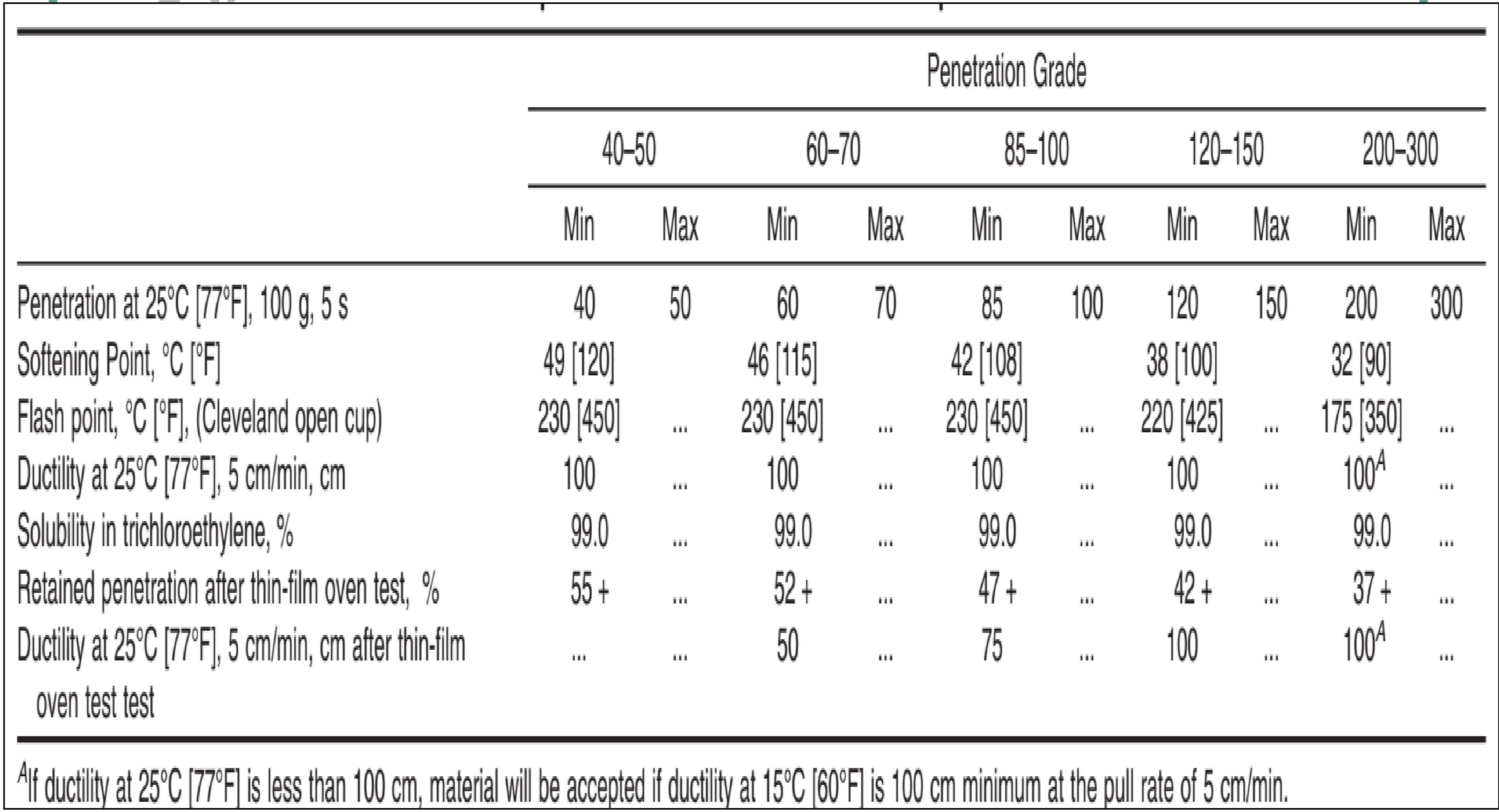


	Penetration	
Grade	min.	max.
40–50	40	50
60–70	60	70
85–100	85	100
120–150	120	150
200–300	200	300

Penetration Grading system

- The selection of the most suitable grade is based on the climatic and traffic conditions encountered.
    - The softest grade (200-300) is used in cold climate, while the hardest grade (40-50) is used in hot areas.
- The system also add specification for:
    - Flash point test
    - Ductility
    - Solubility
    - Thin film oven aging
        - Penetration
        - Ductility

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.

JORDAN PETROLEUM REFINERY CO. LTD

Specifications of Asphalt 60-70

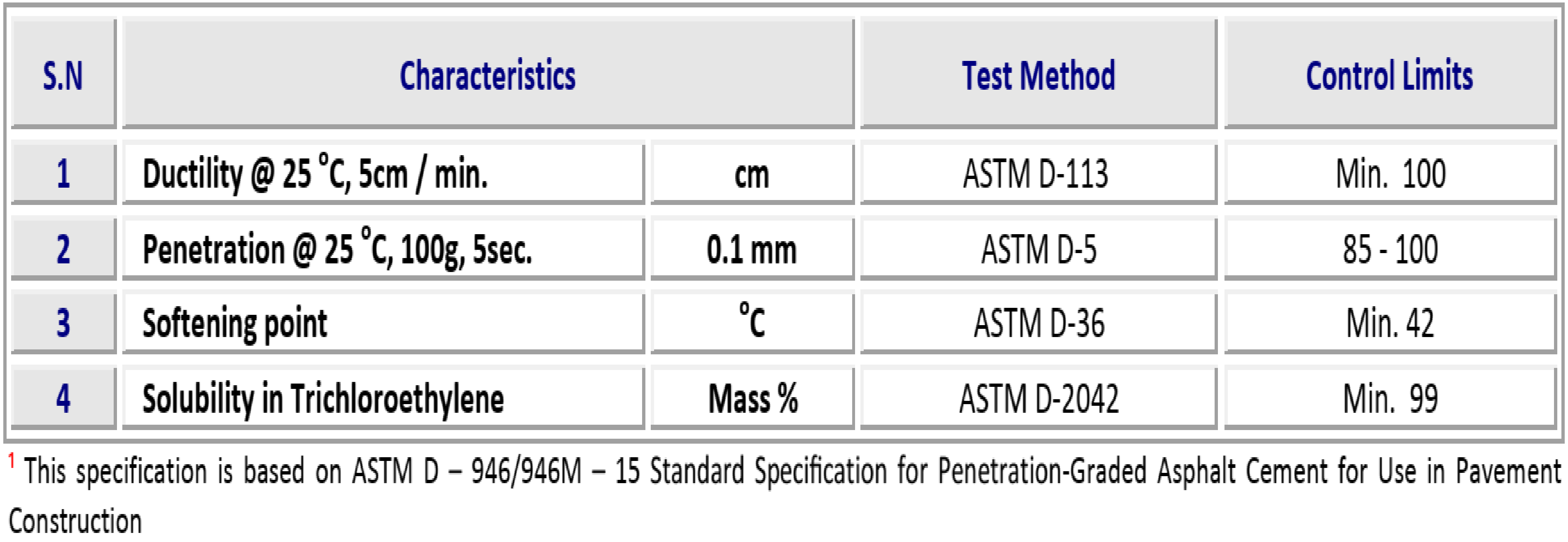
S.N	Characteristics		Test Method	Control Limits
1	Ductility @ 25 °C, 5cm / min.	cm	ASTM D113	Min. 100
2	Flash Point	°C	ASTM D92	Min. 232
3	Penetration @ 25 °C, 100g, 5 sec.	0.1 mm	ASTM D5	60 - 70
4	Solubility in Trichloroethylene	Mass %	ASTM D2042	Min. 99.0
5	Performance after Thin-film Oven Test_ ASTM D1754			
5.1	Retained Penetration.	%	ASTM D5	Min. 52+
5.2	Ductility at 25°C, 5 cm/min.	cm	ASTM D113	Min. 50

[1] This specification is based on Jordanian Technical Regulation # JS 612:1989, and ASTM D946/D946M-15 for Asphalt- Penetration Graded Asphalt Cement for Use in Pavement Construction.

[2] The asphalt binder shall be homogeneous, free from water and foreign matter, and shall not foam when heated to 175°C.

JORDAN PETROLEUM REFINERY CO. LTD

Specifications of Asphalt 85-100



S.N	Characteristics		Test Method	Control Limits
1	Ductility @ 25 °C, 5cm / min.	cm	ASTM D-113	Min. 100
2	Penetration @ 25 °C, 100g, 5sec.	0.1 mm	ASTM D-5	85 - 100
3	Softening point	°C	ASTM D-36	Min. 42
4	Solubility in Trichloroethylene	Mass %	ASTM D-2042	Min. 99

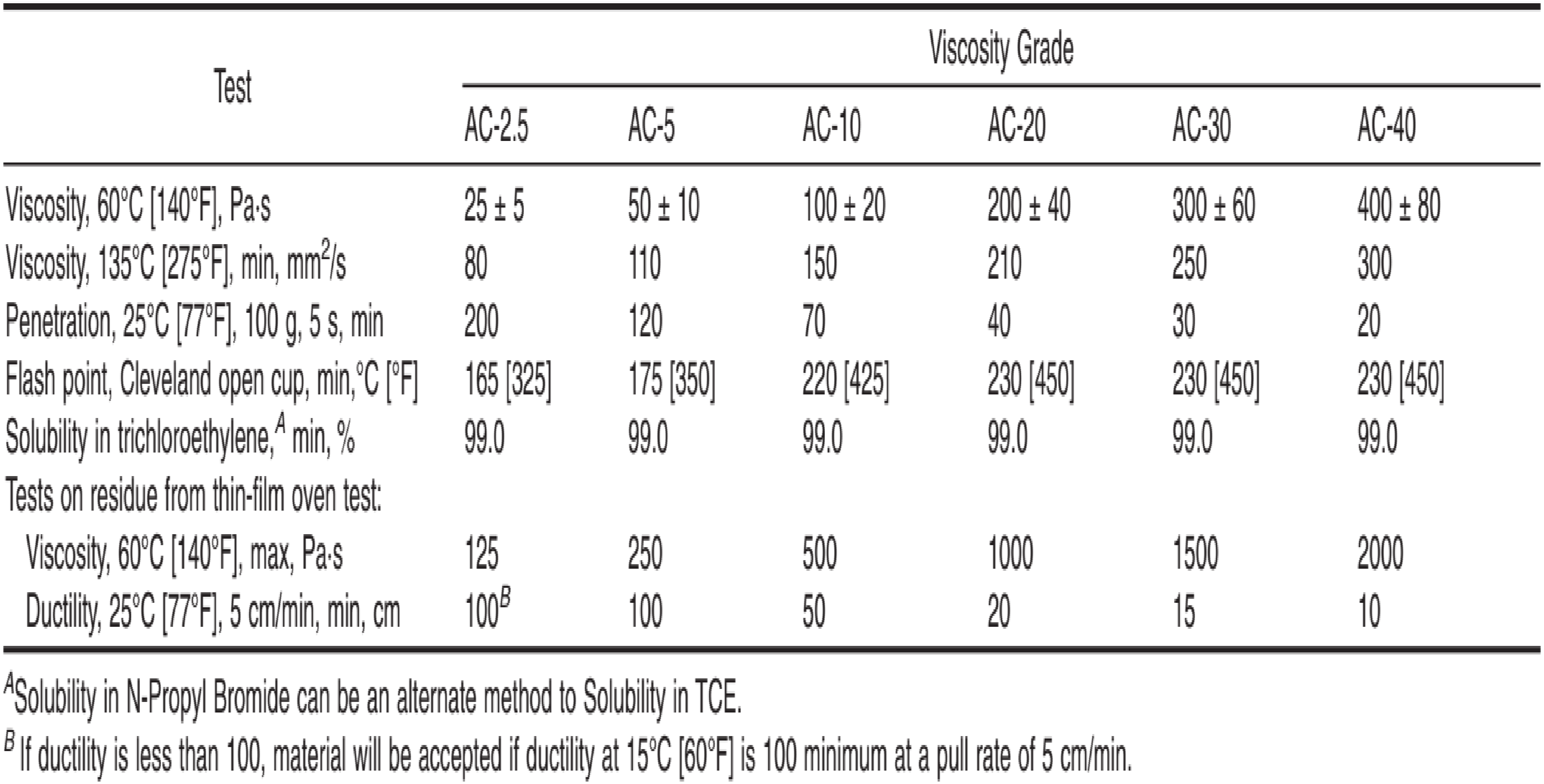
[1] This specification is based on ASTM D – 946/946M – 15 Standard Specification for Penetration-Graded Asphalt Cement for Use in Pavement Construction

Viscosity Grading system based on original asphalt cement (AC system)

- This specification covers asphalt cements graded by viscosity of original sphalt cement at 60 °C for use in pavement construction.
- Six penetration grades are specified

Grade	Viscosity, 60°C , Pa·s
AC-2.5	25 ± 5
AC-5	50 ± 10
AC-10	100 ± 20
AC-20	200 ± 40
AC-30	300 ± 60
AC-40	400 ± 80

Requirements for Asphalt Cement, Viscosity Graded at 60°C Based on Original Asphalt



Test	Viscosity Grade					
	AC-2.5	AC-5	AC-10	AC-20	AC-30	AC-40
Viscosity, 60°C [140°F], Pa·s	25 ± 5	50 ± 10	100 ± 20	200 ± 40	300 ± 60	400 ± 80
Viscosity, 135°C [275°F], min, mm^2/s	80	110	150	210	250	300
Penetration, 25°C [77°F], 100 g, 5 s, min	200	120	70	40	30	20
Flash point, Cleveland open cup, min, °C [°F]	165 [325]	175 [350]	220 [425]	230 [450]	230 [450]	230 [450]
Solubility in trichloroethylene,[A] min, %	99.0	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:						
Viscosity, 60°C [140°F], max, Pa·s	125	250	500	1000	1500	2000
Ductility, 25°C [77°F], 5 cm/min, min, cm	100[B]	100	50	20	15	10

[A] Solubility in N-Propyl Bromide can be an alternate method to Solubility in TCE.

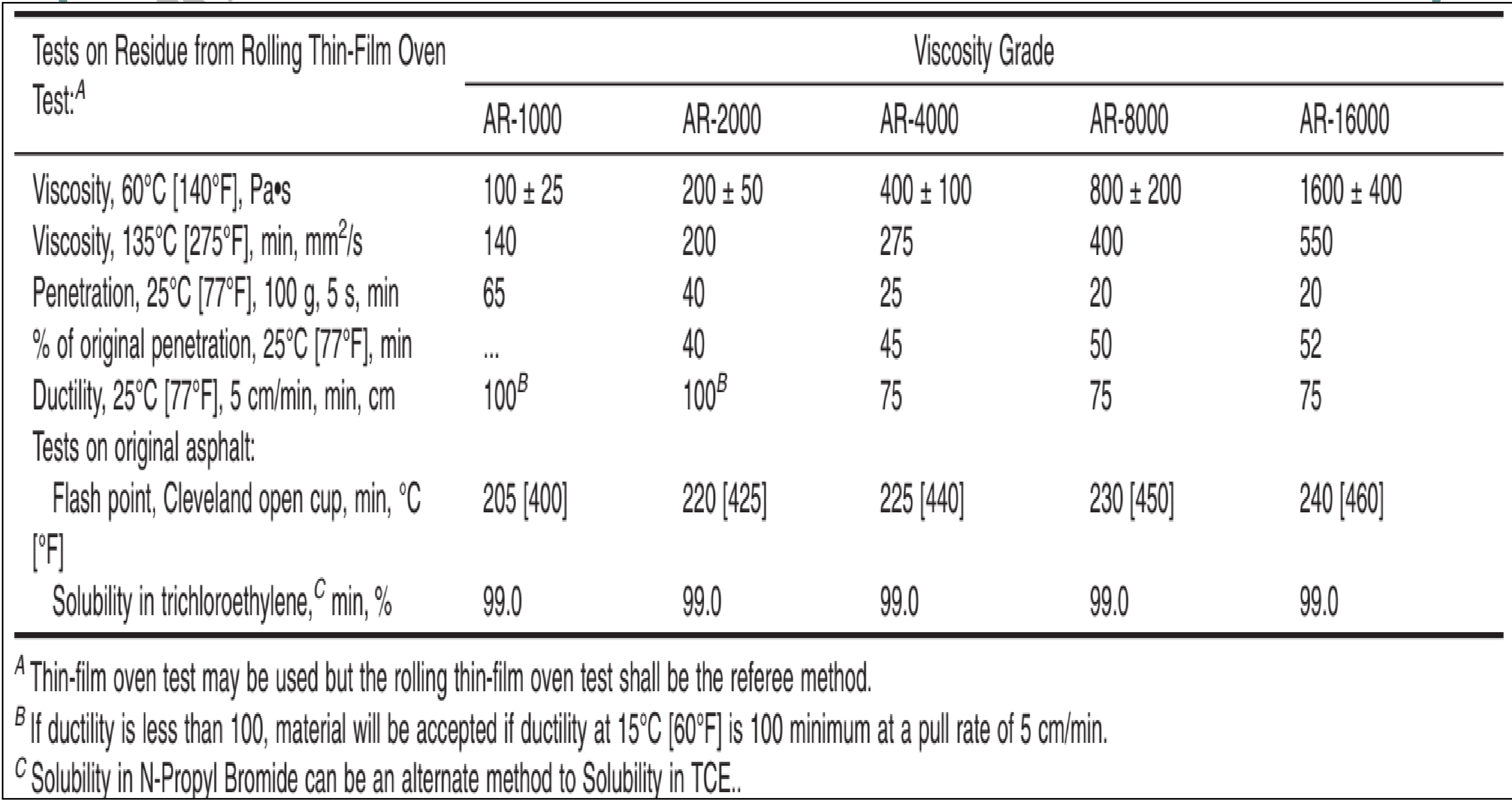
[B] If ductility is less than 100, material will be accepted if ductility at 15°C [60°F] is 100 minimum at a pull rate of 5 cm/min.

Viscosity Grading system based on aged asphalt cement (AR system)

- This specification covers asphalt cements graded by viscosity of aged asphalt cement at 60 °C for use in pavement construction.
  - Tests are performed on Residue from Rolling Thin-Film Oven
- Six penetration grades are specified

Grade	Viscosity, 60°C, Pa·s
AR-1000	100 ± 25
AR-2000	200 ± 50
AR-4000	400 ± 100
AR-8000	200 ± 40
AR-16000	1600 ± 400

Requirements for Asphalt Cement, Viscosity Graded at 60°C Based on Residue from Rolling Thin-Film Oven Test



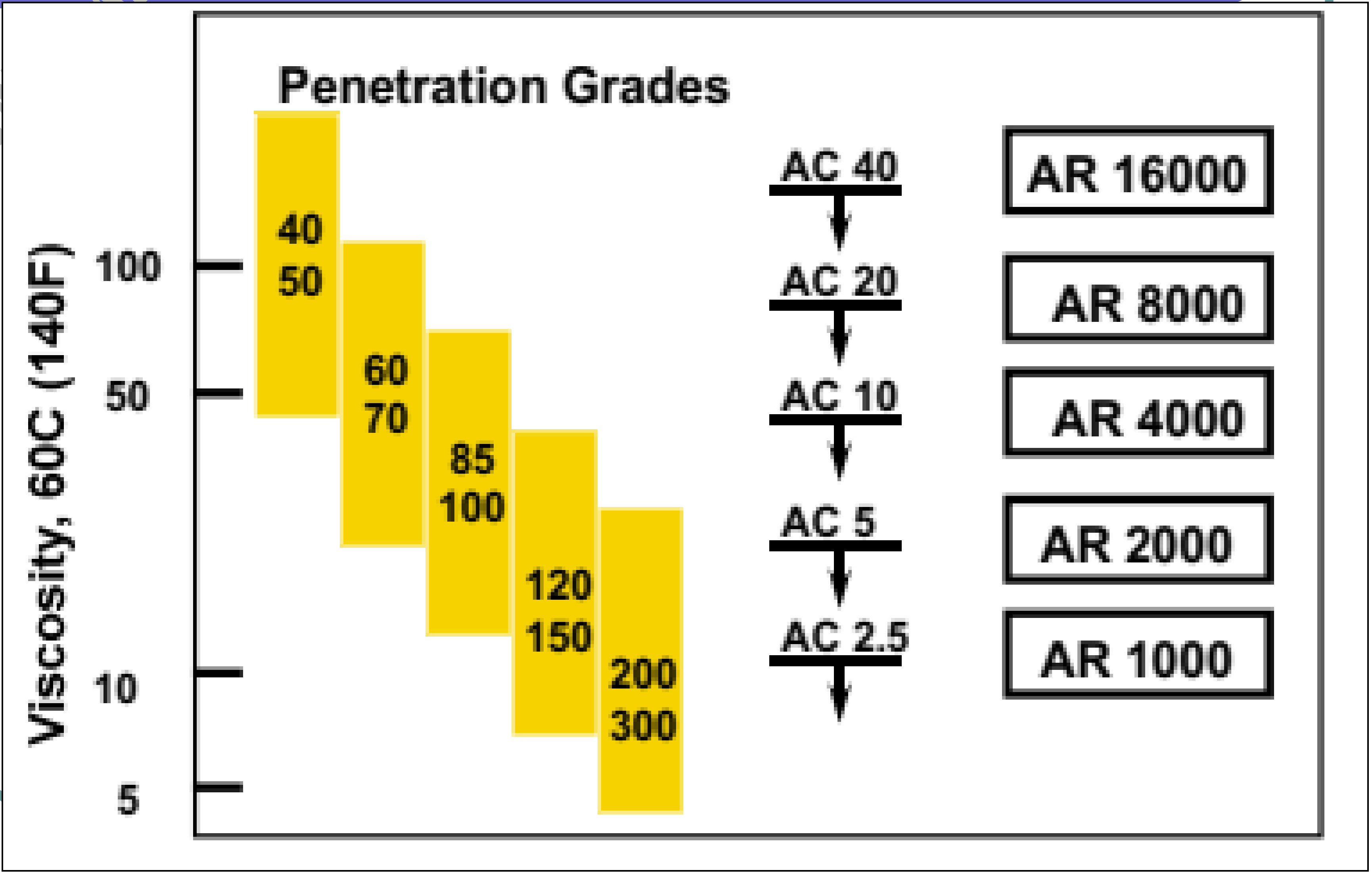
Tests on Residue from Rolling Thin-Film Oven Test:[A]	Viscosity Grade				
	AR-1000	AR-2000	AR-4000	AR-8000	AR-16000
Viscosity, 60°C [140°F], Pa•s	100 ± 25	200 ± 50	400 ± 100	800 ± 200	1600 ± 400
Viscosity, 135°C [275°F], min, mm^2/s	140	200	275	400	550
Penetration, 25°C [77°F], 100 g, 5 s, min	65	40	25	20	20
% of original penetration, 25°C [77°F], min	...	40	45	50	52
Ductility, 25°C [77°F], 5 cm/min, min, cm	100[B]	100[B]	75	75	75
Tests on original asphalt:					
Flash point, Cleveland open cup, min, °C [°F]	205 [400]	220 [425]	225 [440]	230 [450]	240 [460]
Solubility in trichloroethylene,[C] min, %	99.0	99.0	99.0	99.0	99.0

[A] Thin-film oven test may be used but the rolling thin-film oven test shall be the referee method.

[B] If ductility is less than 100, material will be accepted if ductility at 15°C [60°F] is 100 minimum at a pull rate of 5 cm/min.

[C] Solubility in N-Propyl Bromide can be an alternate method to Solubility in TCE..

Relation between different grading systems



Superpave: The Future of Asphalt

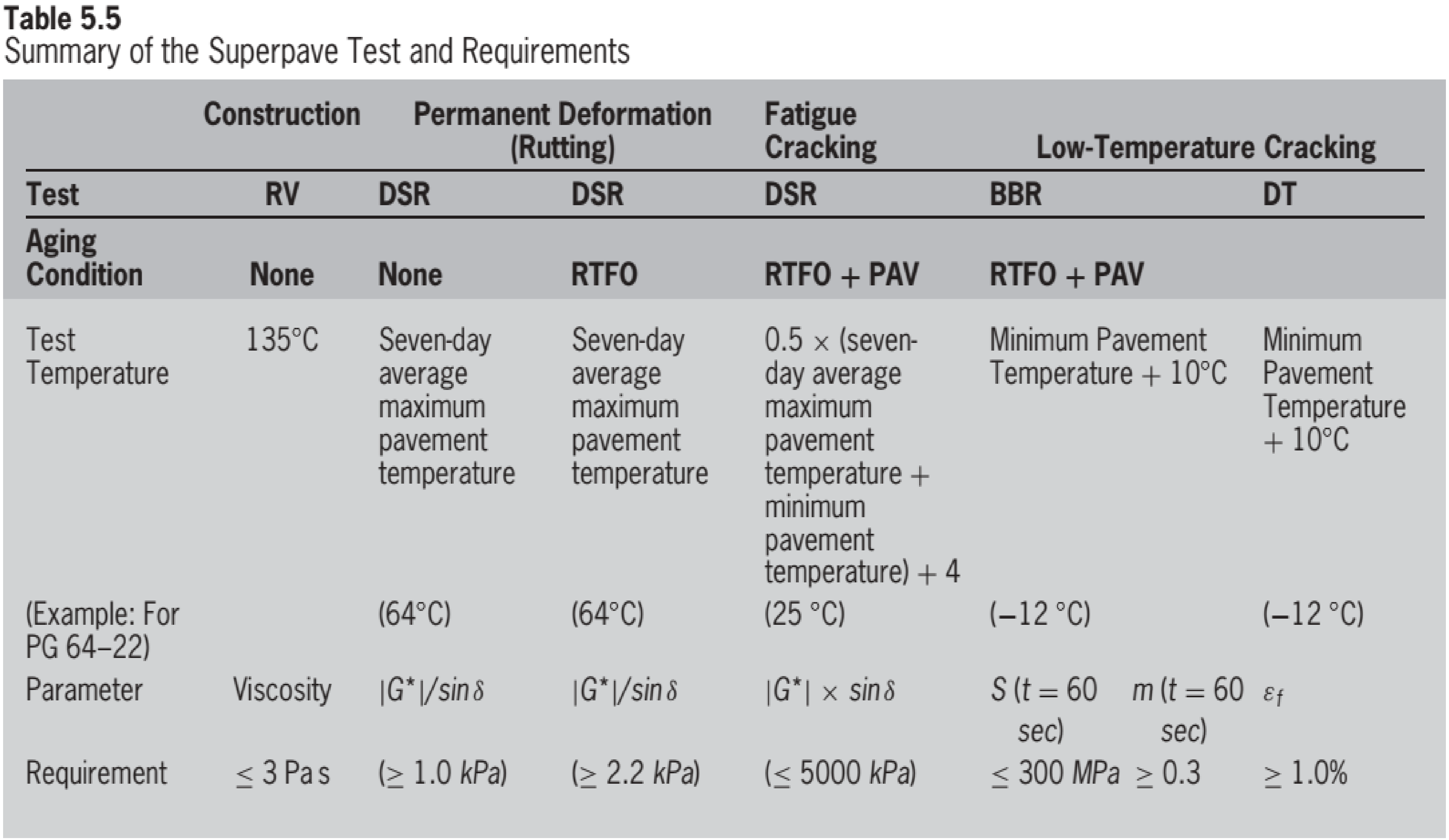
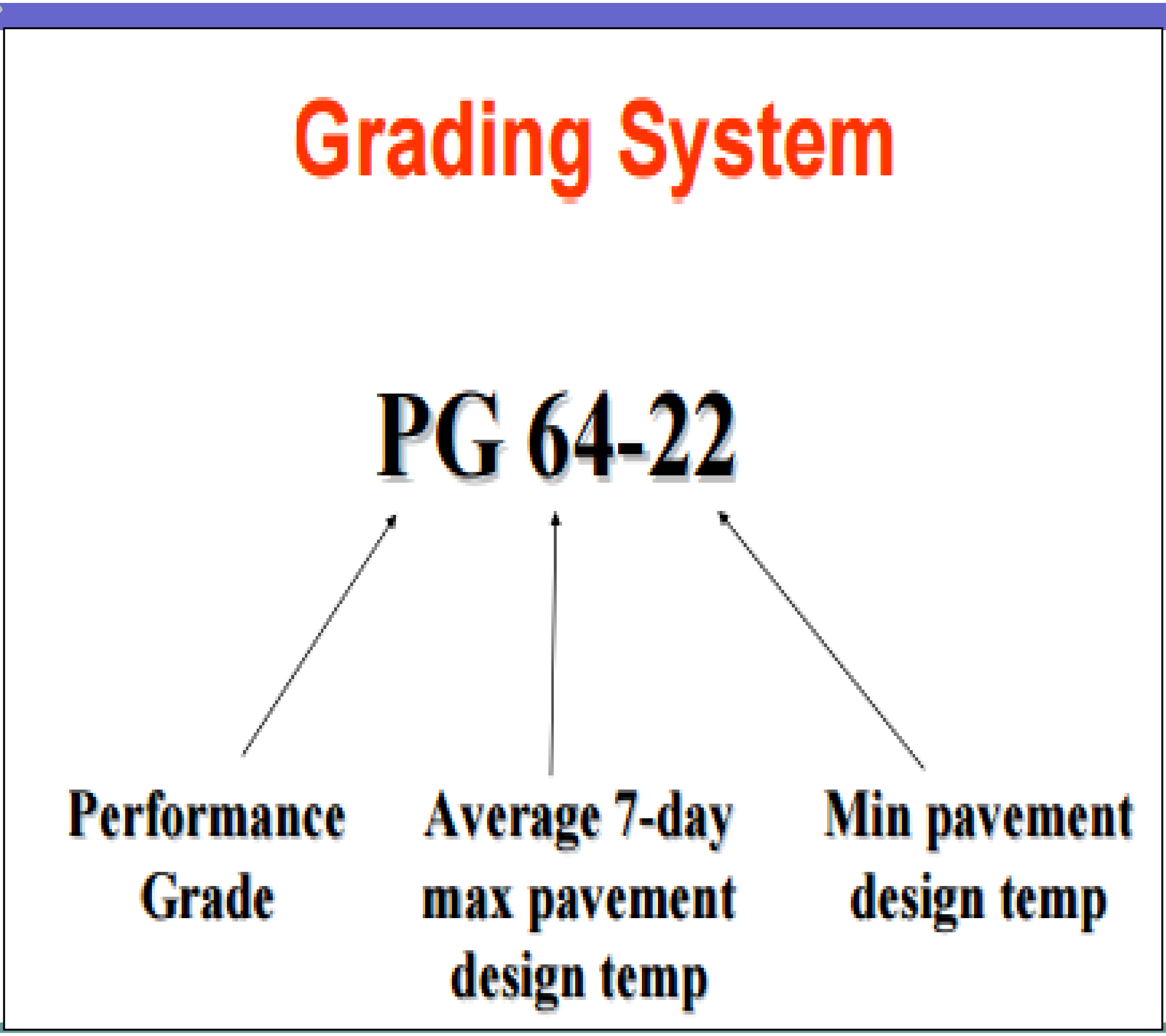


Table 5.5
Summary of the Superpave Test and Requirements

	Construction	Permanent Deformation (Rutting)		Fatigue Cracking	Low-Temperature Cracking		
Test	**RV**	**DSR**	**DSR**	**DSR**	**BBR**		**DT**
Aging Condition	**None**	**None**	**RTFO**	**RTFO + PAV**	**RTFO + PAV**		
Test Temperature	135°C	Seven-day average maximum pavement temperature	Seven-day average maximum pavement temperature	0.5 × (seven-day average maximum pavement temperature + minimum pavement temperature) + 4	Minimum Pavement Temperature + 10°C		Minimum Pavement Temperature + 10°C
(Example: For PG 64–22)		(64°C)	(64°C)	(25 °C)	(−12 °C)		(−12 °C)
Parameter	Viscosity	$\lvert G^* \rvert / \sin\delta$	$\lvert G^* \rvert / \sin\delta$	$\lvert G^* \rvert \times \sin\delta$	S ($t = 60$ sec)	m ($t = 60$ sec)	ε_f
Requirement	$\leq$ 3 Pa s	($\geq$ 1.0 kPa)	($\geq$ 2.2 kPa)	($\leq$ 5000 kPa)	$\leq$ 300 MPa	$\geq$ 0.3	$\geq$ 1.0%

Superpave Performance Grading



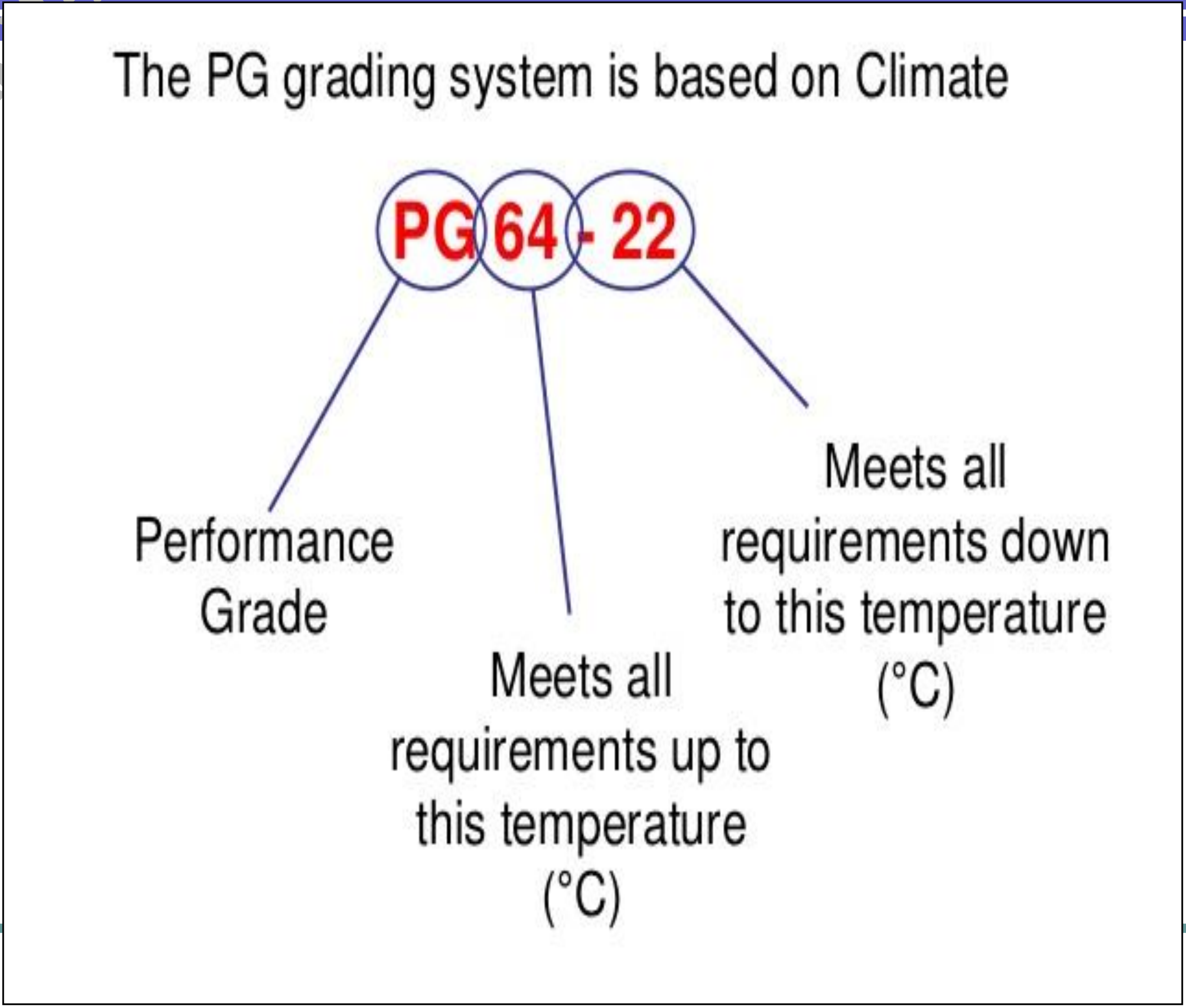
Grading System

PG 64-22

- Performance Grade
- Average 7-day max pavement design temp
- Min pavement design temp

Image source: http://rahabitumen.com/performance-grade-pg-bitumen/

Superpave Performance Grading



The PG grading system is based on Climate

PG 64 - 22

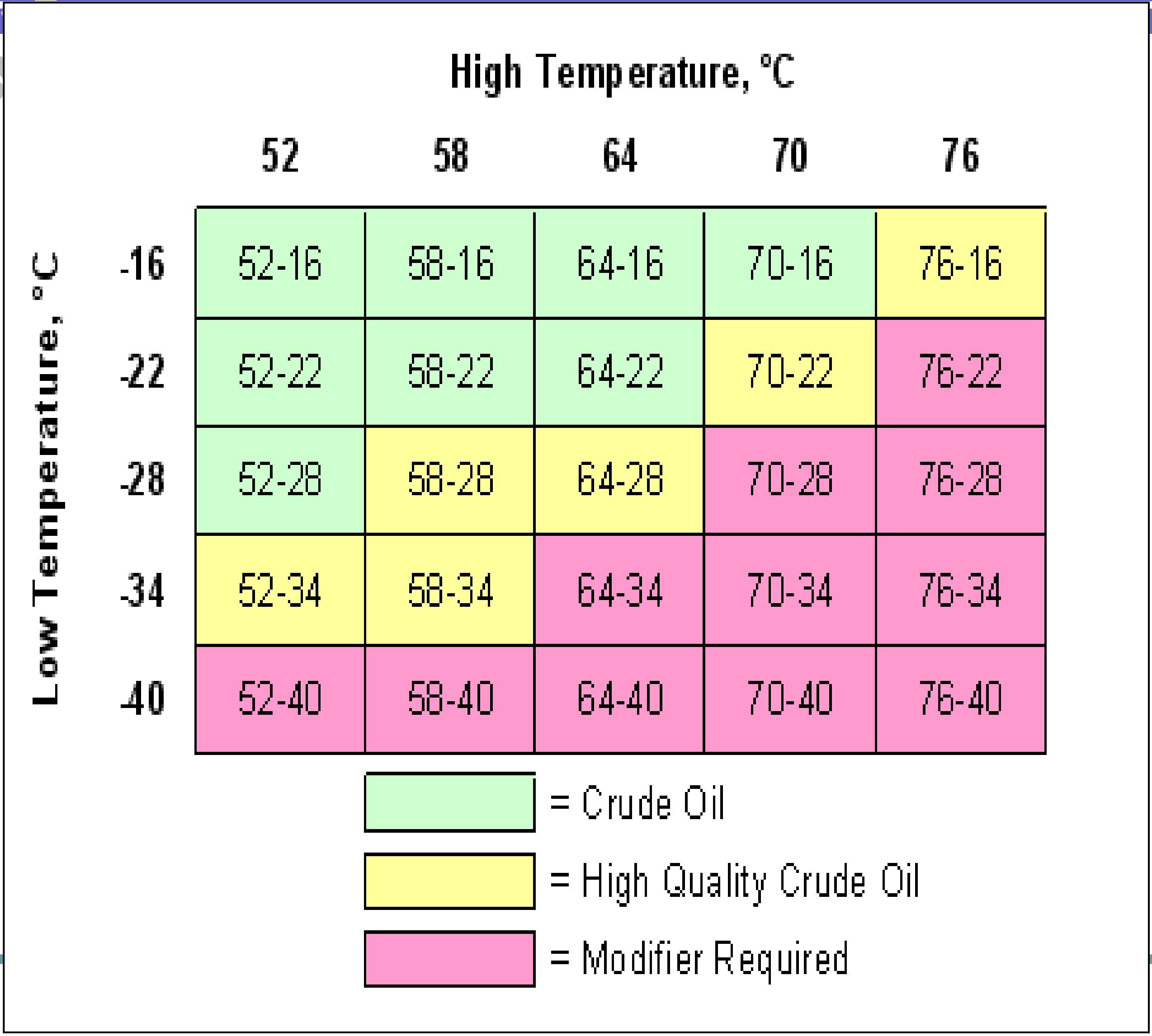
Performance Grade

Meets all requirements up to this temperature (°C)

Meets all requirements down to this temperature (°C)

Image source: https://www.slideshare.net/CaliforniaAsphalt/asphalt-binders-101

Superpave Performance Grading



High Temperature, °C

Low Temperature, °C

	52	58	64	70	76
-16	🟩 52-16	🟩 58-16	🟩 64-16	🟩 70-16	🟨 76-16
-22	🟩 52-22	🟩 58-22	🟩 64-22	🟨 70-22	🟥 76-22
-28	🟩 52-28	🟨 58-28	🟨 64-28	🟥 70-28	🟥 76-28
-34	🟨 52-34	🟨 58-34	🟥 64-34	🟥 70-34	🟥 76-34
-40	🟥 52-40	🟥 58-40	🟥 64-40	🟥 70-40	🟥 76-40

🟩 = Crude Oil

🟨 = High Quality Crude Oil

🟥 = Modifier Required

Superpave Performance Grading

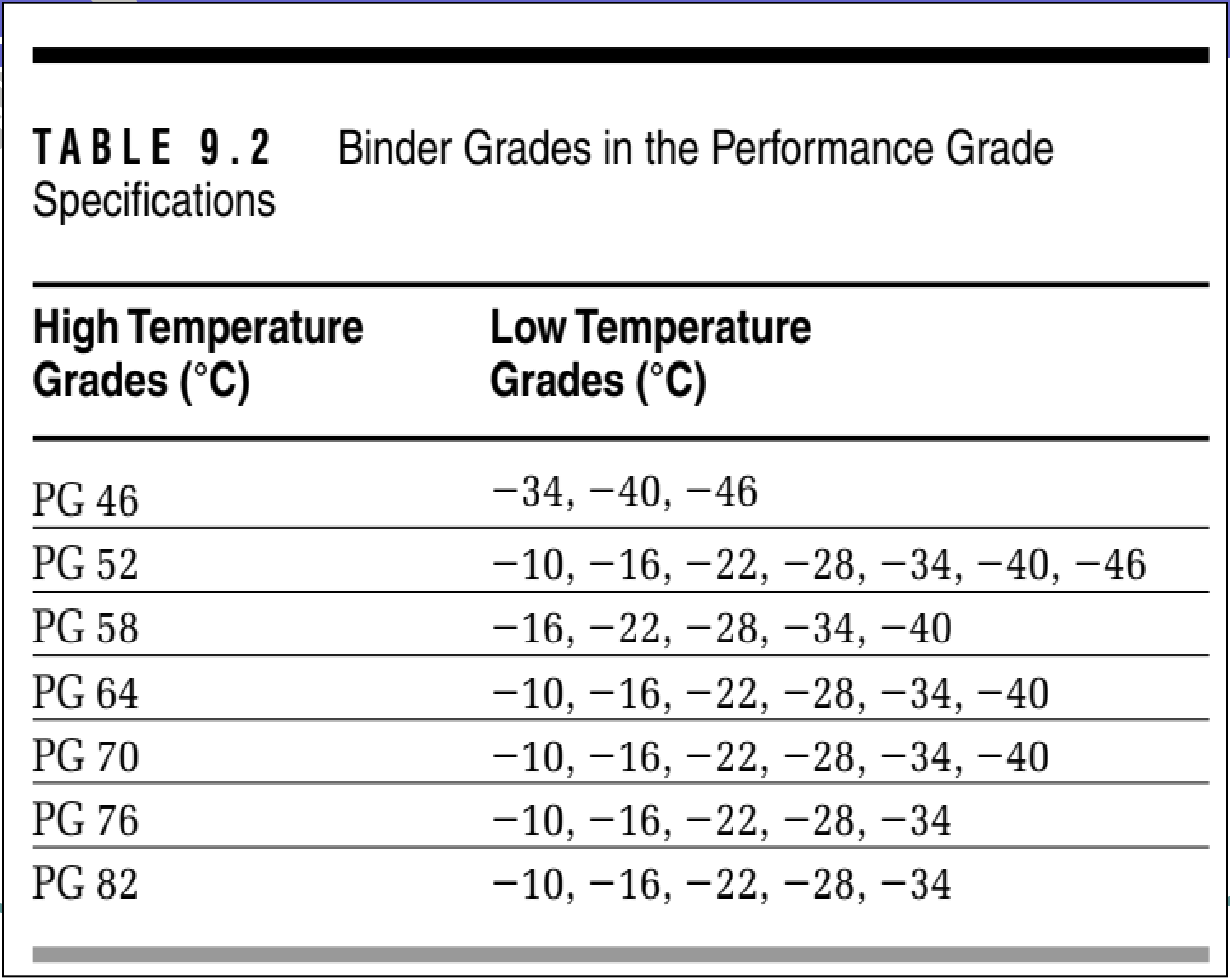


TABLE 9.2 Binder Grades in the Performance Grade Specifications

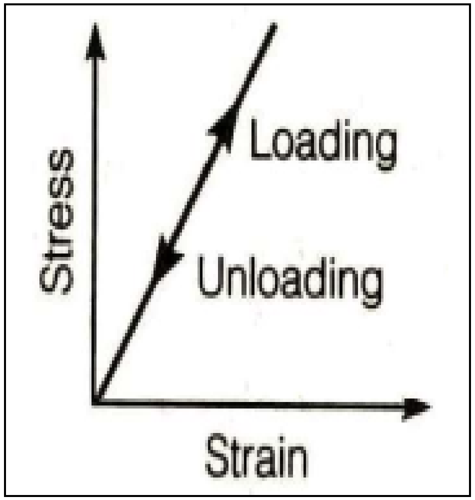
High Temperature Grades (°C)	Low Temperature Grades (°C)
PG 46	−34, −40, −46
PG 52	−10, −16, −22, −28, −34, −40, −46
PG 58	−16, −22, −28, −34, −40
PG 64	−10, −16, −22, −28, −34, −40
PG 70	−10, −16, −22, −28, −34, −40
PG 76	−10, −16, −22, −28, −34
PG 82	−10, −16, −22, −28, −34

Asphalt Binder Selection

Grading System	Climate	Traffic	Structural Design	Layer Location	Fundamental Properties Measured
Penetration	✓				
Viscosity	✓				✓
PG	✓	✓	✓	✓	✓

How Asphalt Behaves

- Elastic behavior
  - Returns to its original shape upon unloading
    - Such as a rubber



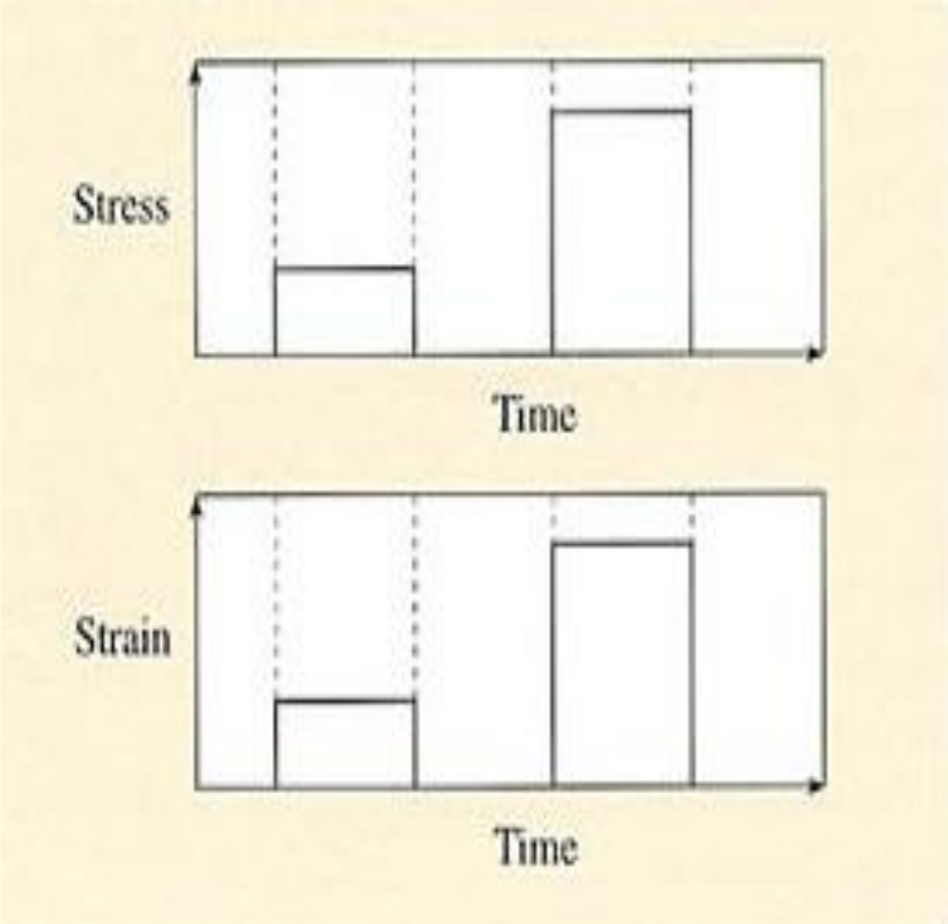
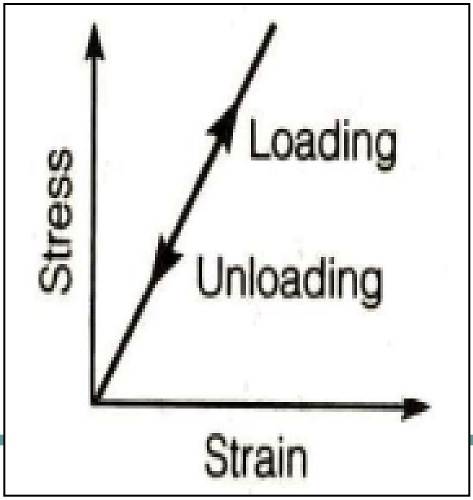
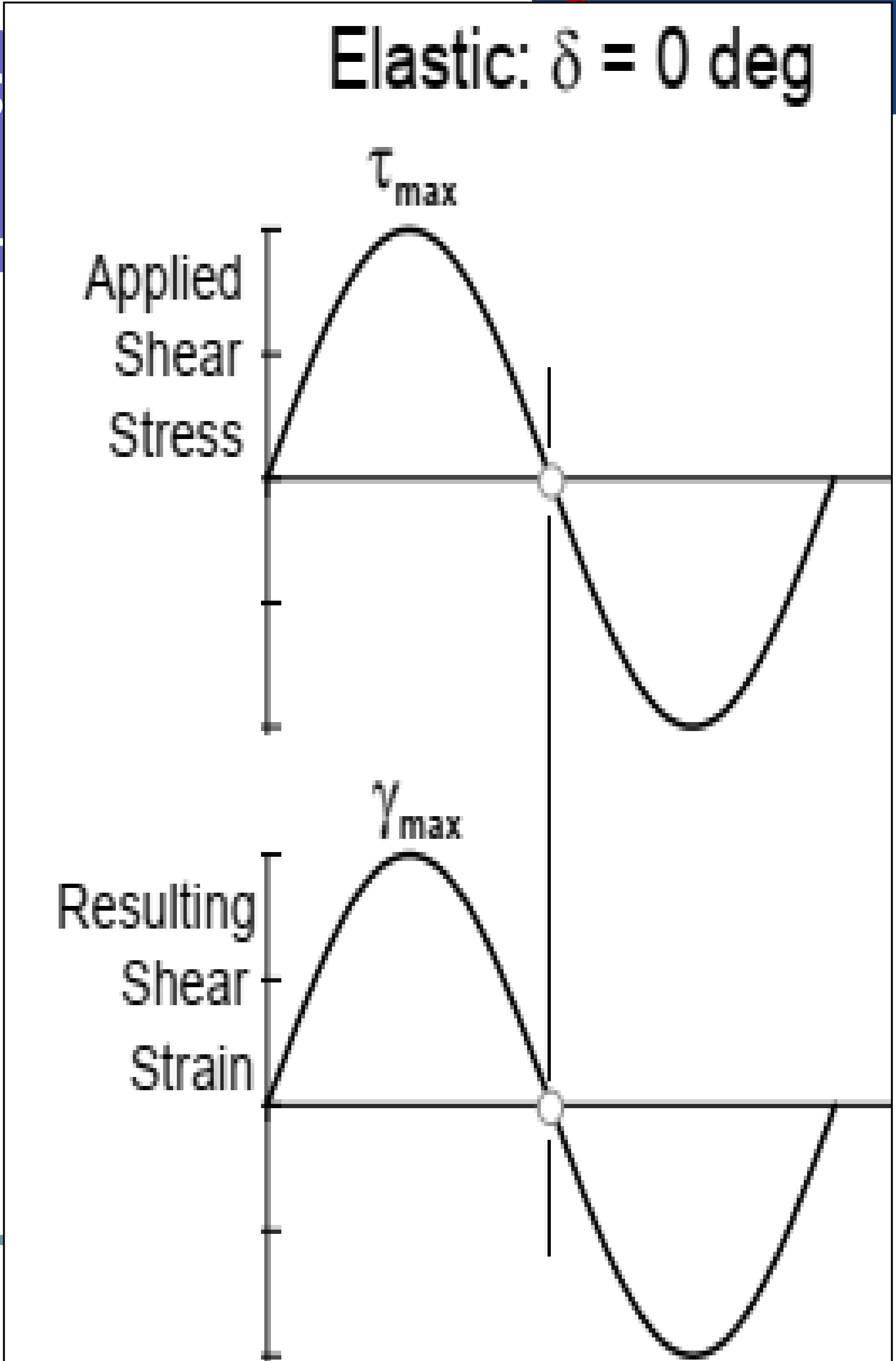


Image source: https://www.open.edu/openlearn/science-maths-technology/science/chemistry/introduction-polymers/content-section 5.2.1

How Asphalt Behaves

- Elastic behavior
  - Instantaneous response to load
    - Such as a rubber





How Asphalt Behaves/ Viscous Behavior

- Viscous Behavior
  - Viscosity is a measure of a fluid’s resistance to flow.
    - A fluid with large viscosity resists motion.
    - A fluid with low viscosity flows.
      - For example, water flows more easily than syrup because it has a lower viscosity
  - Viscous flow is not recoverable
    - When the stress is removed from a viscous fluid the strain remains

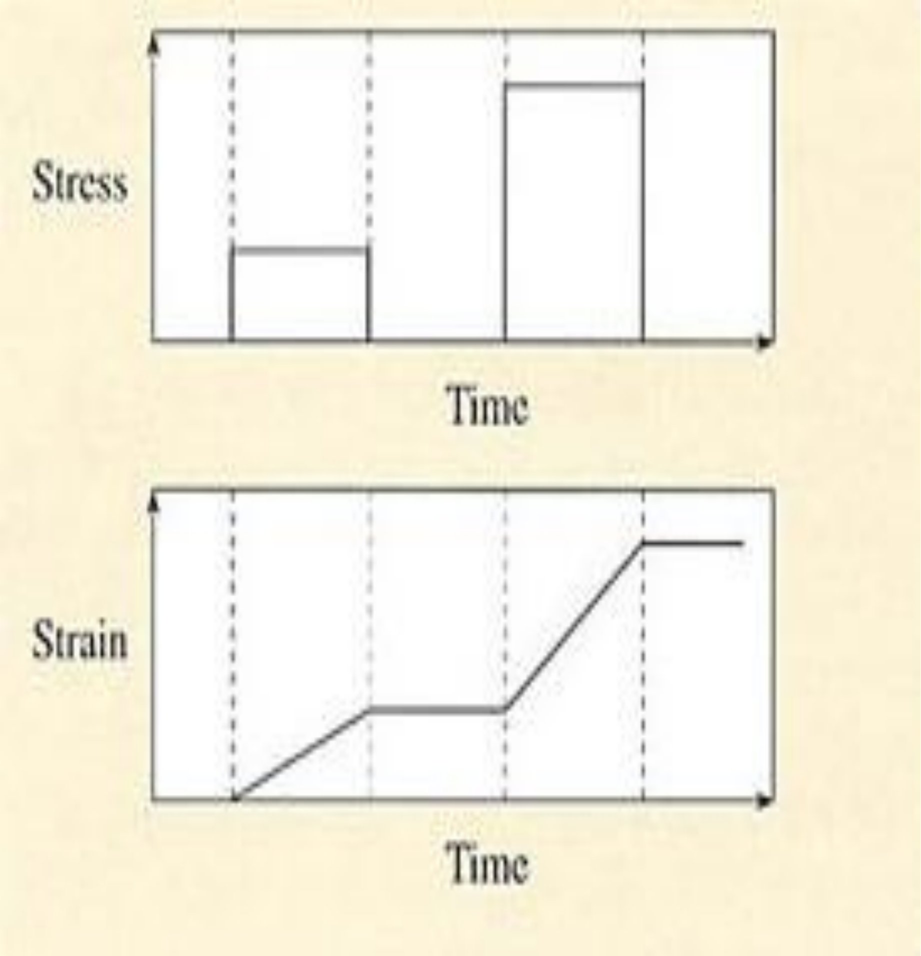
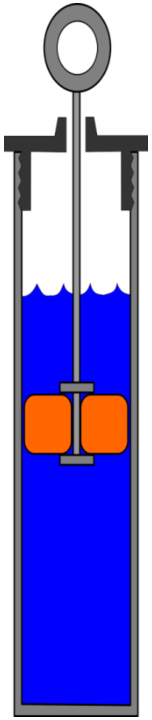


Image source: https://www.open.edu/openlearn/science-maths-technology/science/chemistry/introduction-polymers/content-section-5.2.2

How Asphalt Behaves

- Viscous Behavior
  - Have delayed response



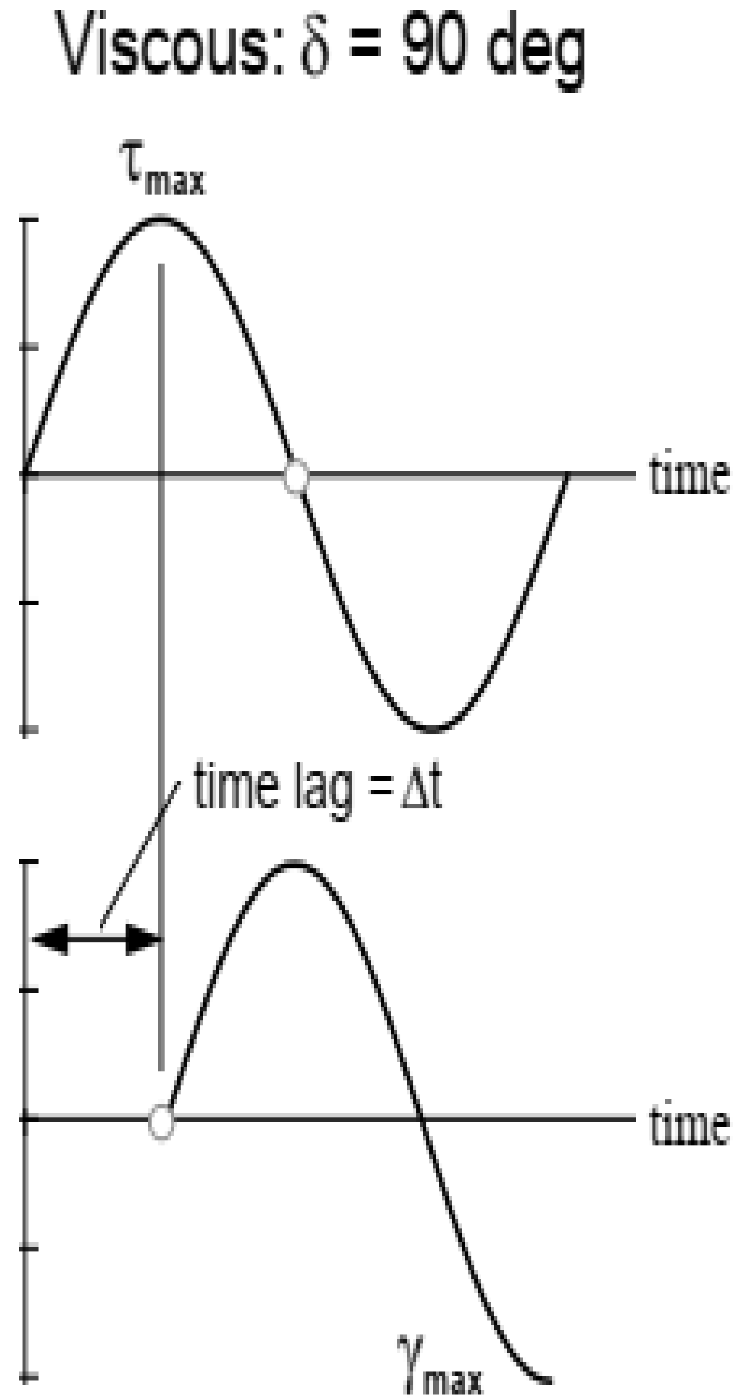
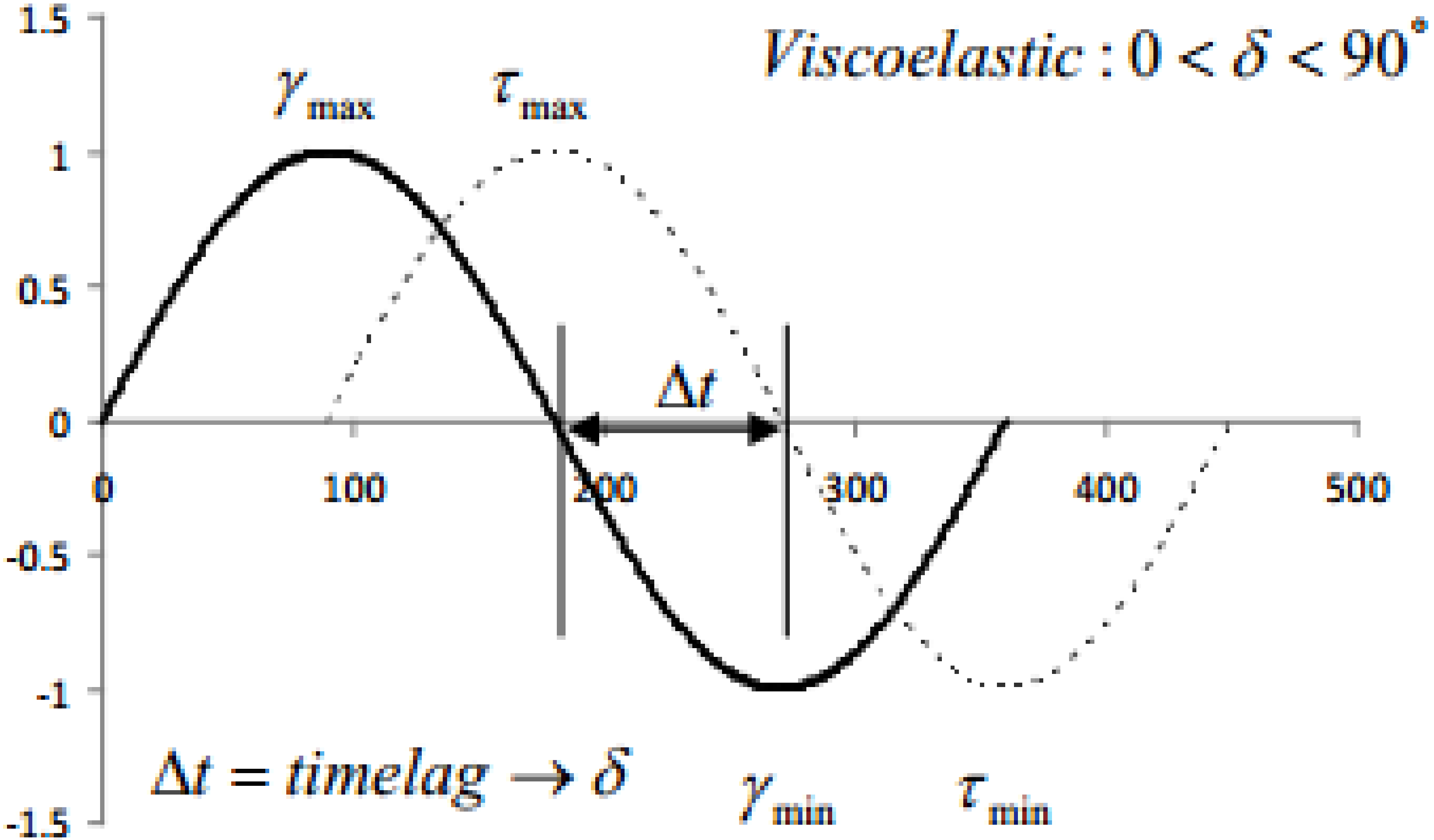
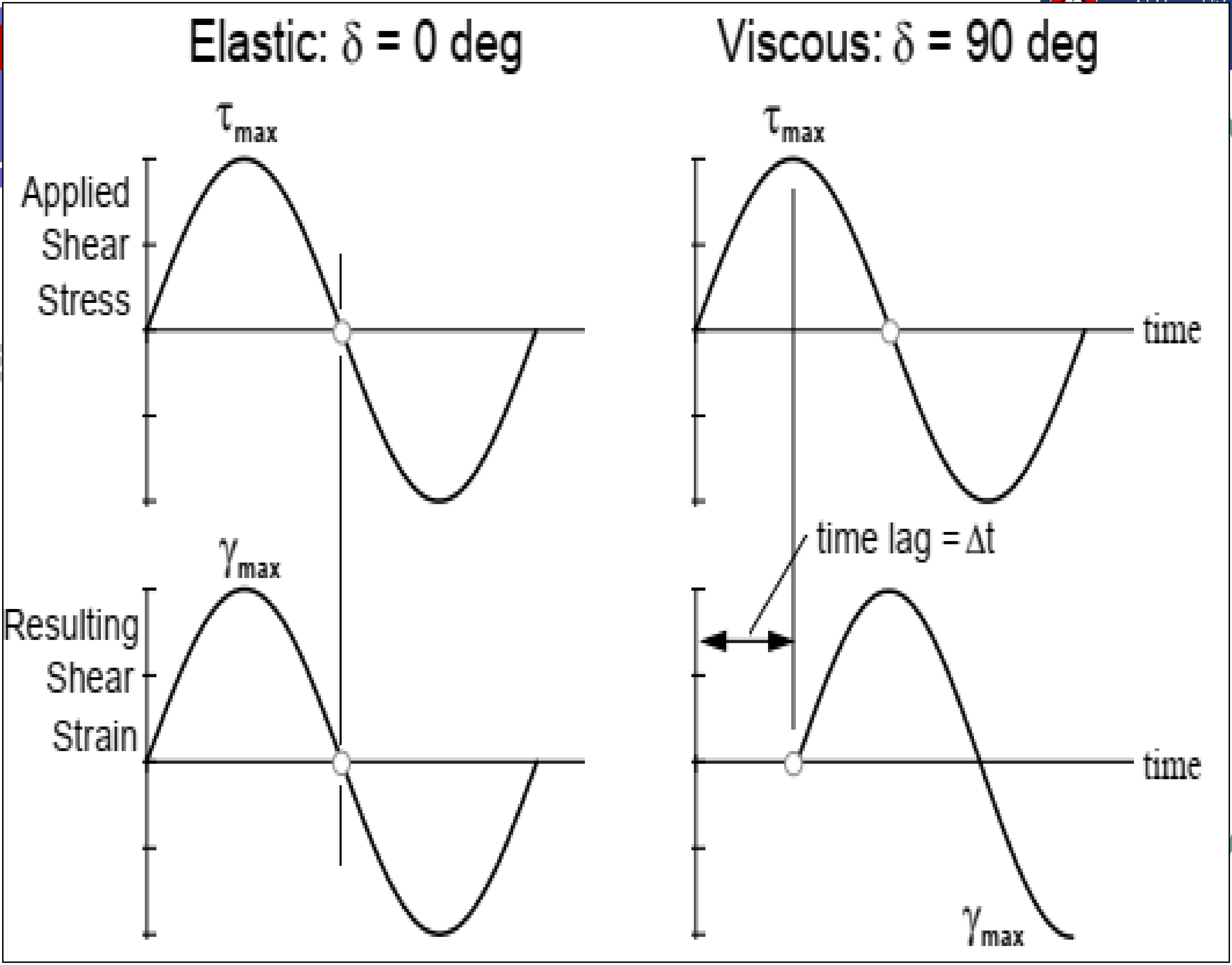


Image source: https://www.wikiwand.com/en/Dashpot

How Asphalt Behaves/ Viscoelastic Behavior



https://www.researchgate.net/publication/275353265_Predicting_Complex_Shear_Modulus_Using_Artificial_Neural_Networks


Elastic: δ = 0 deg
Viscous: δ = 90 deg
τmax
τmax
Applied Shear Stress
time
time lag = Δt
γmax
Resulting Shear Strain
time
γmax

How Asphalt Behaves/ Viscoelastic Behavior

- Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation

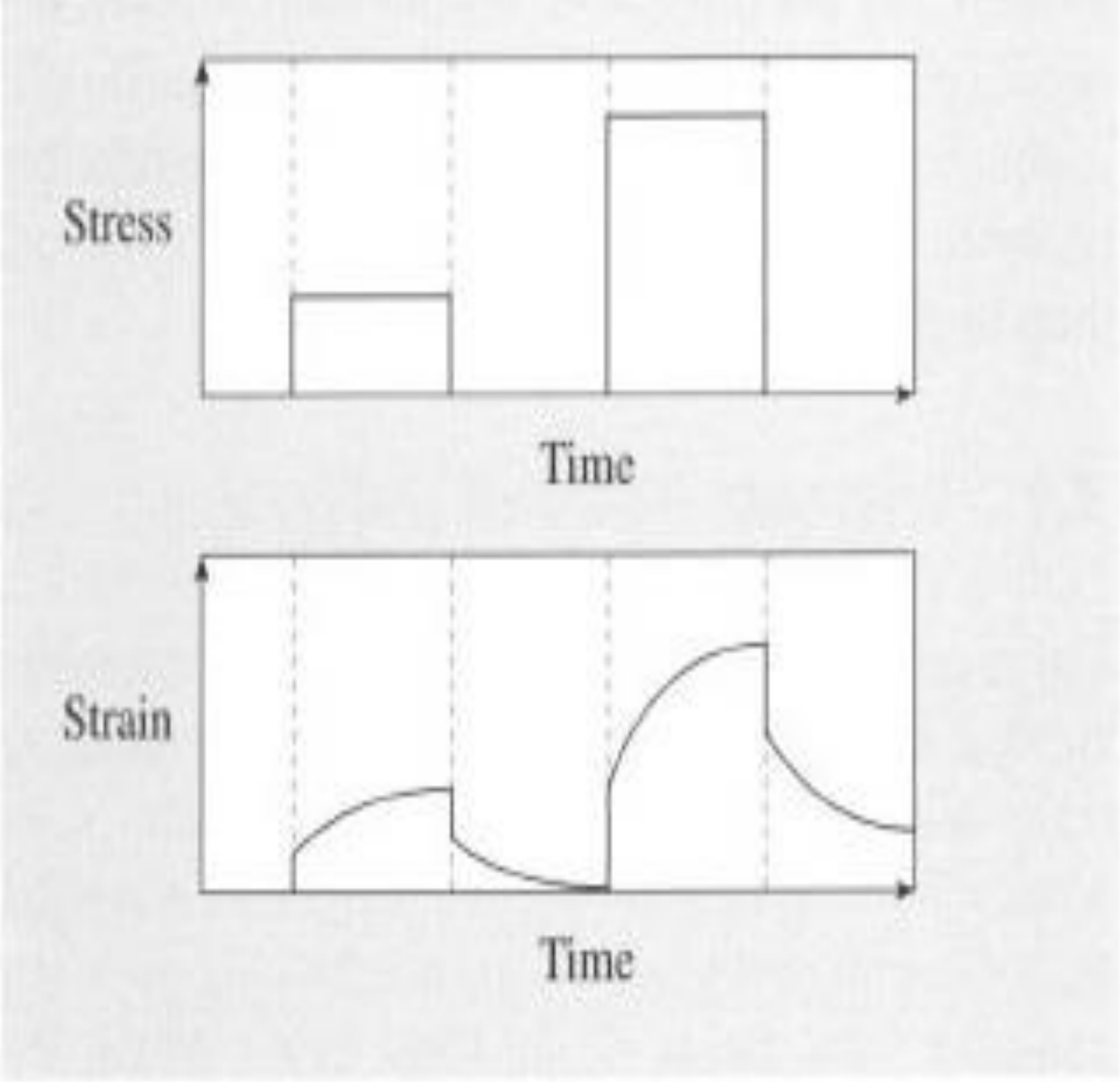
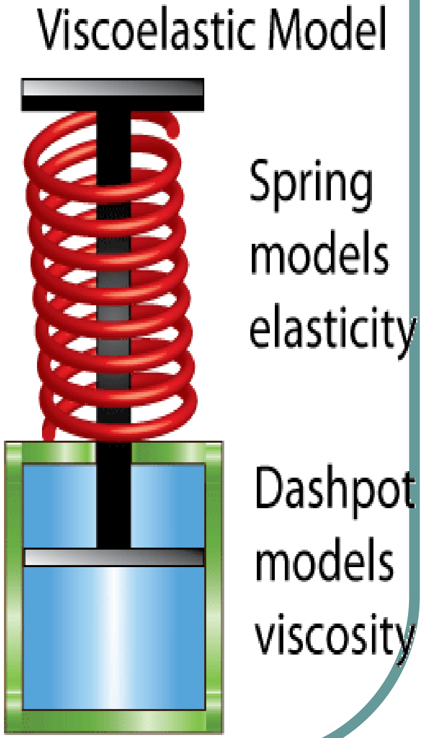


Image source: https://www.open.edu/openlearn/science-maths-technology/science/chemistry/introduction-polymers/content-section-5.3

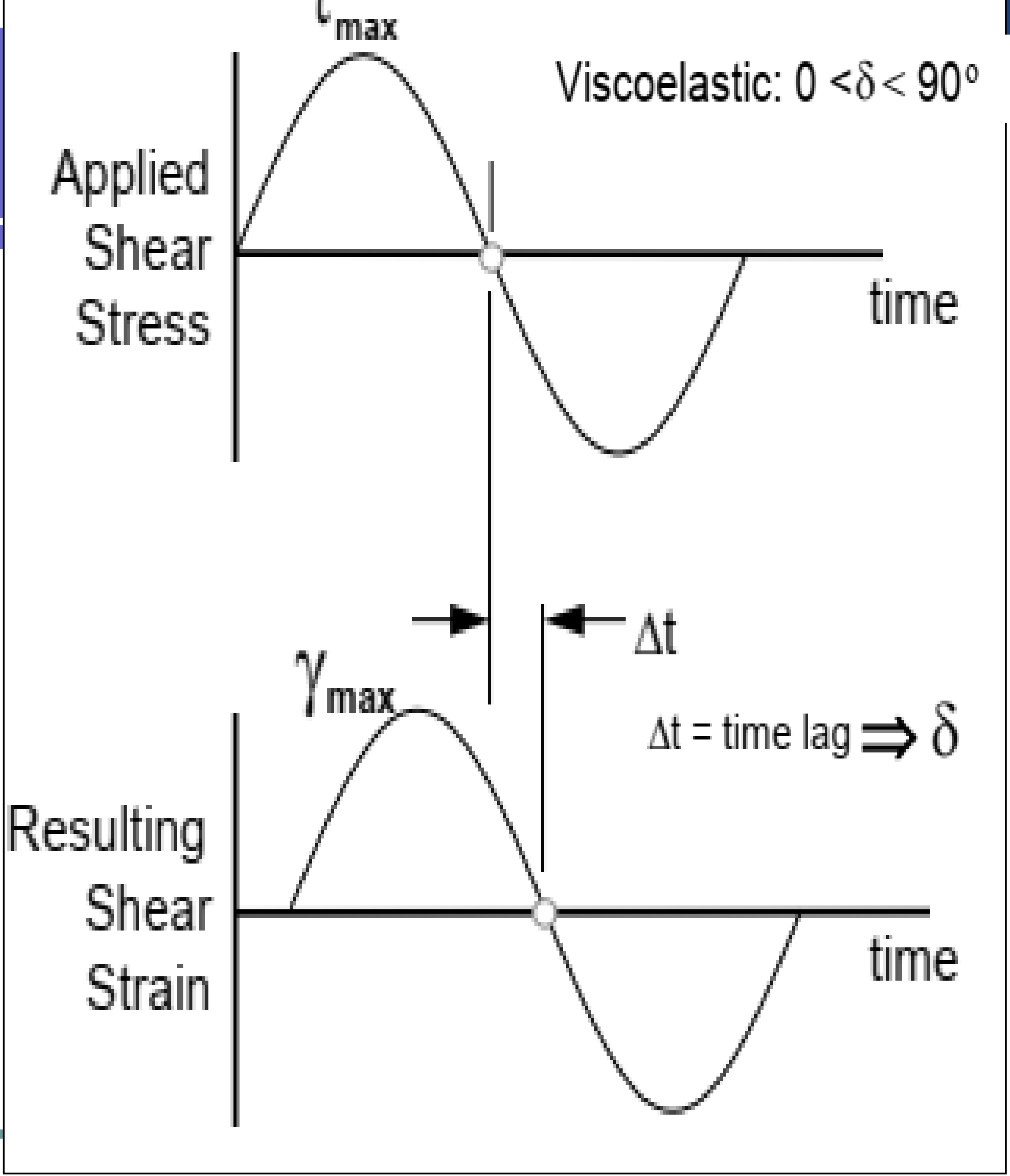
How Asphalt Behaves/ Viscoelastic Behavior

- Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation
- Viscoelastic Materials
  - Have both elastic and viscous response
  - Have delayed response
  - Deformation depends on
    - Duration of Load
    - Rate of Loading
    - Temperature

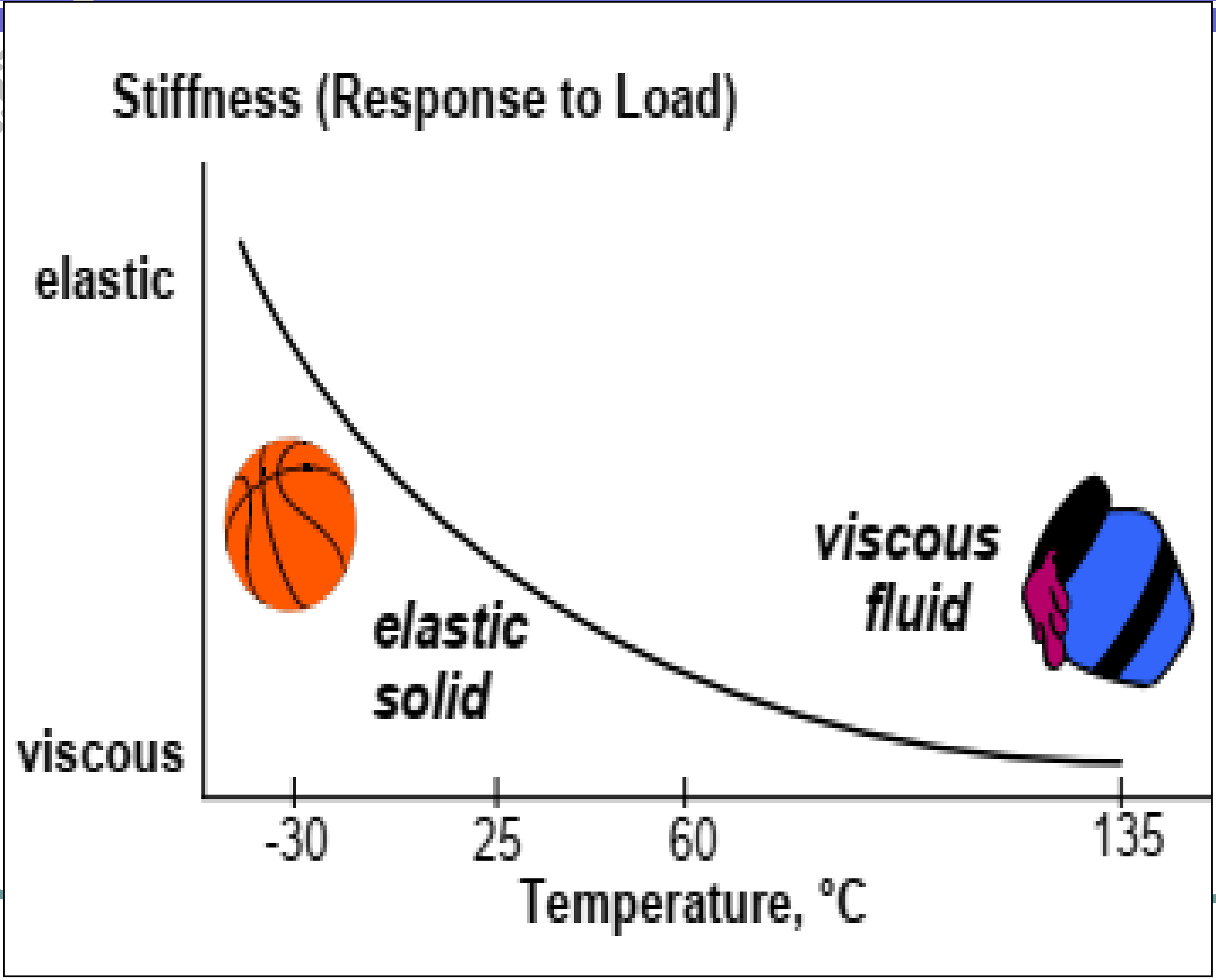


How Asphalt Behaves

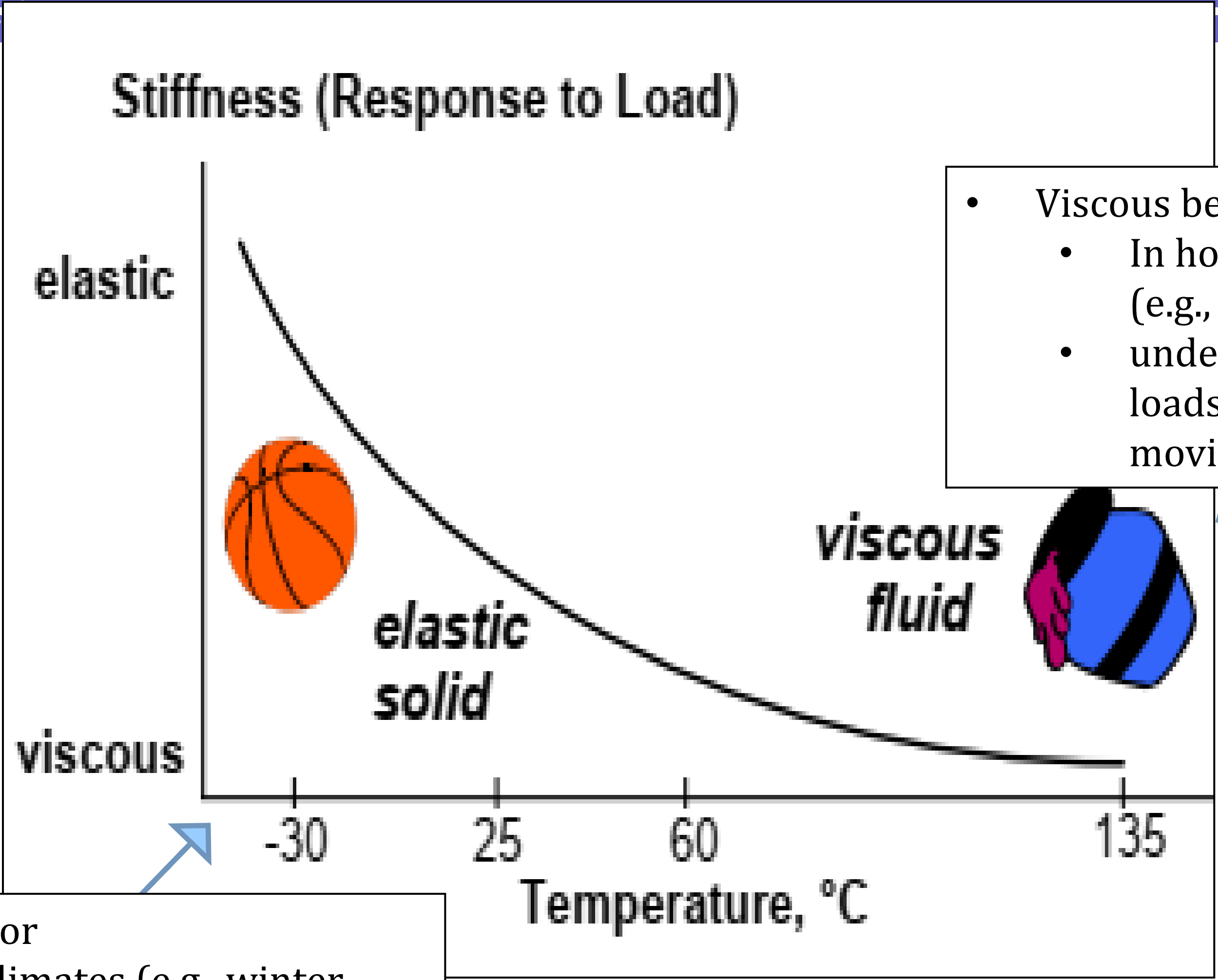
Have delayed response



How Asphalt Behaves/ Temperature Dependency



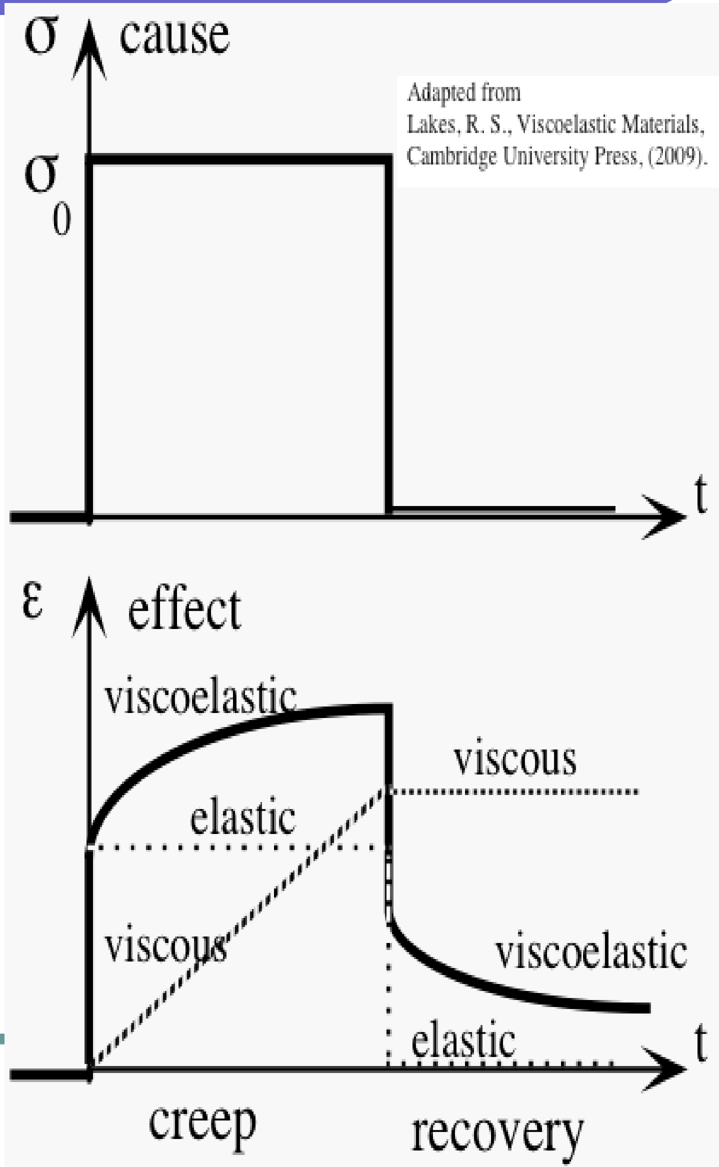
How Asphalt Behaves/ Temperature Dependency



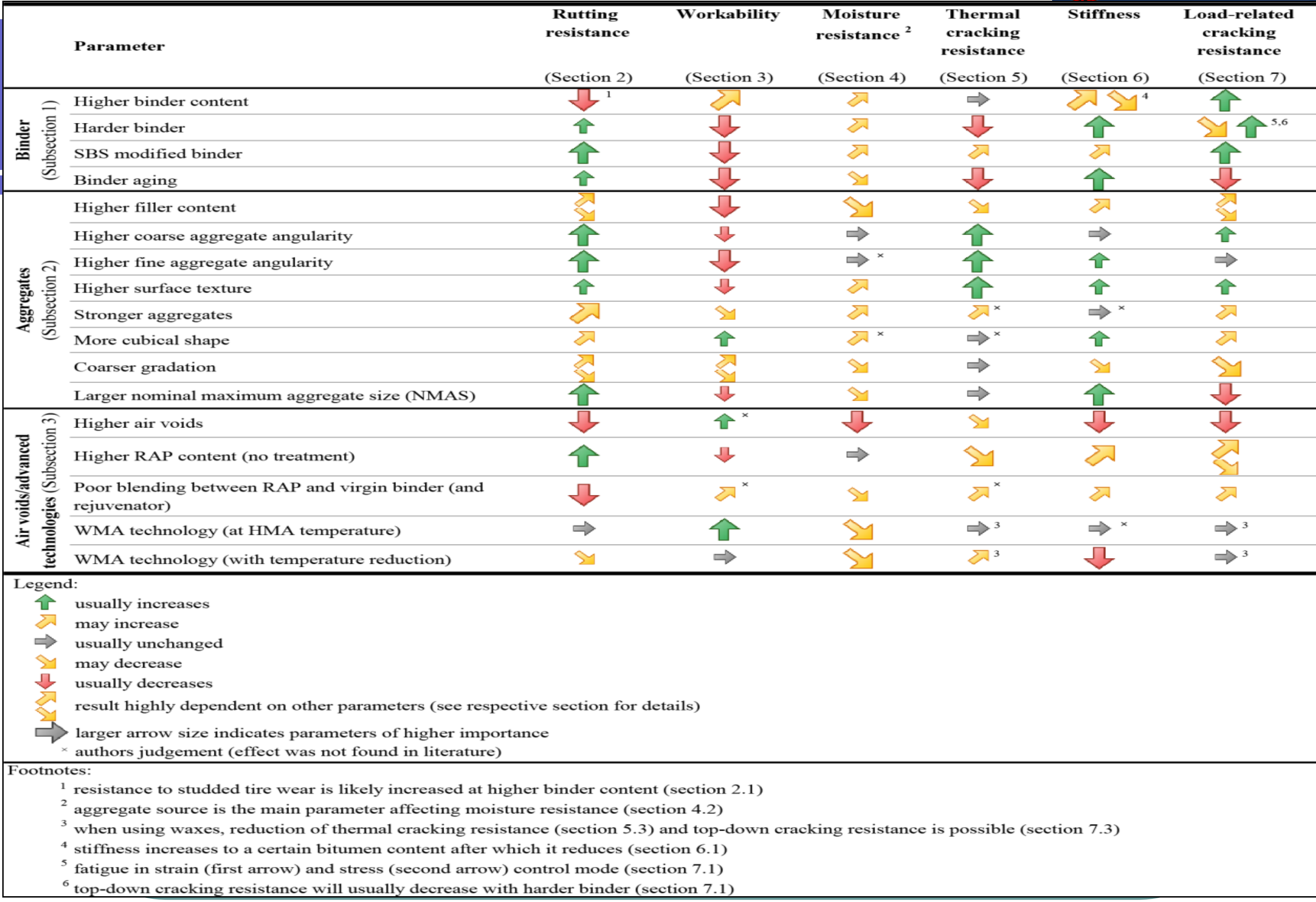
- Viscous behavior
    - In hot conditions (e.g., desert climate)
    - under sustained loads (e.g., slow moving trucks)

- Elastic behavior
    - In cold climates (e.g., winter days)
    - Under rapid loading (e.g., fast moving trucks)

How Asphalt Behaves/ Time of Loading Dependency



Adapted from
Lakes, R. S., Viscoelastic Materials,
Cambridge University Press, (2009).



	Parameter	Rutting resistance (Section 2)	Workability (Section 3)	Moisture resistance [2] (Section 4)	Thermal cracking resistance (Section 5)	Stiffness (Section 6)	Load-related cracking resistance (Section 7)
Binder (Subsection 1)	Higher binder content	↓ [1]	↗	↗	→	↗ ↘ [4]	↑
	Harder binder	↑	↓	↗	↓	↑	↘ ↑ [5,6]
	SBS modified binder	↑	↓	↗	↗	↗	↑
	Binder aging	↑	↓	↘	↓	↑	↓
Aggregates (Subsection 2)	Higher filler content	↗↘	↓	↘	↘	↗	↗↘
	Higher coarse aggregate angularity	↑	↓	→	↑	→	↑
	Higher fine aggregate angularity	↑	↓	→ ×	↑	↑	→
	Higher surface texture	↑	↓	↗	↑	↑	↑
	Stronger aggregates	↗	↘	↗	↗ ×	→ ×	↗
	More cubical shape	↗	↑	↗ ×	→ ×	↑	↗
	Coarser gradation	↗↘	↗↘	↘	→	↘	↘
	Larger nominal maximum aggregate size (NMAS)	↑	↓	↘	→	↑	↓
Air voids/advanced technologies (Subsection 3)	Higher air voids	↓	↑ ×	↓	↘	↓	↓
	Higher RAP content (no treatment)	↑	↓	→	↘	↗	↗↘
	Poor blending between RAP and virgin binder (and rejuvenator)	↓	↗ ×	↘	↗ ×	↗	↗
	WMA technology (at HMA temperature)	→	↑	↘	→ [3]	→ ×	→ [3]
	WMA technology (with temperature reduction)	↘	→	↘	↗ [3]	↓	→ [3]

Legend:

↑ usually increases

↗ may increase

→ usually unchanged

↘ may decrease

↓ usually decreases

↗↘ result highly dependent on other parameters (see respective section for details)

➡ larger arrow size indicates parameters of higher importance

× authors judgement (effect was not found in literature)

Footnotes:

[1] resistance to studded tire wear is likely increased at higher binder content (section 2.1)

[2] aggregate source is the main parameter affecting moisture resistance (section 4.2)

[3] when using waxes, reduction of thermal cracking resistance (section 5.3) and top-down cracking resistance is possible (section 7.3)

[4] stiffness increases to a certain bitumen content after which it reduces (section 6.1)

[5] fatigue in strain (first arrow) and stress (second arrow) control mode (section 7.1)

[6] top-down cracking resistance will usually decrease with harder binder (section 7.1)

Image source: M. Zaumanis, L.D. Poulikakos, M.N. Partl , Performancebased design of asphalt mixtures and review of key parameters. The address for the corresponding author was captured as affiliation for all authors. Please check if appropriate. Jmade(2017), https://doi.org/10.1016/j.matdes.2017.12.035

What do You think ?

What do You think ?

https://in.pinterest.com/pin/433541901607683832/

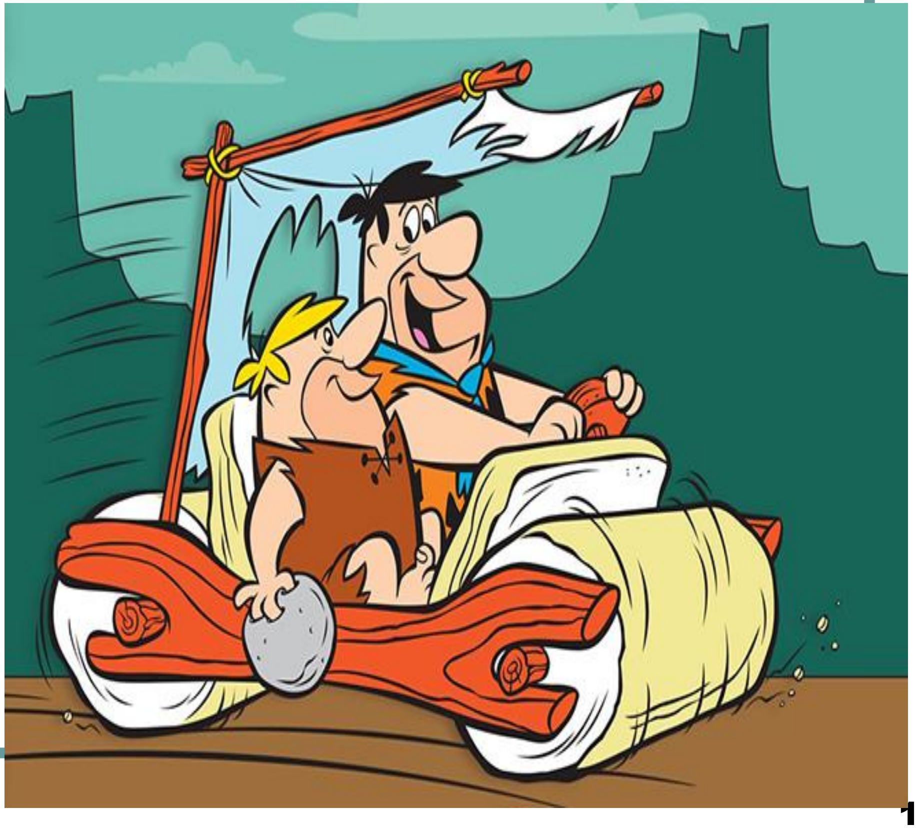
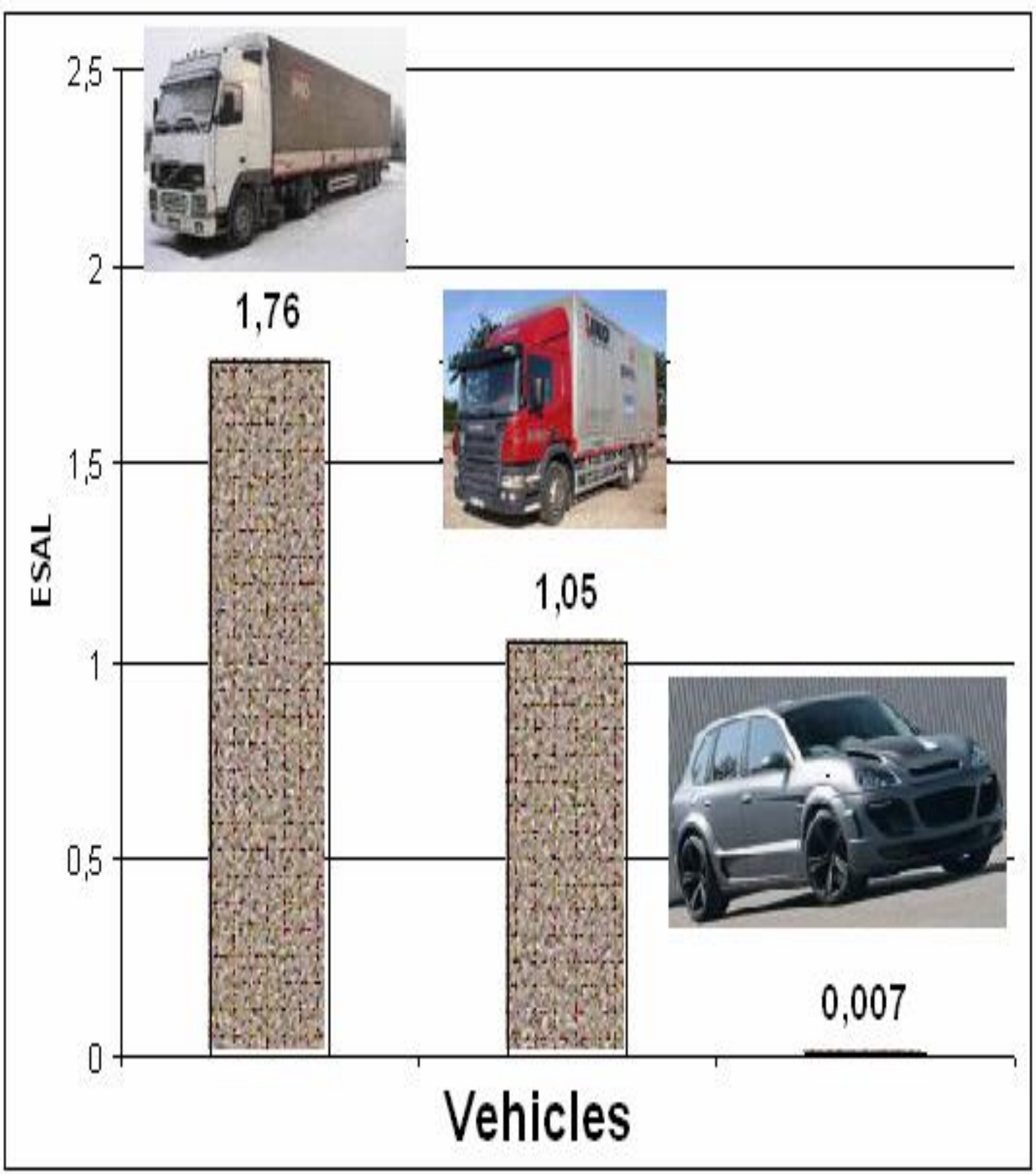


Image source : https://www.whichcar.com.au/car-style/12-cartoon-cars

What do You think ?

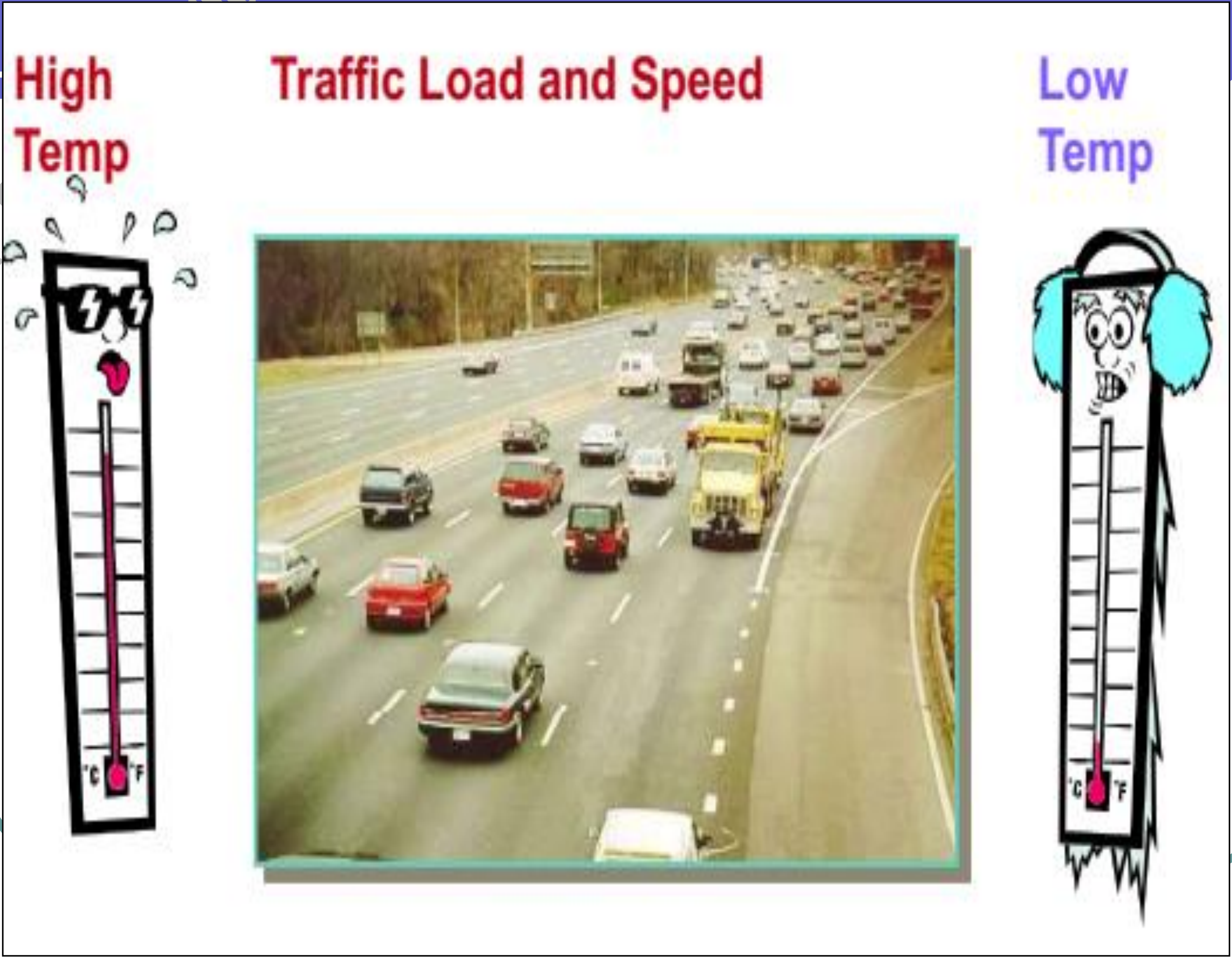
Image source https://www.behance.net/gallery/67086875/Iconic-Cars-Animated-GIF

Some Typical Load Equivalency Factors for Vehicles on the Heavily Loaded Latvian Roads



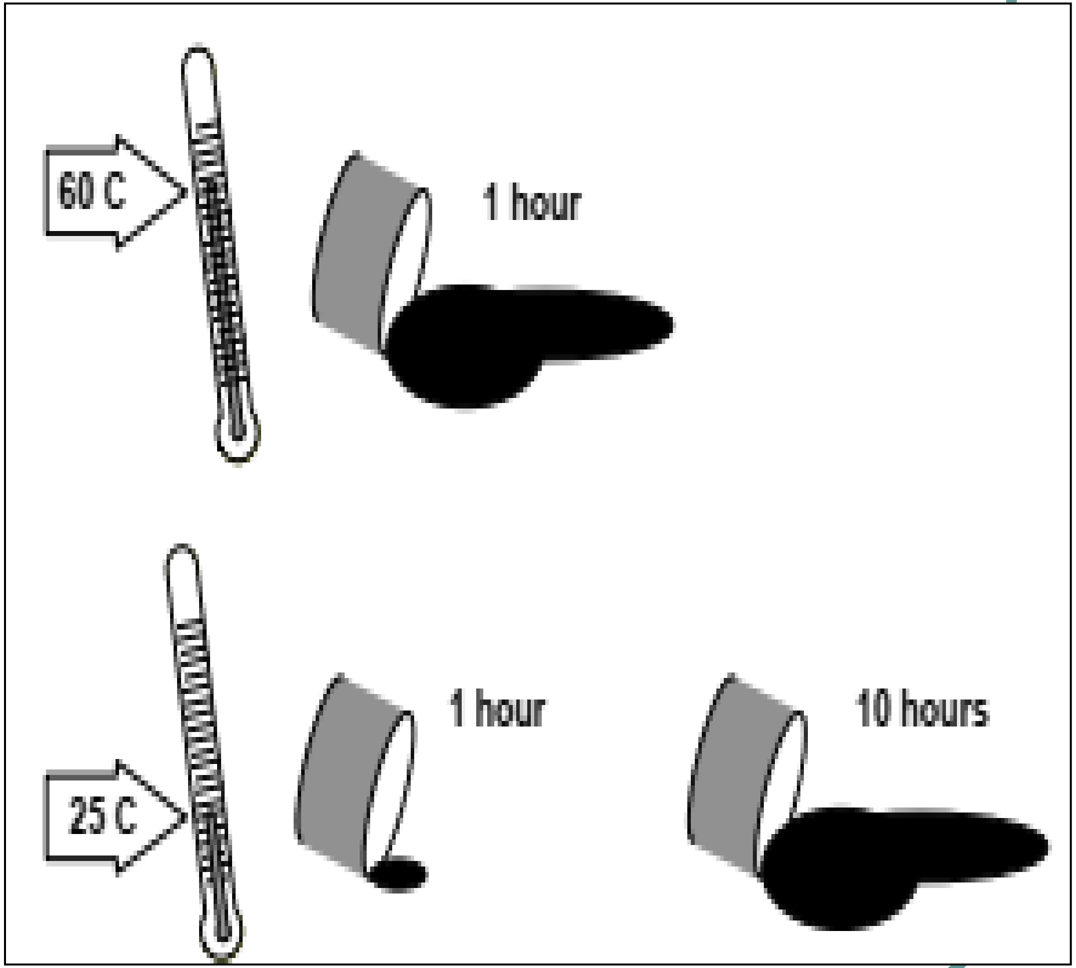
Haritonovs, Viktors & Smirnovs, Juris & Naudžuns, Juris. (2010). Prediction of Rutting Formation in Asphalt Concrete Pavement. Baltic Journal of Road and Bridge Engineering - BALT J ROAD BRIDGE ENG. 5. 38-42. 10.3846/bjrbe.2010.05.

What do You think ?

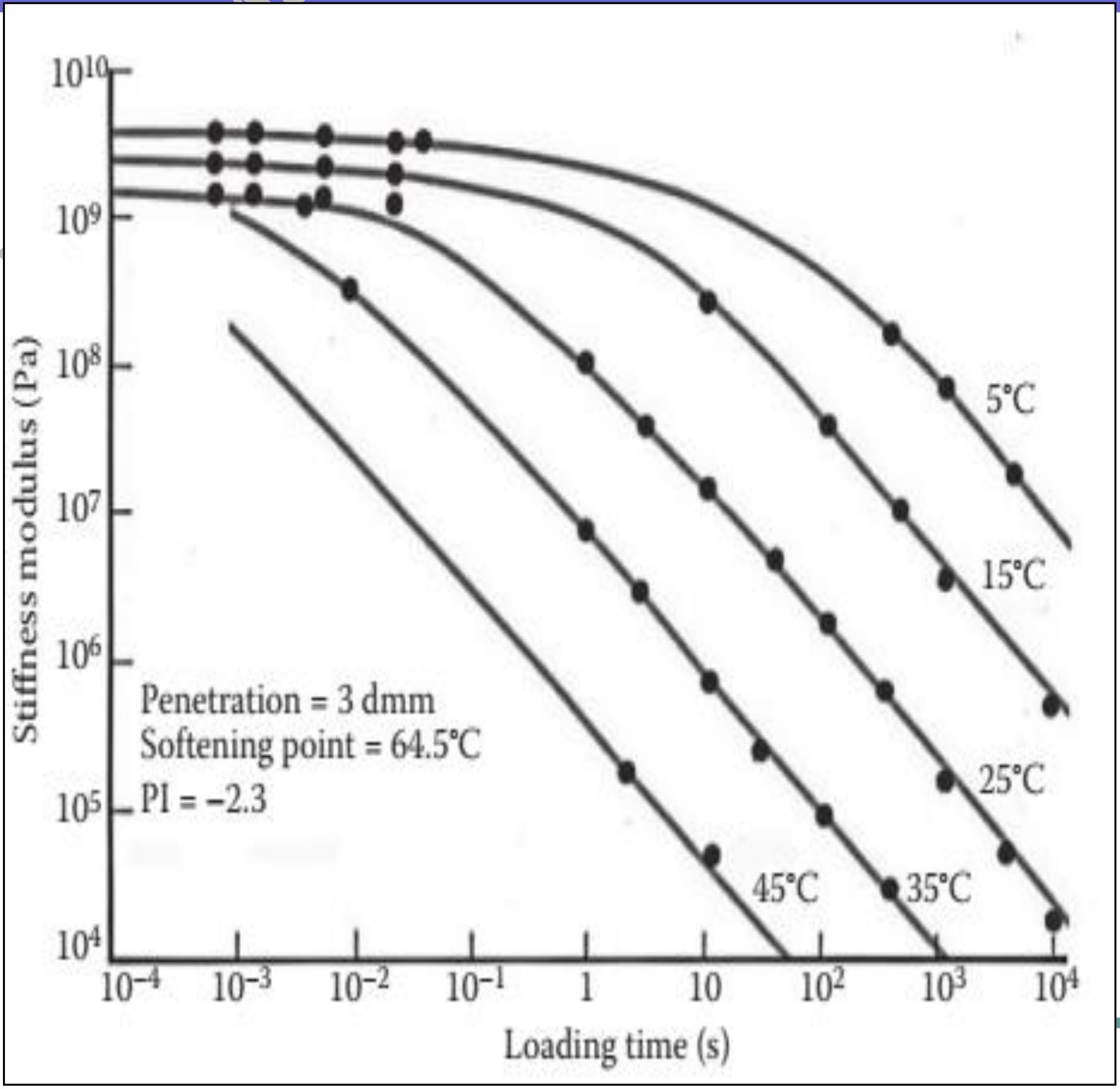


How Asphalt Behaves/ Time-Temperature shift (or superposition)

- The flow behavior of an asphalt could be the same for
  - One hour at 60 °C
  - 10 hours at 25 °C
- The behavior at high temperatures over short time periods is **equivalent** to what occurs at lower temperatures and longer times.
  - This is often referred to as the time-temperature shift or superposition concept of asphalt cement



The effect of temperature and loading time on the stiffness of low PI asphalt

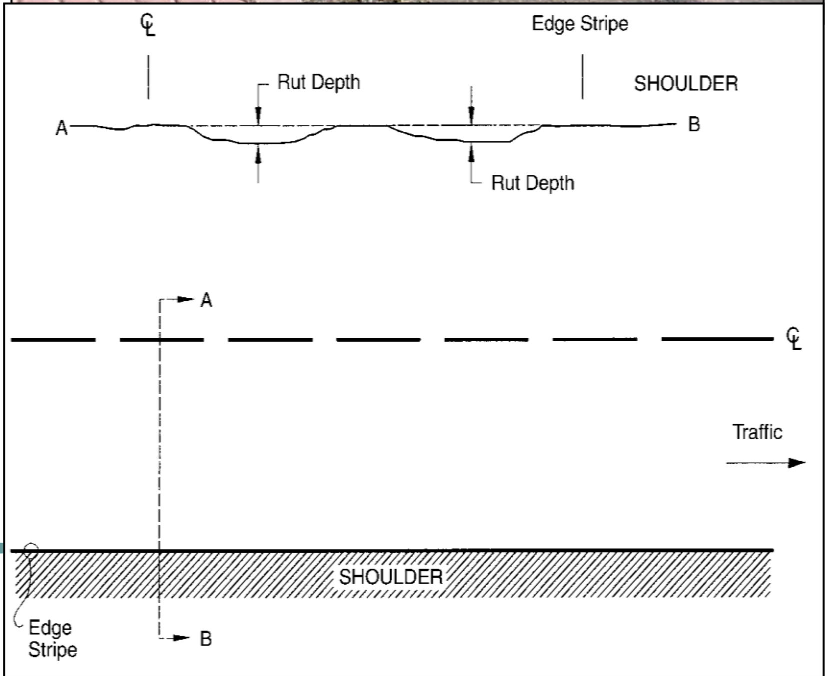


PI: penetration Index. The value of PI ranges from **around -3 for high temperature susceptible** bitumen to around +7 for highly blown low temperature susceptible (high PI) bitumen.

High Temperature Behavior

- Asphalts cements behave like viscous liquids and flow.
  - In hot conditions
    - Desert climate
  - Under sustained loads
    - Slow moving trucks

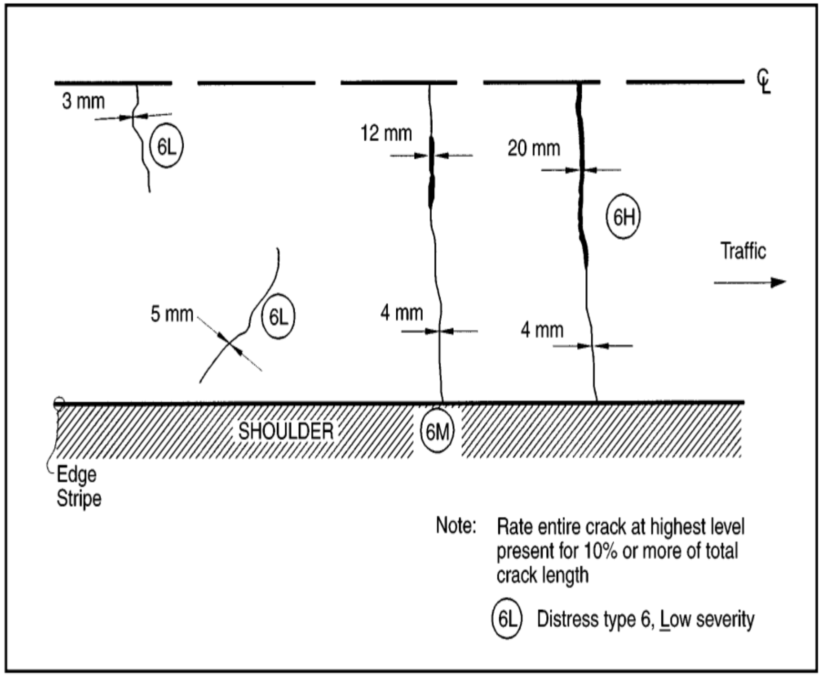

High severity rutting



Low Temperature Behavior

- Asphalt cement behaves like an *elastic* solid
  - In cold climates
    - Winter days
  - Under rapid loading
    - Fast moving trucks

High severity transverse cracking



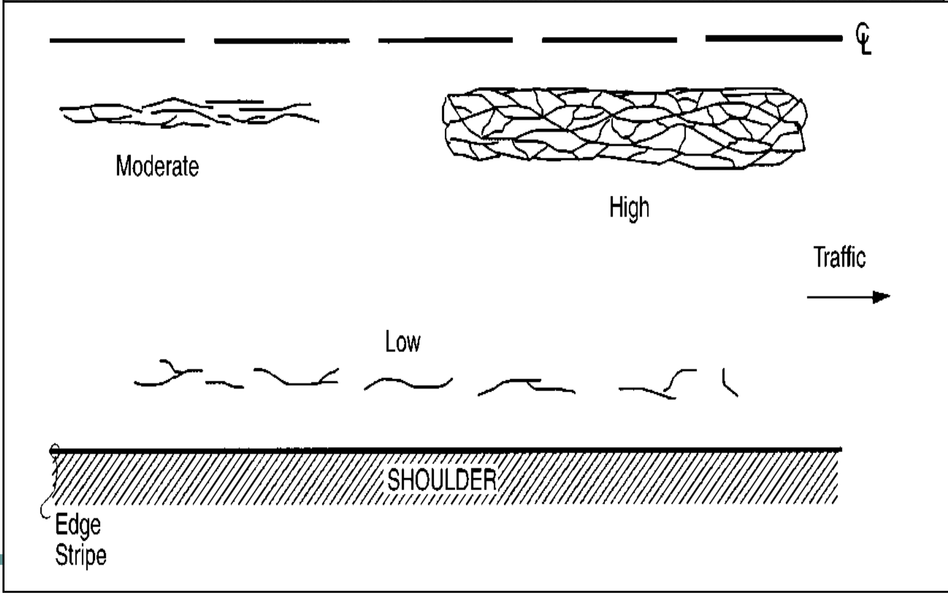
Note: Rate entire crack at highest level present for 10% or more of total crack length

6L Distress type 6, Low severity

Intermediate Temperature Behavior

- Asphalt binders exhibit the characteristics of both viscous liquids and elastic solids
    - Most environmental conditions lie between the extreme hot and cold situations

High severity Alligator or fatigue cracking



Pavement Materials & Design (110401466/2104011466)

Aggregates

Instructor:

Prof. TALEB M. AL-ROUSAN

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

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

CAT
320 L
12 3 '00

Transportation

1 5 88


'99 2 1

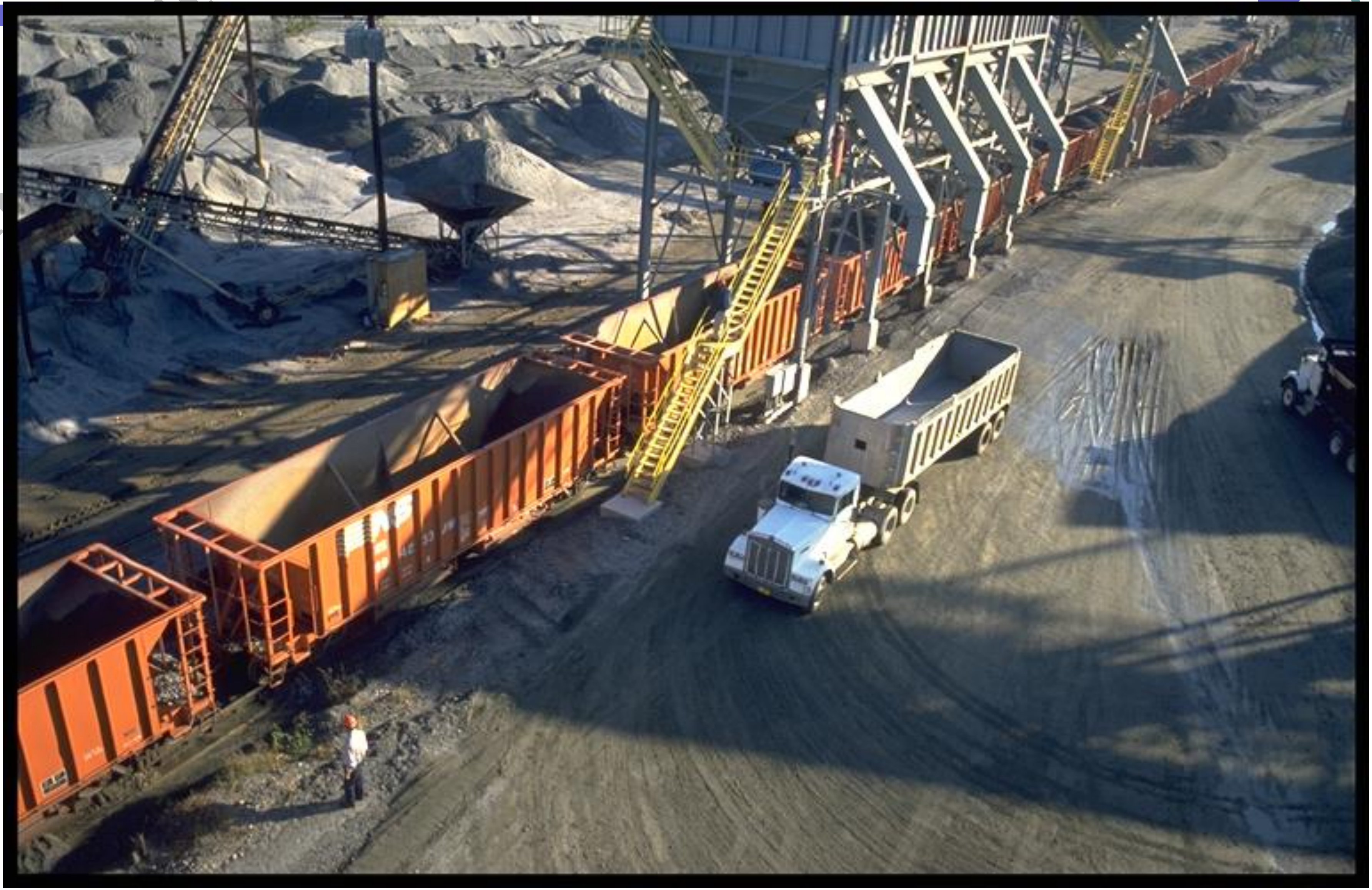

1 5 66

Crushing

Sizing

Stockpiling

Moving for Usage



'99 2 1

Properties of Aggregates

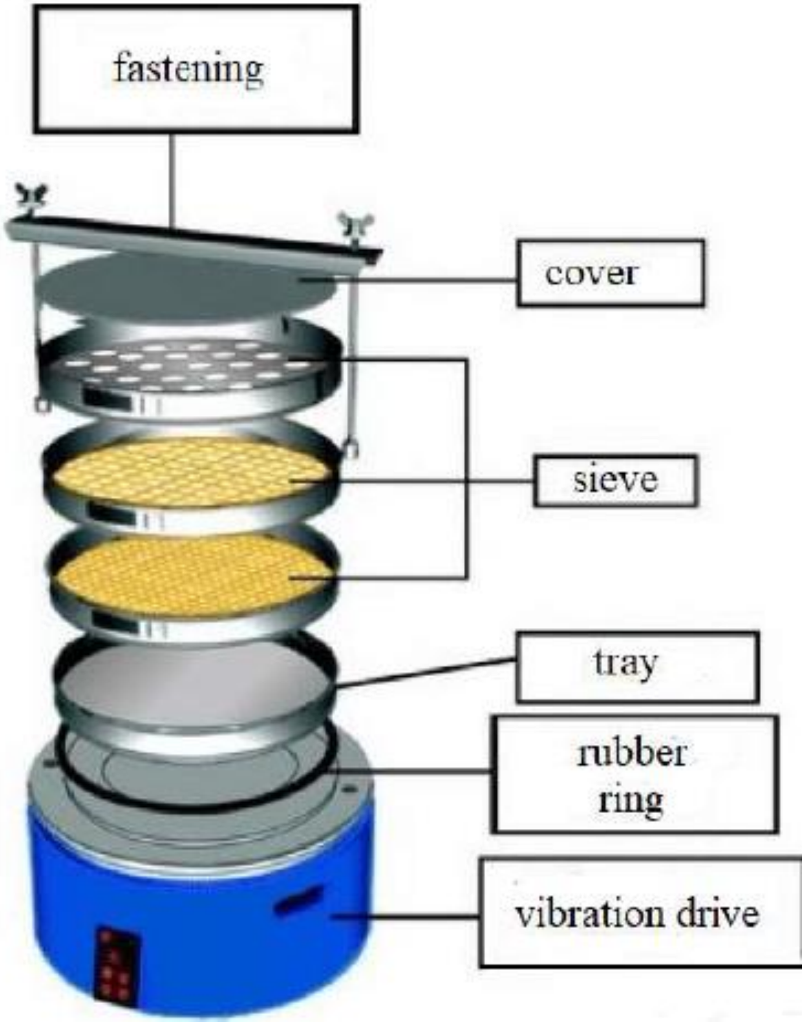
1. Particle size and gradation.
2. Hardness or resistance to wear.
3. Durability or resistance to weathering.
4. Specific gravity & absorption.
5. Chemical stability
6. Particle shape and surface texture.
7. Freedom from deleterious particles or substances.

Particle Size & Gradation

- Gradation: Blend of particle sizes in the mix.
- Gradation affects: Density; Strength; Workability, Durability, Stability, Stiffness, Permeability, Resistance to water damage, Fatigue resistance, Friction resistance, and Economy of pavement structure.
- Particles are separated by sieve analysis.(ASTM C136 / C136M - 19 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates)
- 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..

Mechanical Sieve

Mechanical Sieve



Aggregate

Aggregate classifications- by size based on

- **ASTM standard**
  - *Coarse aggregate:*
    - Aggregate retained on Sieve No. 4 (4.75 mm)
  - *Fine aggregate:*
    - Aggregate passing Sieve No. 4 (4.75 mm) and retained on Sieve No. 200 (0.075 mm)
  - *Mineral fillers/dust/fines:*
    - Aggregate passing Sieve No. 200 (0.075 mm)

In Pavements
Coarse : Retain # 8
Fine : pass # 8 Retain # 200
Fines : pass # 200

Aggregate Classification By Size

Local classification


العدسية


الفولية


الجوزية


رمل

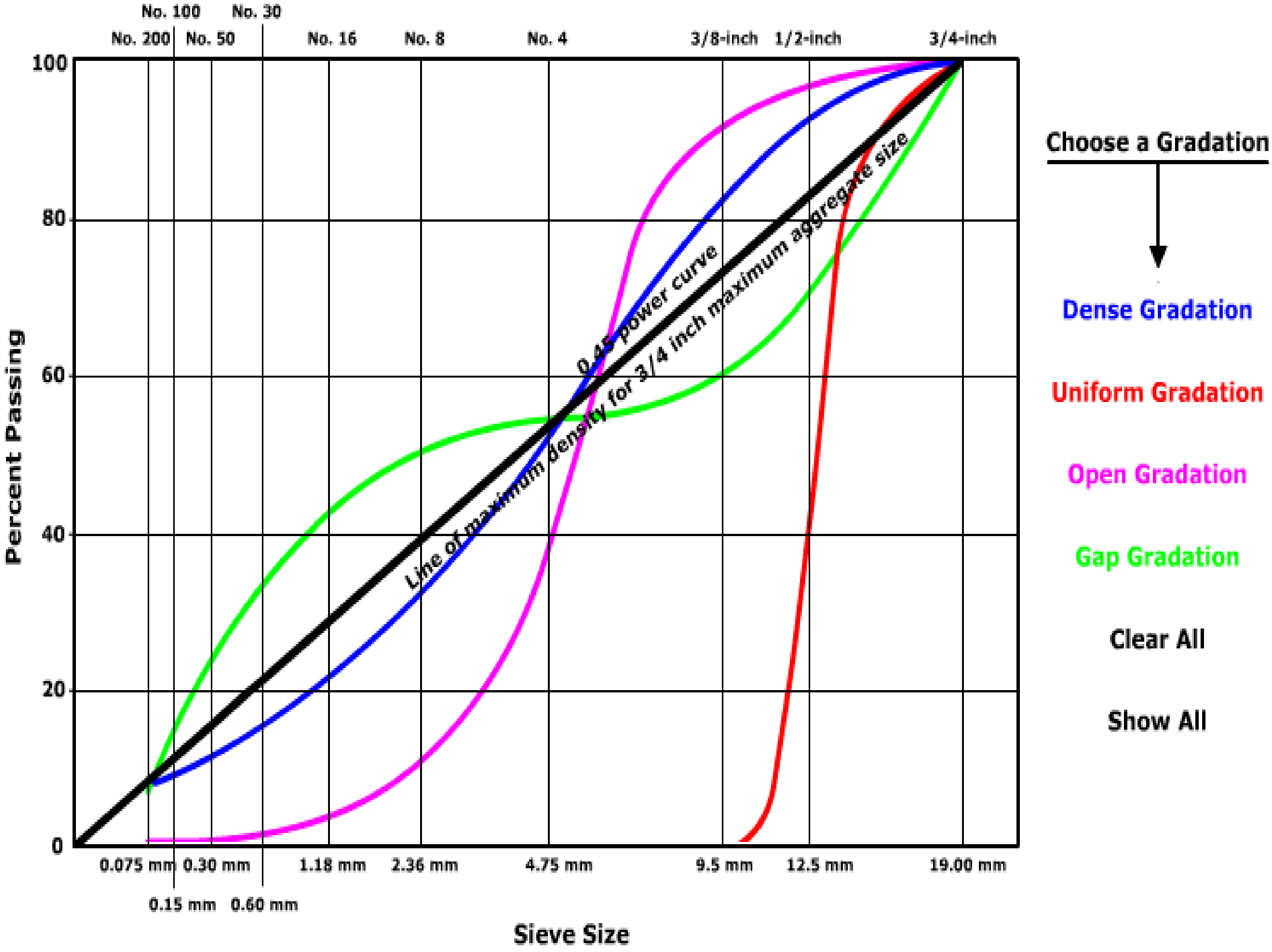

الناعمة (السمسية)


الحمصية

Aggregate Identification		Coarse Agg.	Medium Agg.	Medium-Fine Agg.	Fine Agg.
		Limestone Aggregate			
		حصمة	عدسية	سمسمية	ناعمة
		ركام جيري			
Test Name		Test Result			
- Sieve Analysis: -		% Passing by Weight			
Sieve Number (Size, mm):	1" (25.4)	100	100	100	100
	3/4" (19.0)	100	100	100	100
	1/2" (12.7)	39	98	100	100
	3/8" (9.50)	3	32	100	100
	No. 4 (4.75)	1	4	18	100
	No. 8 (2.36)	1	3	4	66
	No. 20 (0.85)	1	3	4	38
	No. 50 (0.30)	1	3	4	24
	No. 80 (0.18)	1	3	3	20
	No. 200 (0.075)	0.6	2.6	3.2	16

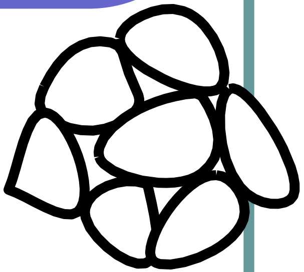
Typical Gradations

- **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
0.075 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
0.45 power curve
Line of maximum density for 3/4 inch maximum aggregate size
Choose a Gradation
Dense Gradation
Uniform Gradation
Open Gradation
Gap Gradation
Clear All
Show All

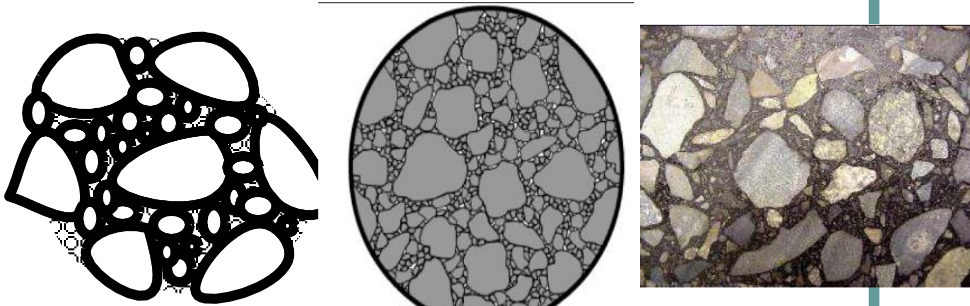
Types of Gradations

* Uniformly graded



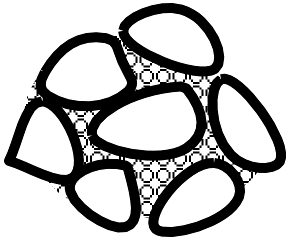
- Few points of contact
- Poor interlock (shape dependent)
- High permeability

* Dense or Well graded



- Good interlock
- Low permeability

* Gap graded



- Only limited sizes
- Good interlock
- Low permeability

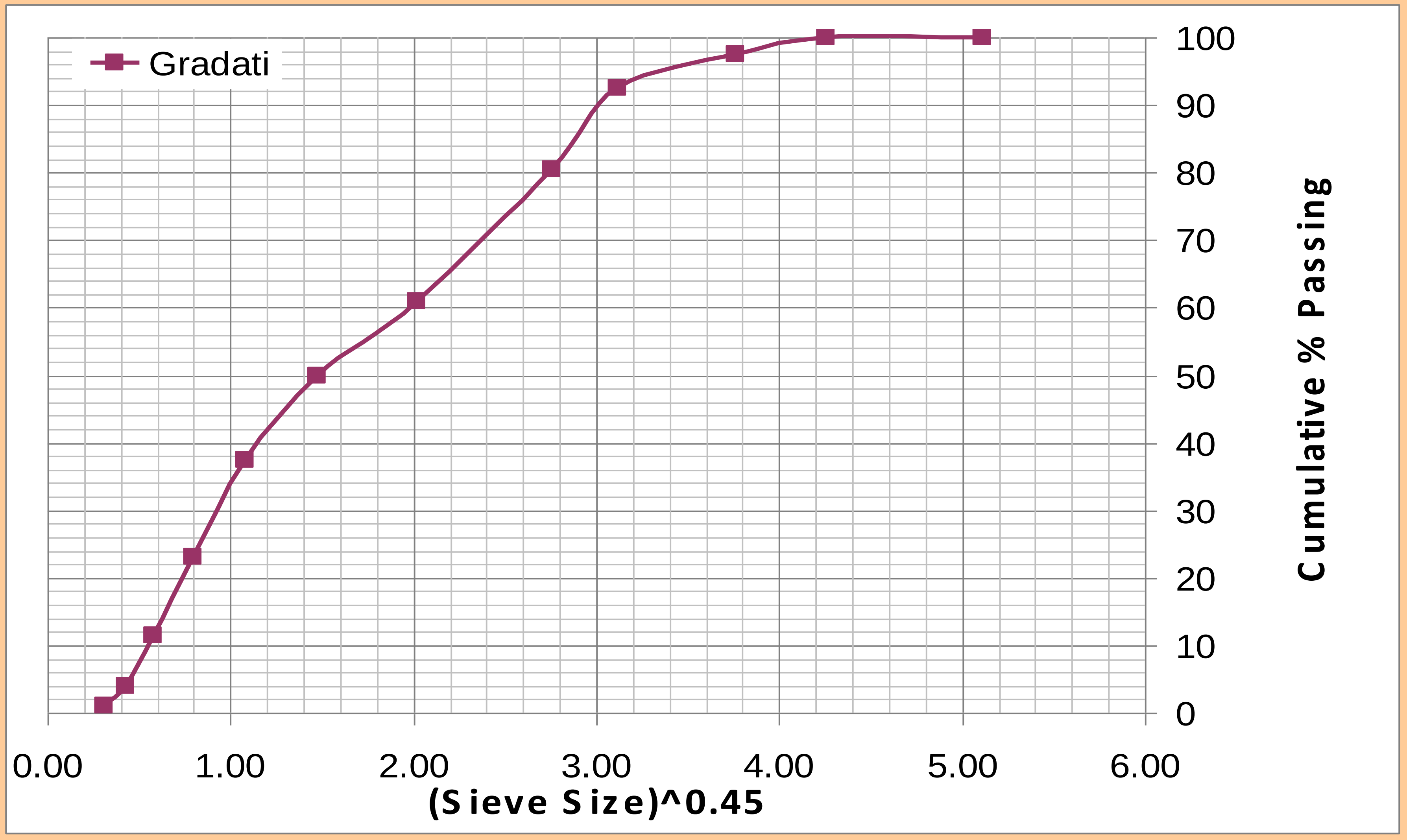
Sieve Analysis Example

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

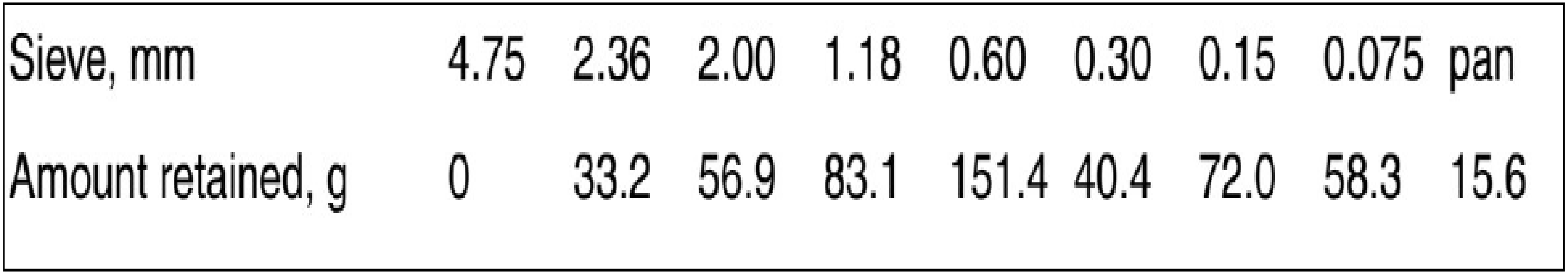
Sieve Size	Log (Sieve Size)	(Sieve Size)^0.45	Cum. % Passing
mm			100 - Cum. Ret.
37.5	1.57	5.11	100
25	1.40	4.26	100
19	1.28	3.76	97.5
12.5	1.10	3.12	92.5
9.5	0.98	2.75	80.5
4.75	0.68	2.02	61
2.36	0.37	1.47	50
1.18	0.07	1.08	37.5
0.6	-0.22	0.79	23
0.3	-0.52	0.58	11.5
0.15	-0.82	0.43	4
0.075	-1.12	0.31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

Gradation Chart



Sieve Analysis Example 2

- A sieve analysis test was performed on a sample of fine aggregate and produced the following results

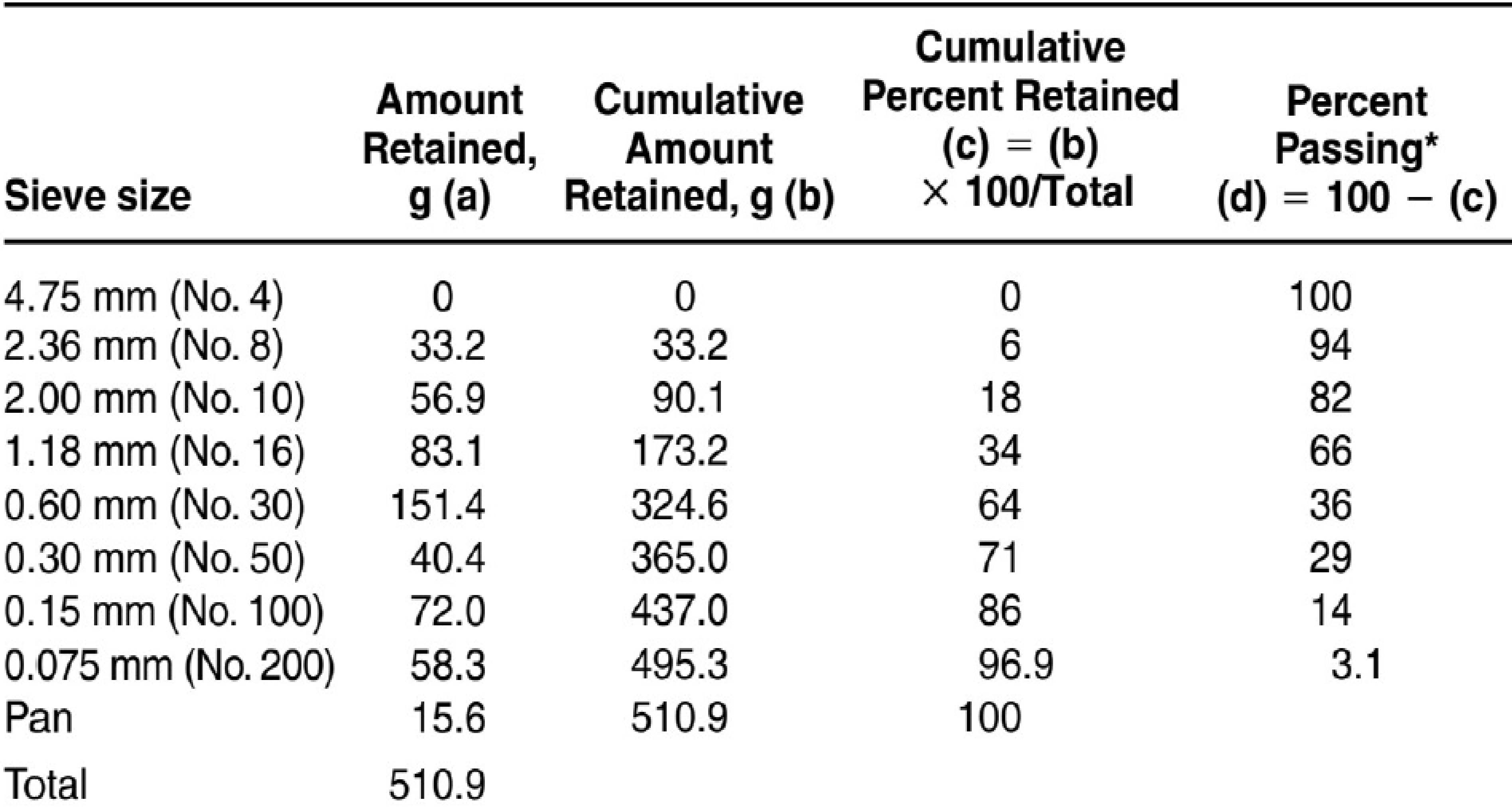


Sieve, mm	4.75	2.36	2.00	1.18	0.60	0.30	0.15	0.075	pan
Amount retained, g	0	33.2	56.9	83.1	151.4	40.4	72.0	58.3	15.6

- Calculate the percent passing each sieve
- Draw a 0.45 power gradation chart with the use of a spreadsheet program.

Sieve Analysis Example 2

Percent passing each sieve

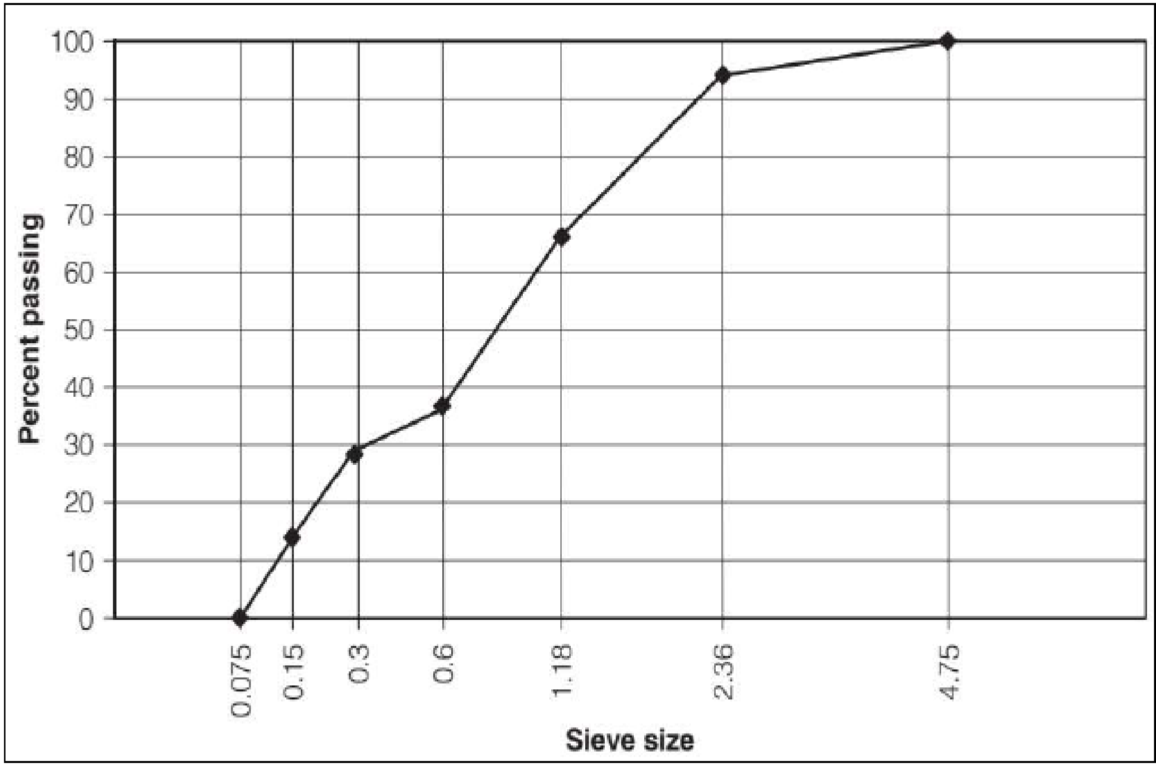


Sieve size	Amount Retained, g (a)	Cumulative Amount Retained, g (b)	Cumulative Percent Retained (c) = (b) × 100/Total	Percent Passing* (d) = 100 − (c)
4.75 mm (No. 4)	0	0	0	100
2.36 mm (No. 8)	33.2	33.2	6	94
2.00 mm (No. 10)	56.9	90.1	18	82
1.18 mm (No. 16)	83.1	173.2	34	66
0.60 mm (No. 30)	151.4	324.6	64	36
0.30 mm (No. 50)	40.4	365.0	71	29
0.15 mm (No. 100)	72.0	437.0	86	14
0.075 mm (No. 200)	58.3	495.3	96.9	3.1
Pan	15.6	510.9	100	
Total	510.9			

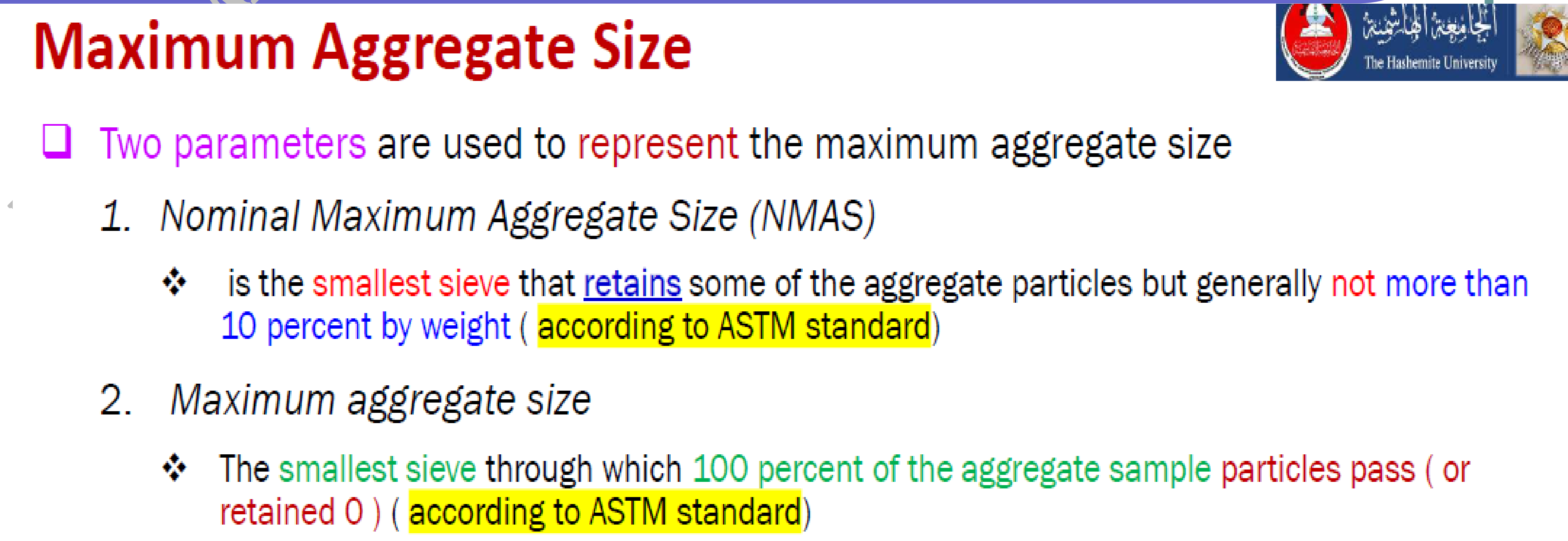
Sieve Analysis Example 2

Draw a 0.45 power gradation chart

1	2	3
Sieve Size (mm)	Sieve to the 0.45 Power	Percent Passing
4.75	2.02	100
2.36	1.47	94
2	1.37	82
1.18	1.08	66
0.6	0.79	36
0.3	0.58	29
0.15	0.43	14
0.075	0.31	3.1



Maximum & Nominal Max. Agg. Size



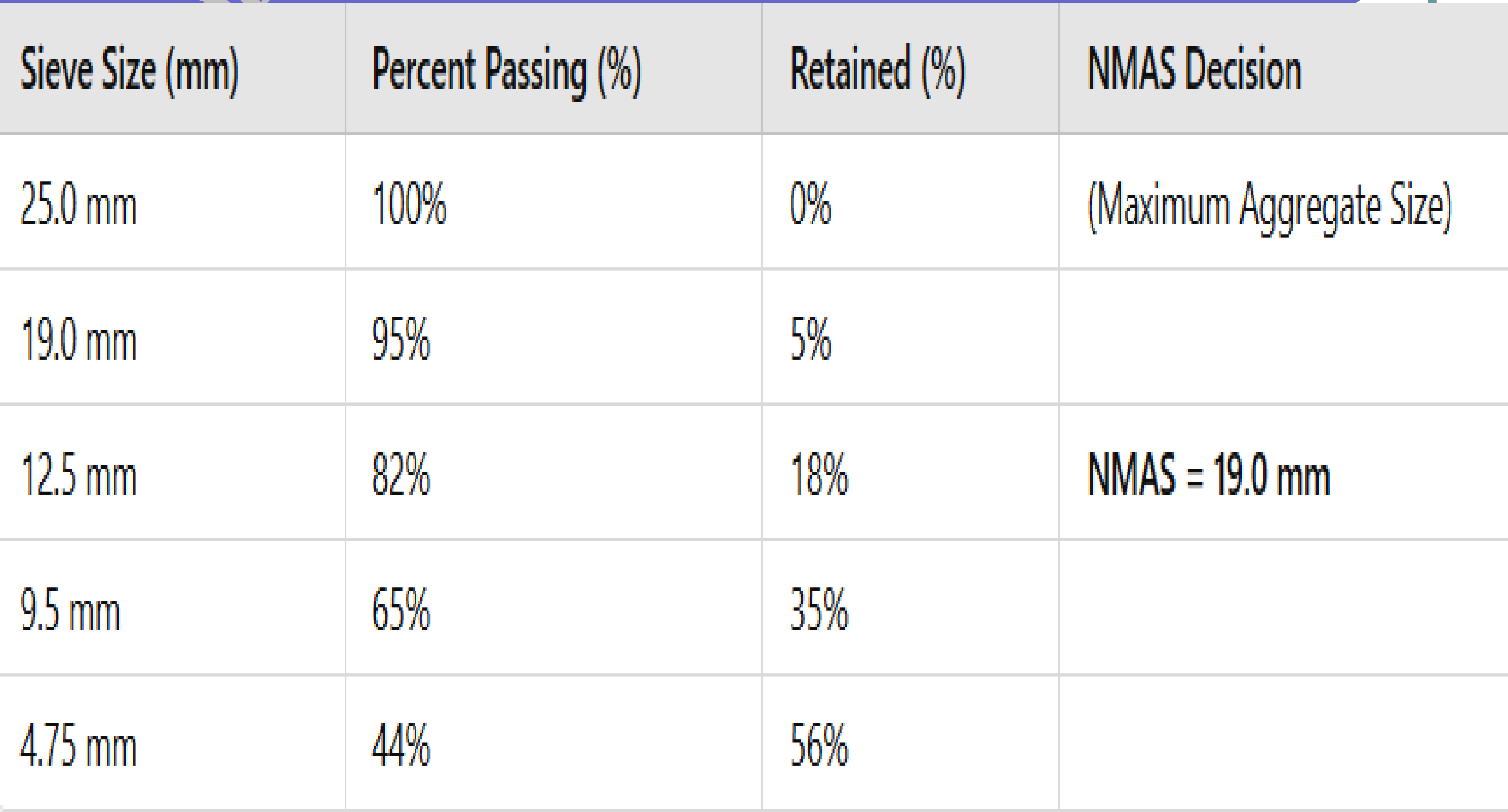
Maximum Aggregate Size

- ☐ Two parameters are used to represent the maximum aggregate size

1. *Nominal Maximum Aggregate Size (NMAS)*
   - is the smallest sieve that retains some of the aggregate particles but generally not more than 10 percent by weight (according to ASTM standard)
2. *Maximum aggregate size*
   - The smallest sieve through which 100 percent of the aggregate sample particles pass (or retained 0) (according to ASTM standard)

According to the American Association of State Highway and Transportation Officials (AASHTO**) & SuperPave**, the Nominal Maximum Aggregate Size (NMAS) is defined as:"**One sieve size larger than the first sieve that retains more than 10% of the total aggregate sample**.“

NMAS

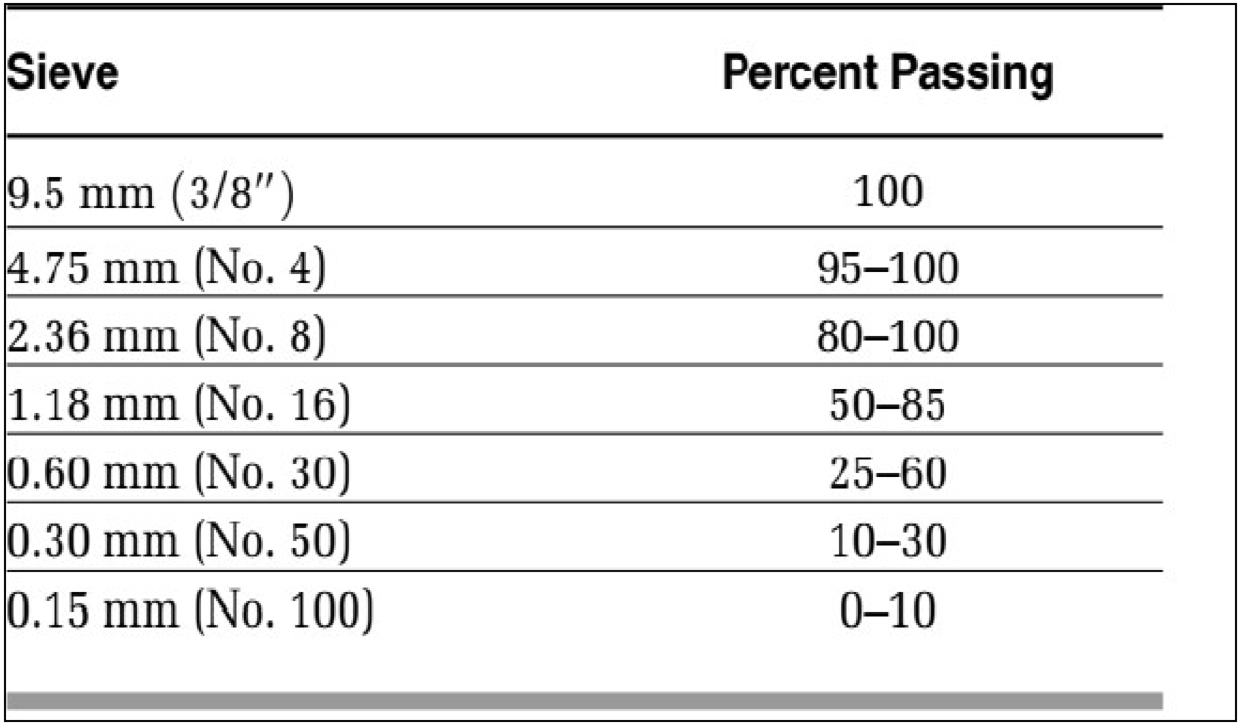


Sieve Size (mm)	Percent Passing (%)	Retained (%)	NMAS Decision
25.0 mm	100%	0%	(Maximum Aggregate Size)
19.0 mm	95%	5%	
12.5 mm	82%	18%	NMAS = 19.0 mm
9.5 mm	65%	35%	
4.75 mm	44%	56%	

Gradation Specification Limits

Gradation specifications (limits)

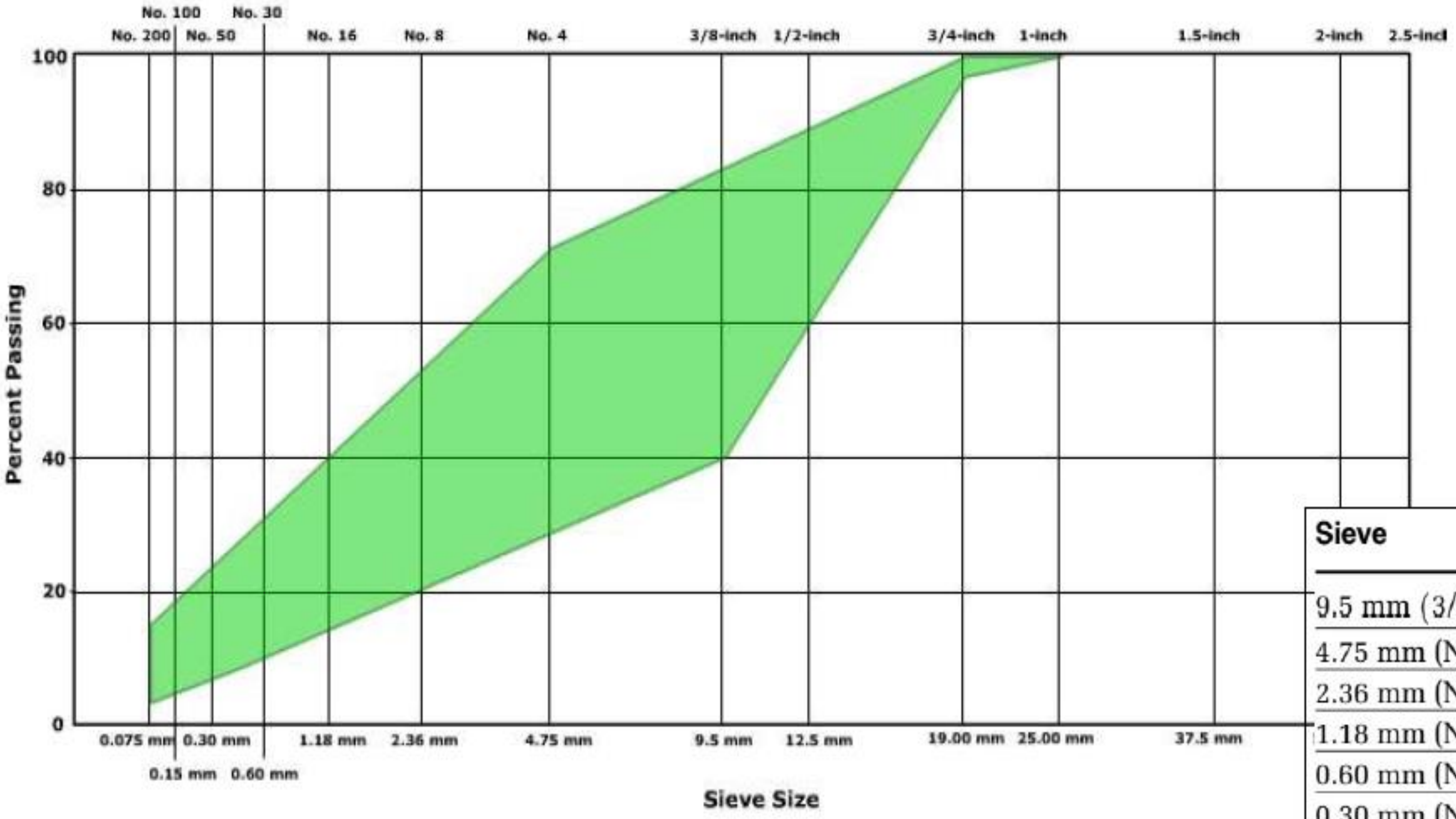
- Gradation specifications is used to define maximum and minimum cumulative percentages of material passing each sieve



Sieve	**Percent Passing**
9.5 mm (3/8″)	100
4.75 mm (No. 4)	95–100
2.36 mm (No. 8)	80–100
1.18 mm (No. 16)	50–85
0.60 mm (No. 30)	25–60
0.30 mm (No. 50)	10–30
0.15 mm (No. 100)	0–10

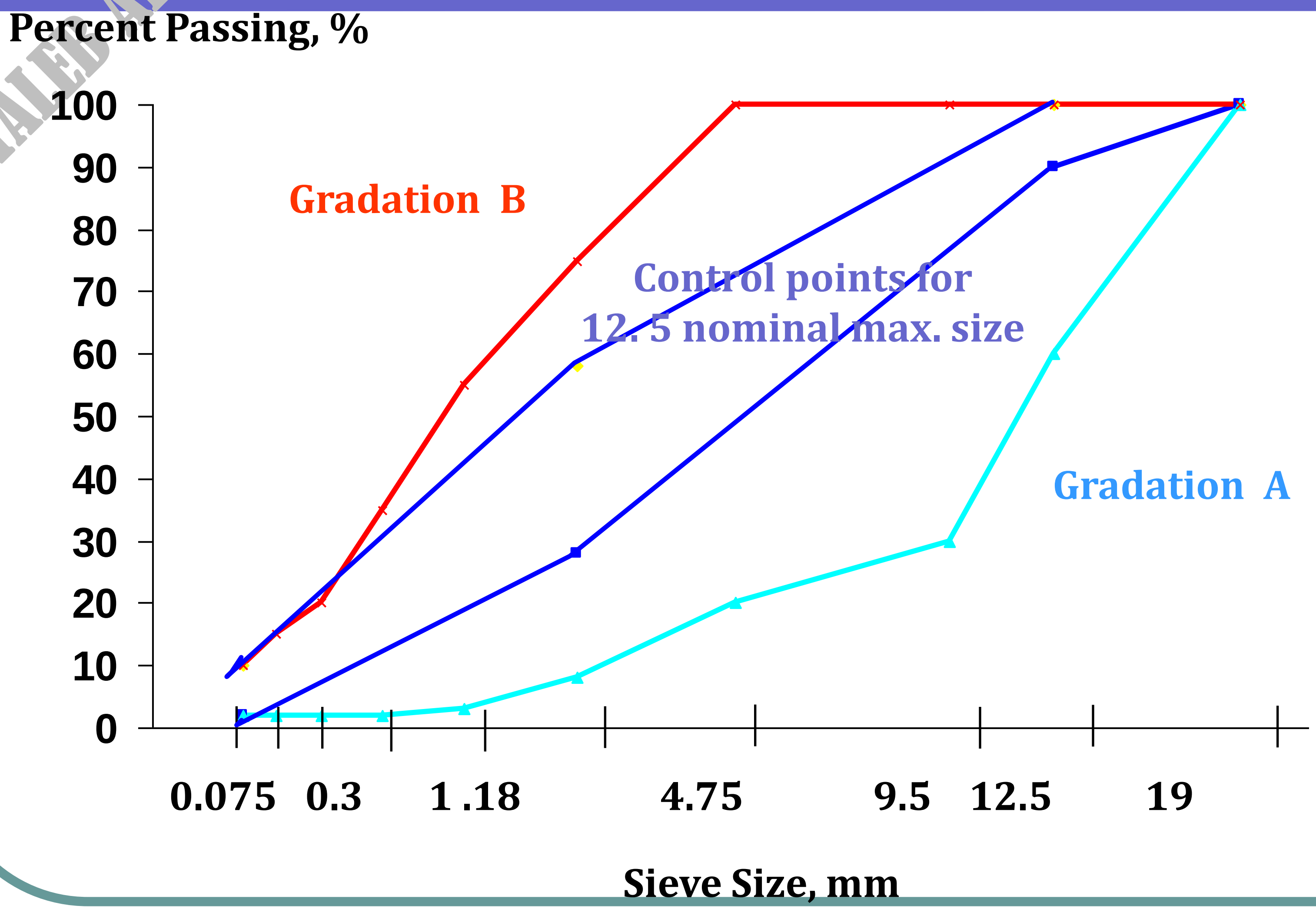
Gradation Specifications

Representative Gradation Specifications for surface Course

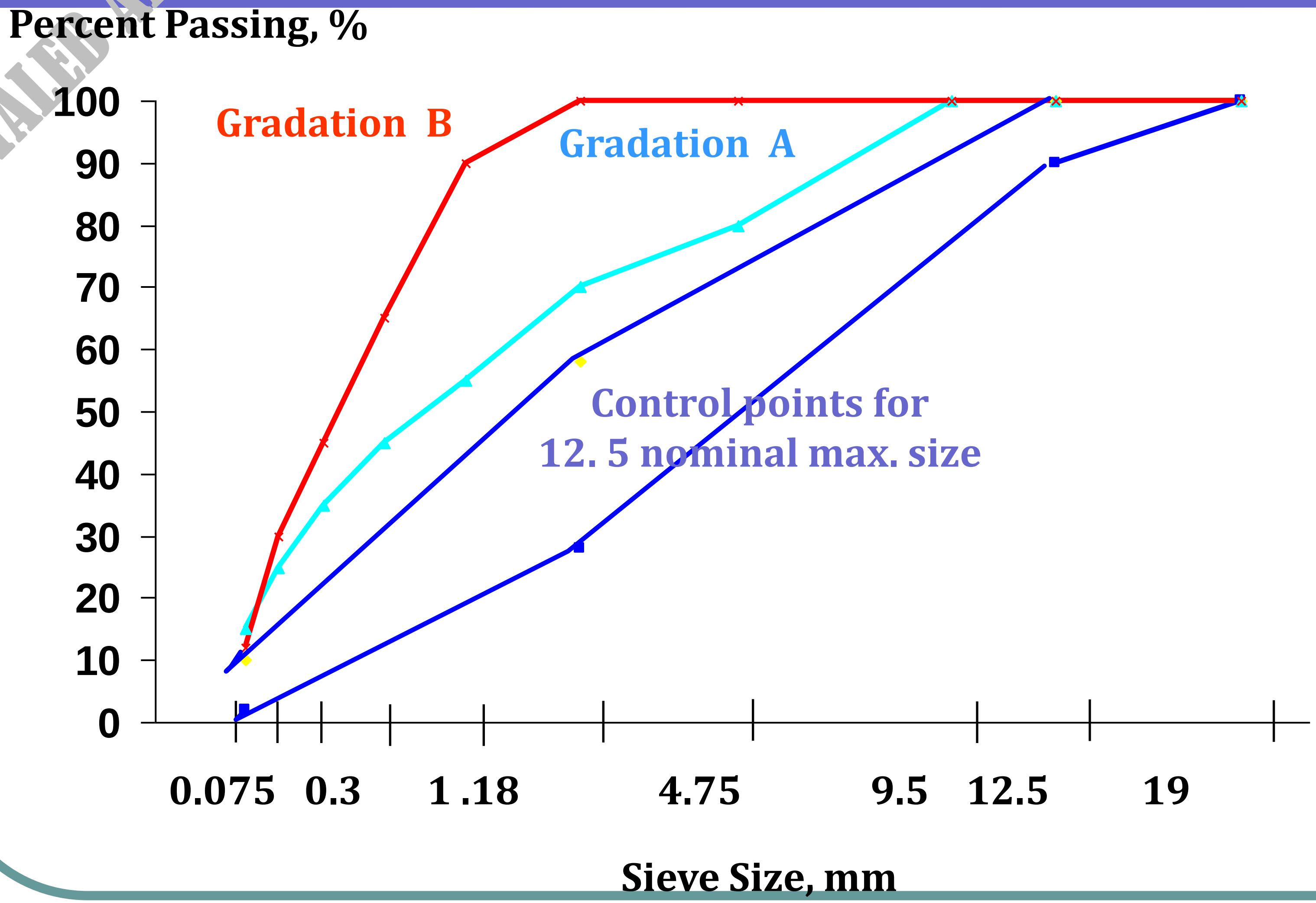


Sieve	Percent Passing
9.5 mm (3/8″)	100
4.75 mm (No. 4)	95–100
2.36 mm (No. 8)	80–100
1.18 mm (No. 16)	50–85
0.60 mm (No. 30)	25–60
0.30 mm (No. 50)	10–30
0.15 mm (No. 100)	0–10

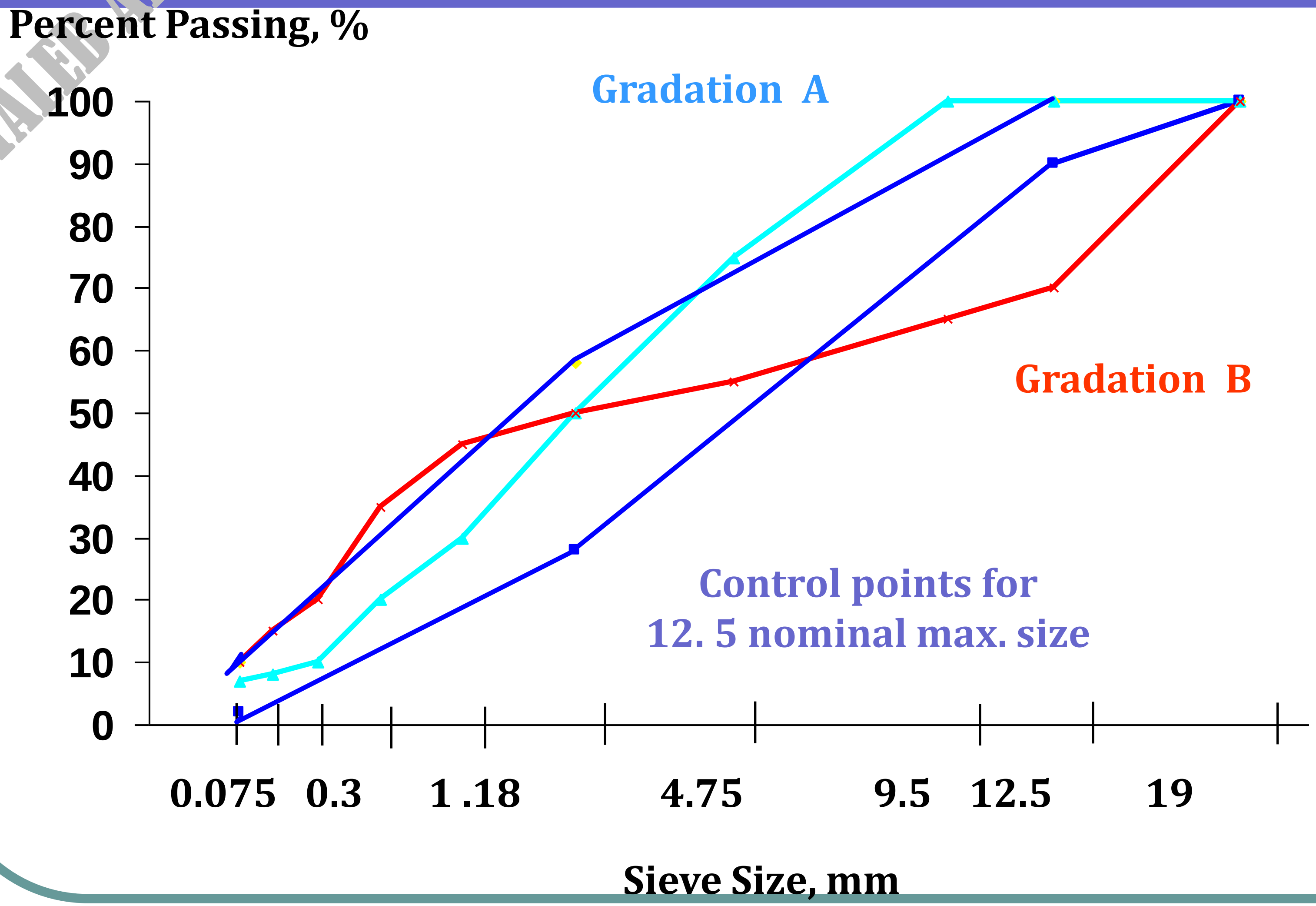
All possible combinations fall between A and B



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 Angeles (LA) abrasion test.
- ASTM C131 / C131M - 20 Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

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

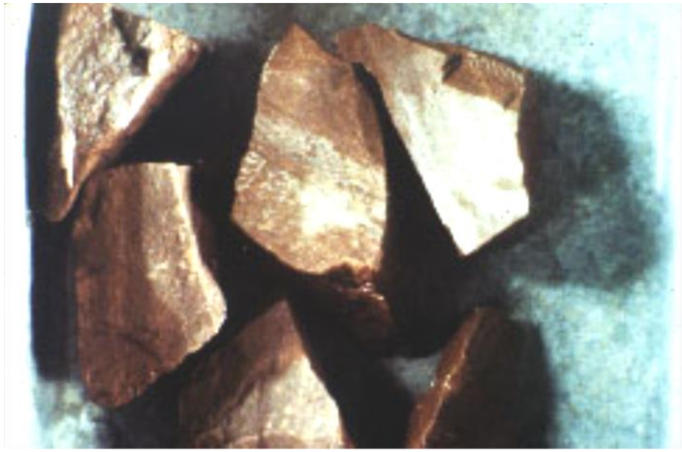
- Approx. 10% loss for extremely hard igneous rocks
- Approx. 60% loss for soft limestones and sandstones

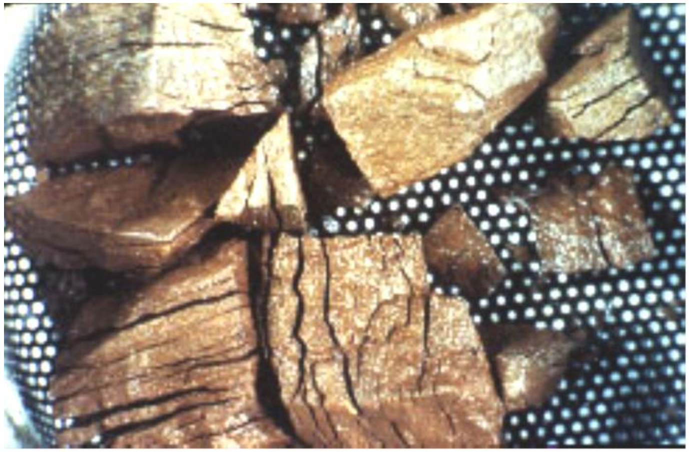
Durability & Resistance to Weathering (Soundness Test)

- Soundness Test AASHTO T104, (ASTM C88 / C88M - 18 Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate)
- 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



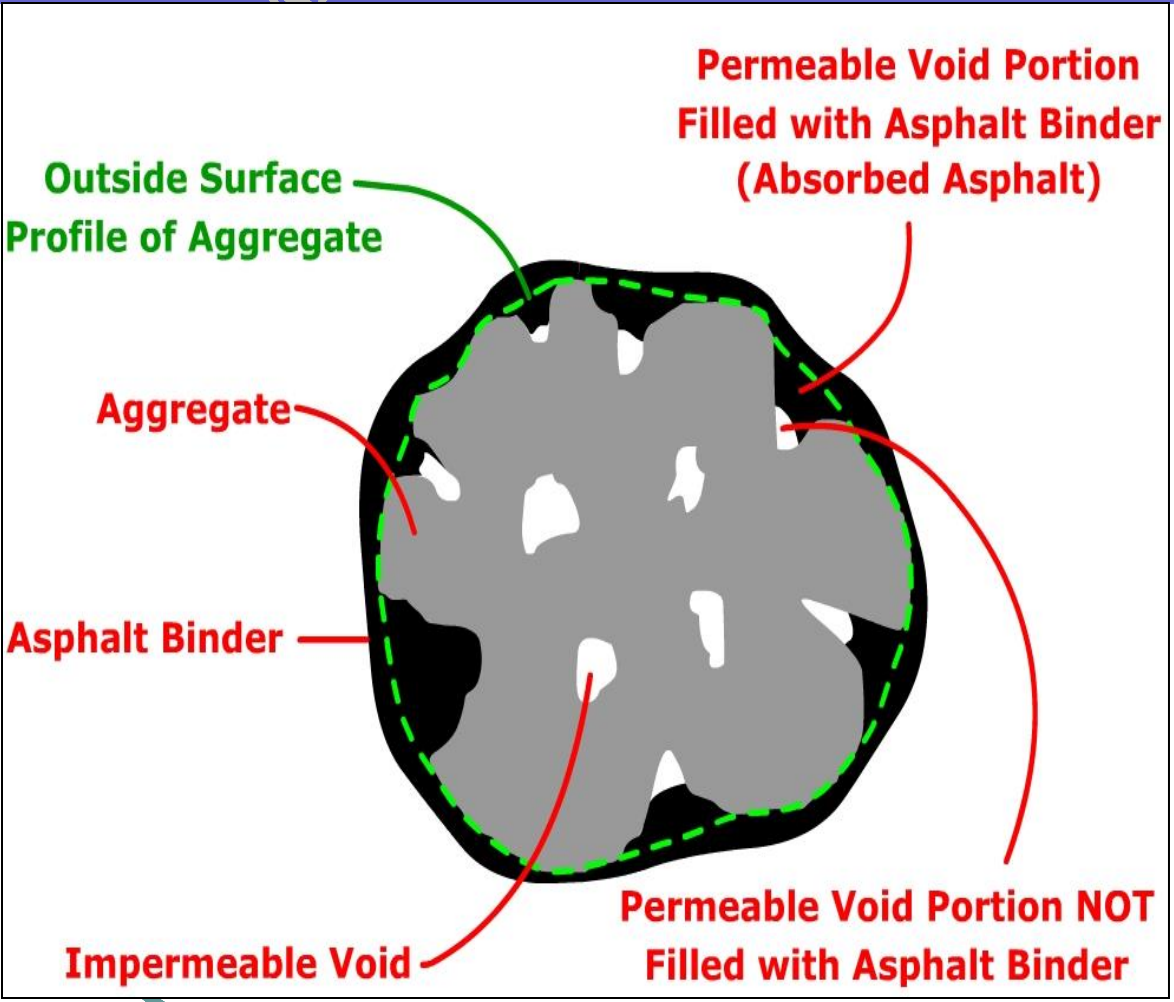


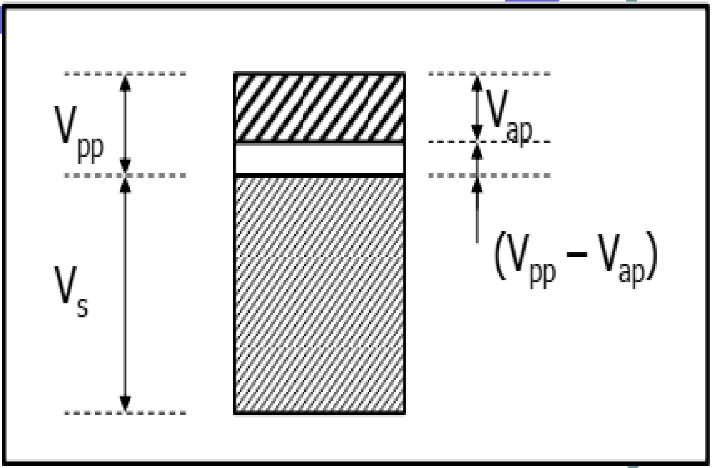
After

Specific Gravity & Absorption

- ASTM C127 - 15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate
- ASTM C128 - 15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate
- 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

Aggregate Specific Gravity

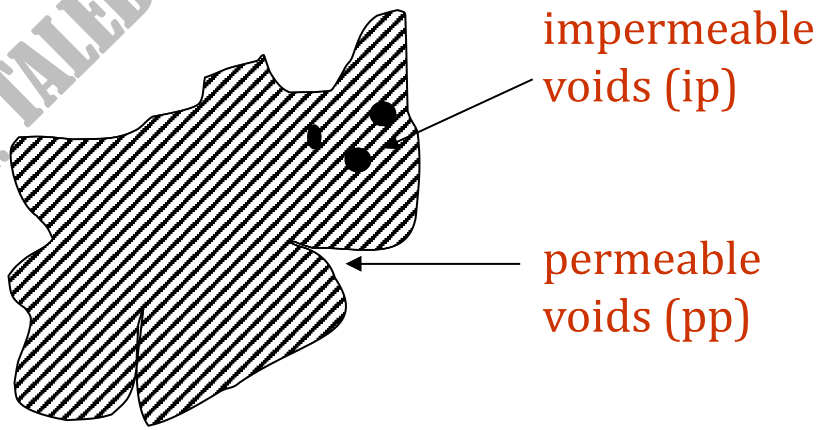


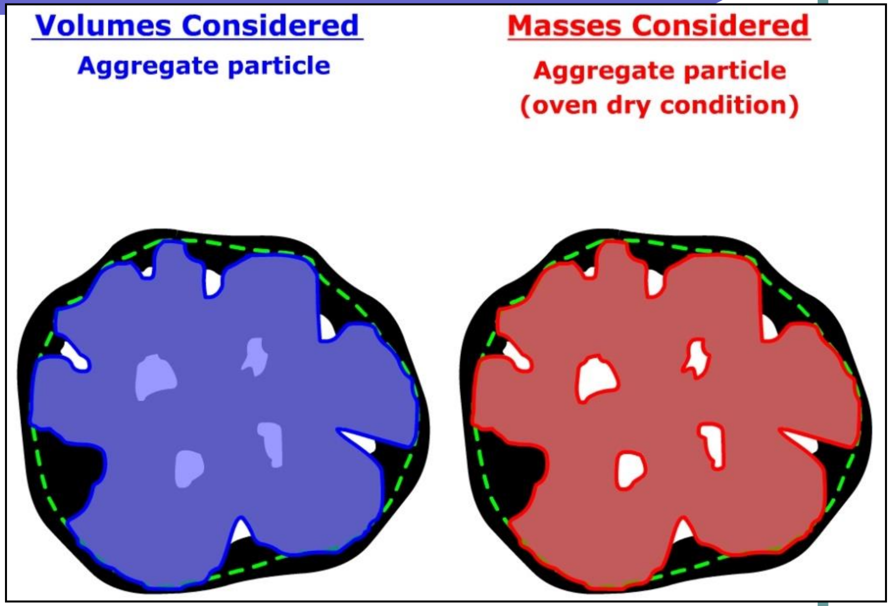


- V_s : Volume of solids
- V_{pp} : Volume of water permeable pores
- V_{ap} : Volume of pores absorbing asphalt
  - *$V_{pp} - V_{ap}$: Volume of water permeable pores not filled with asphalt*

Apparent Specific Gravity (G_{sa})

Computed based on net volume of the aggregates



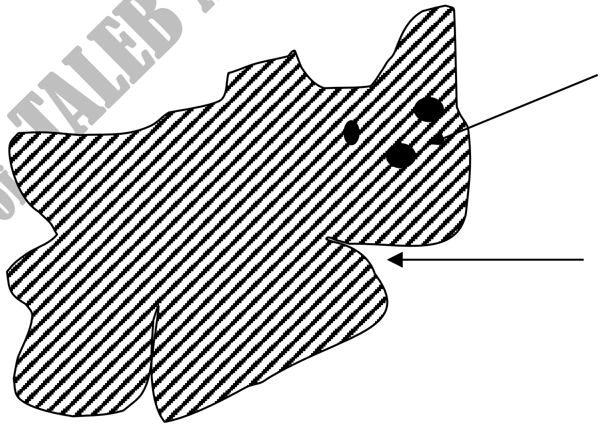


$$G_{sa} = \frac{W_s}{(V_s + V_{ip})\gamma_w}$$

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

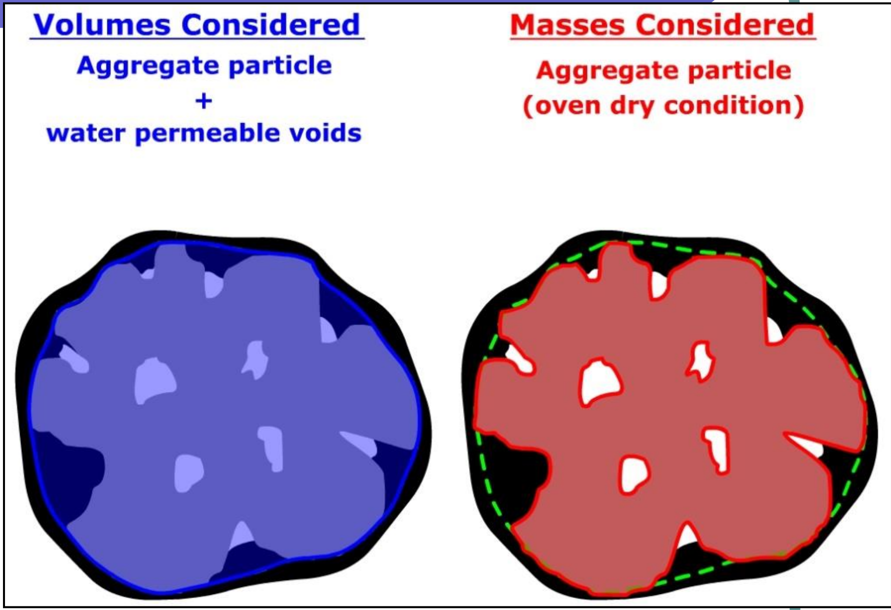
Bulk Specific Gravity (G_{sb})

Computed based on total volume of the aggregates



impermeable voids (ip)

permeable voids (pp)



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

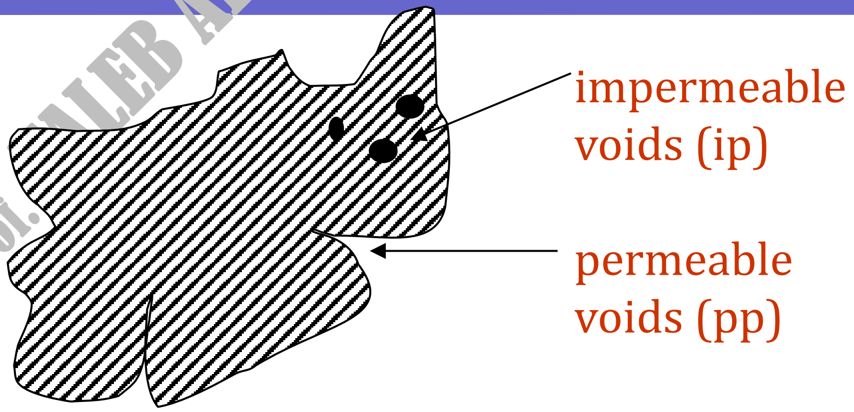
$$G_{sb} = \frac{W_s}{W_{ssd} - W_{sub}} = \frac{W_s}{W_{pyc+w1} + W_{ssd} - W_{pyc+agg+w2}}$$

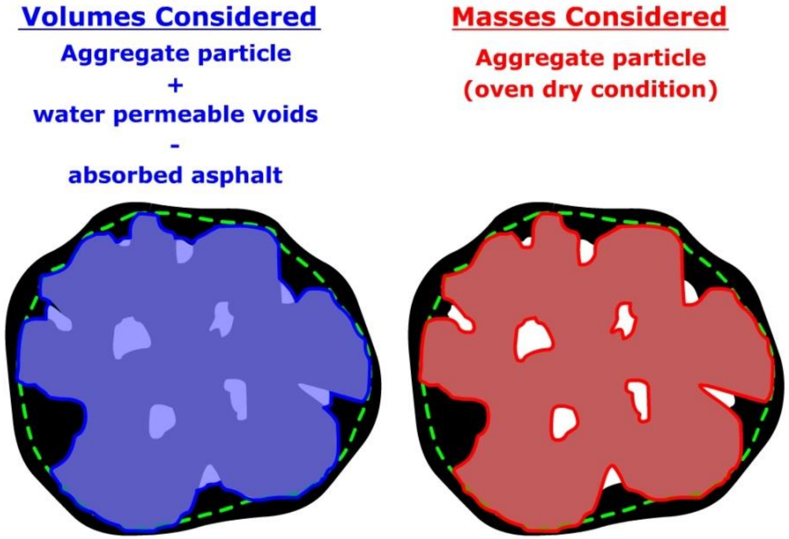
Effective Specific Gravity (G_{se})

- 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

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

ASTM C127 - 15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate

- Wash 5 kg of aggregate retained on No. 4 sieve.
- Oven dry to a constant weight.
- Soak in water for 24 hours.
- Decant water.
- Use pre-dampened towel to get SSD condition, weigh and record (B)
- Place the SSD sample in a wire basket, submerge in water, then the submerged weight is determined and recorded (C)
- Oven dry the sample to a constant weight, weigh
  and record (A)

☐ A: Oven-dry wt. of agg.(g)

☐ B: SSD wt. of agg. (g)

☐ C: submerged wt. of SSD agg. In water (g

$$G_{sa} = \frac{A}{A-C}$$

$$G_{sb} = \frac{A}{B-C}$$

$$G_{s,SSD} = \frac{B}{B-C}$$

$$\text{Apsorption, \%} = \frac{(B-A)\times 100}{A}$$

ASTM C128 - 15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate

- Fill flask with water and record weight as (B)
- Oven-dry 1000 g of fine aggregate.
- Soak in water for 24 hours
- Spread out and dry (warm air moving current) to SSD?
- Add 500 g of SSD aggregate (D) to pycnometer of known volume pre-filled with some water
- Add more water and agitate until air bubbles have been removed
- Fill to line and determine the mass of the pycnometer, aggregate and water (C)
- Empty aggregate into pan and dry to constant mass
- Determine oven dry mass (A)

❑ A: Oven-dry wt. of agg. (g)

❑ B: wt. of flask filled with water (to mark), (g)

❑ C: wt. of flask + SSD specimen + water (to mark), (g)

❑ D: SSD wt. (500 ⍰ 10 g)

$$G_{sa} = \frac{A}{B+A-C}$$

$$G_{sb} = \frac{A}{B+D-C}$$

$$G_{s,SSD} = \frac{D}{B+D-C}$$

$$\text{Apsorption, \%} = \frac{(D-A)\times 100}{A}$$

Specific Gravity for Aggregate Blend

- For stockpiles that include More than two aggregate sources
  - One value must be determined for the stockpile.
- The average G_{sb} can be calculated as follows:

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

- G_{sb} = bulk (dry) specific gravity of the aggregate blend
- P_1, P_2, P_3 , P_n = Percentages by weight of aggregates 1, 2, through n
- G_1, G_2, G_3 , G_n = S.G of aggregates 1, 2, through n

$$G_{sb} = \frac{P_{coarse} + P_{fine}}{\frac{P_{coarse}}{G_{coarse}} + \frac{P_{fine}}{G_{fine}}},$$

Absorption for Aggregate

- The absorptiveness of aggregate is of significant interest to the mixture designer and specifier.
- Absorption can be an indicator regarding aggregate quality along with increased binder demand.
- The binder absorption is *typically 40 –80 percent* of the water absorption rate.
- The water absorption rate is calculated by the following equation as outlined in AASHTO T 85

$$\boldsymbol{Absorption, \% = \frac{B-A}{A} \times 100}$$

- A = mass of the oven-dry test sample
- B = mass of the saturated surface-dry sample

Absorption for Aggregate Blend

- The average water absorption for the total aggregate blend as shown in AASHTO T 85 is calculated as follows

$$\boldsymbol{Absorption\ \% = \frac{P_1 \times A_1 + P_2 \times A_2 + \cdots \ldots P_n \times A_n}{100}},$$

- P_1, P_2, P_n = Percentages by weight of aggregates 1, 2, through n
- A_1, A_2, A_n = absorption of aggregates 1, 2, through n

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 limestone aggregates.

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

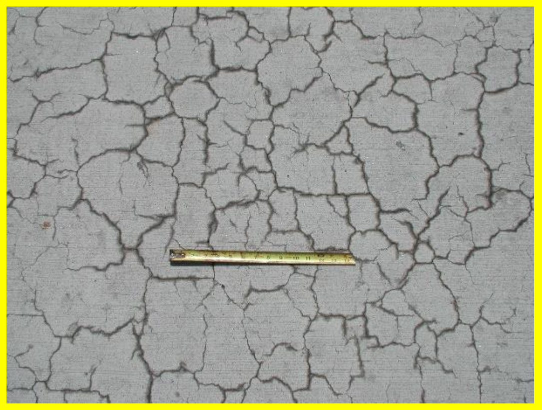
Chemical Stability Cont.

- 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.



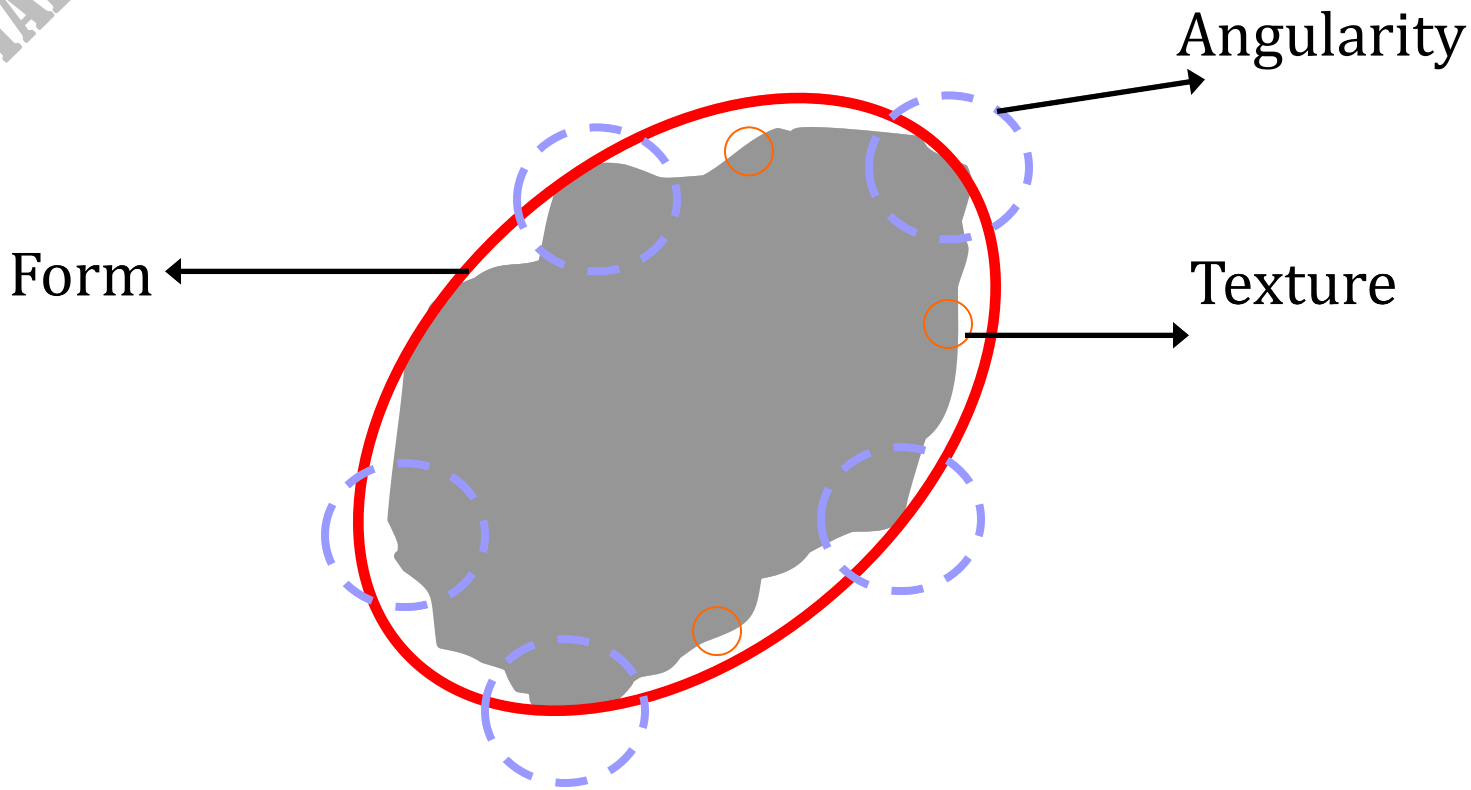
Aggregate Shape & Surface Texture

- Results from Processing
- Shape: circular, semi circular, semi elongated, elongated. Or high sphericity, ,moderate sphericity, low sphericity, flat/elongated.
- Angularity: rounded, subrounded, sub-angular, angular.
- surface texture: High roughness, moderate roughness, low roughness, 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))

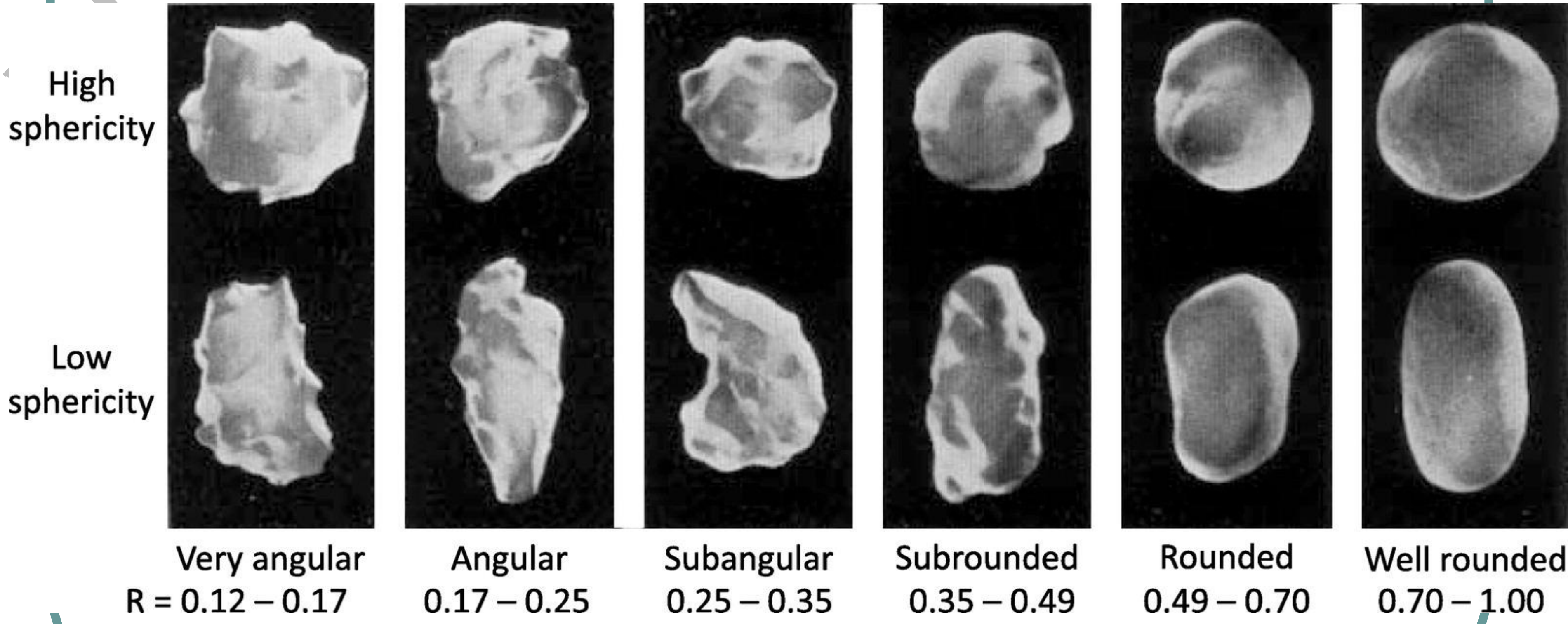
AASHTO TP56 Uncompacted Void Content of Coarse Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)

- 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.

Examples on Sphericity and Angularity



% 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

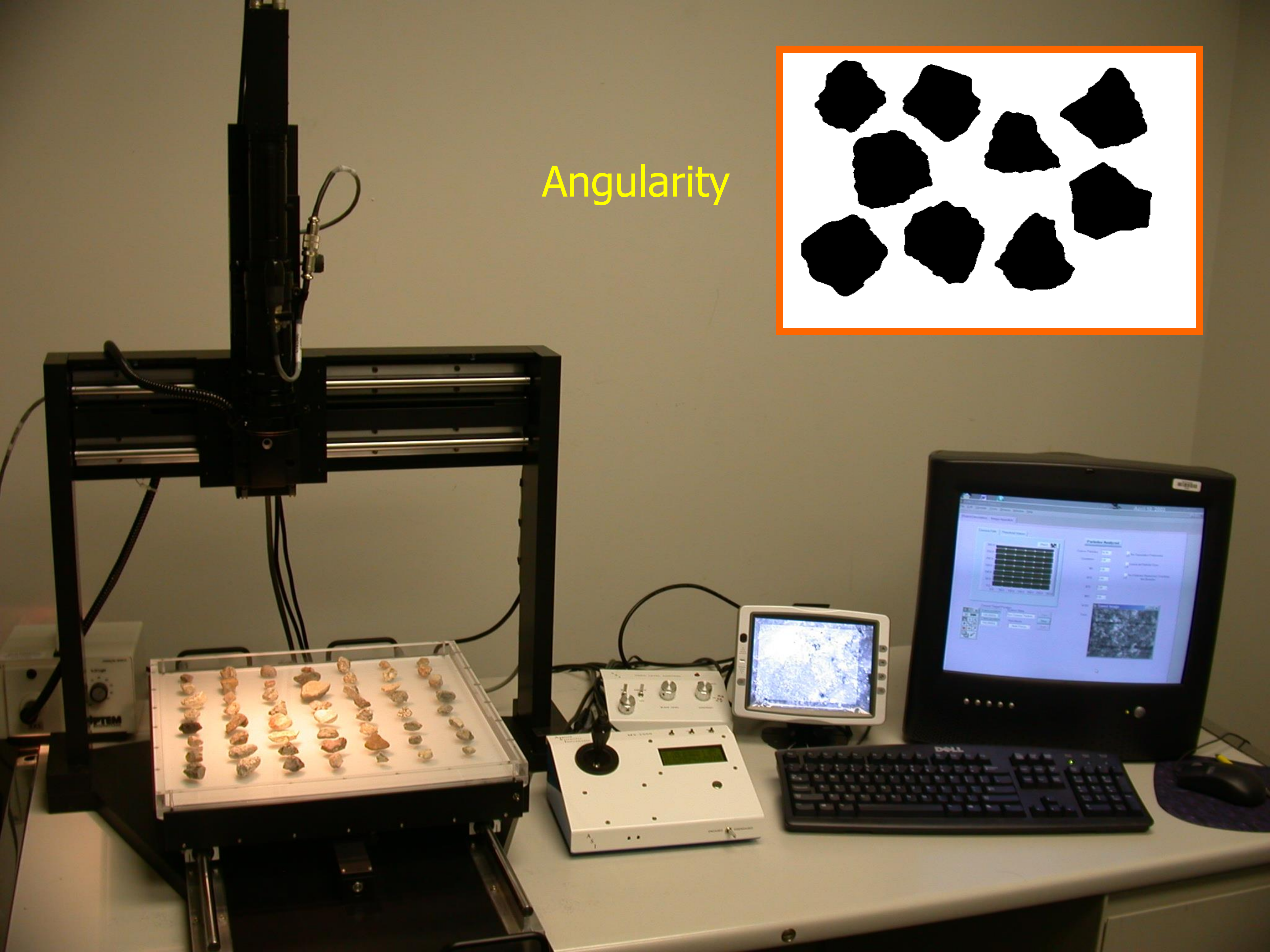
Form of Aggregates

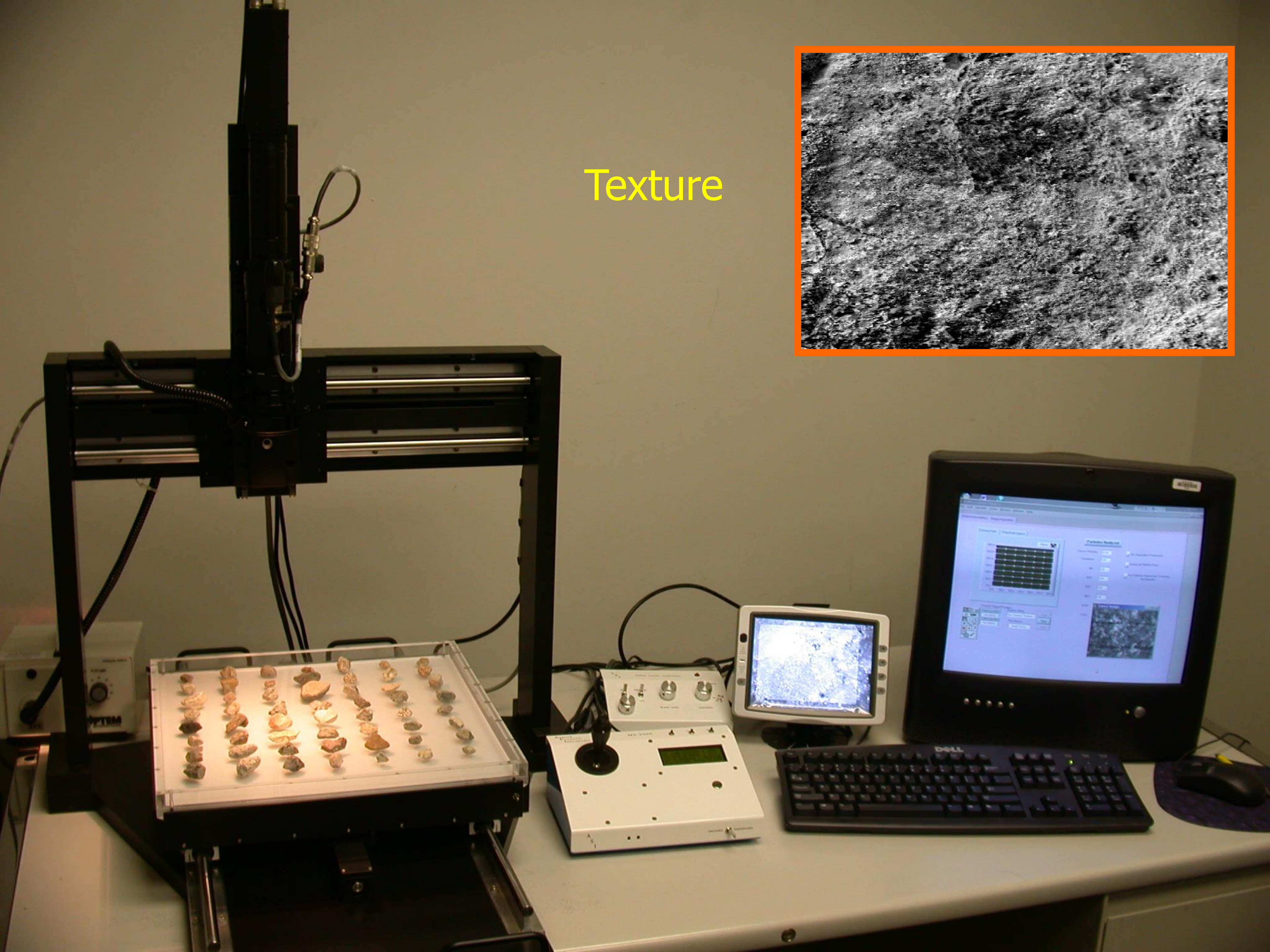
- ASTM D4791 - 19 Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
- This method provides the percentage by number or weight of flat, elongated, or both flat and elongated particles in a given sample of coarse aggregate.
- The procedure 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

Aggregate Imaging System AIMS

Angularity





Texture

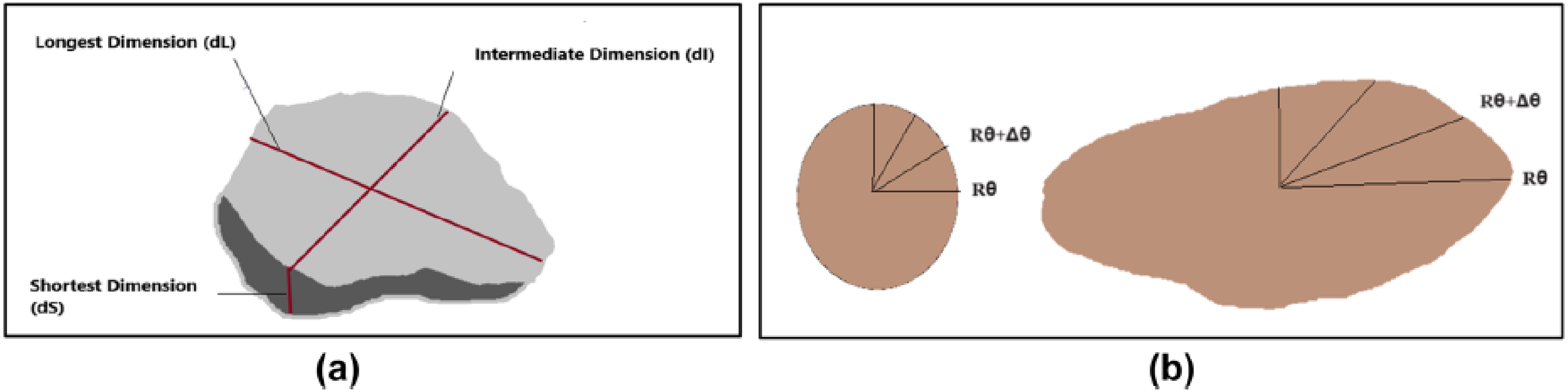


Fig. 5 Illustrations for measure principles of: **a** Sphericity; **b** 2-D form

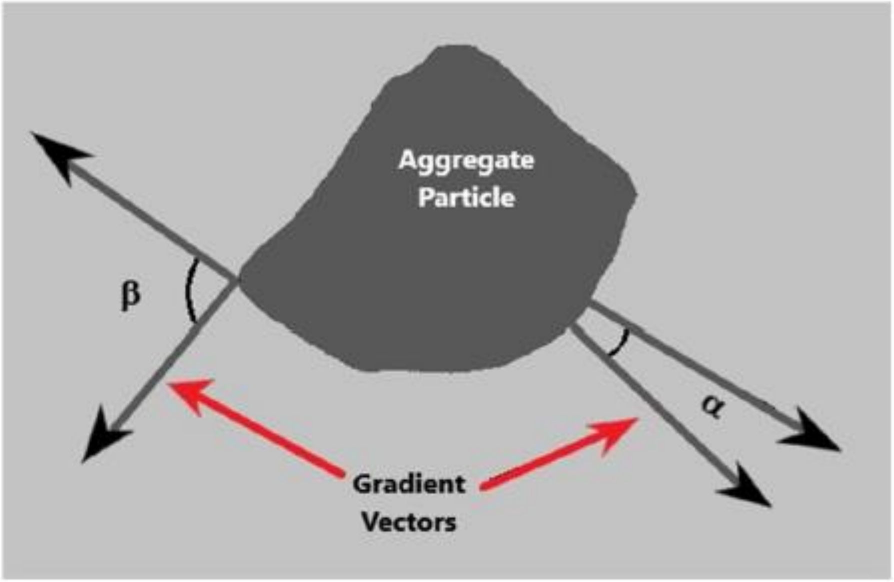


Fig. 6 Comparing angularity of rounded corners and sharp corners on the outline of an aggregate image

as represented by Eqs. (1–4). Sphericity is a parameter to describe the form of coarse particles. Sphericity defines the relationship between the particle dimensions, as represented by Eq. (1).

$$\text{Sphericity} = \sqrt[3]{\frac{d_S d_I}{d_L^2}} \tag{1}$$

where d_S is the particle's shortest dimension; d_I the particle's intermediate dimension; and d_L the particle's longest dimension. An illustration showing particle dimensions is shown in Fig. 5a. Sphericity values range from 0 to 1 with higher values to equidimensional particles (spherical and cubical).

The form index (2-D form) is calculated based on particle radius incremental changes as described by Eq. (2).

$$2-D\text{Form Index} = \sum_{\theta=0}^{\theta=360-\Delta\theta} \left| \frac{R_{\theta+\Delta\theta} - R_\theta}{R_\theta} \right| \tag{2}$$

where θ is the directional angle and R is the radius in different directions. For a perfect circle, the form index calculated by Eq. (2) would be zero. Figure 5b illustrates the 2-D form

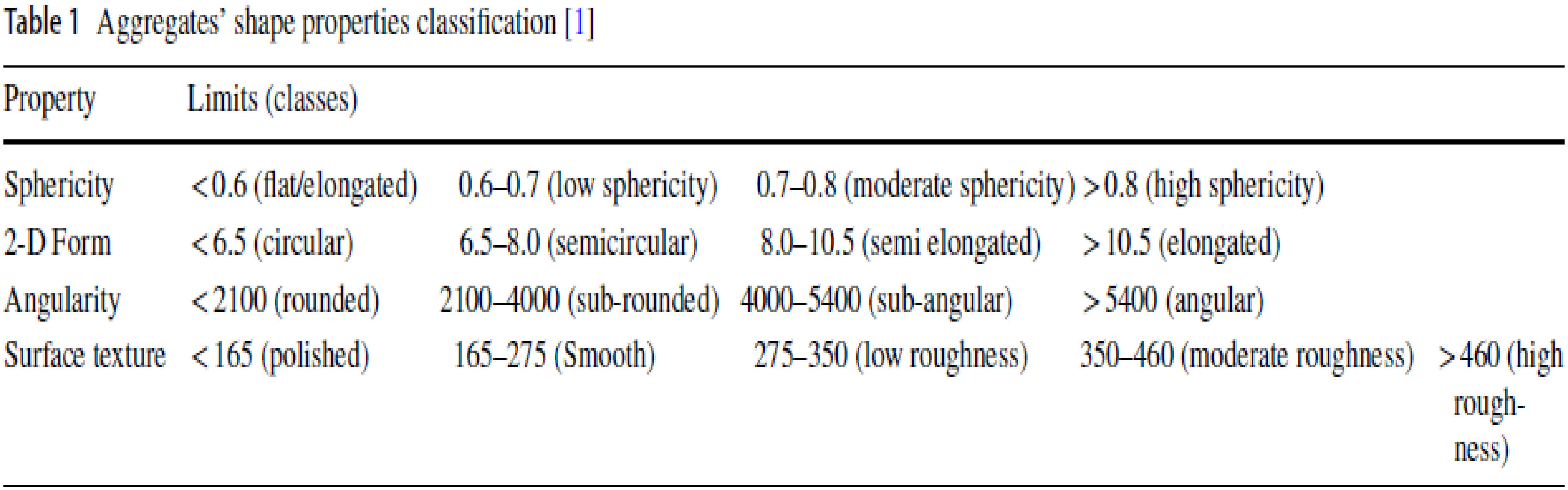


Table 1 Aggregates' shape properties classification [1]

Property	Limits (classes)				
Sphericity	< 0.6 (flat/elongated)	0.6–0.7 (low sphericity)	0.7–0.8 (moderate sphericity)	> 0.8 (high sphericity)	
2-D Form	< 6.5 (circular)	6.5–8.0 (semicircular)	8.0–10.5 (semi elongated)	> 10.5 (elongated)	
Angularity	< 2100 (rounded)	2100–4000 (sub-rounded)	4000–5400 (sub-angular)	> 5400 (angular)	
Surface texture	< 165 (polished)	165–275 (Smooth)	275–350 (low roughness)	350–460 (moderate roughness)	> 460 (high roughness)

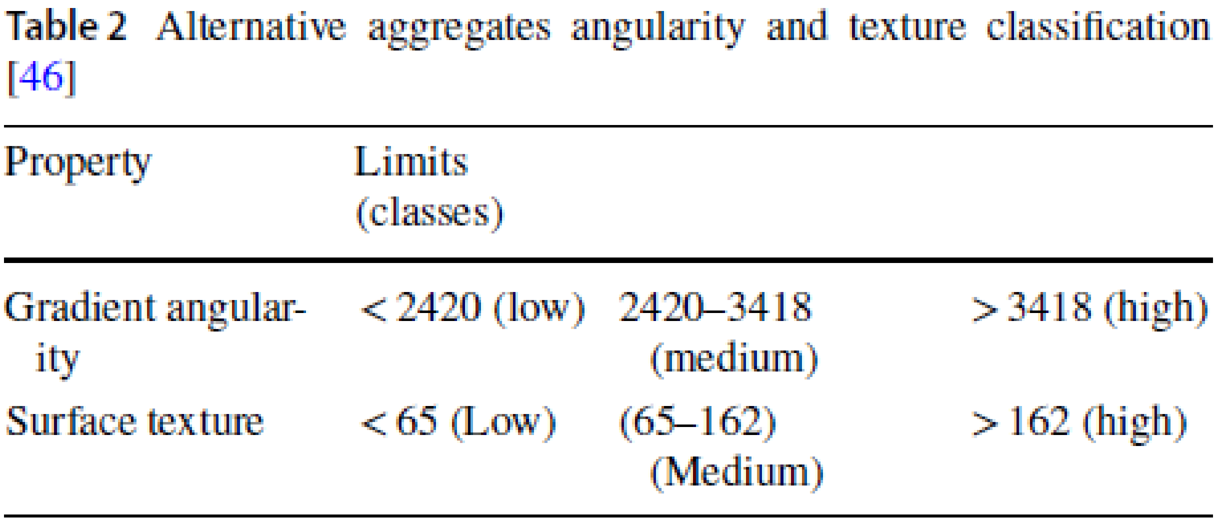


Table 2 Alternative aggregates angularity and texture classification [46]

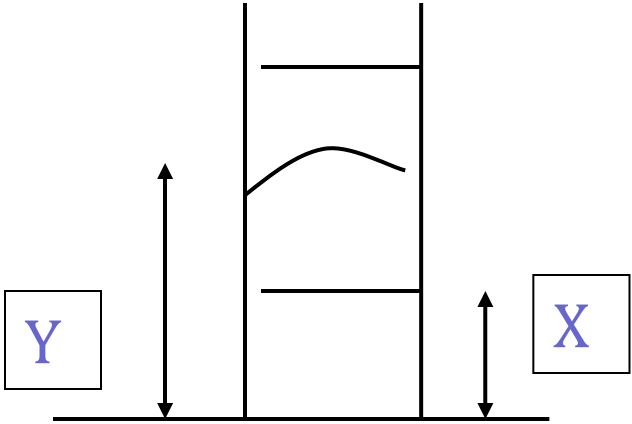
Property	Limits (classes)		
Gradient angularity	< 2420 (low)	2420–3418 (medium)	> 3418 (high)
Surface texture	< 65 (Low)	(65–162) (Medium)	> 162 (high)

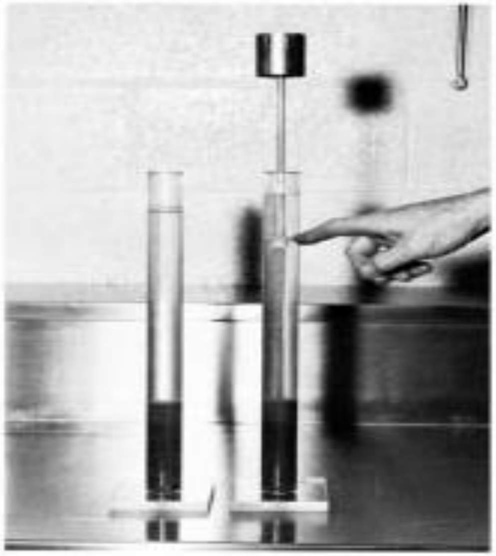
Disintegration/ Cleanliness

- Clay Lumbs & Friable Particle (AASHTO T112). ASTM C142 / C142M - 17 Standard Test Method for Clay Lumps and Friable Particles in Aggregates
- 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

- ASTM D2419 - 14 Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate
- Sand equivalent SE = X/Y *100
  - specify min.
  - Stock Solution used is **calcium chloride solution** to flush the clay-size particles from the sand.



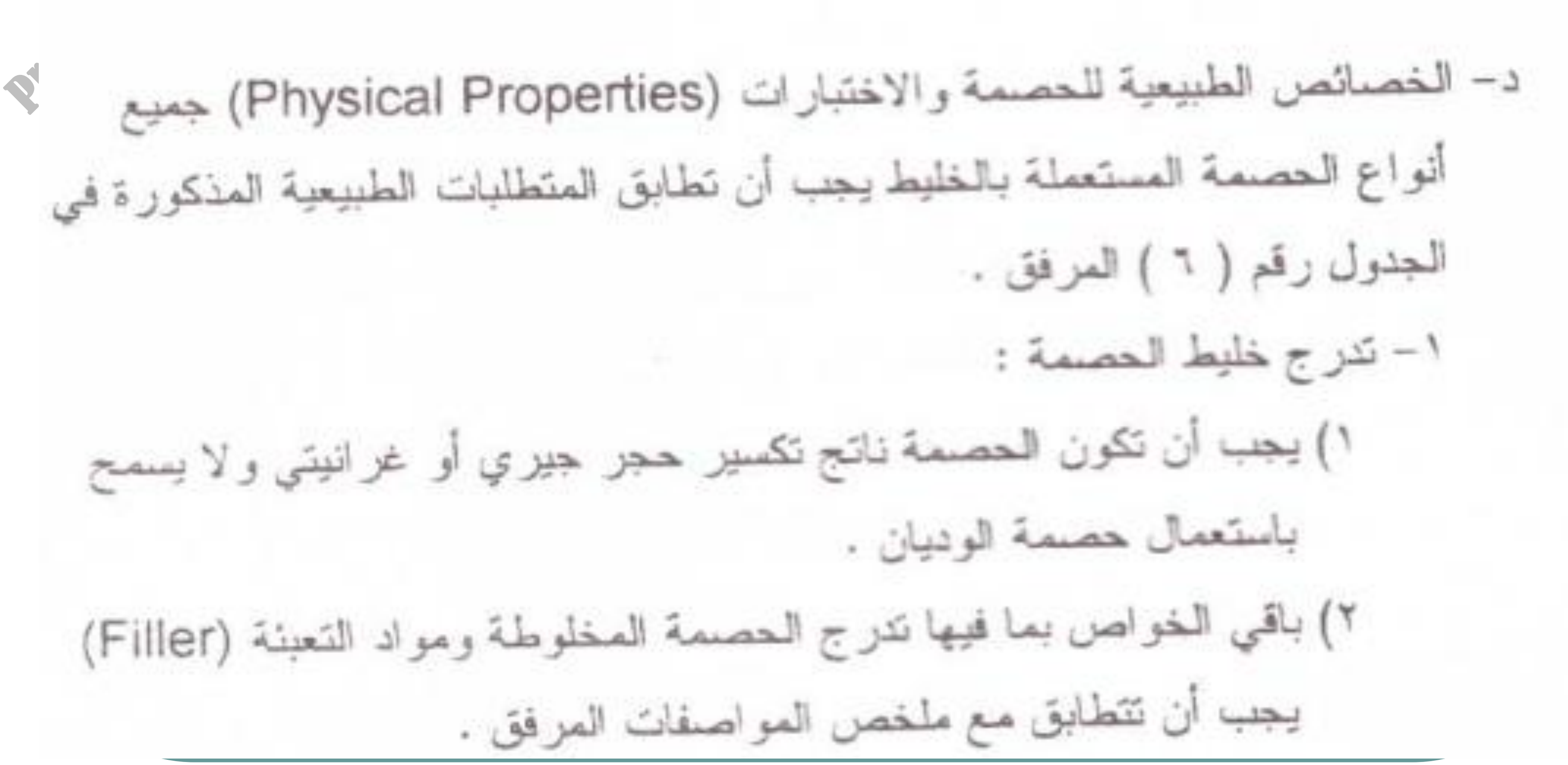


Things to Remember

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

Ministry of Public Works and Housing

- Specifications for secondary and village roads construction



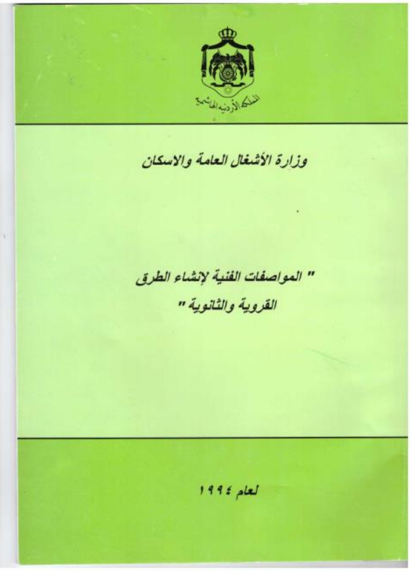
د- الخصائص الطبيعية للحصمة والاختبارات (Physical Properties) جميع أنواع الحصمة المستعملة بالخليط يجب أن تطابق المتطلبات الطبيعية المذكورة في الجدول رقم (٦) المرفق .

١- تدرج خليط الحصمة :

١) يجب أن تكون الحصمة ناتج تكسير حجر جيري أو غرانيتي ولا يسمح باستعمال حصمة الوديان .

٢) باقي الخواص بما فيها تدرج الحصمة المخلوطة ومواد التعبئة (Filler) يجب أن تتطابق مع ملخص المواصفات المرفق .

د- الخصائص الطبيعية للحصمة والاختبارات (Physical Properties) جميع أنواع الحصمة المستعملة بالخليط يجب أن تطابق المتطلبات الطبيعية المذكورة في الجدول رقم (٦) المرفق .



المملكة الأردنية الهاشمية

وزارة الأشغال العامة والاسكان

" المواصفات الفنية لإنشاء الطرق
القروية والثانوية "

لعام ١٩٩٤

TABLE (6) :

TECHNICAL SPECIFICATION FOR SECONDARY & VILLAGE ROADS :

ASPHALT PAVEMENT , (BINDER AND WEARING)

ITEM OF SPECS.	HOT MIX. LAYER	
	WEARING	BINDER
AGG. SPECS.		
- ABRASION (%)	35 MAX.	35 MAX.
- RATIO OF WEAR LOSS $\left(\frac{100\text{ REV}}{500\text{ REV}}\right)$	0.22 MAX.	0.22 MAX.
- SAND EQUIVALENT	50 MIN.(HOT BINS)	50 MIN.(HOT BINS)
- P.I	N.P (HOT BINS)	N.P (HOT BINS)
-FLAKINESS INDEX(B.S)	20 MAX.	25 MAX.
ELONGATION INDEX(B.S)	20 MAX.	25 MAX.
-CLAY LUMPS & FRIABLE PARTICLES (%)	1.0 MAX.	1.0 MAX.

AASHTO Spec. for Base Course Materials

- Materials for this course shall be sound, durable crushed rock, crushed slag, crushed boulder, ….
- Coarse and fine aggregate materials may be mixed to obtain the required specifications as set out below.
- Fine aggregate material passing the 2.00 mm sieve (#8) shall consist of crushed stone screenings, natural sand, and non-plastic soil binder passing the 0.425 mm sieve (#40).

AASHTO Spec. for Base Course Materials

- The materials shall be uniformly blended by mixing predetermined quantities of coarse and fine aggregate and at the time of compaction **the moisture content shall be plus or minus 2% of the optimum moisture content.**
- The aggregate shall meet the grading B, C or D of AASHTO standard Specification M147-65. The fraction passing the 0.075 mm sieve (#200) shall be not more than (1/3) of the fraction passing the 0.425 mm sieve (#40).

AASHTO Standard Specification Designation M147-65-

Sieve Designation mm	% BY MASS PASSING SQUARE MESH SIEVE					
	Grading A	Grading B	Grading C	Grading D	Grading E	Grading F
50	100	100				
25		75-95	100	100	100	100
9.5	30-65	40-75	50-85	60-100		
4.75	25-55	30-60	35-65	50-85	55-100	70-100
2.0	15-40	20-45	25-50	40-70	40-100	55-100
0.425	8-20	15-30	15-30	25-45	20-50	30-7-
0.075	2-8	5-20		5-20	6-20	8-25

AASHTO Spec. for Base Course Materials

- The fraction of the material passing a 0.425 mm sieve (#40) shall have a **liquid limit not greater than 30** and a **plasticity index of not more than 6.**
- Coarse aggregate sizes shall have **at least 90 % by weight of pieces with two fractured faces and at least 98 % by weight shall have at least one fractured faces.**
- Thin flat flaky or over sized aggregate detrimental to compaction and effective choking shall not be used. The **flakiness index as determined in accordance with BS 812 shall be not greater than 35%.**

AASHTO Spec. for Base Course Materials

- When tested in accordance with the Method of **Test of Soundness** of Aggregates by use of Sodium Sulphate, AASHTO Test Method T-104, and the weighted average **loss in five cycles shall not exceed 15% by weight.**

- **The aggregates shall have a Los Angeles Abrasion loss of not more than 30 %.**

- **The California Bearing Ratio (CBR) value of this material compacted and tested at the approved density and moisture content shall be not less than 80%.**

Pavement Materials & Design (110401466/2104011466) Soil

Instructor:

Prof. TALEB M. AL-ROUSAN

Source:

Chapter 17. Traffic & Highway Engineering Nicholas Garber and Lester Hoel, Fifth Edition, Brooks/Cole.

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

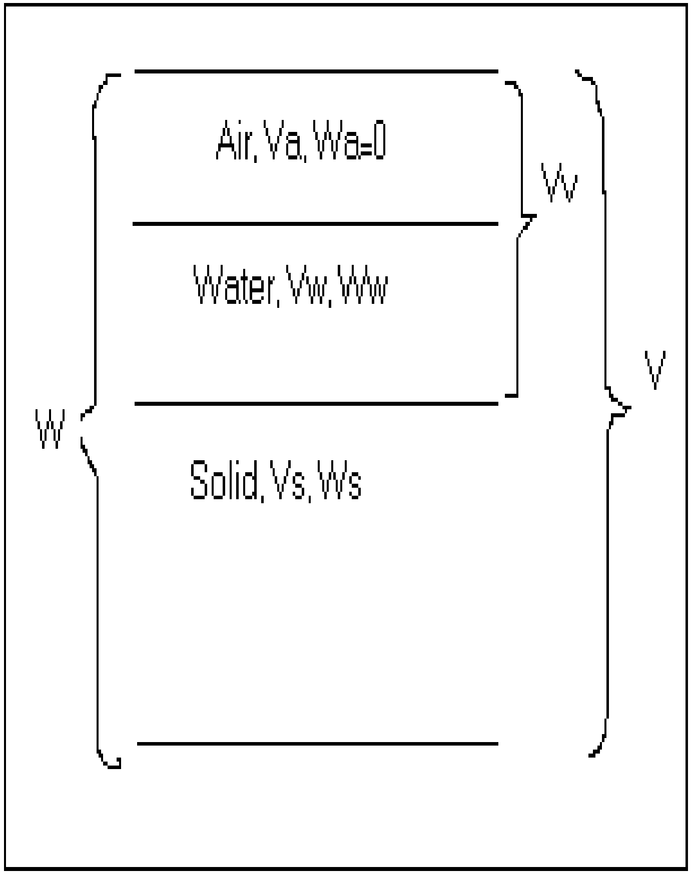
- Loam: Agricultural term used for well-graded soil that is productive for plant life (Sandy, silty, or clayey loam depending on predominant size).
- Loes: Fine-grained Aeolin soils, uniform size, predominantly silt, low density.
- Muck: Soft silt or clay, high organic content, swampy areas and lake 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.
  - $n = [V_v / V]$
- **Void Ratio**
  - The ratio of the volume of voids to the volume of solids.
  - $e = [V_v / V_s]$
  - *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.

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

$$\omega = [W_w / W_s]\ x100\%$$

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

Degree of Saturation

- The percentage of void spaces occupied by water.

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

- 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)]**
- **When soil is staurated, bulk density = γ sat**

  Y sat = [W/V] = [(Ws + Ww) / (Vs + Vw)]
- **Dry Density (γd) = [Ws/V] = [(Ws) / (Vs + Vw + Va)]**
- **Dry unit wt. = Wet unit wt. / [(100 + *ω* %)/ 100] = [Y/ (1+*ω*)]**

Used to evaluate degree of compaction of embankment soil.

- **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).

SIGNIFICANCE OF PLASTICITY INDEX

- Plasticity index of soil depends chiefly on clay content in soil. So Soils that have high plasticity index are considered to tend to clay.
-

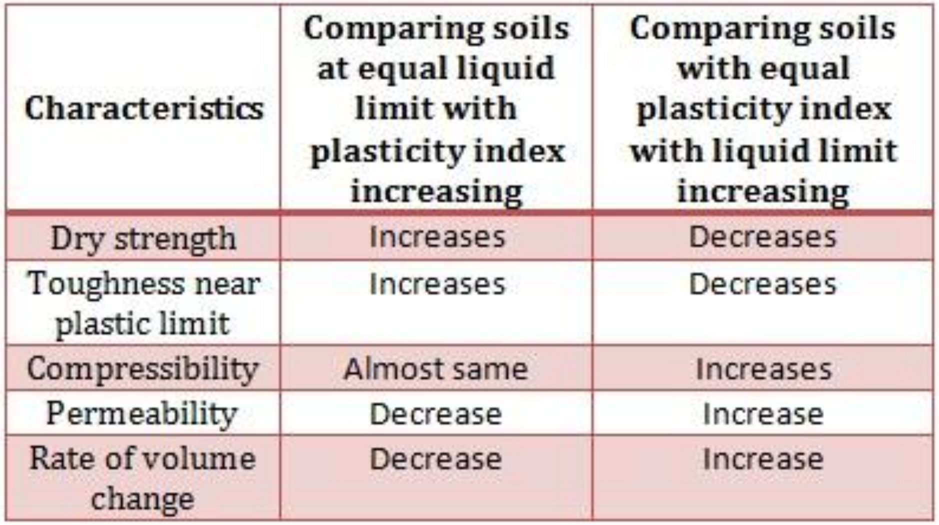
• With the decrease in particle size, a rapid increase in plasticity index is observed. Thus plasticity index is a measure of fineness of particles.

• Plasticity index in relation with liquid limit, provide us valuable information for soil classification.

• For a same plasticity index, when liquid limit increases permeability and compressibility are found to be increased whereas toughness and dry strength is decreased.

• For a same liquid limit of two samples, when plasticity index is increased, permeability decreases whereas toughness and dry strength are increased. But compressibility is found almost unchanged.

SIGNIFICANCE OF PLASTICITY INDEX



Characteristics	Comparing soils at equal liquid limit with plasticity index increasing	Comparing soils with equal plasticity index with liquid limit increasing
Dry strength	Increases	Decreases
Toughness near plastic limit	Increases	Decreases
Compressibility	Almost same	Increases
Permeability	Decrease	Increase
Rate of volume change	Decrease	Increase

- Soils having high plasticity index are considered clay and those having lower value are considered silt. In case of zero value, soil are considered to have little/no clay or silt and called non-plastic soil.
  • A lower plasticity index of two soil is indicative to have high

  organic matter in soil.

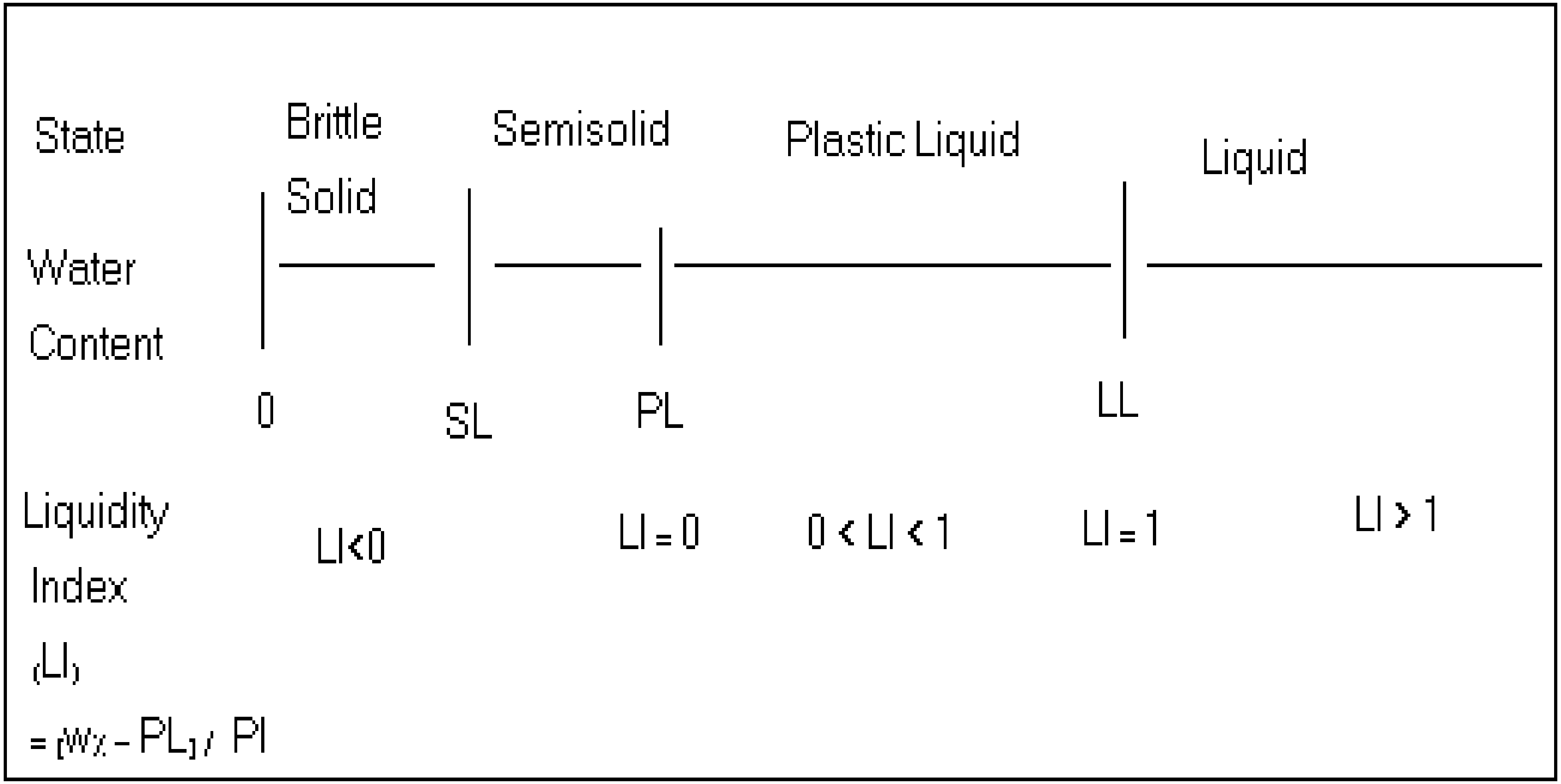
Atterberg Limits Cont.

- 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

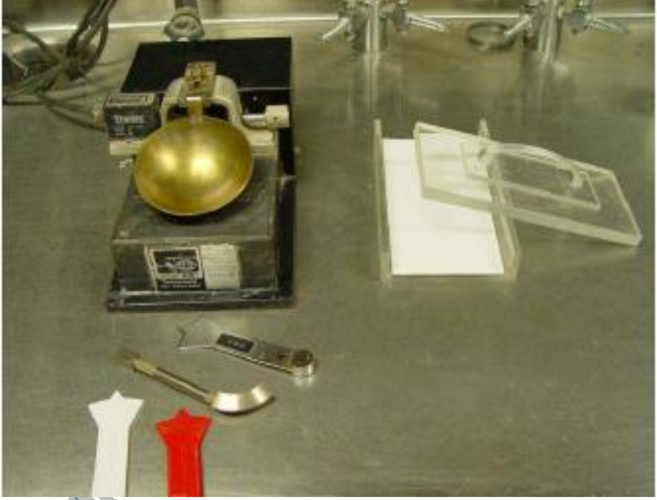


State: Brittle Solid | Semisolid | Plastic Liquid | Liquid

Water Content: 0 | SL | PL | LL

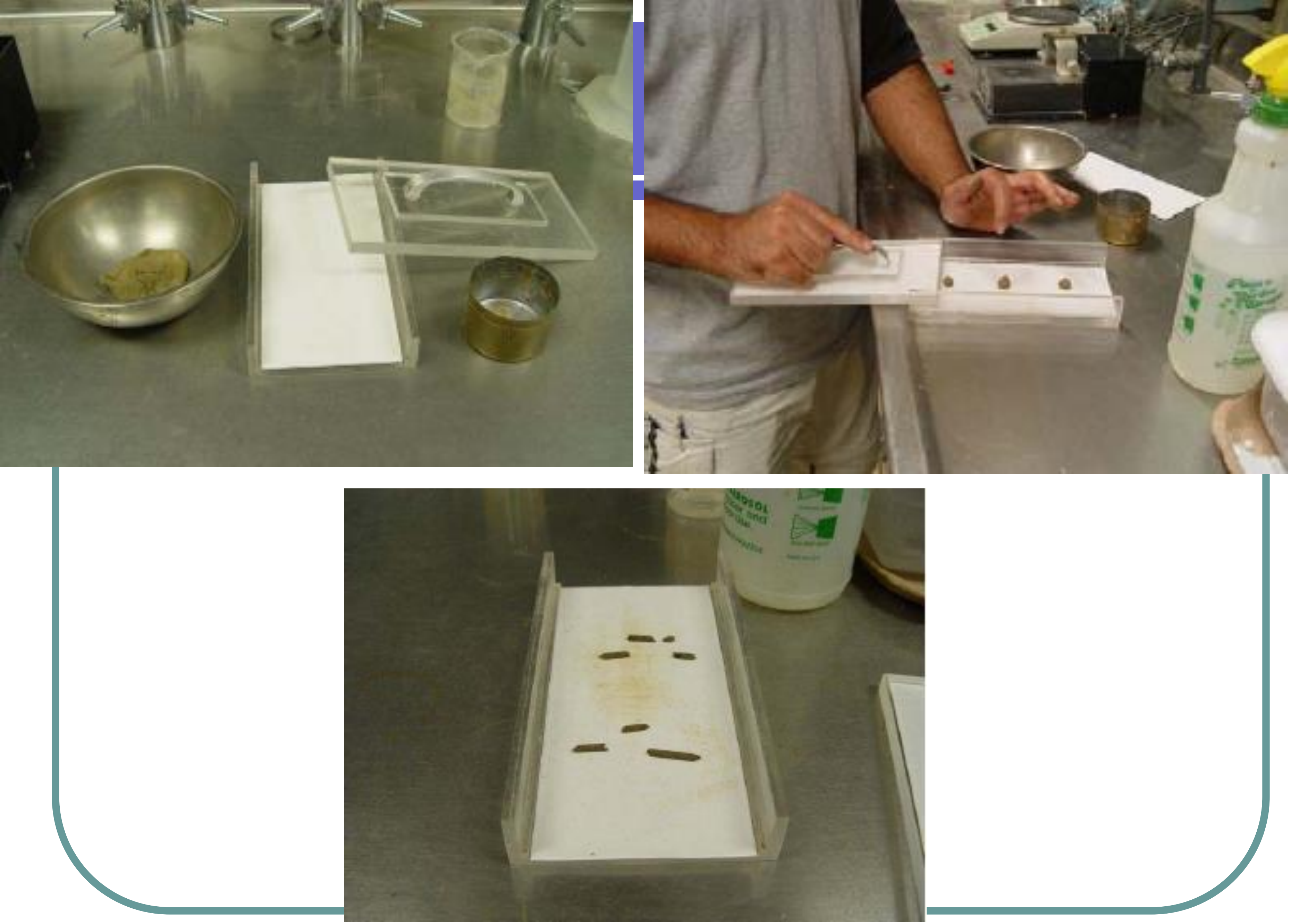
Liquidity Index (LI) $= (W\% - PL) / PI$

$LI < 0$ | $LI = 0$ | $0 < LI < 1$ | $LI = 1$ | $LI > 1$






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]

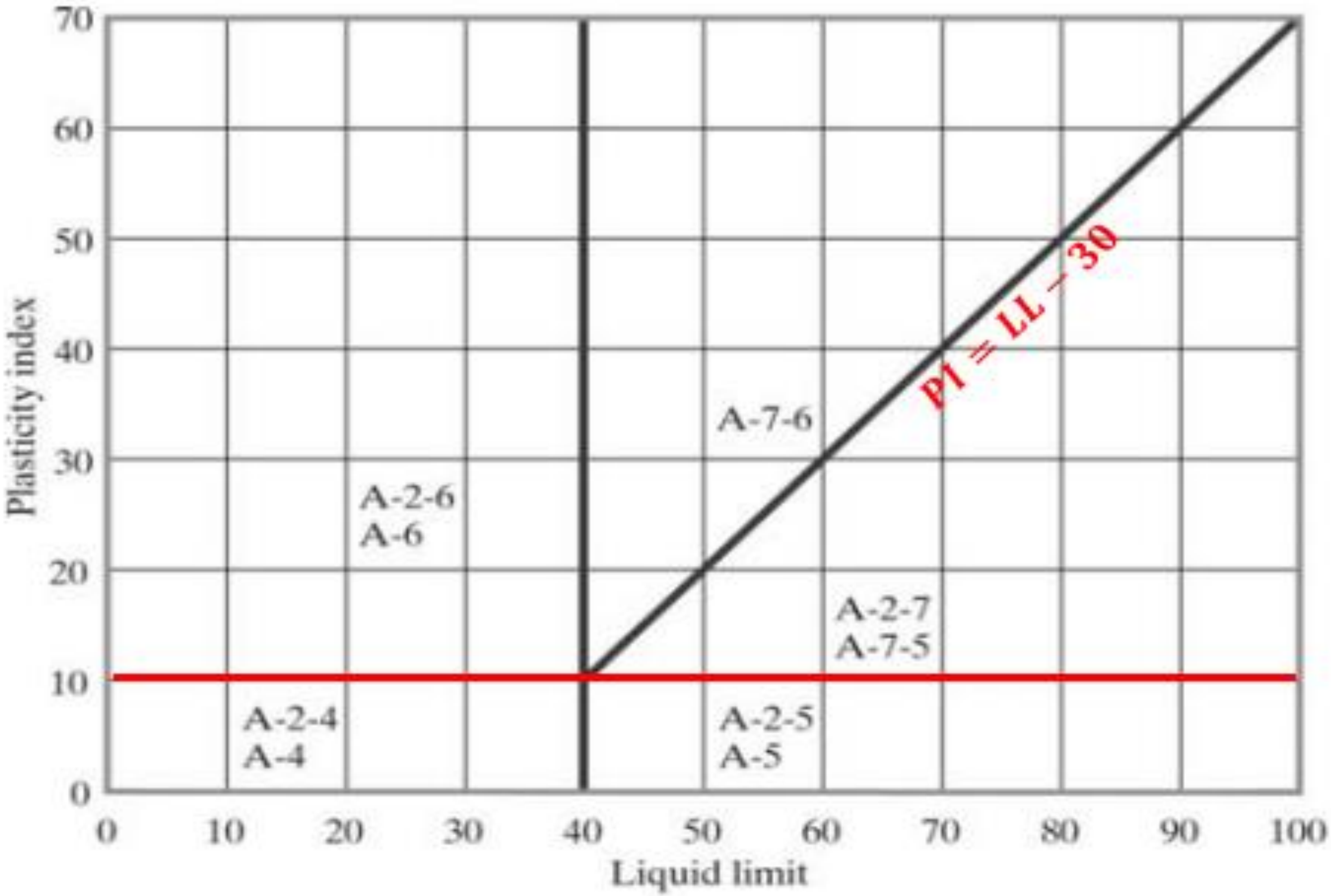
General Classification	*Granular Materials (35% or less passing No. 200)*							*Silt-Clay Materials (more than 35% passing No. 200)*			
	A-1			*A-2*							*A-7*
Group Classification	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*	*A-4*	*A-5*	*A-6*	*A-7-5, A-7-6*
Sieve analysis, percent passing											
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			

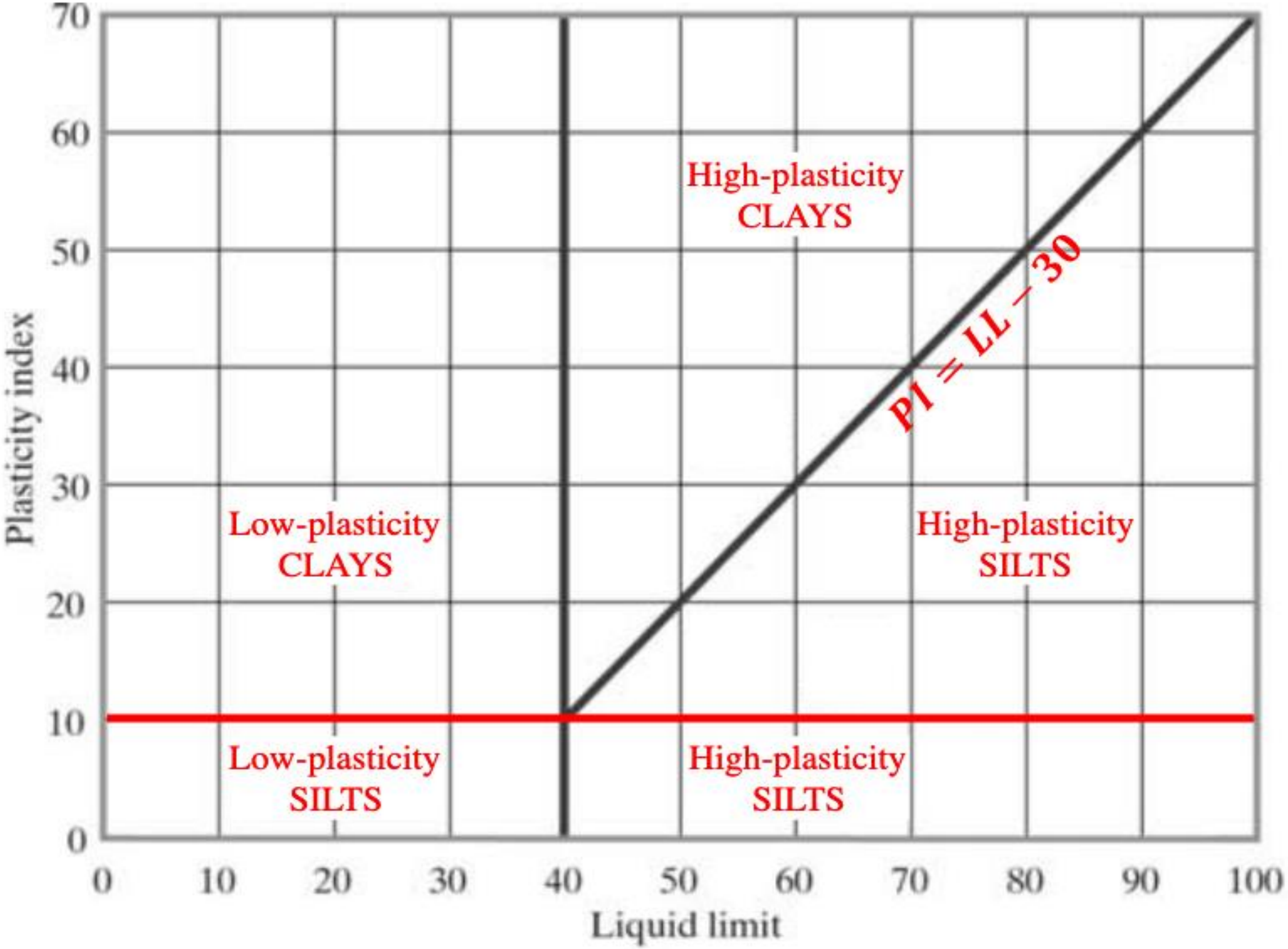
[a] Classification procedure: With required test data available, proceed from left to right on the chart, and correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

[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.

AASHTO


70
60
50
40
30
20
10
0
Plasticity index
0
10
20
30
40
50
60
70
80
90
100
Liquid limit
A-7-6
PI = LL − 30
A-2-6
A-6
A-2-7
A-7-5
A-2-4
A-4
A-2-5
A-5


High-plasticity
CLAYS
PI = LL − 30
Low-plasticity
CLAYS
High-plasticity
SILTS
Low-plasticity
SILTS
High-plasticity
SILTS
Plasticity index
0
10
20
30
40
50
60
70
Liquid limit
0
10
20
30
40
50
60
70
80
90
100

Group Index

$$GI = (\underset{\substack{\uparrow \\ \text{\% passing} \\ \text{No. 200}}}{F} - 35)[0.2 + 0.005(LL - 40)] + \underbrace{0.01(F - 15)(PI - 10)}_{\substack{\text{Partial Index for} \\ \text{A-2-6 and A-2-7}}}$$

Group index is always reported as a non-negative integer value
Group index is always zero for groups A-1, A-3, A-2-4, A-2-5

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. / $(1+\omega\%)$

- 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) Standard Method of Test for Moisture–Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop	Modified Proctor (Modified AASHTO T180) Standard Method of Test for Moisture–Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
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

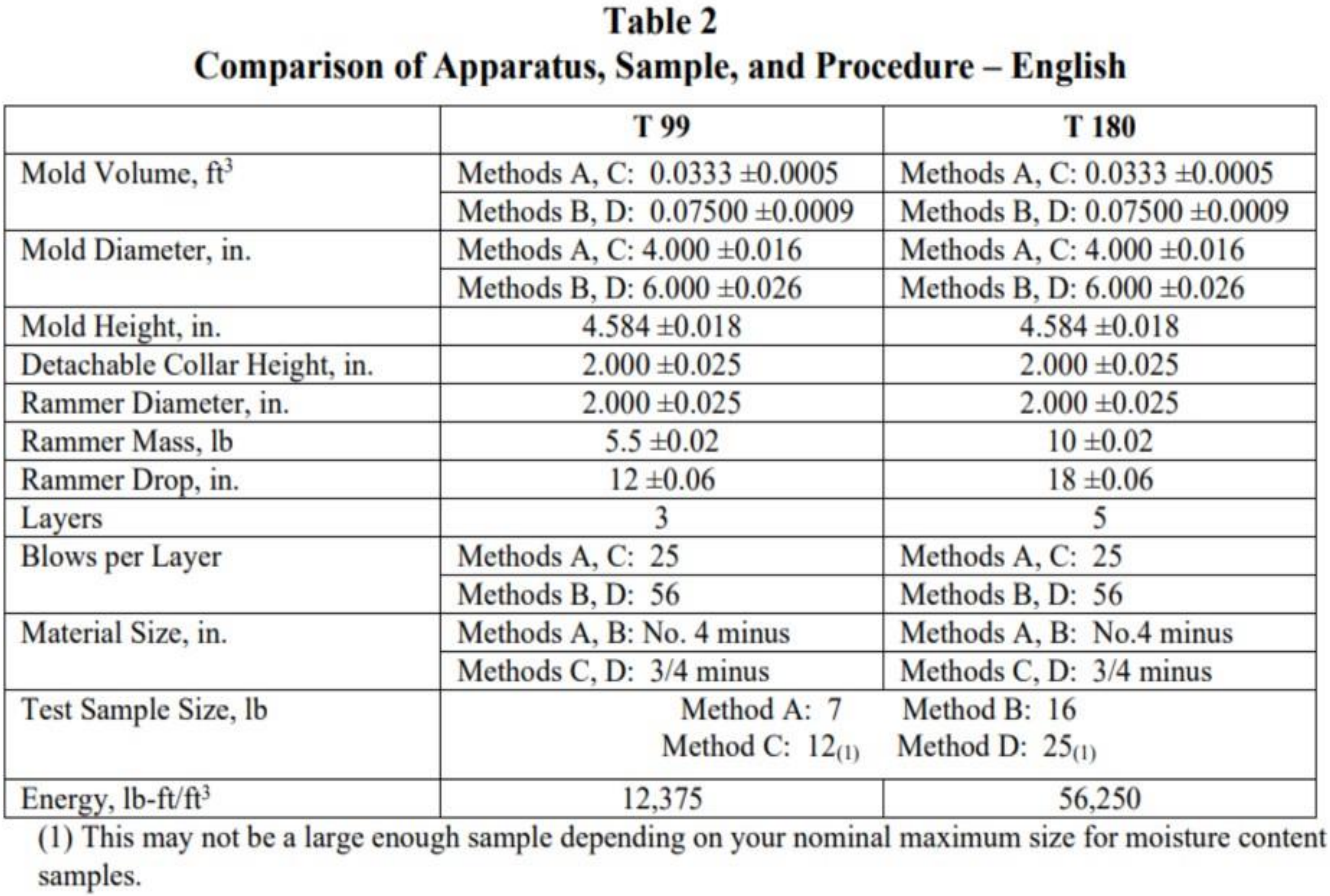


Table 2

Comparison of Apparatus, Sample, and Procedure – English

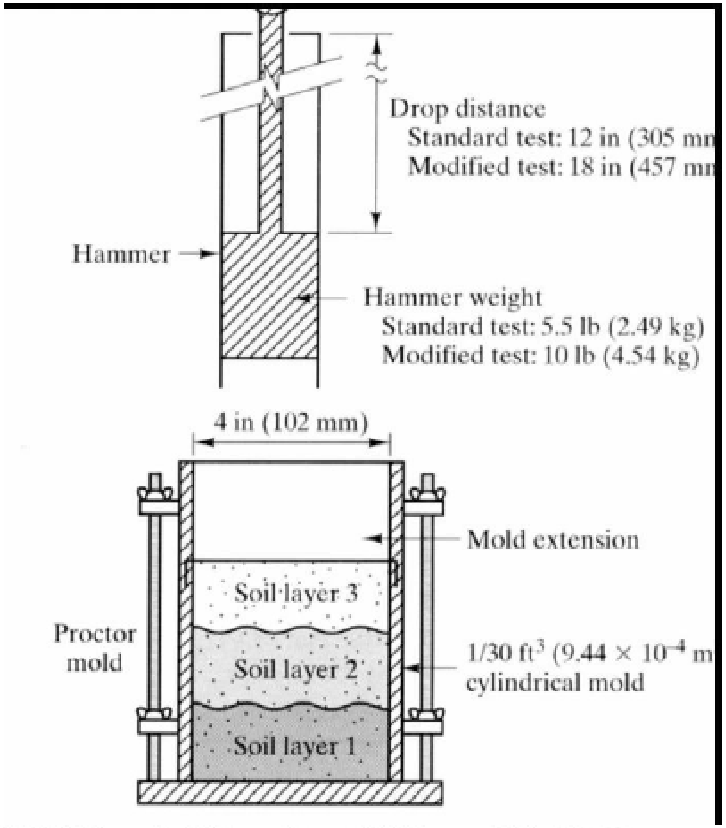
	T 99	T 180
Mold Volume, ft^3	Methods A, C: 0.0333 ±0.0005 Methods B, D: 0.07500 ±0.0009	Methods A, C: 0.0333 ±0.0005 Methods B, D: 0.07500 ±0.0009
Mold Diameter, in.	Methods A, C: 4.000 ±0.016 Methods B, D: 6.000 ±0.026	Methods A, C: 4.000 ±0.016 Methods B, D: 6.000 ±0.026
Mold Height, in.	4.584 ±0.018	4.584 ±0.018
Detachable Collar Height, in.	2.000 ±0.025	2.000 ±0.025
Rammer Diameter, in.	2.000 ±0.025	2.000 ±0.025
Rammer Mass, lb	5.5 ±0.02	10 ±0.02
Rammer Drop, in.	12 ±0.06	18 ±0.06
Layers	3	5
Blows per Layer	Methods A, C: 25 Methods B, D: 56	Methods A, C: 25 Methods B, D: 56
Material Size, in.	Methods A, B: No. 4 minus Methods C, D: 3/4 minus	Methods A, B: No.4 minus Methods C, D: 3/4 minus
Test Sample Size, lb	Method A: 7 Method C: 12(1)	Method B: 16 Method D: 25(1)
Energy, lb-ft/ft^3	12,375	56,250

(1) This may not be a large enough sample depending on your nominal maximum size for moisture content samples.

5.1. The sample shall be handled and specimen(s) for compaction shall be prepared in accordance with the procedures given in T 99 or T 180 for compaction in a 152.4-mm (6-in.) mold except as follows:

Proctor compaction test

- There are two tests that are used to obtain the optimum moisture content and the corresponding **maximum dry density (MDD)**.
- The tests are known as
  - *Standard Proctor test (Standard AASHTO T99)*
  - *Modified Proctor test (Modified AASHTO T180)*
- Both tests use a falling hammer to compact the material in a mould, which roughly corresponds to the compactive effort in the field.

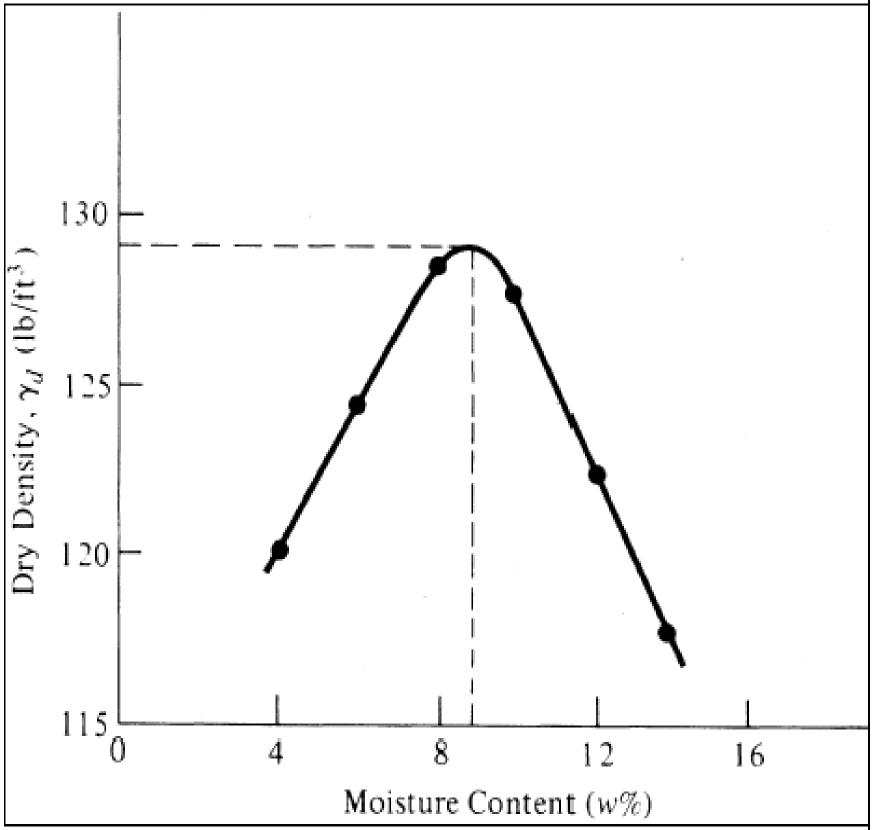


- *Method A*—A 101.60-mm (4-in.) mold: Soil material passing a 4.75-mm (No. 4) sieve Sections 4 and 5.
- *Method B*—A 152.40-mm (6-in.) mold: Soil material passing a 4.75-mm (No. 4) sieve Sections 6 and 7.
- *Method C*—A 101.60-mm (4-in.) mold: Soil material passing a 19.0-mm ($^3/_4$-in.) sieve Sections 8 and9.
- *Method D*—A 152.40-mm (6-in.) mold: Soil material passing a 19.0-mm ($^3/_4$-in.) sieve Sections 10 and 11.

Proctor test output

Compaction curve

- ☐ The output of Proctor test is the compaction curve
- ☐ Compaction curve
  - *is the curve of the dry densities of each specimen plotted versus their respective water contents*
  - Each-data point on the curve represents a single compaction test
- ☐ The peak point of the compaction curve is an important point, which represent
  - *The maximum dry density (MDD)*
  - *Optimum water content*
    - The water content corresponding to the maximum dry density

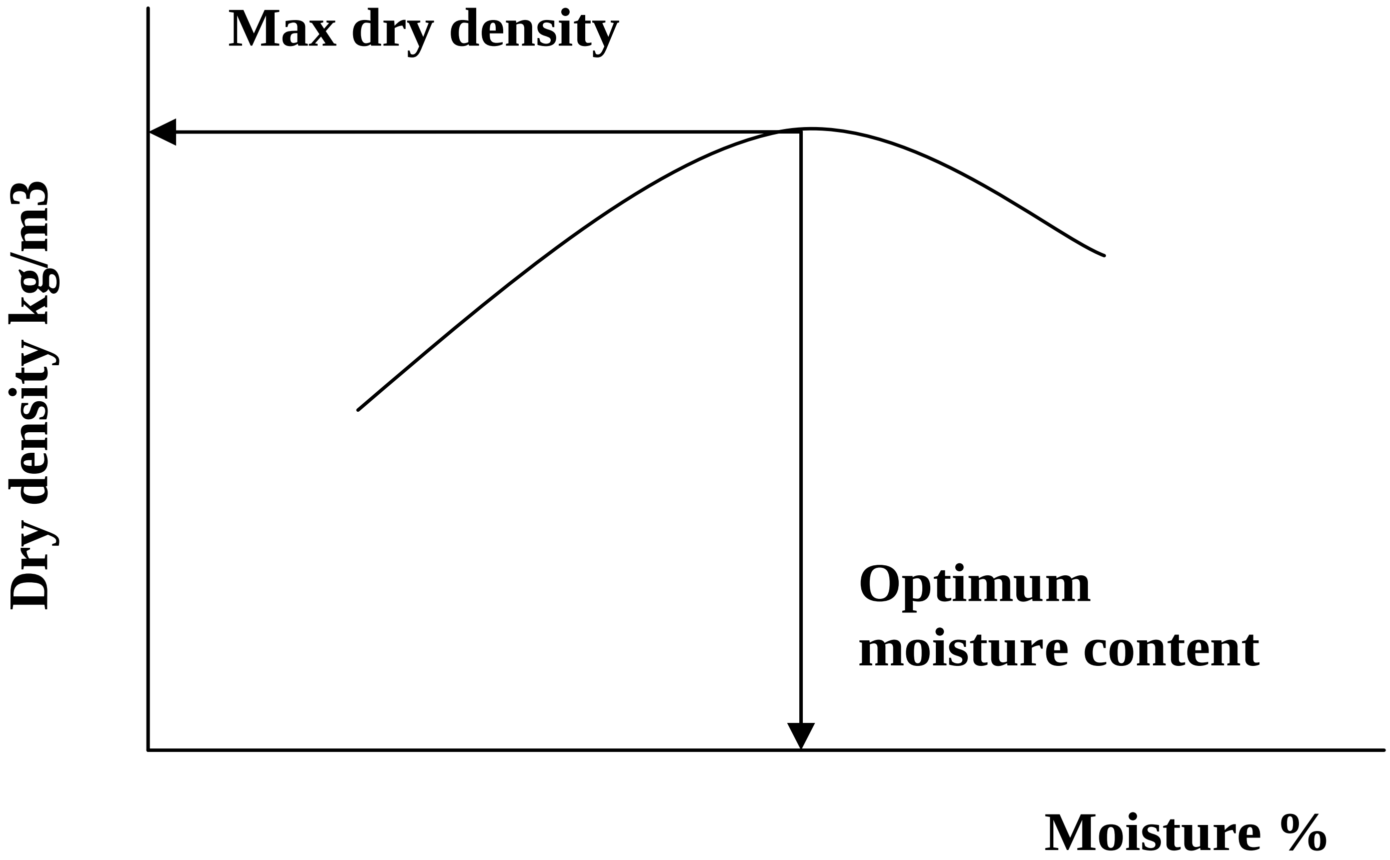


Dry unit wt. = Wet unit wt. / (1+ω%)

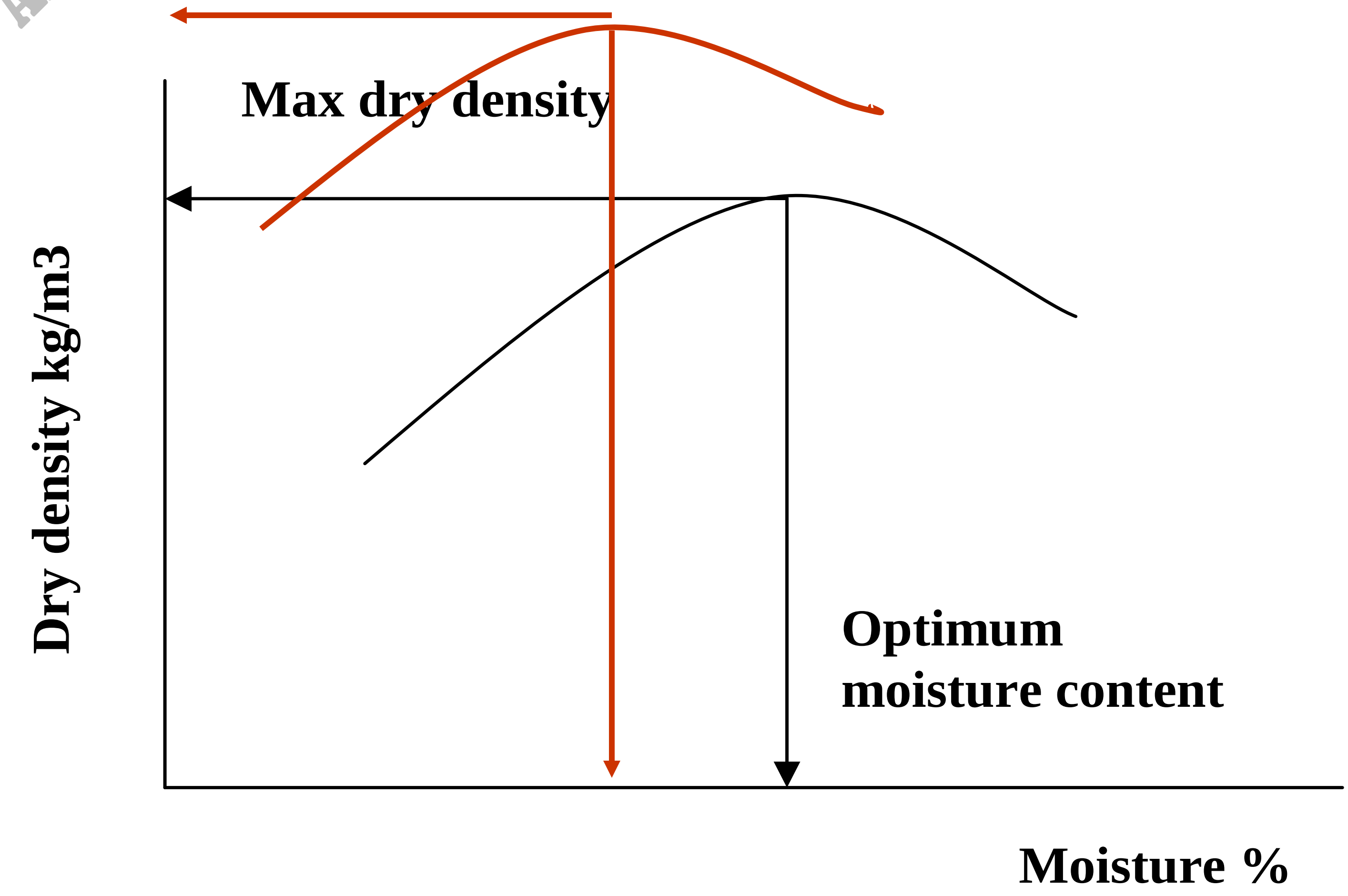
This curve is unique

for a given soil type, method of compaction, and (constant) compactive effort

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

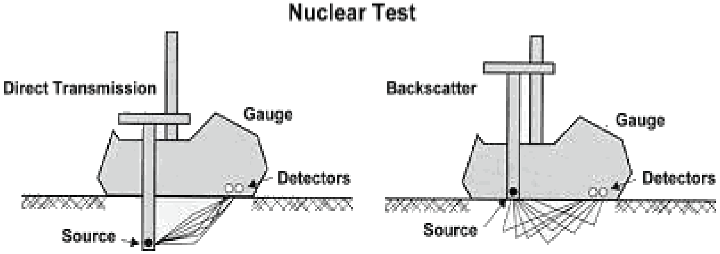
- When moisture is less than optimum, the soil doesn’t contain sufficient moisture to flow readily under the blows of the hammer.

- 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.

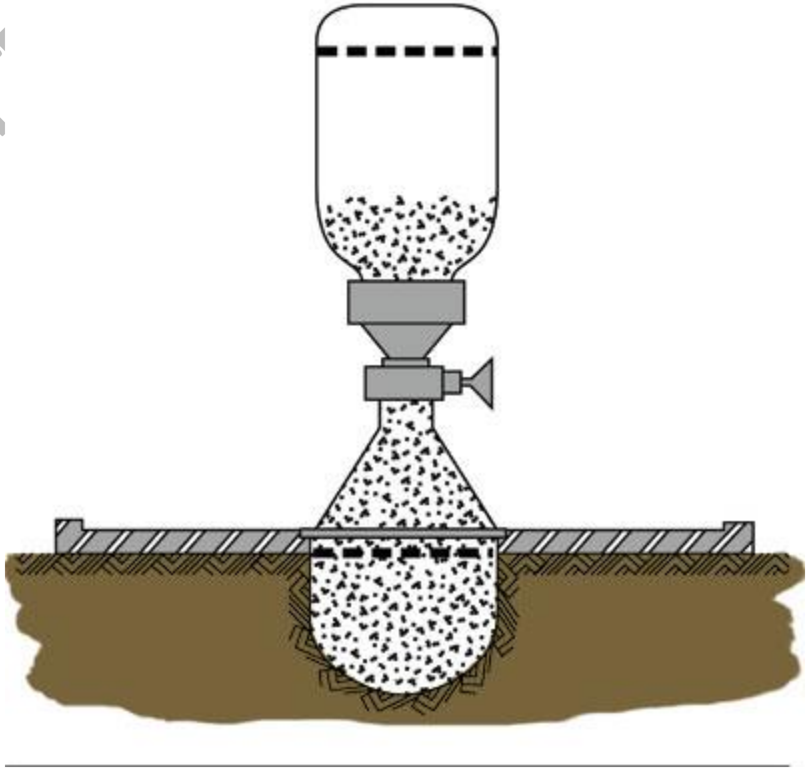
- Further increase tends to overfill the voids, forcing the soil particles to move apart and unit wt. decrease.

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



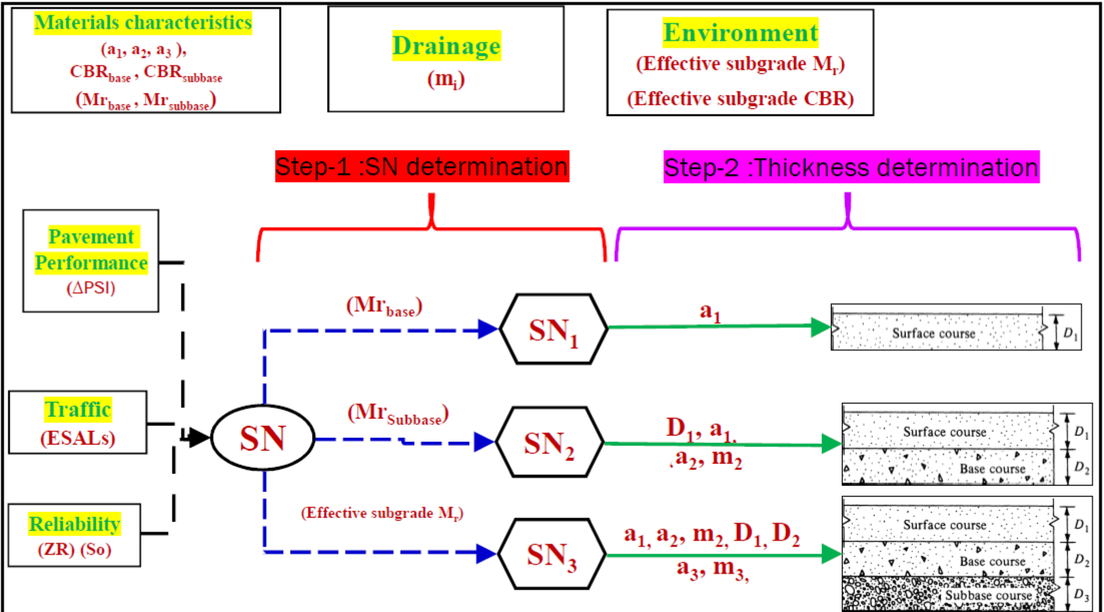
field density test using sand cone method



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.



Soils and Aggregates Characterization tests

- ☐ Characterization tests used to describe fundamental parameters of soils and aggregates
- ☐ Bearing Capacity (Strength) tests
  - *In laboratory*
    - CBR test (Most common)
    - R-value test
  - *in-situ*
    - Field CBR
    - Dynamic Cone Penetrometer (DCP) (Most common)
- ☐ Stiffness tests (Modulus of resilience, Mr)
  - *In laboratory*
    - Repeated load triaxial test
  - *in-situ*
    - Plate Load test, k value
    - Dynamic plate test using the light weight deflectometer

CBR

History

- The basic testing procedure employed in the determination of the CBR was developed by the California Division of Highways before World War II and was used by that agency in the design of flexible pavements.
- The basic procedures of this test were adopte by the Corps of Engineers of the U.S. Army during the early stages of the war and served as a basis for the development of design curves that were used for determining the required thickness of flexible pavements for airport runways and taxiways.
- Certain modifications were made in the test procedure, and it became a standardized test procedure

SCOPE

This test method covers the determination of the California Bearing Ratio (CBR) of pavement subgrade, subbase, and base/course materials from laboratory compacted specimens. The test method is primarily intended for, but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than 19 mm ($^3/_4$ in.).

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

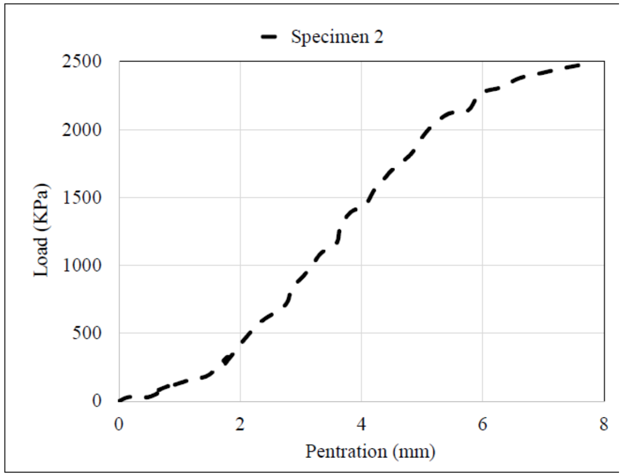
CBR

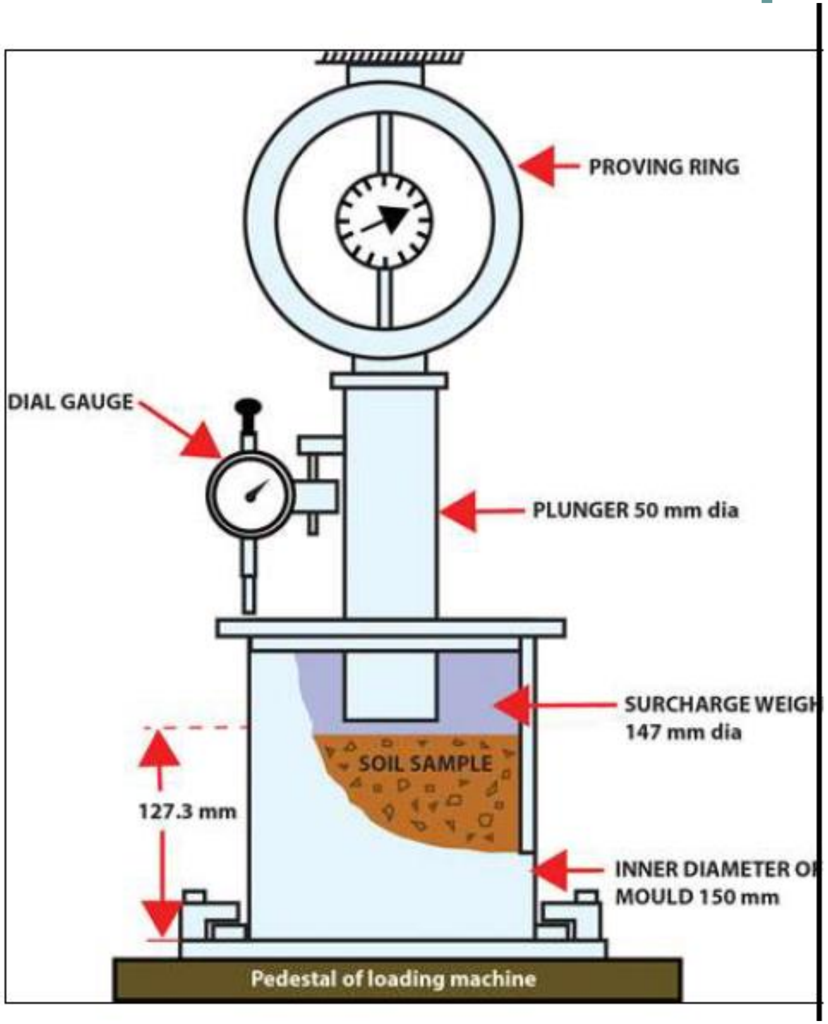
- It is a penetration test wherein a standardized piston, having an end diameter of 49.53mm (1.95in), is caused to penetrate the soil at a standard rate of 1.27mm/min (0.05in/min).
- The CBR value is calculated as the ratio of the load or stress at 2.54mm (0.1in) penetration to a standard load or stress.

CBR (California Bearing Ratio)

Summary of Test Method

- ❑ The laboratory test uses a circular piston to penetrate material compacted in a mold at a **constant rate** of penetration.
- ❑ The CBR is expressed as the ratio of the unit load on the piston **required** to penetrate 0.1 in. (2.5 mm) and 0.2 in (5 mm) of the test soil to the unit load required to penetrate a standard material of well-graded crusted stone



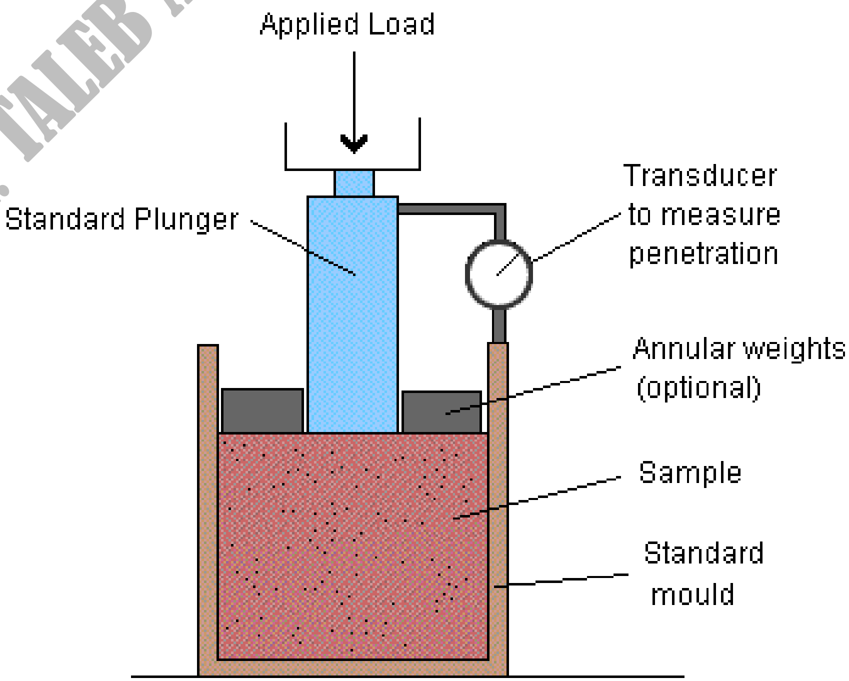


CBR (California Bearing Ratio)

Determination

- ☐ **CBR** compares the bearing capacity of a tested material with that of obtained from an excellent coarse base material (a well-graded crushed stone)
- ☐ $CBR(\%) = \frac{Unit\ load\ of\ test\ materils}{Unit\ load\ of\ standard\ crushed\ stone}$ at specific penetration
- ☐ Two penetration points are used to determine CBR
  - ➢ *2.5 mm penetration*
  - ➢ *5.0 mm penetration*
- ☐ The unit load for the standard crushed stones are
  - ➢ *6.9 MPa (or 1000 psi) at 2.5 mm penetration*
  - ➢ *10.3 MPa (or 1500 psi) at 5.0 mm penetration*

CBR


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


MATEST
MATEST

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:

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

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

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

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

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.

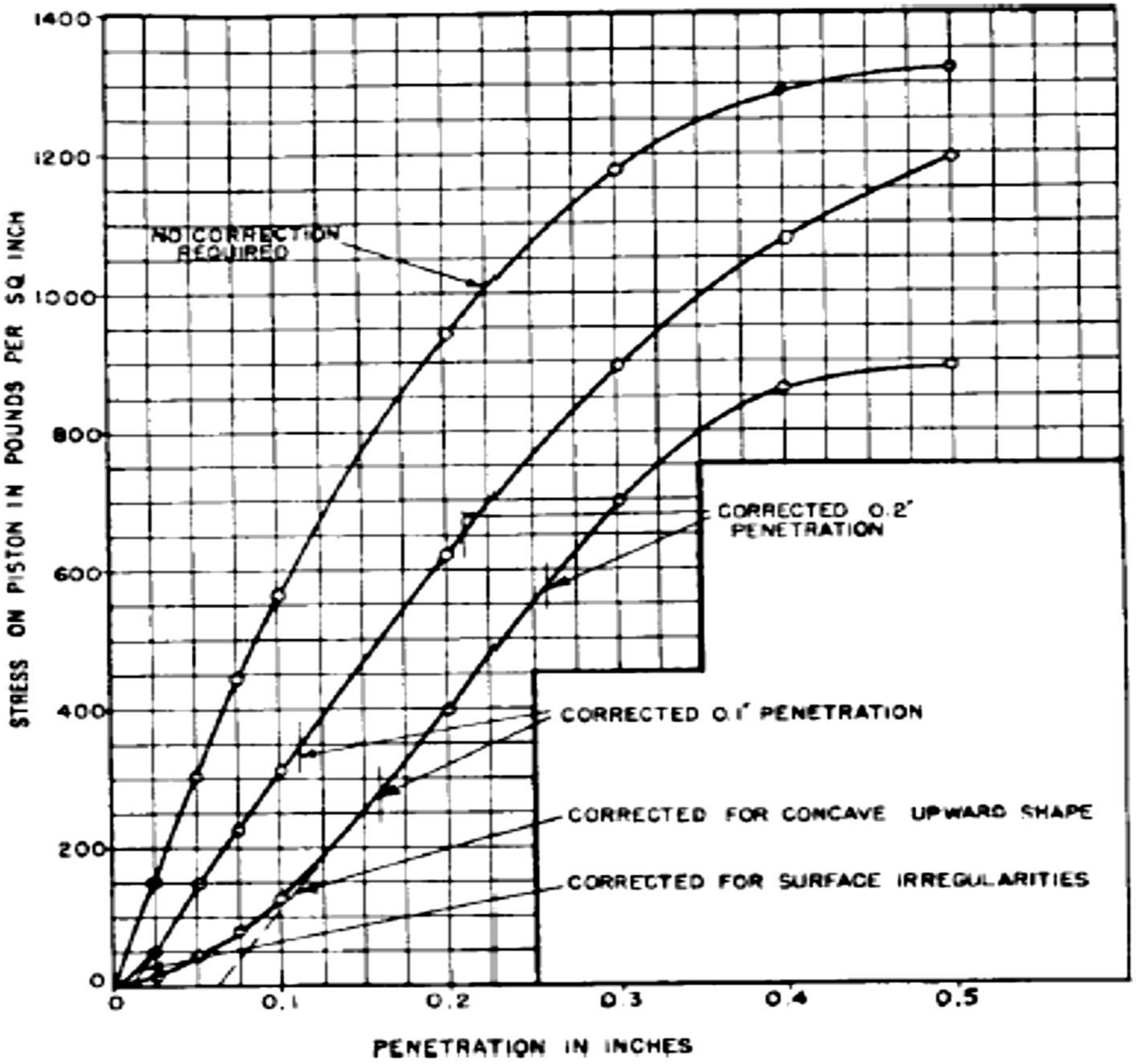
The CBR Plot

- 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.

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

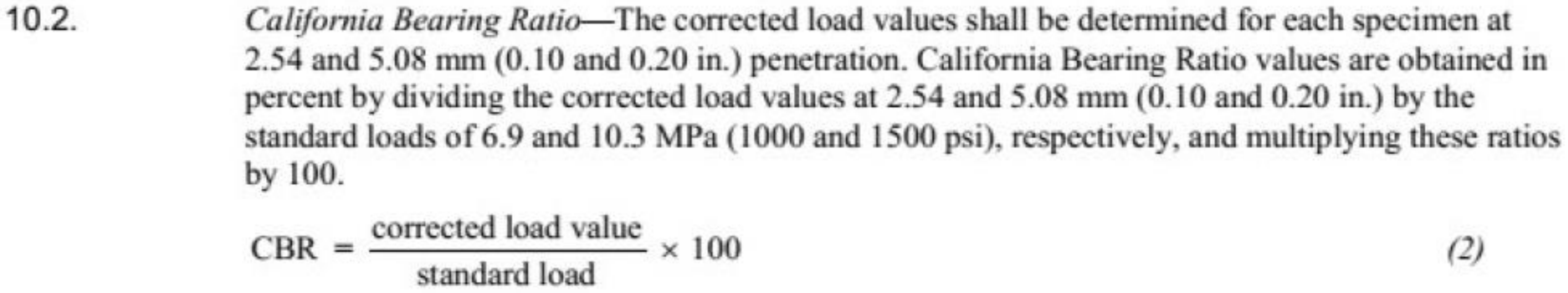
$$CBR\,(\%) = \frac{\text{Load at 5.0mm penetration (kg)}}{2045\,\text{kg}} \times 100$$

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


Plot correction
30000
25000
20000
15000
10000
5000
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Resistance to Penetration (kPa)
Penetration (mm)

Determination



10.2. *California Bearing Ratio*—The corrected load values shall be determined for each specimen at 2.54 and 5.08 mm (0.10 and 0.20 in.) penetration. California Bearing Ratio values are obtained in percent by dividing the corrected load values at 2.54 and 5.08 mm (0.10 and 0.20 in.) by the standard loads of 6.9 and 10.3 MPa (1000 and 1500 psi), respectively, and multiplying these ratios by 100.

$$\mathrm{CBR} = \frac{\text{corrected load value}}{\text{standard load}} \times 100 \qquad (2)$$

CBR (California Bearing Ratio)

Determination

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

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

OR

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

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

OR

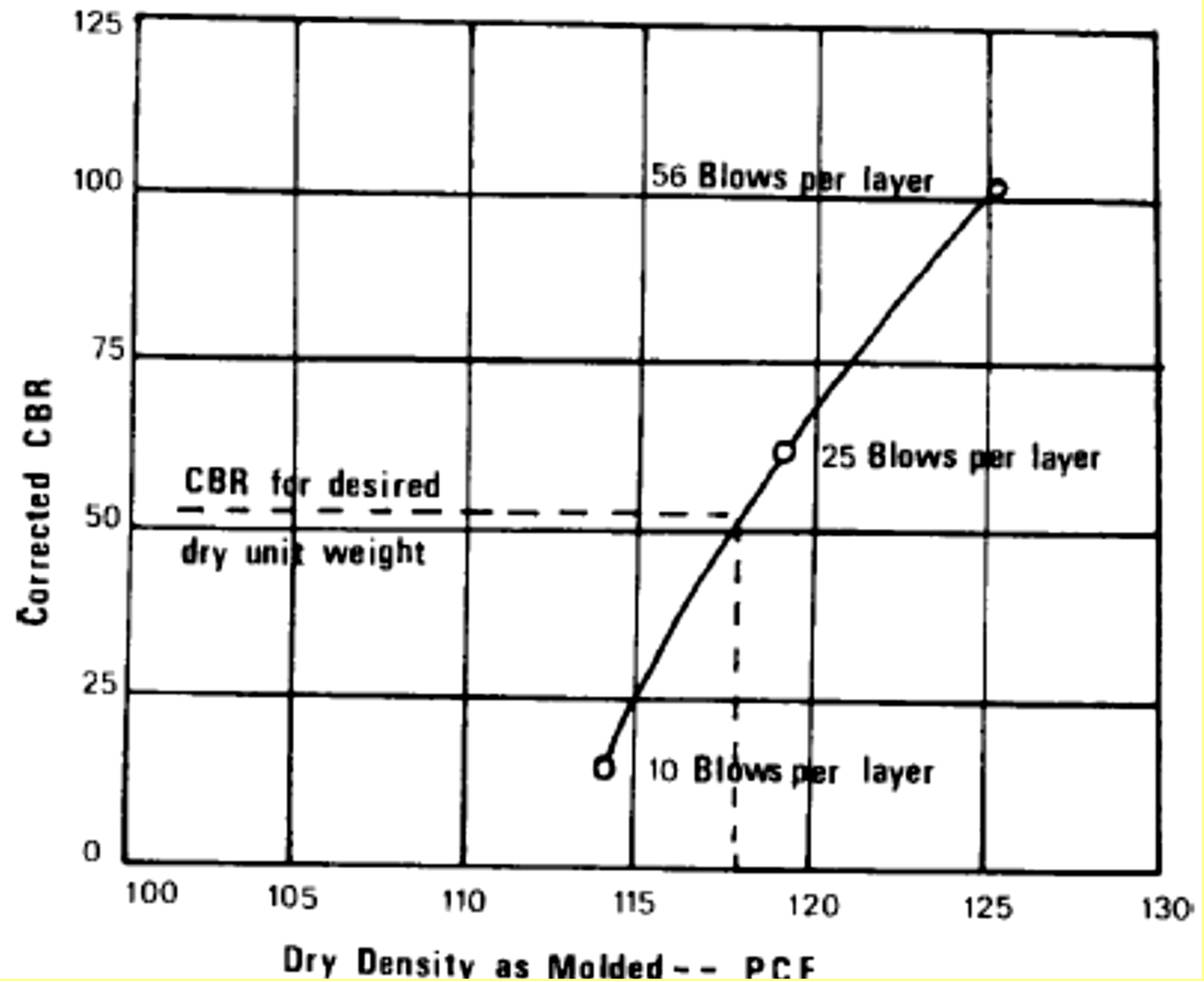
$$CBR\,(\%) = \frac{\text{Load at 2.5mm penetration (kg)}}{1364\,\text{kg}} \times 100$$

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

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).

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

- 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
(110401466/2104011466)
High-Type Bituminous Pavements

Instructor:

Prof. TALEB M. AL-ROUSAN

Source:

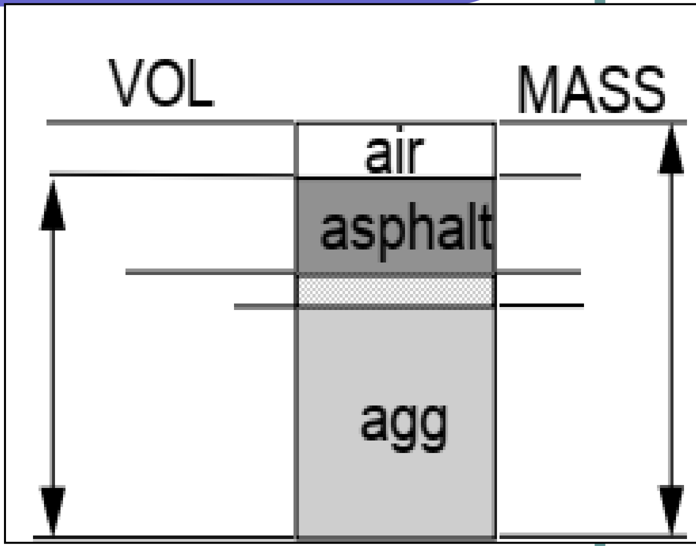
Text Book chapter 19: Traffic & Highway Engineering by Nicholas Garber and Lester Hoel, Fifth Edition, Brooks/Cole.

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

Asphaltic Concretes

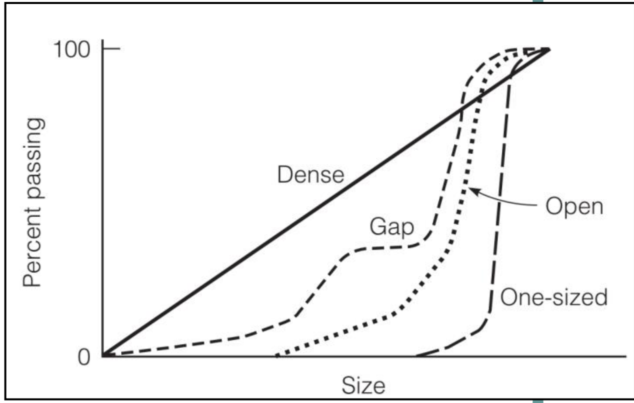
- Asphaltic concrete is a uniformly mixed combination of asphalt cement, coarse aggregate, fine aggregate, and other materials depending on the type of the asphalt concrete.
- Types of asphalt concrete commonly used:
  - Hot-mix, hot laid
  - Hot-mix, cold laid
  - Cold-mix, cold laid
  - Asphalt concrete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

Asphaltic Concretes



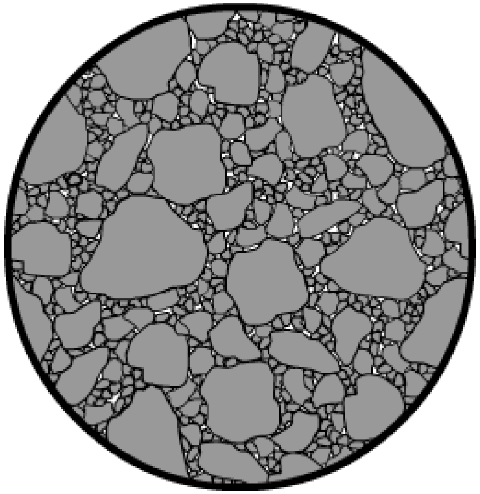
Hot-Mix, Hot-Laid Asphalt Concrete

- Produced by properly blending AC + C.Agg + F. Agg + Filler (Dust) at temperature ranging between (76 – 165 °C) 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"
  - Gap graded or stone matrix asphalt (SMA)
  - The above max sizes of aggregates are for high-type surfaces , bur when used as base the max size used can be larger.



Dense Graded Asphalt Mixtures

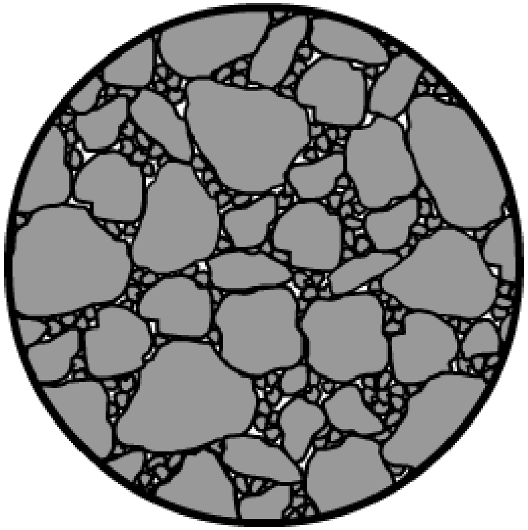
- A dense-graded asphalt mix has a well-distributed aggregate gradation throughout the entire range of sieves used.
- It is the most commonly specified type of mix and can be used in the base, intermediate layers and surface of a pavement structure.
- Superpave, Marshall and Hveem are methods of designing dense-graded Mixtures



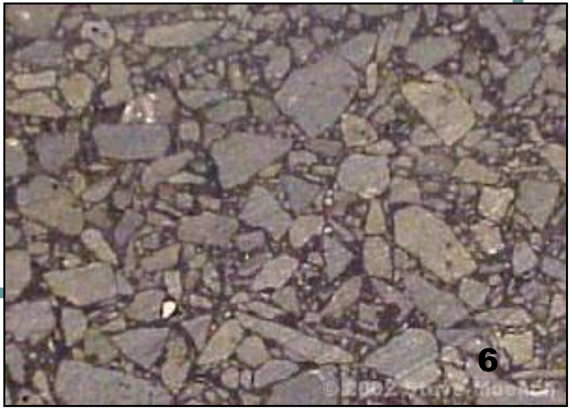
Dense graded HMA contains all sizes of aggregate particles. There are enough fine particles to effectivly separate many of the coarse particles. Therefore, stress transmission through the HMA structure relies on both the coarse and fine particles. VMA is generally between 11 and 17%, air voids are generally near 4%, and asphalt binder content can range between 4.5 to 6%.

Gap Graded or Stone Matrix Asphalt (SMA)

- Gap-graded or SMA is an asphalt mixture with :
    - high-coarse aggregate content (typically 70 to 80 percent),
    - high asphalt content (typically more than 6 percent)
    - high-filler content (approximately 10 percent by weight).
- The result is a durable mixture that has excellent stone-on-stone contact and that is very resistant to rutting.

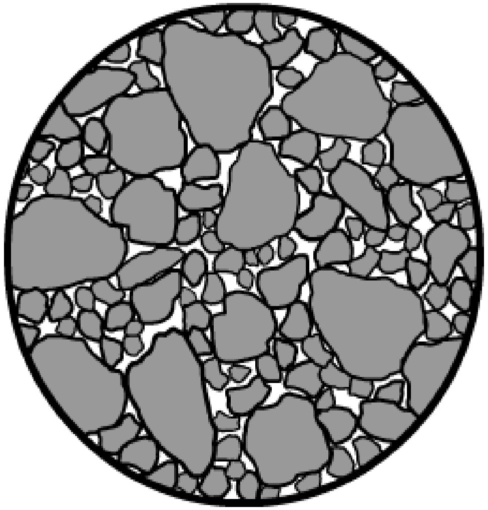


Gap graded HMA contains few mid-sized particles. Stress transmission goes through a coarse particle matrix, while the fine particles generally fill in spac between the coarse particles giving the HMA more resistance to deformation VMA (17%+) is higher than for dense graded HMA but asphalt binder conten (6%+) is higher, which results in about the same volume of air voids (4%).



Open Graded Asphalt Mixtures

- An open-graded layer is an asphalt mixture designed to have a large volume of air voids (typically 18 to 22 percent) so that water will readily drain through the pavement layer.
- It is used as:
  - Open-Graded Friction Course (OGFC) to provide a skid-resistant pavement surface.
  - porous base layer (also called Asphalt Treated Permeable Base, or ATPB) to provide for positive drainage under either an asphalt or Portland cement concrete pavement surface.



Open graded HMA contains fewfine aggregate particles. This creates large air voids between the coarse and medium-sized particles. These air voids, often between 15 and 20% of the total volume, make the HMA water permeable. VMA is generally between 20 and 25%, while asphalt binder content can range between 5 to 8%.

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%.

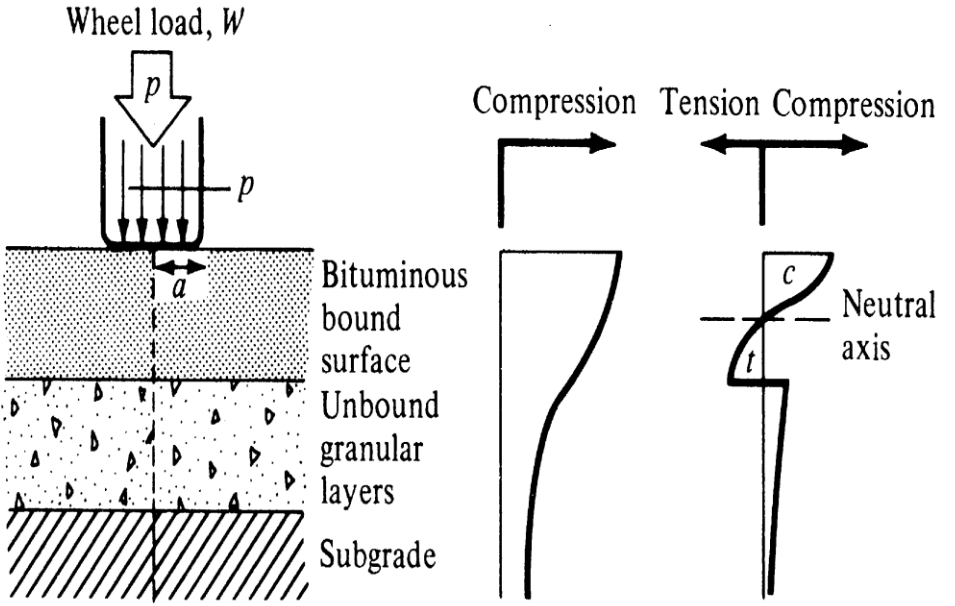
Requirements of HMA

- 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.

Asphalt Mixtures Behavior

When a wheel load is applied to a pavement, the primary stresses that are transmitted to the HMA are :

- Vertical compressive stress, shear stress within the asphalt layer
- Horizontal tensile stress at the bottom of the asphalt layer.



(a) Pavement layers

(b) Distribution of vertical stress under centerline of wheel load

(c) Distribution of horizontal stress under centerline of 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

Asphalt Mixtures Behavior

- The HMA must be internally strong to:
  - Resist compressive and shear stress to prevent permanent deformation (rutting) within the mixture.
  - Have enough tensile strength to withstand tensile stress at the base of the asphalt layer to resist crack initiation, which results in fatigue cracking after many load applications.
  - Resist contraction stresses from rapidly decreasing temperatures or extremely cold temperatures.

Asphalt Mixtures Behavior

- While the individual properties of HMA components are important, asphalt mixture behavior is best explained by considering asphalt cement and mineral aggregate acting together.
- One way to understand asphalt mixture behavior is to consider the primary asphalt pavement distress types that engineers try to avoid:
    - Permanent deformation, fatigue cracking and low temperature cracking.
    - These are the distresses analyzed during mix design.

Desired properties considered for mix design
Resistance to Permanent Deformation

- Permanent deformation results from the accumulation of small amounts of unrecoverable strain (small deformations) from repeated loads applied to the pavement.
    - Wheel path rutting is the most common form of permanent deformation.
- Resistance to permanent deformation is provided by designing and constructing a stable HMA pavement that will resist shoving and rutting under traffic.

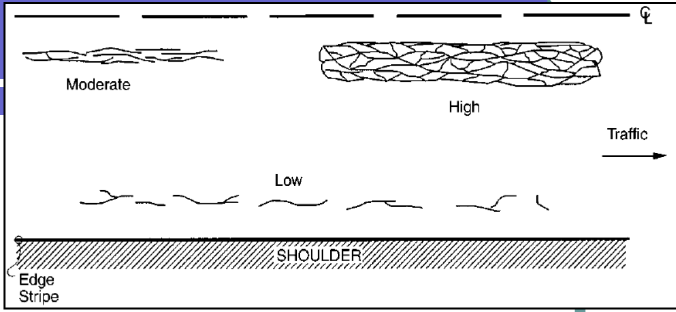
Desired properties considered for mix design
Resistance to Permanent Deformation

<u>Depends primarily </u>on:

- The internal friction provided by the aggregate particles
    - The use of more angular aggregate particles with rougher surface texture will increase the stability of the mix
- A lesser extent the <u>cohesion provided by the asphalt binder</u>
    - Cohesion results from the bonding ability and the stiffness characteristics of the asphalt binder
    - Cohesion increases as
        - The stiffness of the asphalt binder <u>increases</u>
        - The pavement temperature <u>decreases</u>

Images source: https://pavementinteractive.org/reference-desk/pavement-

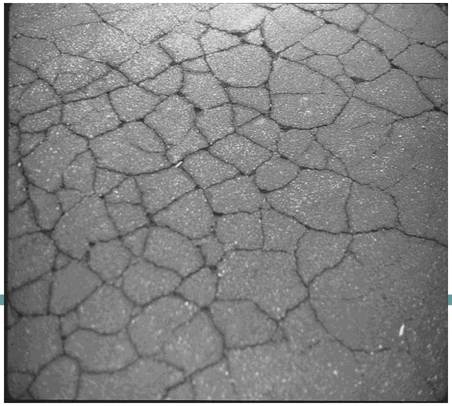
Desired properties considered for mix design
Fatigue Resistance

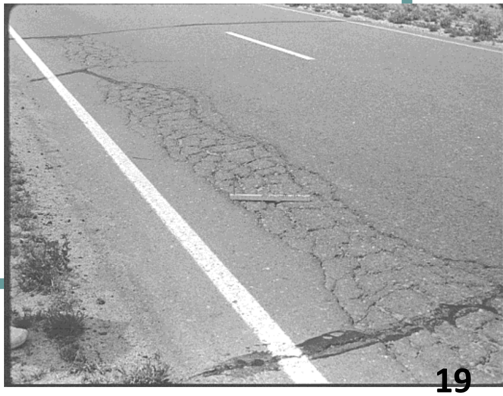


- Fatigue resistance is the pavement's resistance to repeated bending under wheel loads (traffic).

- This type of cracking occurs when the pavement has been stressed to the limit of its life by repeated load applications.

- fatigue cracking is primarily related to
  - Insufficient pavement thickness
  - Air voids
  - Asphalt binder properties





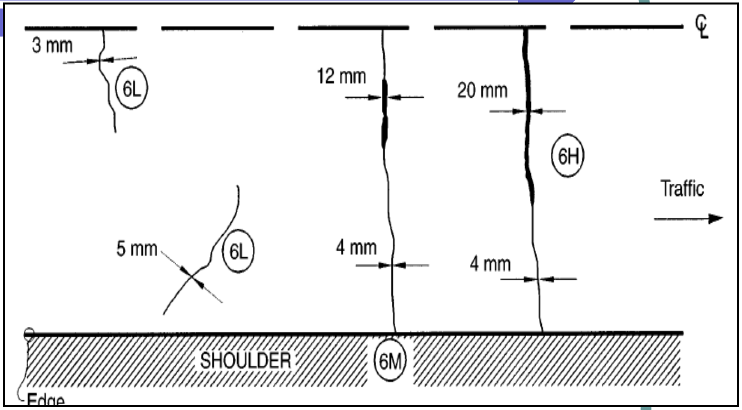
Desired properties considered for mix design
Fatigue Resistance

Methods to overcome fatigue cracking are:

- Adequately account for the number of heavy loads during design.
- Use thicker pavements.
- Provide adequate subgrade drainage.
- Use pavement materials that are not easily weakened by moisture.
- Use HMA that is resilient enough to withstand normal deflections
  - Simply put, soft asphalts have better fatigue properties than hard asphalts
- Use a modified binder.

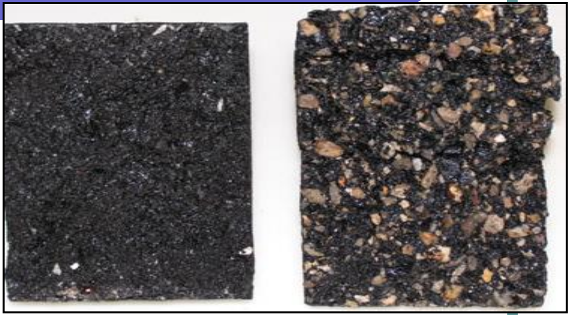
Desired properties considered for mix design
Low Temperature Cracking

- Normally occurs when the temperature at the surface of the pavement drops sufficiently to produce thermally induced stress in the HMA layer that exceeds the tensile strength of the asphalt mixture.
- In general, the solution to this problem is the proper choice of binder.



Desired properties considered for mix design
Moisture Resistance/ Impermeability

- A major durability problem is associated with moisture damage, commonly referred to as "stripping."
  - This typically is the result of water in combination with repeated traffic loadings, causing a scouring effect as the water is pushed into and pulled out of the voids in the pavement
- The best line of defense against stripping is:
  - Having sufficient binder in the mix
  - Constructing an impermeable mat by achieving sufficient compaction



Samples with no moisture damage (left) and moisture damage (right). Notice the amount of uncoated aggregate on the damaged sample.

Fatigue cracking caused by stripping

Images source: https://pavementinteractive.org/reference-desk/testing/asphalt-tests/moisture-susceptibility/

Desired properties considered for mix design
Durability

- The durability of an asphalt pavement is the ability to resist factors such as
  - Aging of the asphalt
  - Disintegration of the aggregate
  - Stripping of the asphalt film from the aggregate
- Generally, the durability of a mixture can be enhanced by three methods:
  - Designing the mix using a dense gradation of moisture-resistant aggregate;
  - Maximizing the asphalt film thickness on the aggregate
  - Compacting the mixture to be impervious (which may be as low as 5 percent in-place air voids, depending on nominal maximum aggregate size and gradation).

Desired properties considered for mix design
Skid Resistance

- **Skid resistance**
  - Is a safety measure represent the ability of an asphalt surface to minimize skidding or slipping of vehicle tires (particularly when the roadway surface is wet
- A rough pavement surface with many little peaks and valleys will have greater skid resistance than a smooth textured surface.
- Best skid resistance is obtained with rough-textured aggregate in an open-graded mixture with an aggregate of about ⅜-inch (9.5 mm) to ½-inch (12.5 mm) maximum size
  - The aggregates must resist polishing (smoothing) under traffic
  - Unstable mixtures that tend to rut or bleed present serious skid-resistance problems

Images sources:
https://www.quora.com/Is-it-possible-to-make-cars-that-move-on-a-surface-by-sliding-instead-of-rolling
https://www.shutterstock.com/search/slippery+road+sign

Desired properties considered for mix design
Workability

- Workability describes the ease with which a paving mixture can be placed and compacted
  - Mixtures with good workability are relatively easy to place and compact; those with poor workability are difficult to place and compact
- Changing mix design parameters, aggregate source and/or gradation can improve workability
  - However, Mixtures that are <u>more workable are generally more prone to permanent deformation</u>.
  - Caution needs to be exercised to ensure a proper balance for a pavement's intended use .
- **Harsh mixtures** (mixtures containing a high percentage of coarse aggregate and/or low asphalt content) have a tendency to segregate during handling and may be difficult to compact.

Desired properties considered for mix design
Workability

- To make a mixture more workable, the aggregate gradation can be adjusted by
  - Increasing the proportion of natural sand versus crushed fines
  - Increasing the asphalt content of the mix.
- ***Care*** should be taken to ensure that the rutting resistance of the mix is not compromised in order to provide a workable mix.
  - Many high-strength mixtures are harsh and difficult to compact.
  - Too high filler content can also affect workability, causing the mix to become gummy.

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.***

Dust to binder (Dust Proportion)

- The dust to binder ratio is the ratio of the percentage of aggregate passing the 0.075-mm (No. 200) sieve(P0.075) to the effective binder (Pbe).
- Dust ratio = P0.075 /Pbe
- This property addresses the workability of asphalt mixtures.
- A low P0.075 /Pbe often results in a tender mix,
- Tender mix lacks cohesion and is difficult to compact in the field because it tends to move laterally under the roller.
- Mixes tend to stiffen as the P0.075 increases, but too much will also result in a tender mix
- A mix with a high P0.075/Pbe will often exhibit a multitude of small stress cracks during the compaction process (lack sufficient durability), called check-cracking.
- The typical allowable range for this property is 0.6–1.2, with the exceptions for 4.75-mm mixes, the allowable range is 0.9 – 2.0
- The allowable range may be increased to 0.8–1.6.

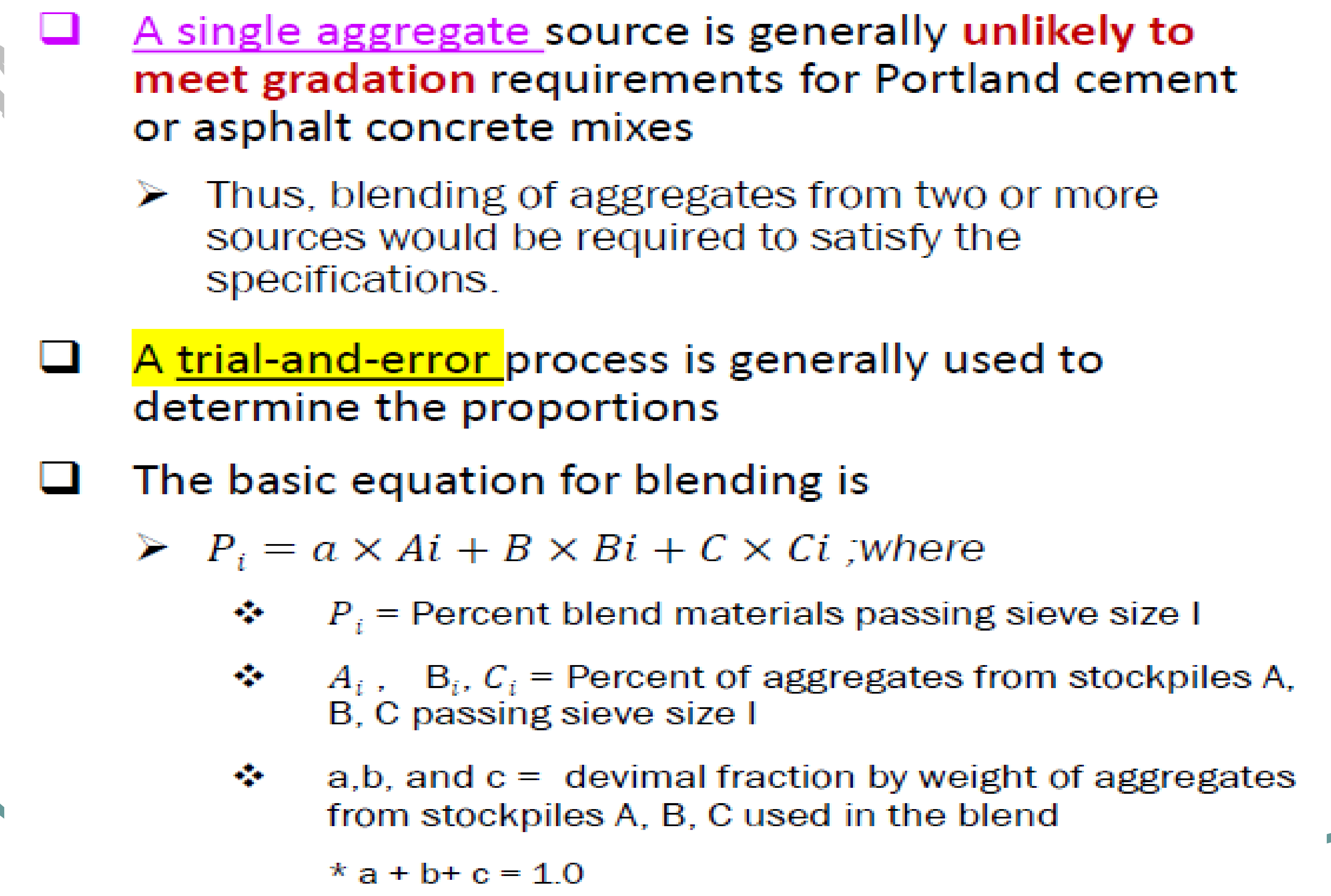
Job Mix Formula (JMF)

- 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.*

Aggregate Blending

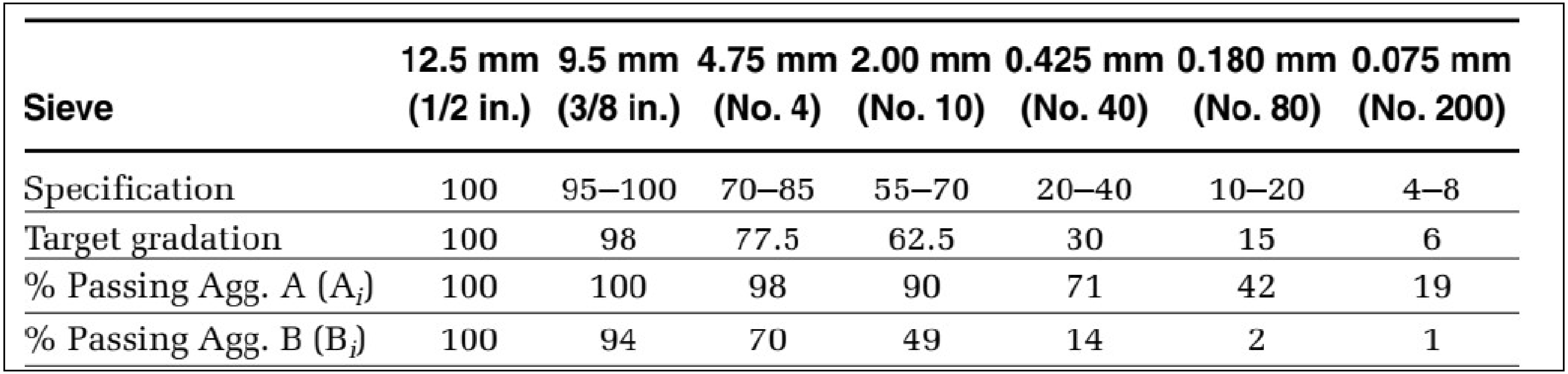


- A single aggregate source is generally **unlikely to meet gradation** requirements for Portland cement or asphalt concrete mixes
  - Thus, blending of aggregates from two or more sources would be required to satisfy the specifications.
- A trial-and-error process is generally used to determine the proportions
- The basic equation for blending is
  - $P_i = a \times Ai + B \times Bi + C \times Ci$;where
    - P_i = Percent blend materials passing sieve size I
    - A_i , B$_i$, C_i = Percent of aggregates from stockpiles A, B, C passing sieve size I
    - a,b, and c = devimal fraction by weight of aggregates from stockpiles A, B, C used in the blend

* a + b+ c = 1.0

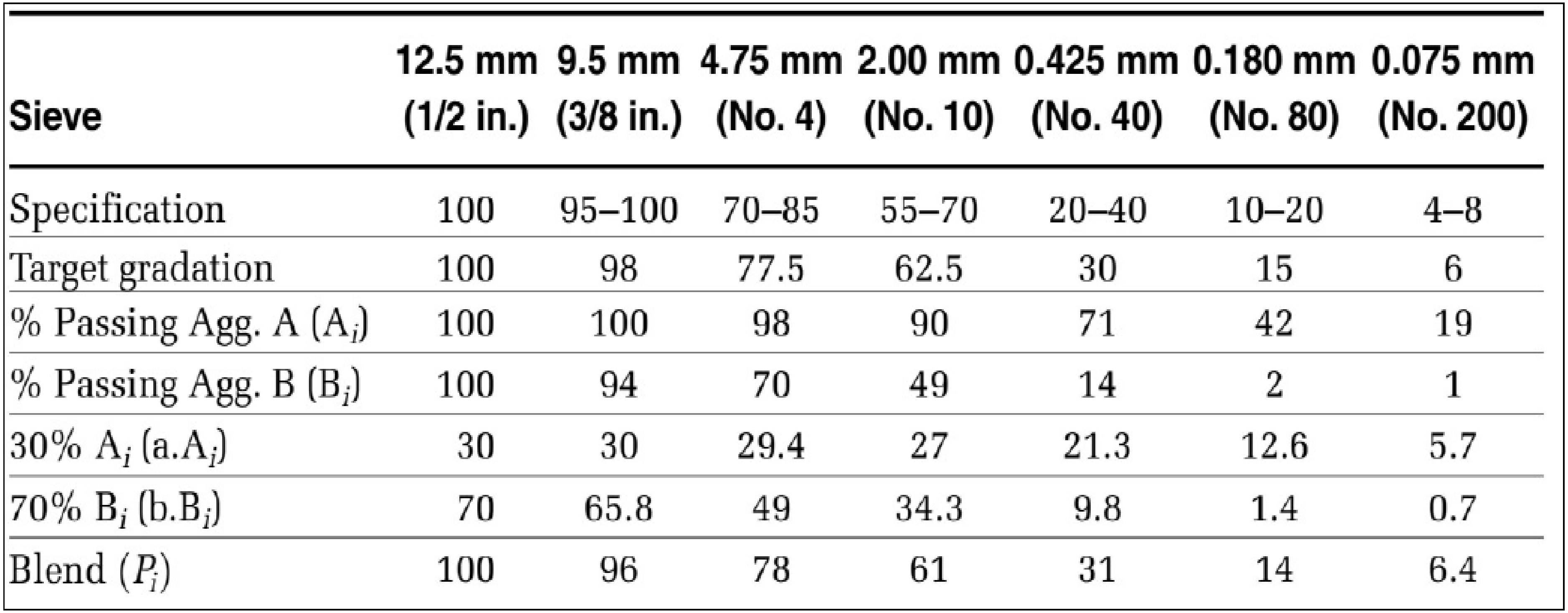
Aggregate Blending Example

- Determine a blend of the two aggregates shown in the table below, which will meet the specifications



Sieve	**12.5 mm (1/2 in.)**	**9.5 mm (3/8 in.)**	**4.75 mm (No. 4)**	**2.00 mm (No. 10)**	**0.425 mm (No. 40)**	**0.180 mm (No. 80)**	**0.075 mm (No. 200)**
Specification	100	95–100	70–85	55–70	20–40	10–20	4–8
Target gradation	100	98	77.5	62.5	30	15	6
% Passing Agg. A (A_i)	100	100	98	90	71	42	19
% Passing Agg. B (B_i)	100	94	70	49	14	2	1

Aggregate Blending Example Solution



Sieve	12.5 mm (1/2 in.)	9.5 mm (3/8 in.)	4.75 mm (No. 4)	2.00 mm (No. 10)	0.425 mm (No. 40)	0.180 mm (No. 80)	0.075 mm (No. 200)
Specification	100	95–100	70–85	55–70	20–40	10–20	4–8
Target gradation	100	98	77.5	62.5	30	15	6
% Passing Agg. A (A_i)	100	100	98	90	71	42	19
% Passing Agg. B (B_i)	100	94	70	49	14	2	1
30% A_i ($a.A_i$)	30	30	29.4	27	21.3	12.6	5.7
70% B_i ($b.B_i$)	70	65.8	49	34.3	9.8	1.4	0.7
Blend (P_i)	100	96	78	61	31	14	6.4

Aggregate Specific Gravity for Blend

Composite G_{sb} for one stockpile

- For stockpiles that include More than two aggregate sources
  - *One value must be determined for the stockpile.*
- The average G_{sb} can be calculated as follows:

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

- G_{sb} = bulk (dry) specific gravity of the aggregate
- P_1, P_2, P_3, P_n = Percentages by weight of aggregates 1, 2, through n
- G_1, G_2, G_3, G_n = P_1, P_2, P_3, P_n = Percentages by weight of aggregates 1, 2, through n

Absorption (A) for the aggregate Blend

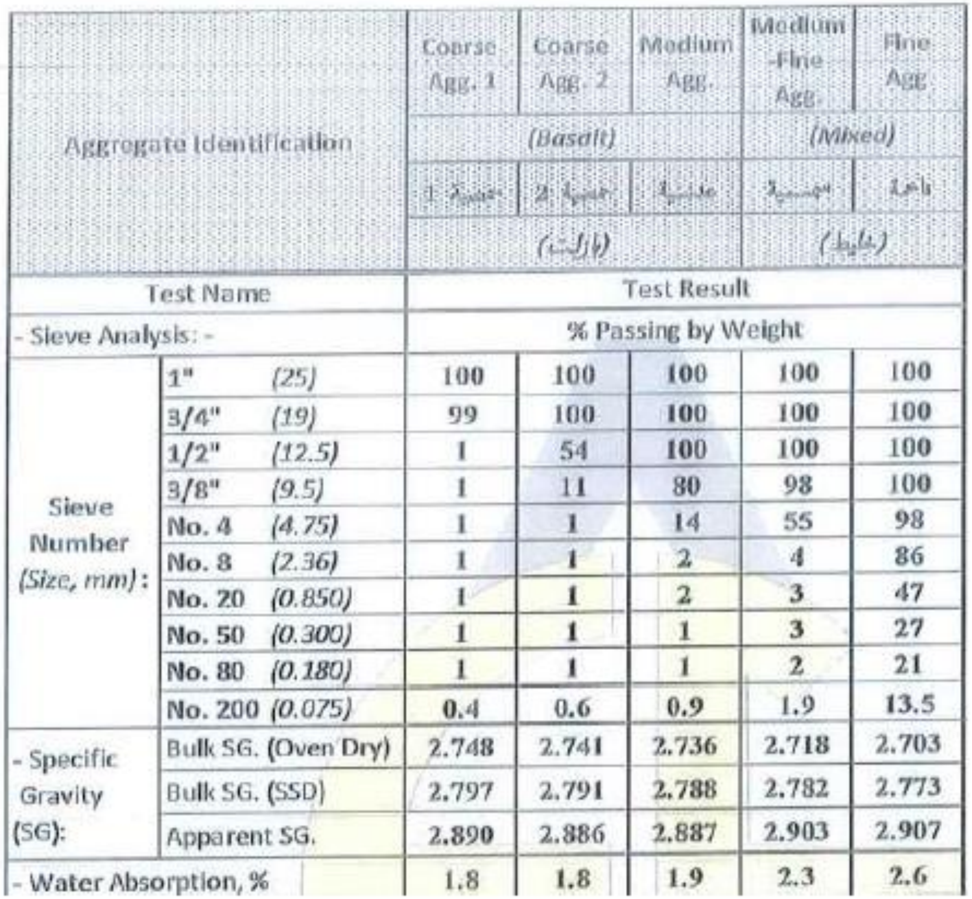
- The absorptiveness of aggregate is of significant interest to the mixture designer and specifier.
  - *Absorption can be an indicator regarding aggregate quality along with increased binder demand.*
- The binder absorption is ***typically 40 –80 percent*** of the water absorption rate
- The water absorption rate is calculated by the following equation as outlined in AASHTO T 85

$$Absorption, \% = \frac{B-A}{A} \times 100$$

  - A = mass of the oven-dry test sample
  - B = mass of the saturated surface-dry sample
- The average water absorption for the total aggregate blend as shown in AASHTO T 85 is calculated as follows

$$Absorption\ \% = \frac{P_1 \times A_1 + P_2 \times A_2 + \cdots \ldots P_n \times A_n}{100}, \text{ where}$$

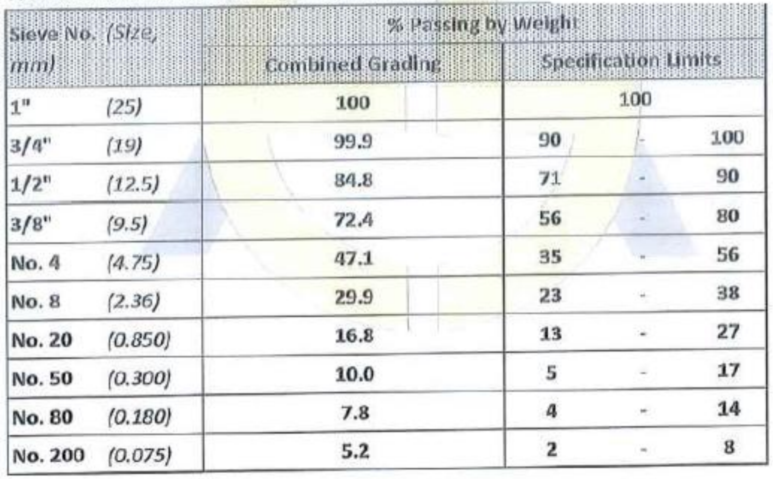
  - P_1, P_2, P_n = Percentages by weight of aggregates 1, 2, through n
  - A_1, A_2, A_n = absorption of aggregates 1, 2, through n



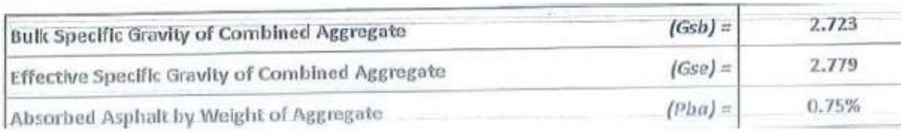
Aggregate Identification		Coarse Agg. 1	Coarse Agg. 2	Medium Agg.	Medium -Fine Agg.	Fine Agg.
		(Basalt)			(Mixed)	
		حصوية 1	حصوية 2	عدسية	حمصية	ناعمة
		(بازلت)			(خليط)	
Test Name		Test Result				
- Sieve Analysis: -		% Passing by Weight				
Sieve Number (Size, mm):	1" (25)	100	100	100	100	100
	3/4" (19)	99	100	100	100	100
	1/2" (12.5)	1	54	100	100	100
	3/8" (9.5)	1	11	80	98	100
	No. 4 (4.75)	1	1	14	55	98
	No. 8 (2.36)	1	1	2	4	86
	No. 20 (0.850)	1	1	2	3	47
	No. 50 (0.300)	1	1	1	3	27
	No. 80 (0.180)	1	1	1	2	21
	No. 200 (0.075)	0.4	0.6	0.9	1.9	13.5
- Specific Gravity (SG):	Bulk SG. (Oven Dry)	2.748	2.741	2.736	2.718	2.703
	Bulk SG. (SSD)	2.797	2.791	2.788	2.782	2.773
	Apparent SG.	2.890	2.886	2.887	2.903	2.907
- Water Absorption, %		1.8	1.8	1.9	2.3	2.6

Hot Bin Components			Hot Bin Proportions, %
Coarse Agg. 1	(Hot Bin 1)	حصوية 1	7.0
Coarse Agg. 2	(Hot Bin 2)	حصوية 2	18.0
Medium Agg.	(Hot Bin 3)	عدسية	21.0
Medium-Fine Agg.	(Hot Bin 4)	حمصية	21.0
Fine Agg.	(Hot Bin 5)	ناعمة	33.0
Total		المجموع	100.0

And the obtained combined grading was as follows: -



Sieve No. (Size, mm)		% Passing by Weight			
		Combined Grading	Specification Limits		
1"	(25)	100	100		
3/4"	(19)	99.9	90	-	100
1/2"	(12.5)	84.8	71	-	90
3/8"	(9.5)	72.4	56	-	80
No. 4	(4.75)	47.1	35	-	56
No. 8	(2.36)	29.9	23	-	38
No. 20	(0.850)	16.8	13	-	27
No. 50	(0.300)	10.0	5	-	17
No. 80	(0.180)	7.8	4	-	14
No. 200	(0.075)	5.2	2	-	8

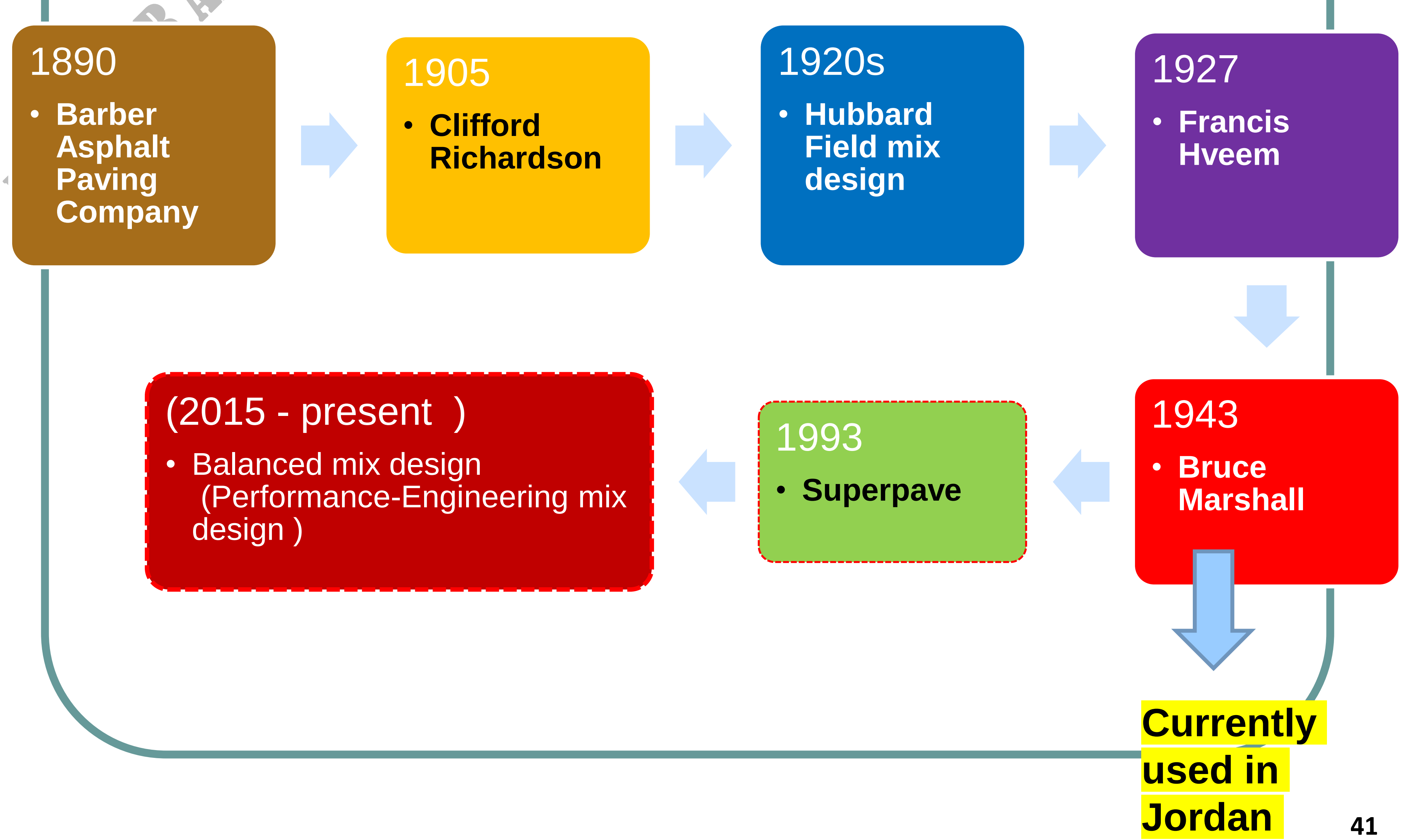


Bulk Specific Gravity of Combined Aggregate	(Gsb) =	2.723
Effective Specific Gravity of Combined Aggregate	(Gse) =	2.779
Absorbed Asphalt by Weight of Aggregate	(Pba) =	0.75%

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.

Asphalt Mix Design Methods



1890
- **Barber Asphalt Paving Company**

1905
- **Clifford Richardson**

1920s
- **Hubbard Field mix design**

1927
- **Francis Hveem**

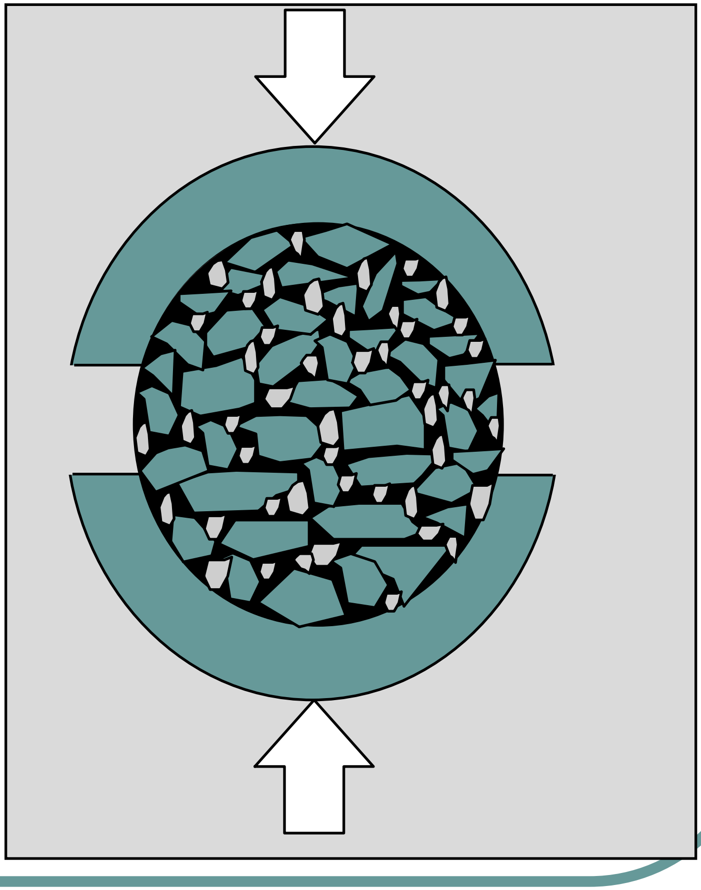
1943
- **Bruce Marshall**

Currently used in Jordan

1993
- **Superpave**

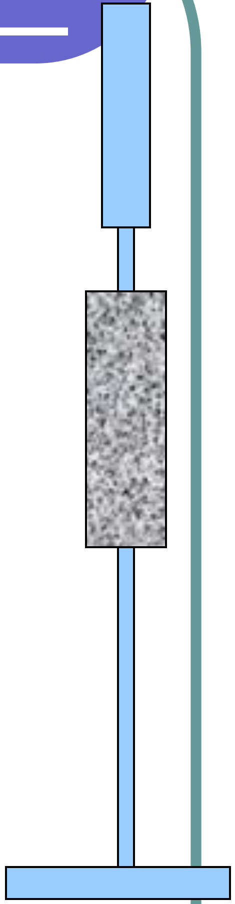
(2015 - present)
- Balanced mix design (Performance-Engineering mix design)

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.

Specimen weigh-out table

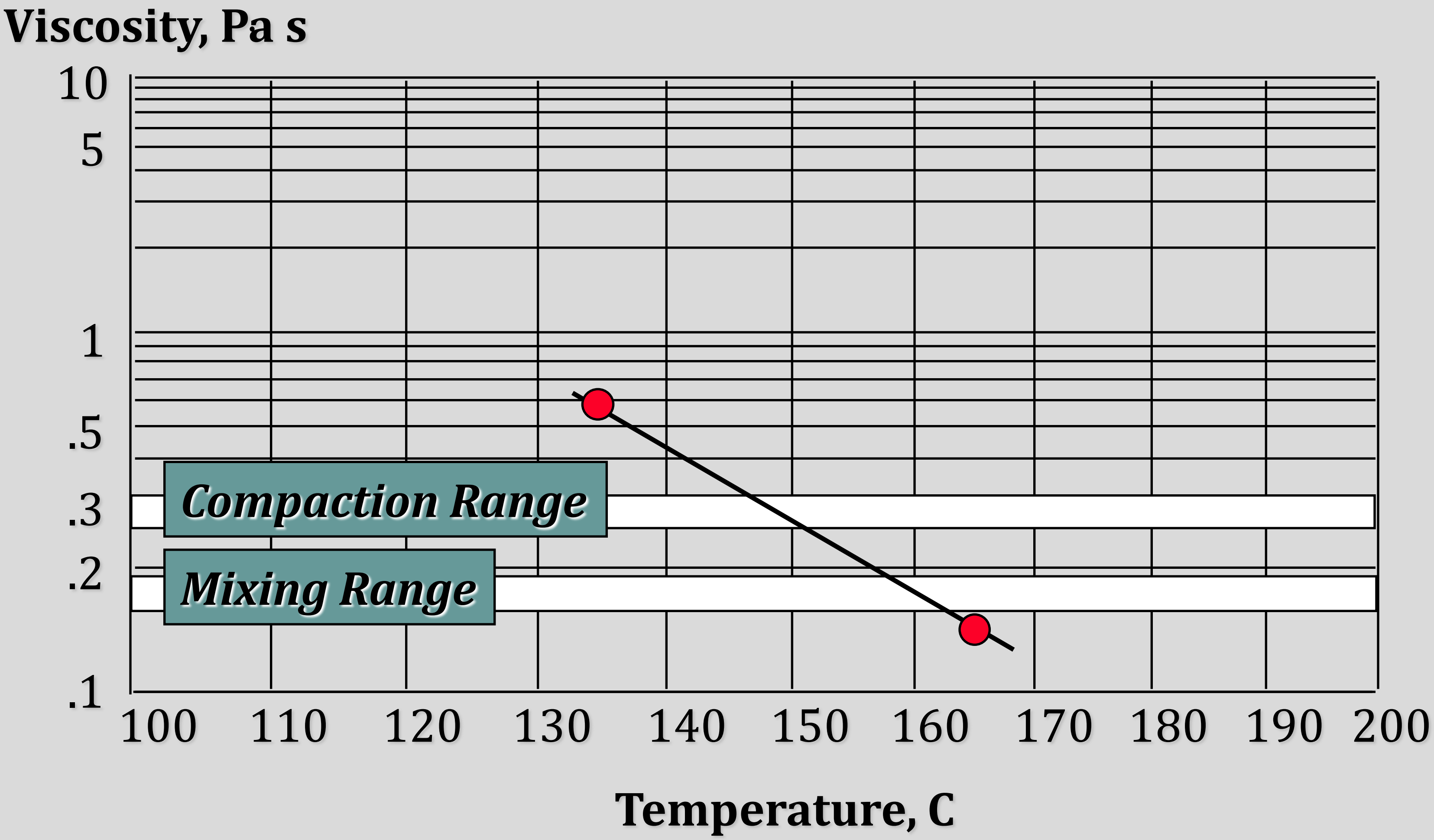
Sample wt	1150							
	Spec	Spec						
Sieve	lower	Uper	Mid	Diff %Pass	Mass (g)	Cumulative		
1"	100	100	100			Mass (g)	Pass	Ret.
3/4"	90	100	95	5	57.5	57.5	1	3/4"
1/2"	71	90	80.5	14.5	166.75	224.25	3/4"	1/2"
3/8"	56	80	68	12.5	143.75	368	1/2"	3/8"
# 4	35	56	45.5	22.5	258.75	626.75	3/8"	# 4
# 8	23	38	30.5	15	172.5	799.25	# 4	# 8
# 16	13	27	20	10.5	120.75	920	# 8	# 16
# 50	5	17	11	9	103.5	1023.5	# 16	# 50
# 100	4	14	9	2	23	1046.5	# 50	# 100
# 200	2	8	5	4	46	1092.5	# 100	# 200
			0	5	57.5	1150	# 200	pan
Total					1150			

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.
- Weigh into separate pans for each test specimen the amount of each size fraction required to produce a batch that will result in a compacted specimen 63.5 ± 1.27 mm (2.5 ± 0.05 in.) in height (about 1200 g).
- 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.

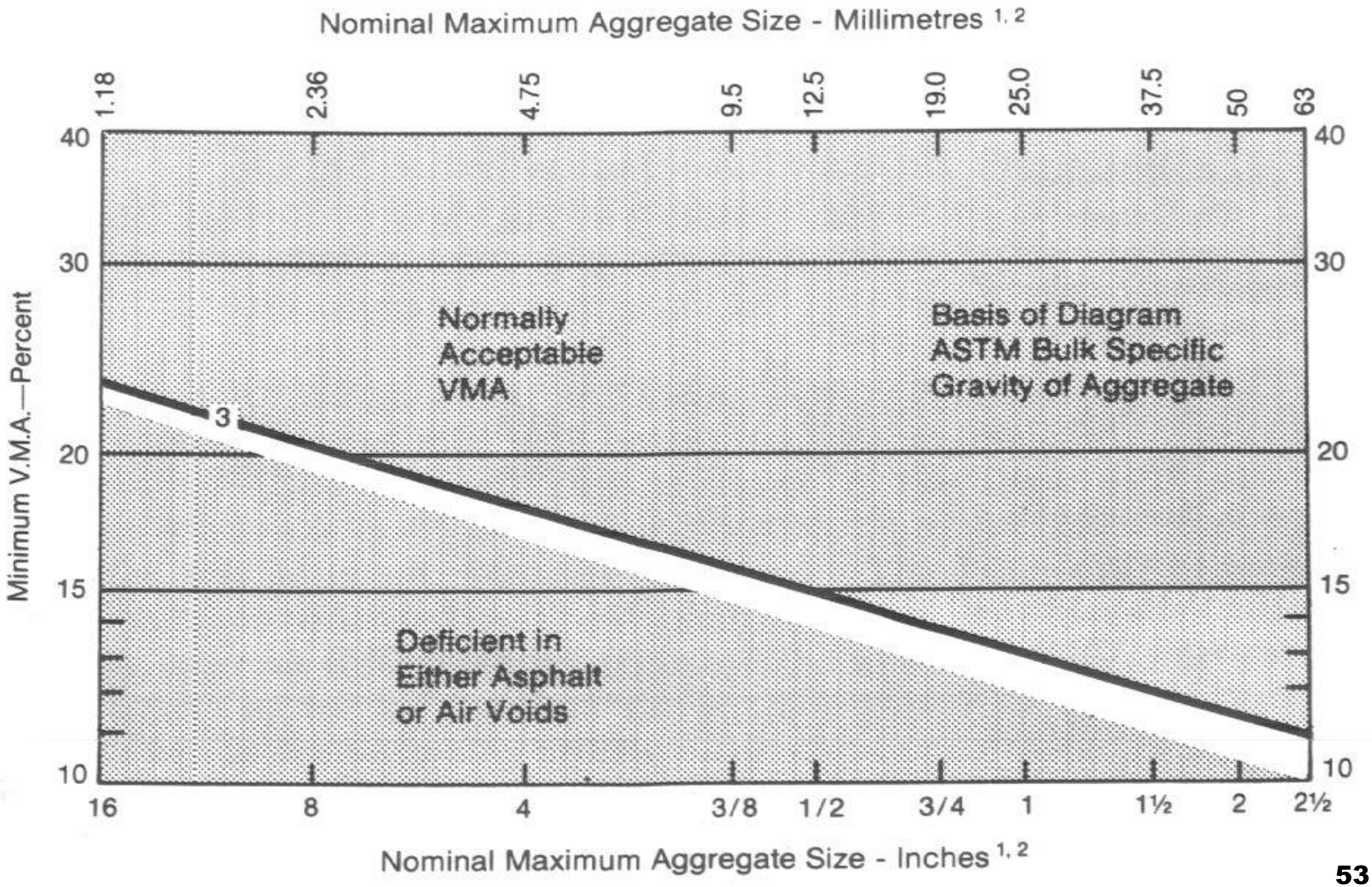
Mixing

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.

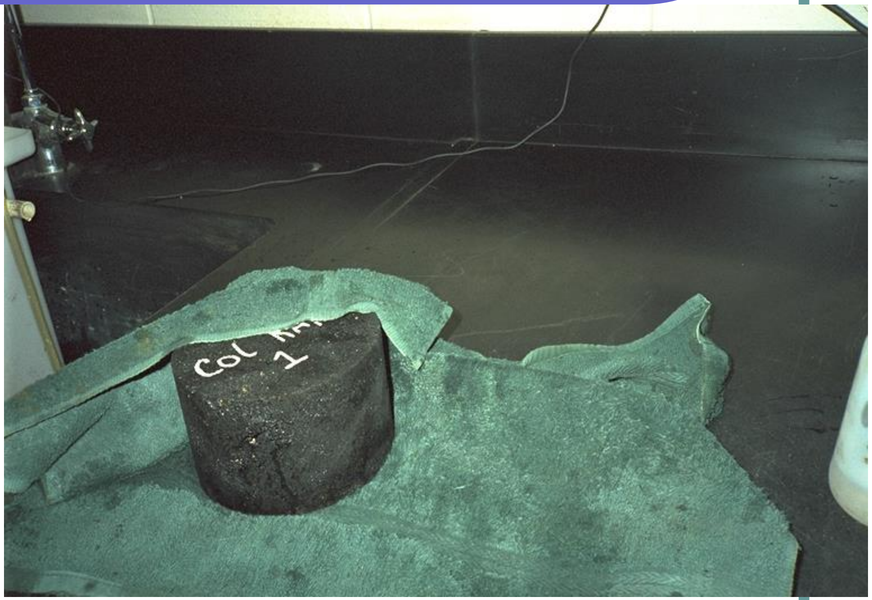
- Remove paper filter from top & bottom of specimen and allow to cool then extrude from mold using hydraulic jack.
- Mark and allow to sit @ room temp. overnight before further testing.
- Determine Bulk S.G. of each compacted specimen.
- Measure Rice S.G. for the loose mix specimen.

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***)]

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

- 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.

Specific Gravity for Asphalt Mixture

Theoretical Maximum Specific Gravity Gmm

Three specimens prepared at specified binder content

No.1

No.2

No.3

Gmm Specimen No.1

Gmm Specimen No.2

Gmm Specimen No.3

$$Gmm_{mix} = \frac{(GmmS_1 + Gmm_{S2} + Gmm_{S3})}{3}$$

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.

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

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.

$$\mathbf{Gmm = (Pmm = 100) / [((100 - Pb) / Gse) + ((Pb / Gb))]}$$

$$\mathbf{= (100) / [((Ps) / Gse) + ((Pb / Gb))]}$$

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

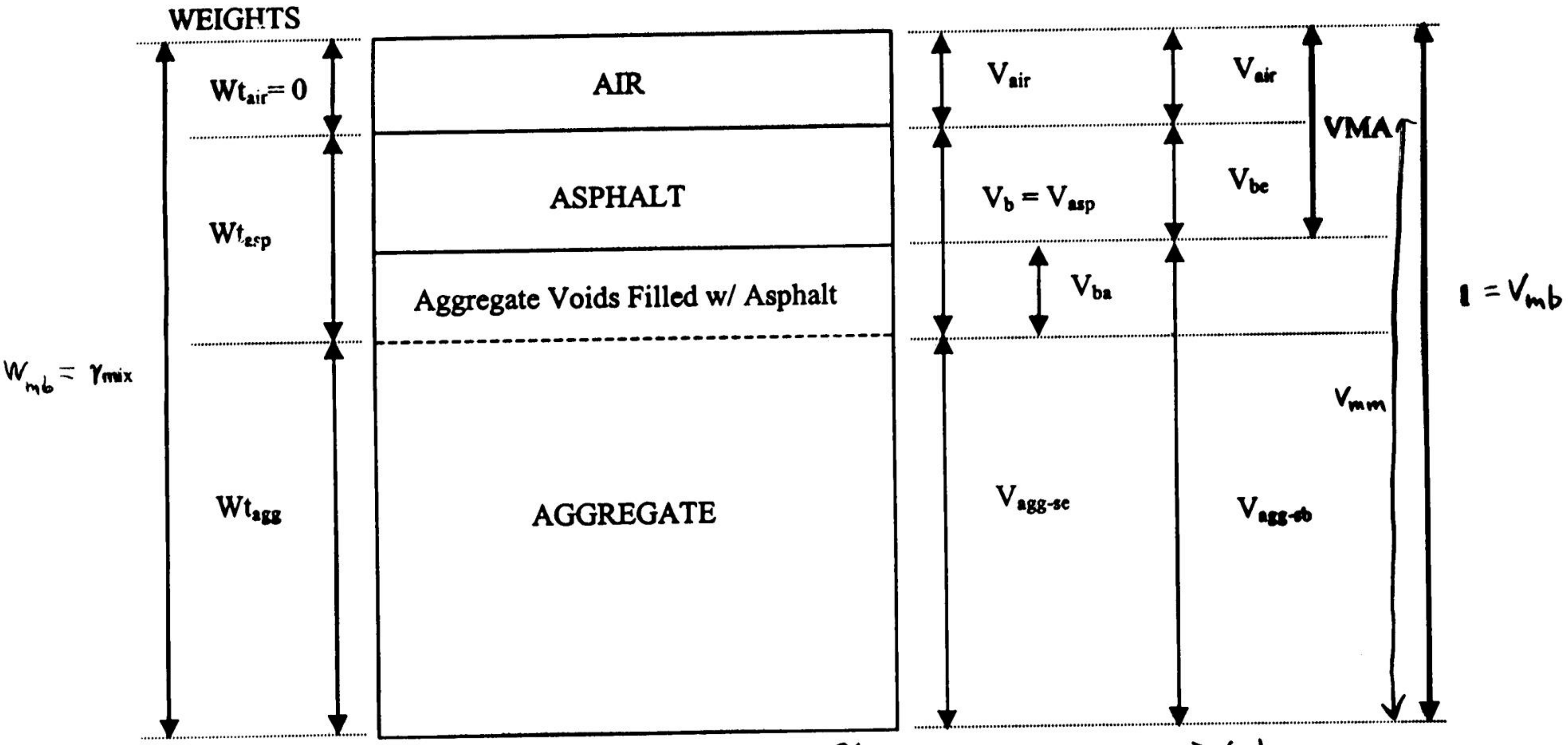
Pb = % of asphalt by total wt. of mixture

Gse = Effective S.G. of aggregates

Gb = S.G. of asphalt

Density Void Analysis

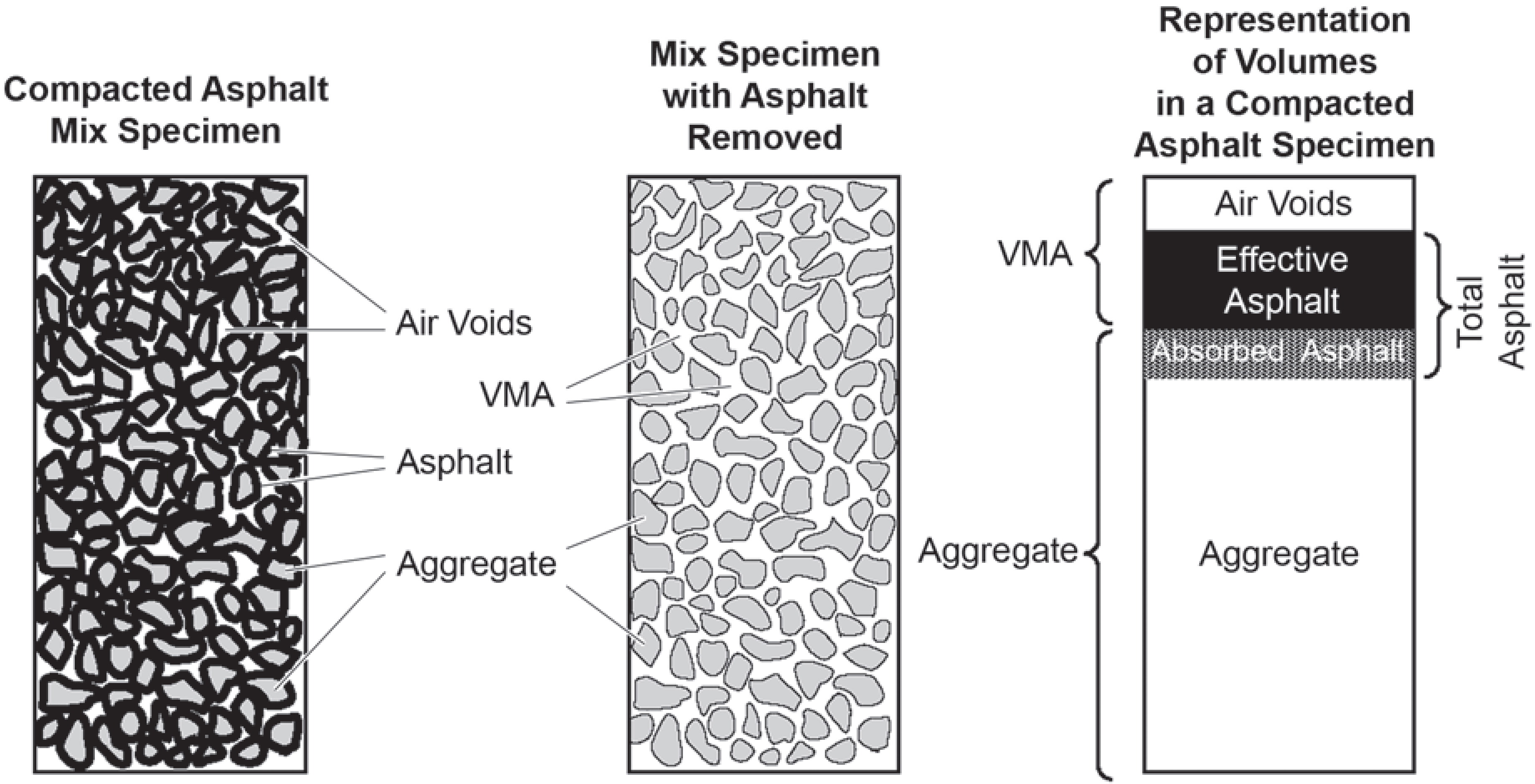
WEIGHT-VOLUME RELATIONSHIPS FOR ASPHALT CONCRETE



given γ_{mix}, % a.c. → weights

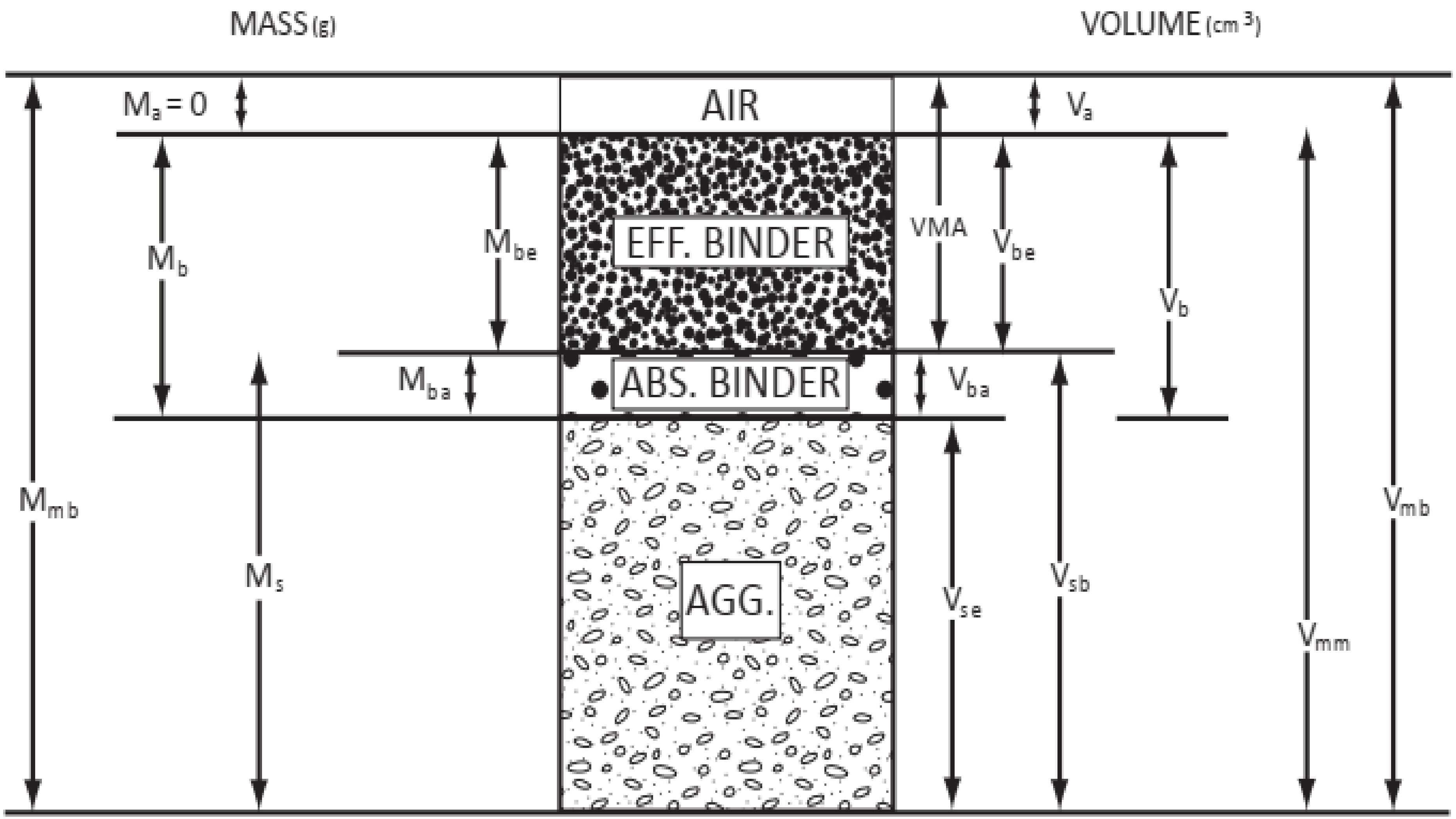
to convert to volumes → G_{sb-od}, G_{se}, G_{mm}, G_{asp}

Volumetric Analysis (Phase Diagram)



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

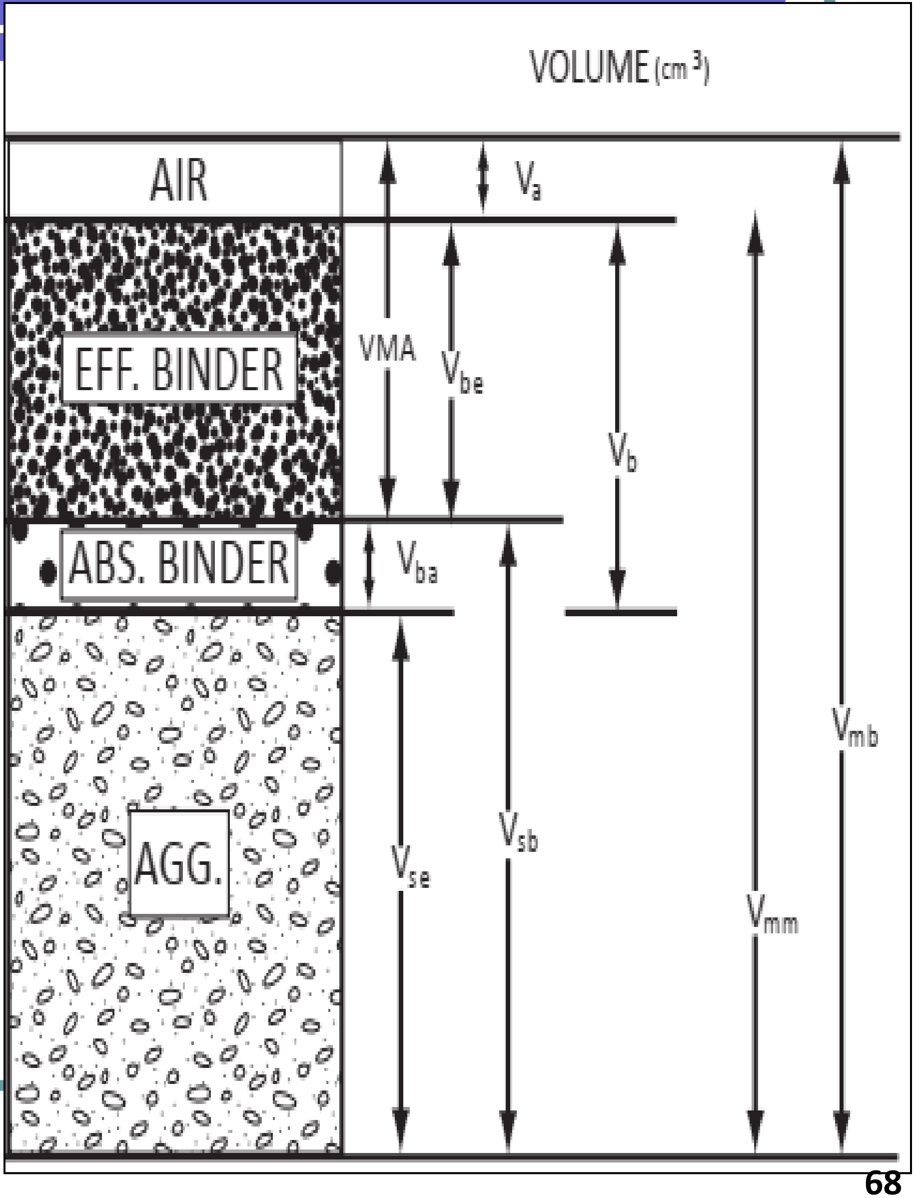
Volumetric Analysis (Phase Diagram)



Phase Diagram

Terms

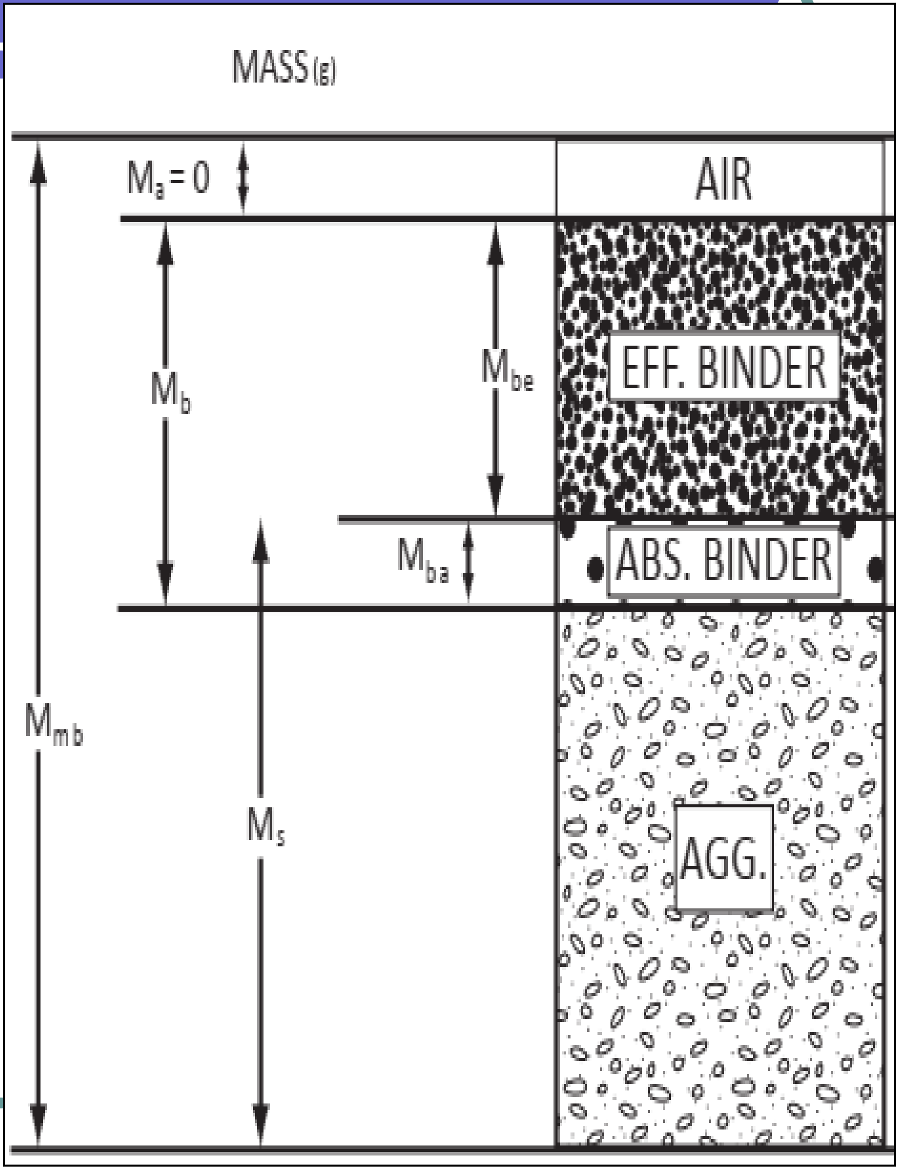
V_{mb}	Total volume of the compacted specimen
V_{mm}	Total volume of the loose mixture
V_a	Volume of air voids
V_b	Volume of asphalt binder
V_{be}	Volume of effective asphalt binder
V_{ba}	Volume of absorbed asphalt binder
V_{Sb}	Volume of aggregate
V_{se}	Effective volume of aggregate
VMA	Voids in the Mineral Aggregate



Phase Diagram

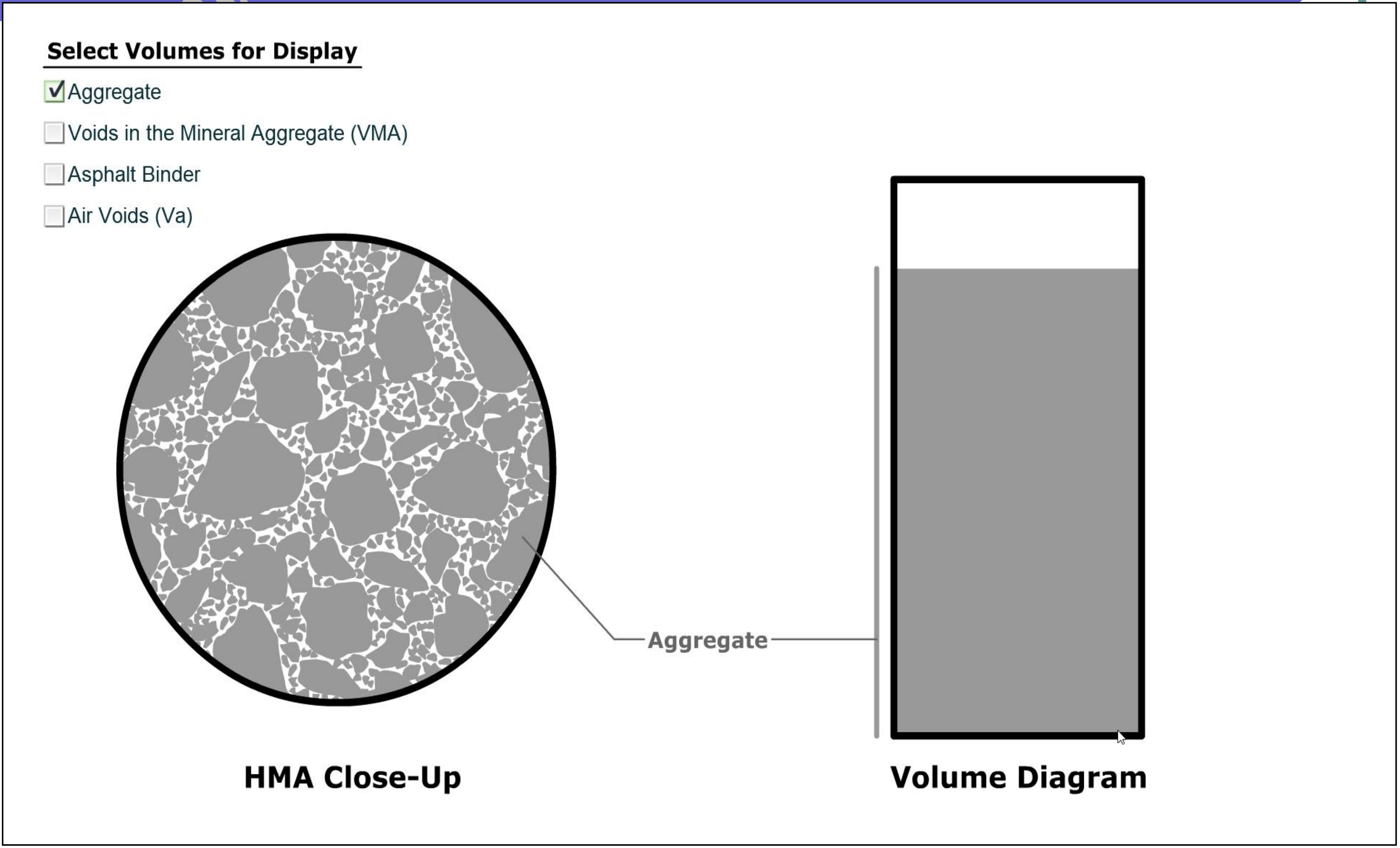
Terms

M_{mb}	Total weight of the compacted specimen
M_a	Total weight of air voids (= ZERO)
M_b	Total weight of asphalt binder
M_{be}	Total weight of effective asphalt binder
M_{ba}	Total weight of absorbed asphalt binder
M_s	Total weight of aggregate
V_{se}	Effective volume of aggregate



Asphalt Mixture

The volumetric relationship HMA



Select Volumes for Display

☑ Aggregate

☐ Voids in the Mineral Aggregate (VMA)

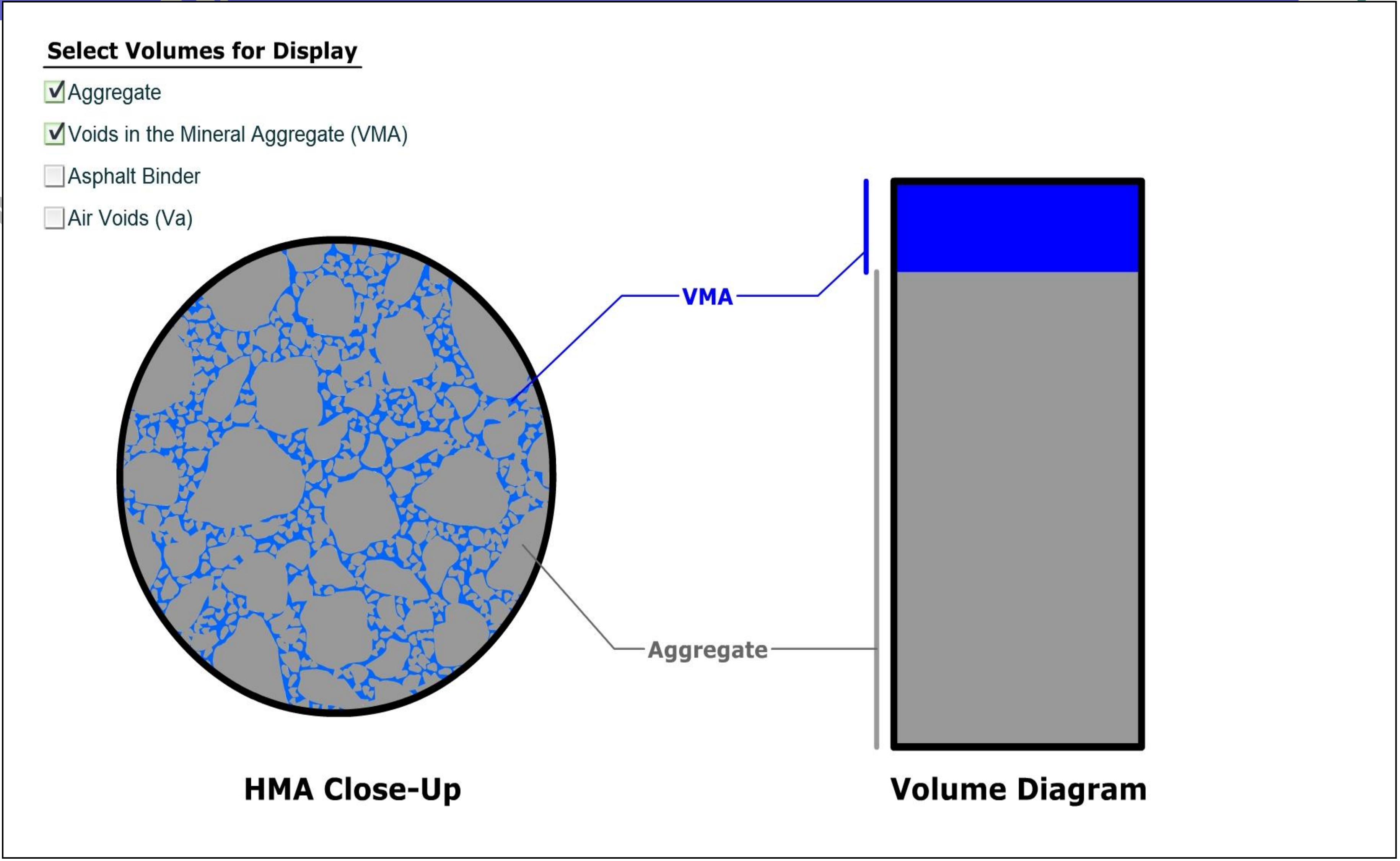
☐ Asphalt Binder

☐ Air Voids (Va)

*Image source:*https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

Asphalt Mixture

The volumetric relationship HMA



Select Volumes for Display

☑ Aggregate

☑ Voids in the Mineral Aggregate (VMA)

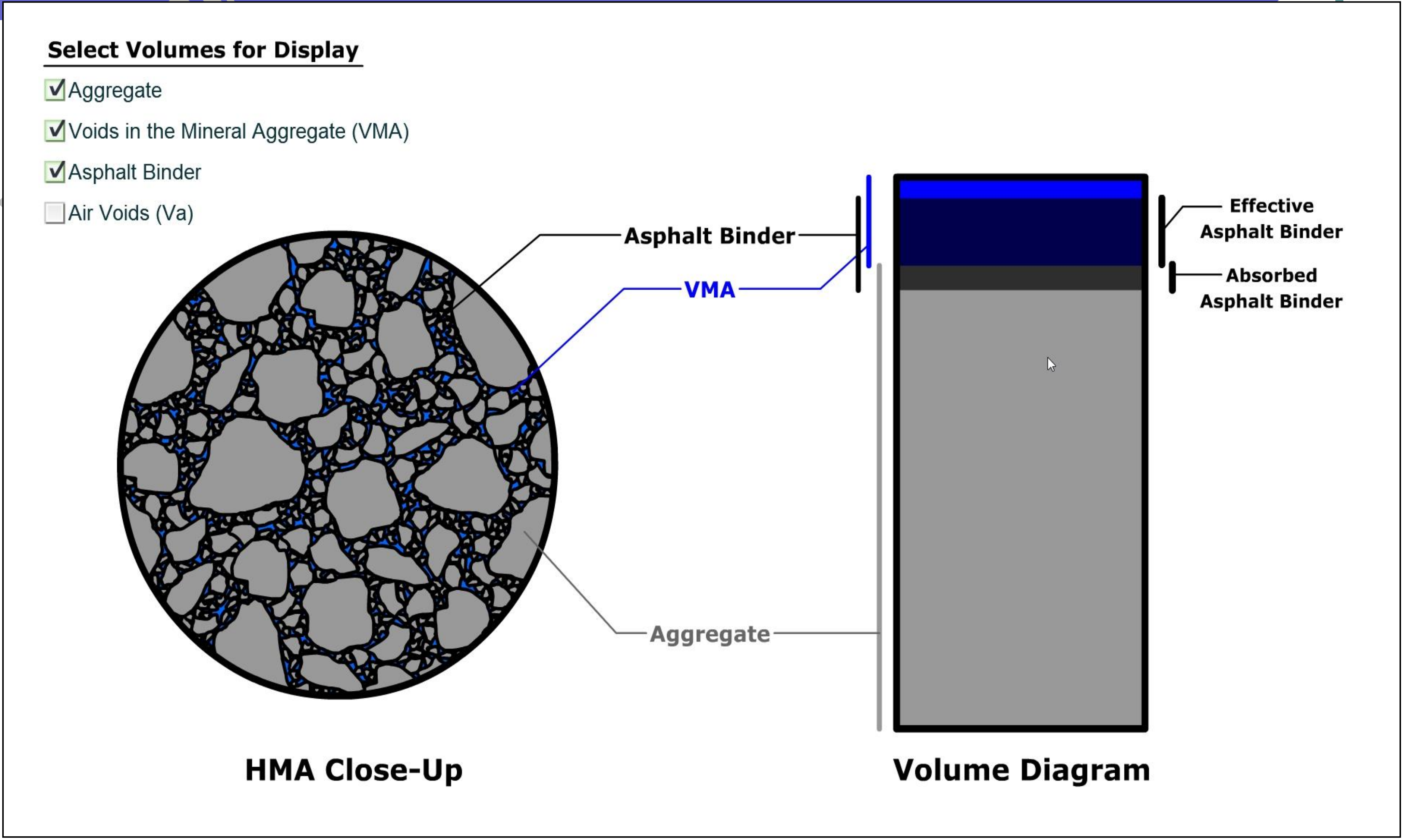
☐ Asphalt Binder

☐ Air Voids (Va)

*Image source:*https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-

Asphalt Mixture

The volumetric relationship HMA



Select Volumes for Display

☑ Aggregate

☑ Voids in the Mineral Aggregate (VMA)

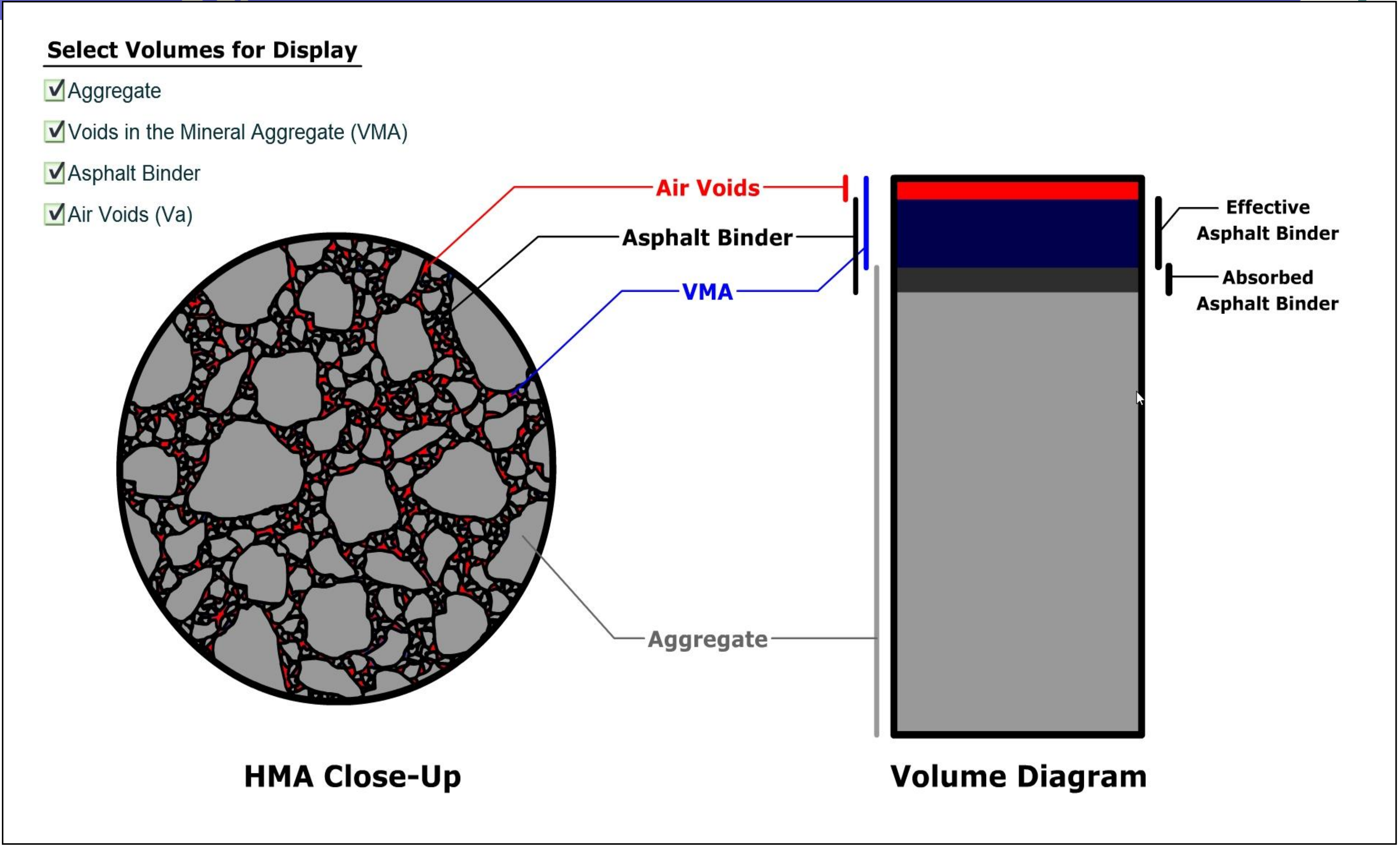
☑ Asphalt Binder

☐ Air Voids (Va)

*Image source:*https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

Asphalt Mixture

The volumetric relationship HMA



Select Volumes for Display

☑ Aggregate

☑ Voids in the Mineral Aggregate (VMA)

☑ Asphalt Binder

☑ Air Voids (Va)

*Image source:*https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

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.

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

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

$3 \leq \%\text{Vair} \leq 8$

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 In Mineral Aggregates (VMA)

- VMA represents the void space between aggregate particles.
- The goal is to furnish enough space for the asphalt binder so it can provide adequate adhesion to bind the aggregates, but without bleeding when the temperatures rise, and the asphalt expands.
- In many cases, the most difficult mix design property to achieve is a minimum amount of VMA
- Therefore, a minimum values for VMA at the design air void content is specified.

Voids In Mineral Aggregates (VMA)

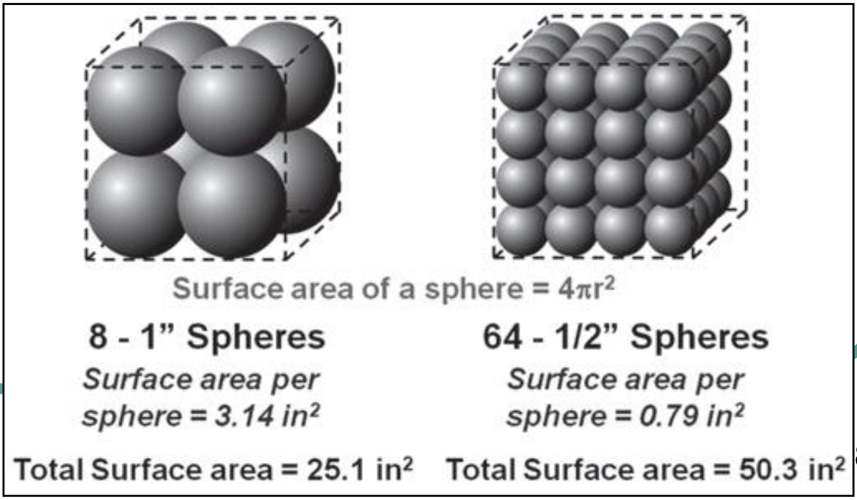
- **Minor Factors affecting VMA:**
  - Binder type: Stiffer binders can increase the resistance to the compaction resulting in increasing VMA.
  - Binder quantity: Asphalt binder will add lubrication to the mix and increase the ability of the aggregate structure to consolidate. Binder content changes around optimum will have minimal changes to VMA.
  - Sample temperature: As the mixture temperature cools…..viscosity will increase……resistance to compaction will increase…… thus resulting in an increased VMA .
  - Aggregate shape, strength and texture
    - More cubical or angular materials will increase the resistance to compaction.
    - Rougher surface textures will increase the resistance to compaction.
    - Aggregate strength is critical since a weak aggregate can degrade or break down during compaction, thus changing the gradation and greatly impacting VMA

Voids In Mineral Aggregates (VMA)

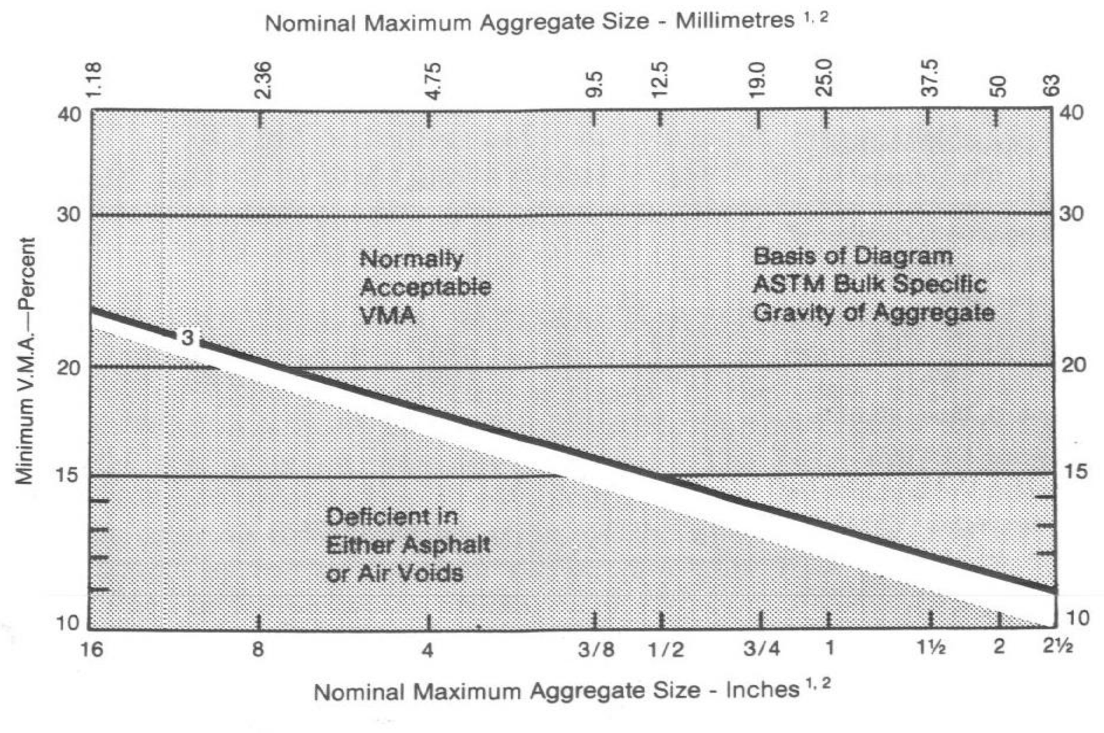
- **Major Factors affecting VMA:**
  - Type and amount of laboratory compactive effort
    - A higher number of gyrations or number of blows will also decrease the VMA in a compacted specimen
    - Gyratory compactors utilized in the Superpave system impart significantly more energy into a specimen than traditional impact hammers used in the Marshall method and Therefore, the Gyratory compactors will result in lower VMA for any given blend of aggregate.
  - Aggregate gradation
    - The gradation of an aggregate blend is perhaps one of the most influential factors governing VMA

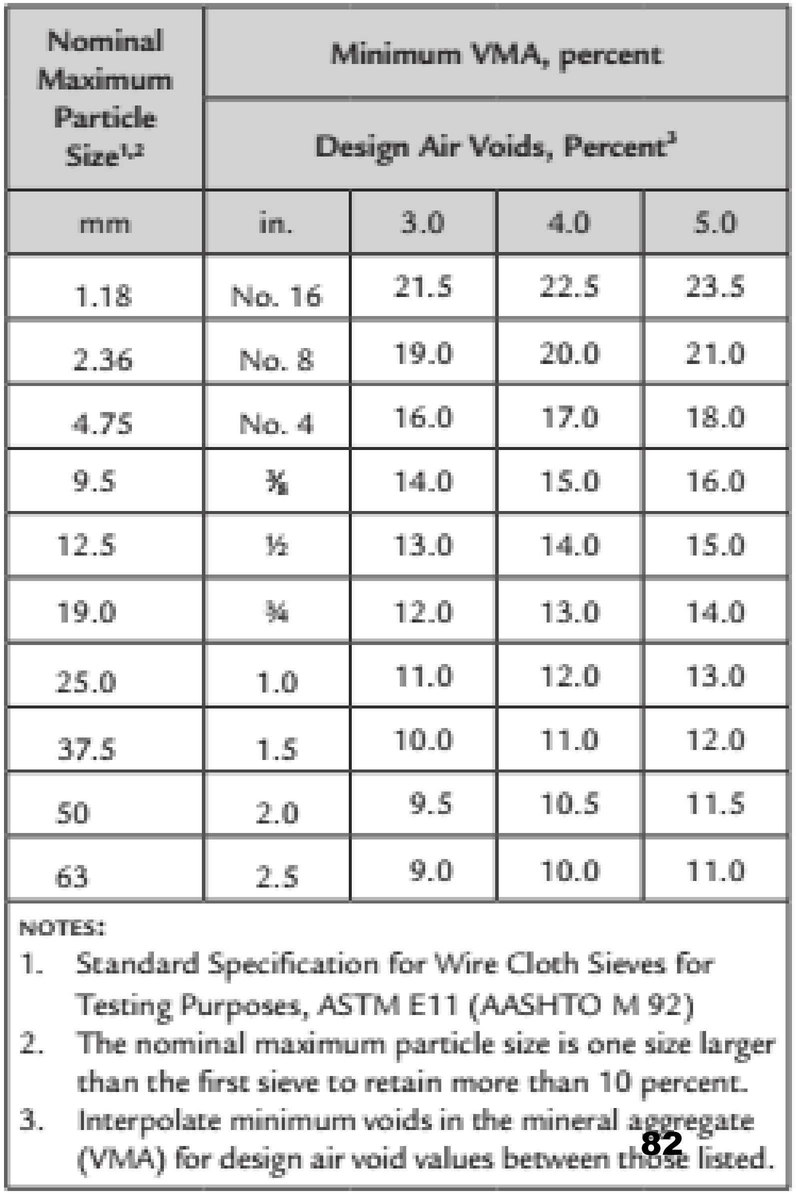
Effect of Aggregate Nominal Max Size on VMA

- As the nominal maximum aggregate size of the mix decreases, the surface area of the total aggregate structure increases.
- Therefore, the percentage of binder necessary to adequately coat the particles increases.
- the target air voids (V_a) typically remains the same,
- The VMA must increase to allow sufficient room for the additional asphalt binder.



Effect of Aggregate Nominal Max Size on VMA





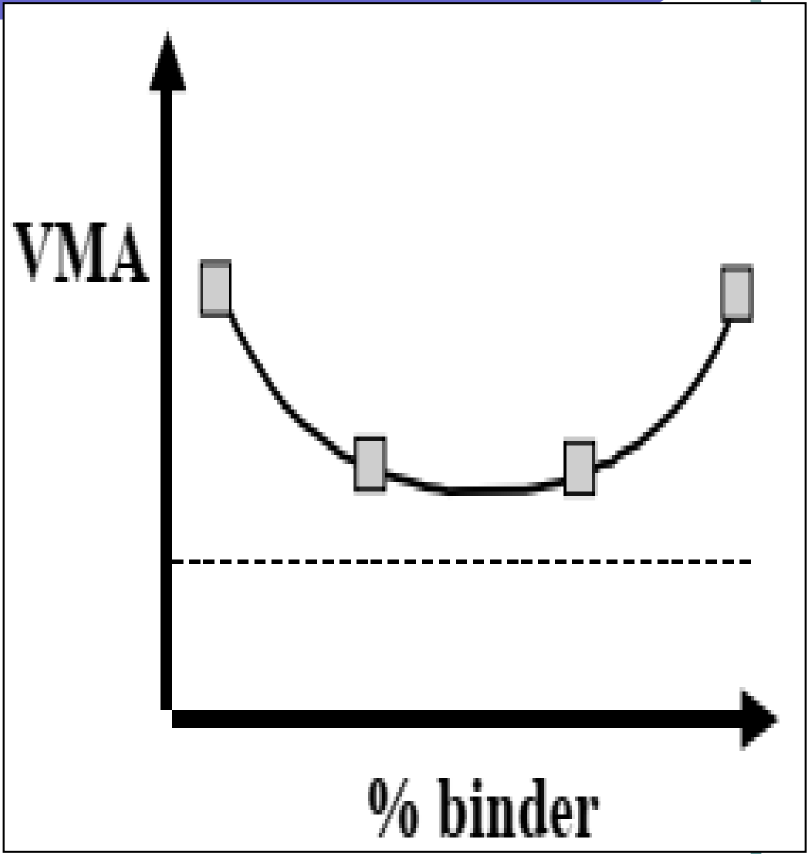
Nominal Maximum Particle Size[1,2]		Minimum VMA, percent		
		Design Air Voids, Percent[3]		
mm	in.	3.0	4.0	5.0
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19.0	20.0	21.0
4.75	No. 4	16.0	17.0	18.0
9.5	⅜	14.0	15.0	16.0
12.5	½	13.0	14.0	15.0
19.0	¾	12.0	13.0	14.0
25.0	1.0	11.0	12.0	13.0
37.5	1.5	10.0	11.0	12.0
50	2.0	9.5	10.5	11.5
63	2.5	9.0	10.0	11.0

NOTES:

1. Standard Specification for Wire Cloth Sieves for Testing Purposes, ASTM E11 (AASHTO M 92)
2. The nominal maximum particle size is one size larger than the first sieve to retain more than 10 percent.
3. Interpolate minimum voids in the mineral aggregate (VMA) for design air void values between those listed.

Evaluation of VMA curve with binder content

- With the increase in asphalt, the mix actually becomes more workable and compacts more easily, meaning more weight can be compressed into the unit volume.
  - Therefore, up to a point, the bulk density of the mix increases and the VMA decreases
- **<u>At some point</u>** as the asphalt content increases (the bottom of the U-shaped curve), the VMA begins to increase
  - because relatively higher specific gravity material (aggregate) is **displaced** and pushed apart by the lower specific gravity material (asphalt cement).



$$VMA = 100 - \frac{G_{mb} - P_s}{G_{sb}}$$

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.

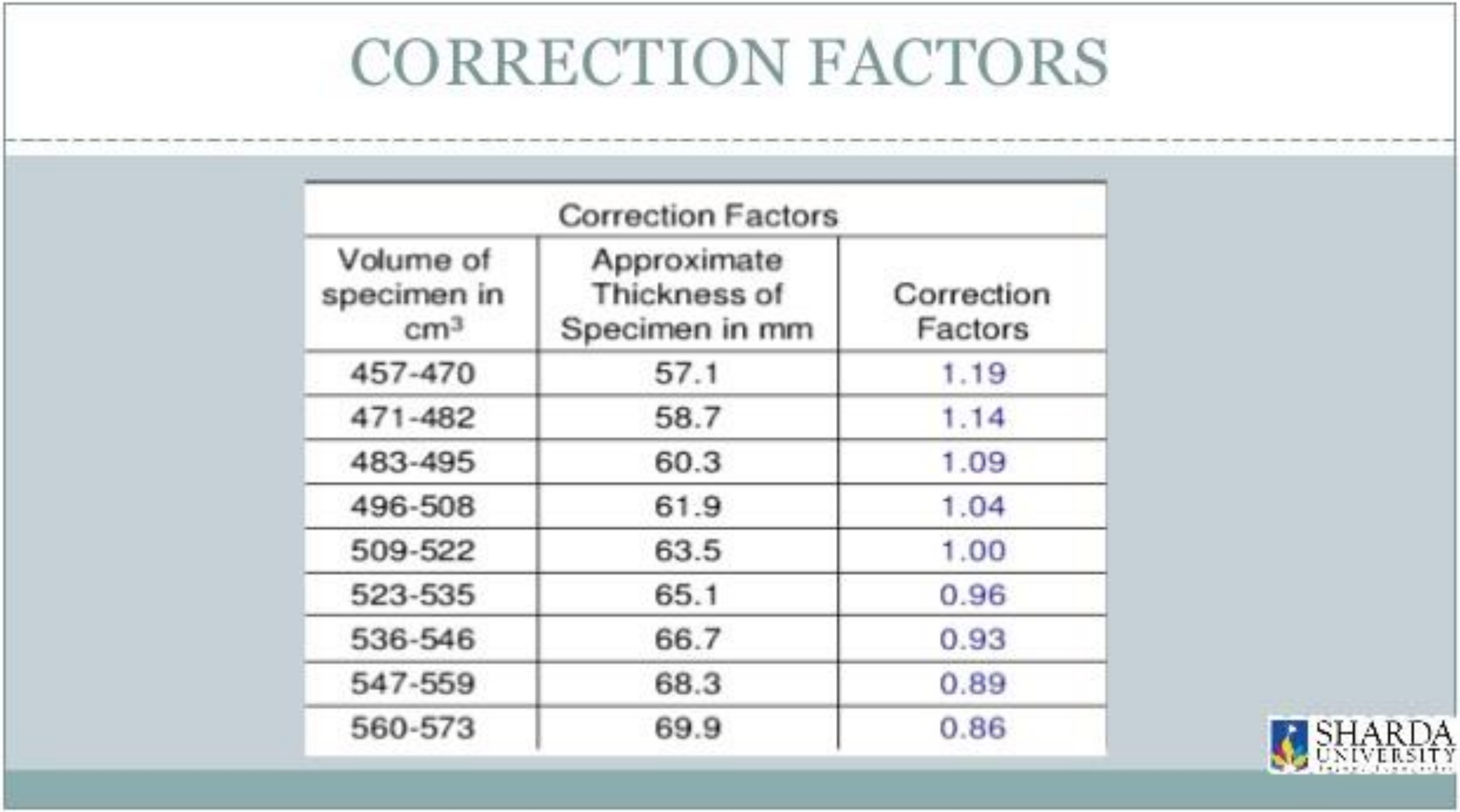
- Heights
  - Used to correct stability measurements.
  - Prepared LAB Specimens within the (63.5+-3 mm = 60.5 mm to 66.5 mm) range are generally acceptable; applying correction factors within this range can still improve the accuracy of the test results, especially when high precision is required.
  - Correction is mainly required for core specimens since they might have thicknesses different than the standard as per ASHTO T245.
- Stability and flow
  - Specimen immersed in water bath @ 60°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

Stability Correction Factor



CORRECTION FACTORS

Correction Factors		
Volume of specimen in cm³	Approximate Thickness of Specimen in mm	Correction Factors
457-470	57.1	1.19
471-482	58.7	1.14
483-495	60.3	1.09
496-508	61.9	1.04
509-522	63.5	1.00
523-535	65.1	0.96
536-546	66.7	0.93
547-559	68.3	0.89
560-573	69.9	0.86

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According to AASHTO-T 245-97 (2008):
Note 7—For core specimens, correct the load when thickness is other than 63.5 mm (21 /2 in.) by
using the proper multiplying factor from Table 2.

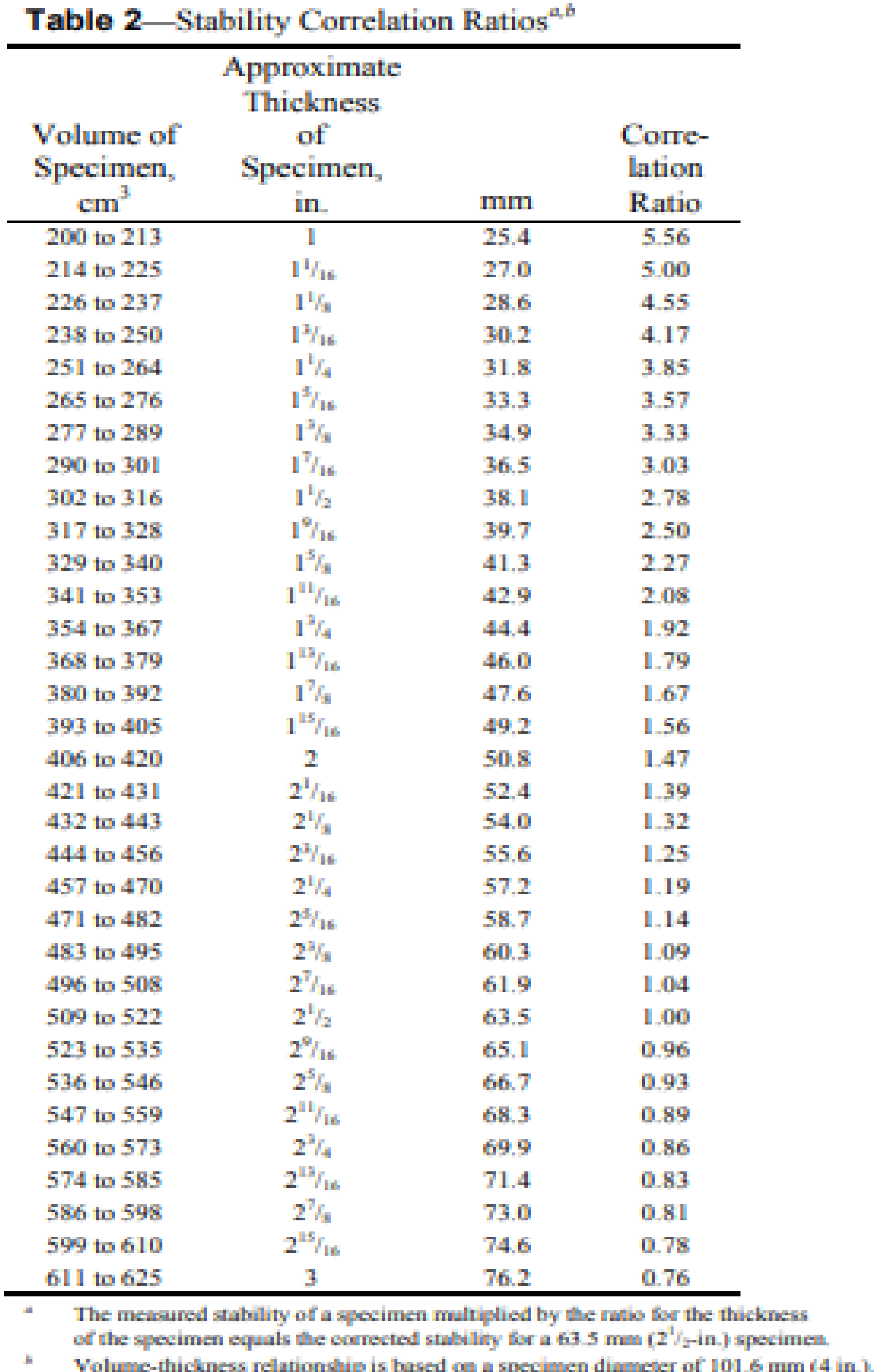


Table 2—Stability Correlation Ratios[a,b]

Volume of Specimen, cm^3	Approximate Thickness of Specimen, in.	mm	Correlation Ratio
200 to 213	1	25.4	5.56
214 to 225	$1^{1}/_{16}$	27.0	5.00
226 to 237	$1^{1}/_{8}$	28.6	4.55
238 to 250	$1^{3}/_{16}$	30.2	4.17
251 to 264	$1^{1}/_{4}$	31.8	3.85
265 to 276	$1^{5}/_{16}$	33.3	3.57
277 to 289	$1^{3}/_{8}$	34.9	3.33
290 to 301	$1^{7}/_{16}$	36.5	3.03
302 to 316	$1^{1}/_{2}$	38.1	2.78
317 to 328	$1^{9}/_{16}$	39.7	2.50
329 to 340	$1^{5}/_{8}$	41.3	2.27
341 to 353	$1^{11}/_{16}$	42.9	2.08
354 to 367	$1^{3}/_{4}$	44.4	1.92
368 to 379	$1^{13}/_{16}$	46.0	1.79
380 to 392	$1^{7}/_{8}$	47.6	1.67
393 to 405	$1^{15}/_{16}$	49.2	1.56
406 to 420	2	50.8	1.47
421 to 431	$2^{1}/_{16}$	52.4	1.39
432 to 443	$2^{1}/_{8}$	54.0	1.32
444 to 456	$2^{3}/_{16}$	55.6	1.25
457 to 470	$2^{1}/_{4}$	57.2	1.19
471 to 482	$2^{5}/_{16}$	58.7	1.14
483 to 495	$2^{3}/_{8}$	60.3	1.09
496 to 508	$2^{7}/_{16}$	61.9	1.04
509 to 522	$2^{1}/_{2}$	63.5	1.00
523 to 535	$2^{9}/_{16}$	65.1	0.96
536 to 546	$2^{5}/_{8}$	66.7	0.93
547 to 559	$2^{11}/_{16}$	68.3	0.89
560 to 573	$2^{3}/_{4}$	69.9	0.86
574 to 585	$2^{13}/_{16}$	71.4	0.83
586 to 598	$2^{7}/_{8}$	73.0	0.81
599 to 610	$2^{15}/_{16}$	74.6	0.78
611 to 625	3	76.2	0.76

[a] The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5 mm ($2^{1}/_{2}$-in.) specimen.

[b] Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.).

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

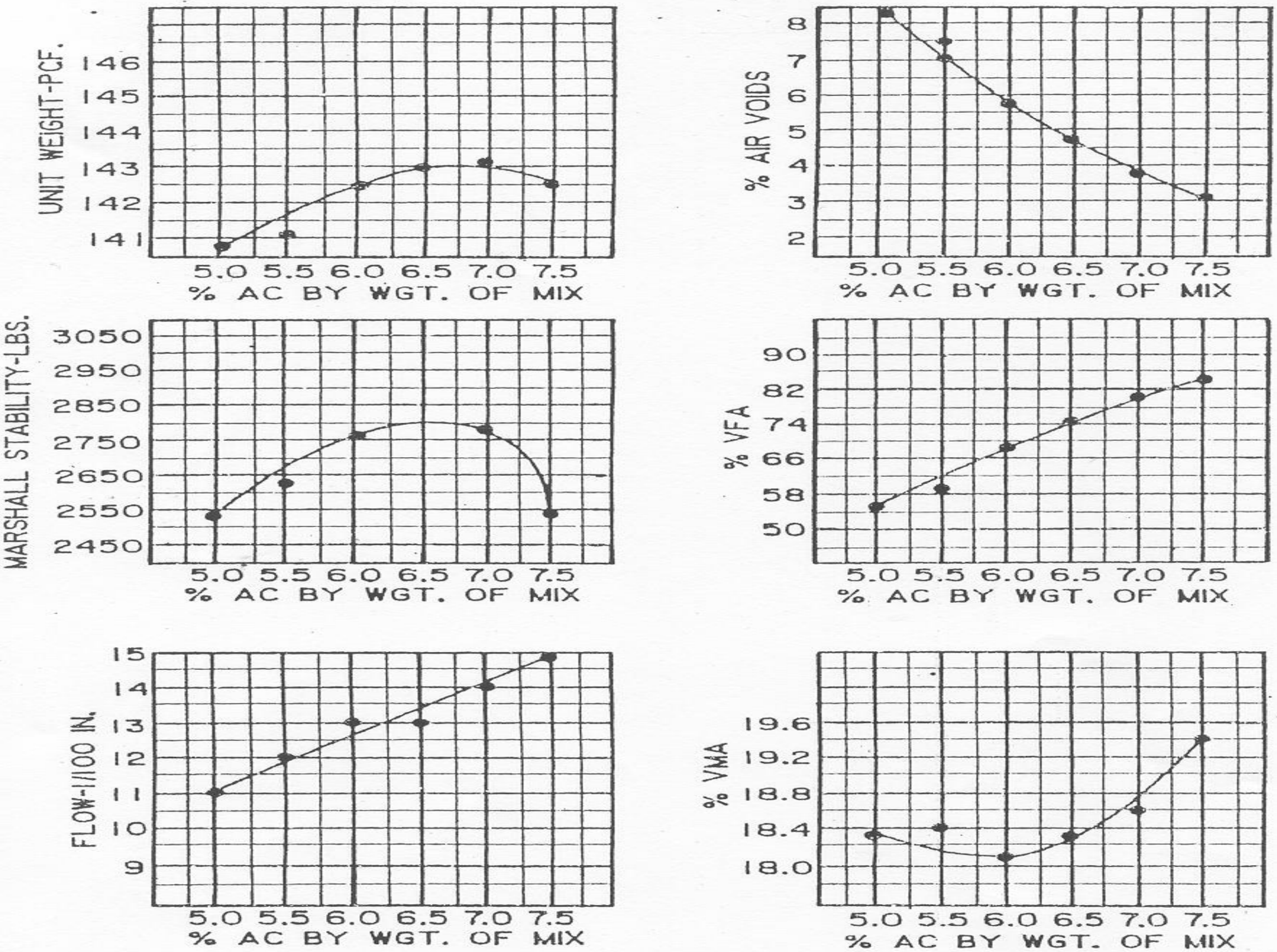
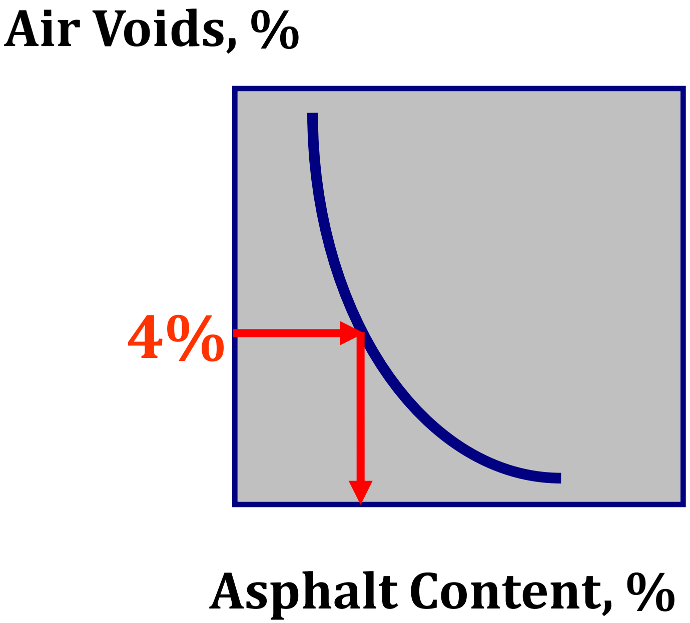


Figure 4–24. Graphical Illustration of HMA Design Data by Marshall Method

Determination of Optimum AC Content

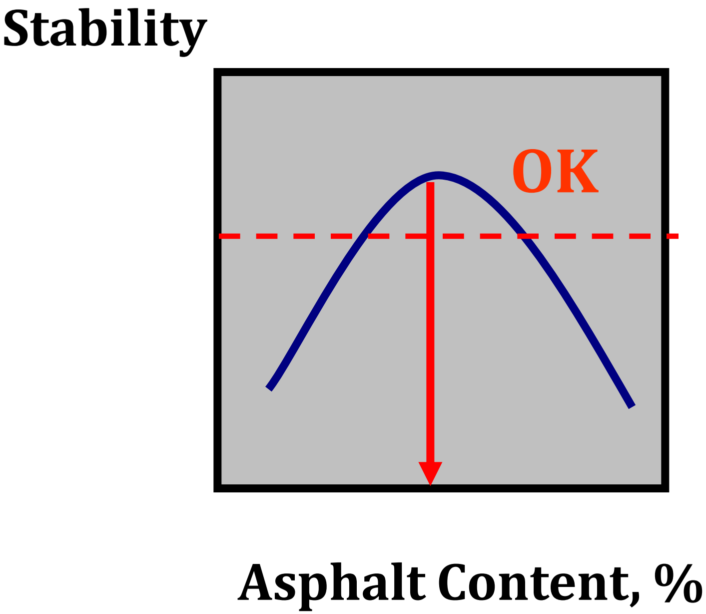
- National Asphalt Pavement Association (NAPA) Procedure
- Asphalt Institute Procedure

(NAPA) Procedure



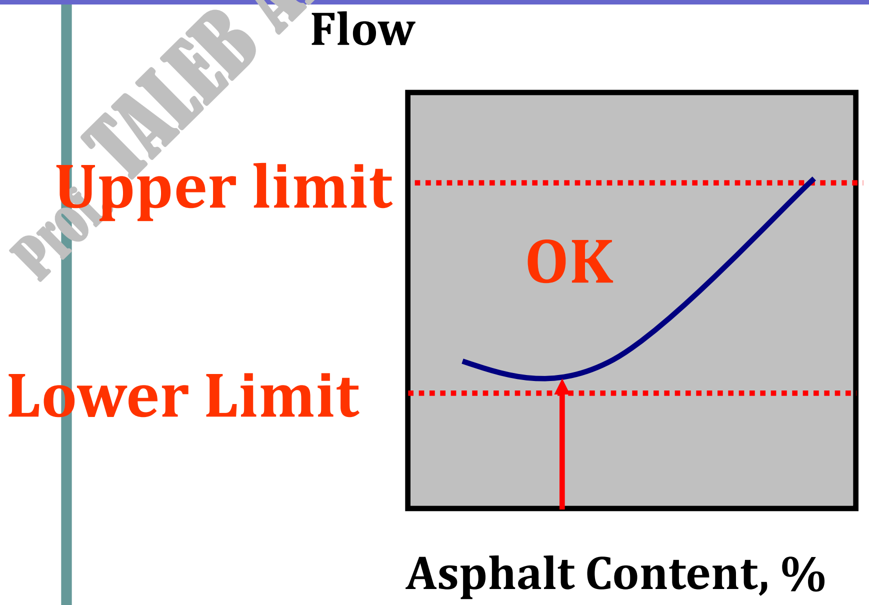
Target optimum asphalt content =
the asphalt content at 4% air voids

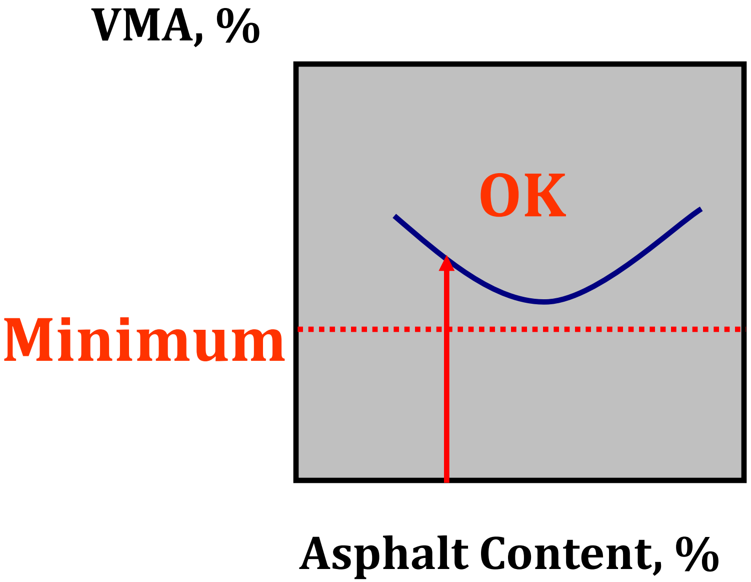
Marshall Design Use of Data NAPA Procedure



The target stability is checked

Marshall Design Use of Data
NAPA Procedure

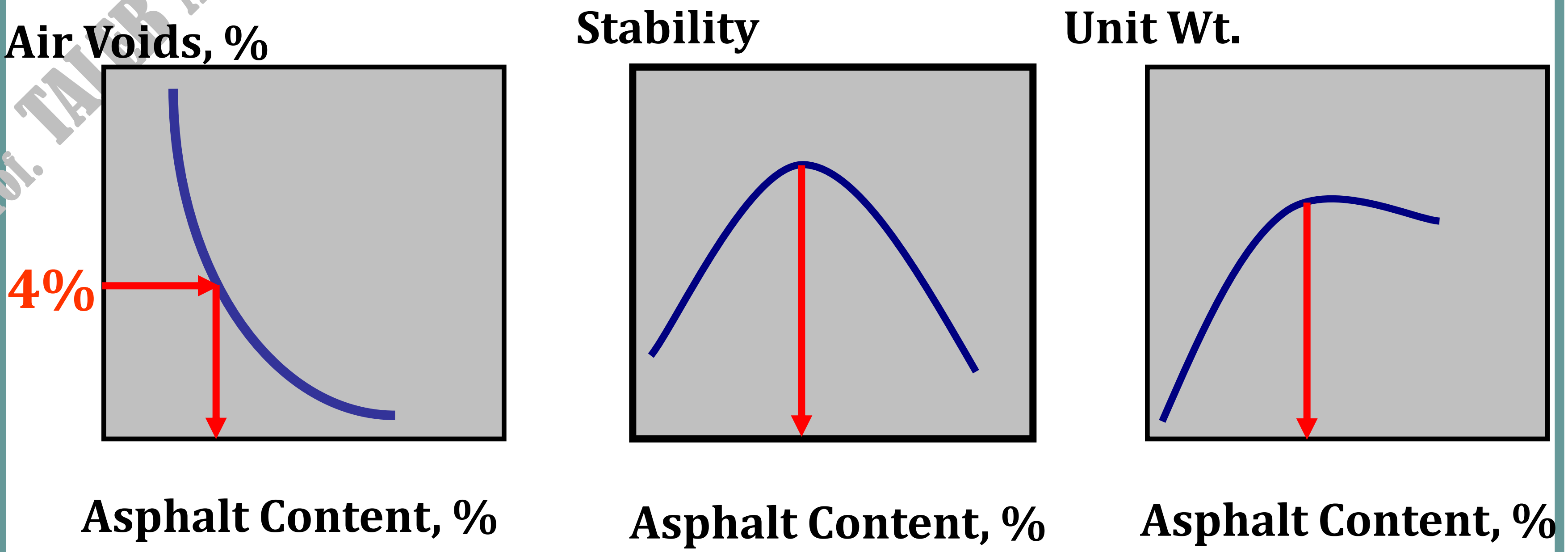




Use target optimum asphalt content to check if these criteria are met

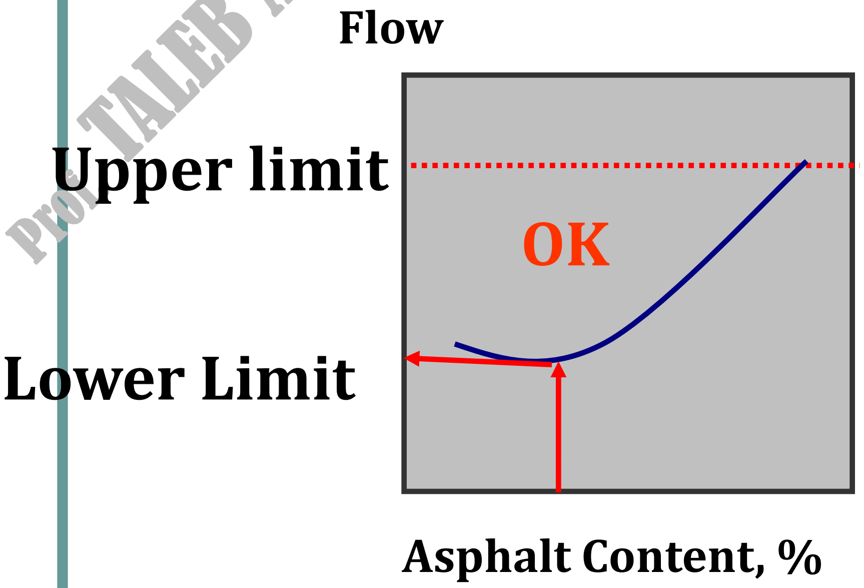
If not - adjust slightly to meet all criteria if possible; else change gradation and repeat analysis

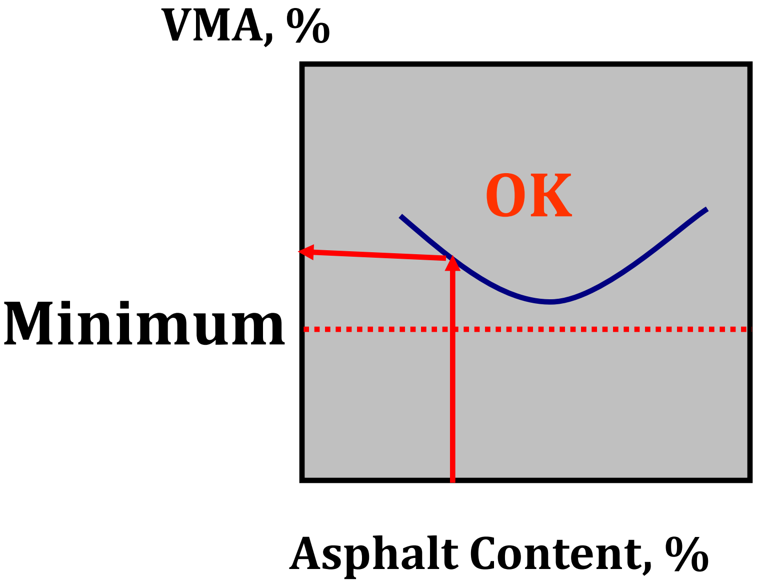
Marshall Design Use of Data
Asphalt Institute Procedure



Target optimum asphalt content = average

Marshall Design Use of Data
Asphalt Institute Procedure





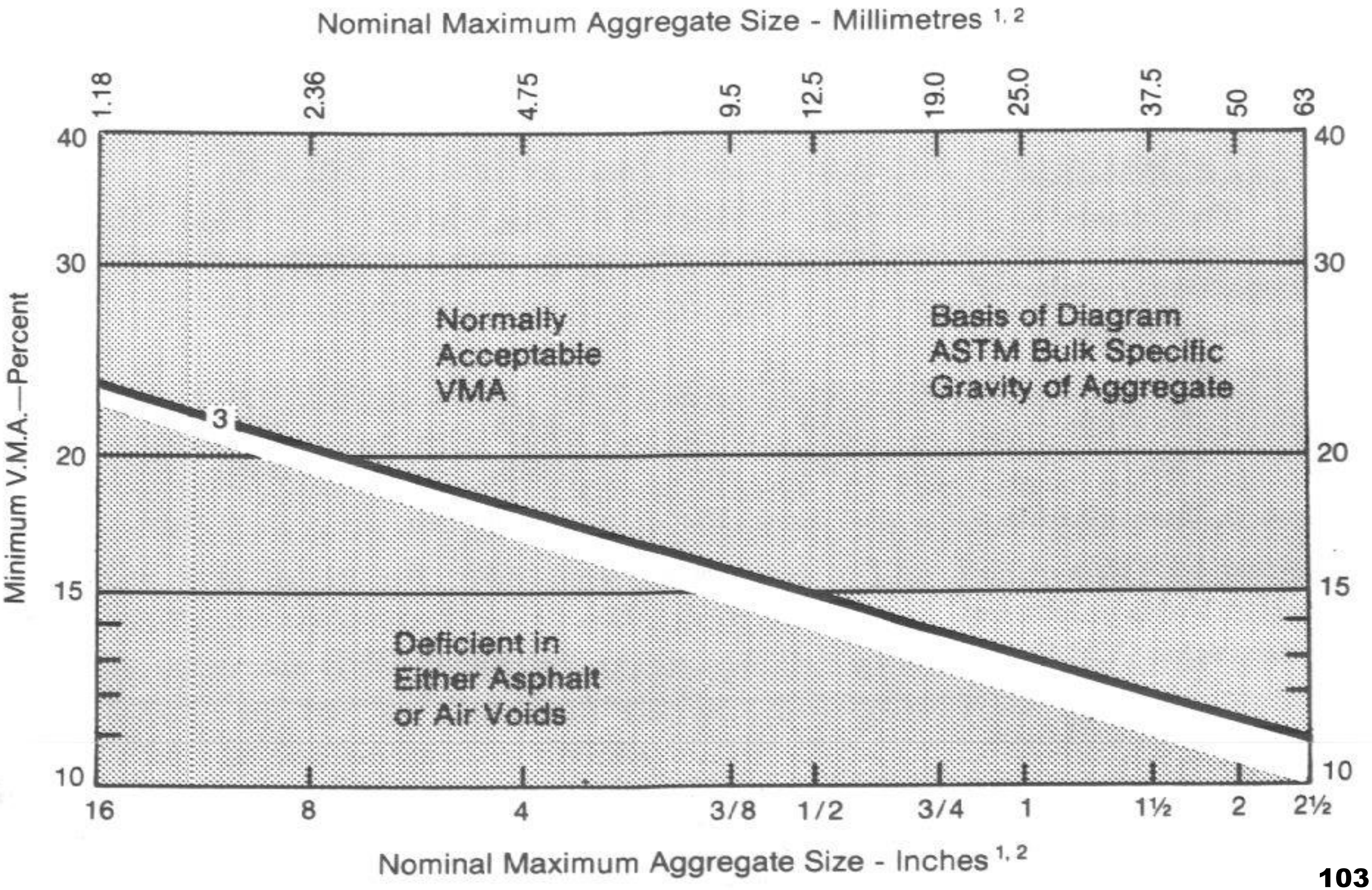
Use target optimum asphalt content to check if ALL criteria are met

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

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



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, ≤ 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).
- the manufactured product should be discharged at a temperature of 170F+-10. To achieve this, the aggregates are cooled to approximately 180F after they are dried but before they are placed into the mixer.
- Aggregates, then 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, Cold-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.

Jordanian National Building council

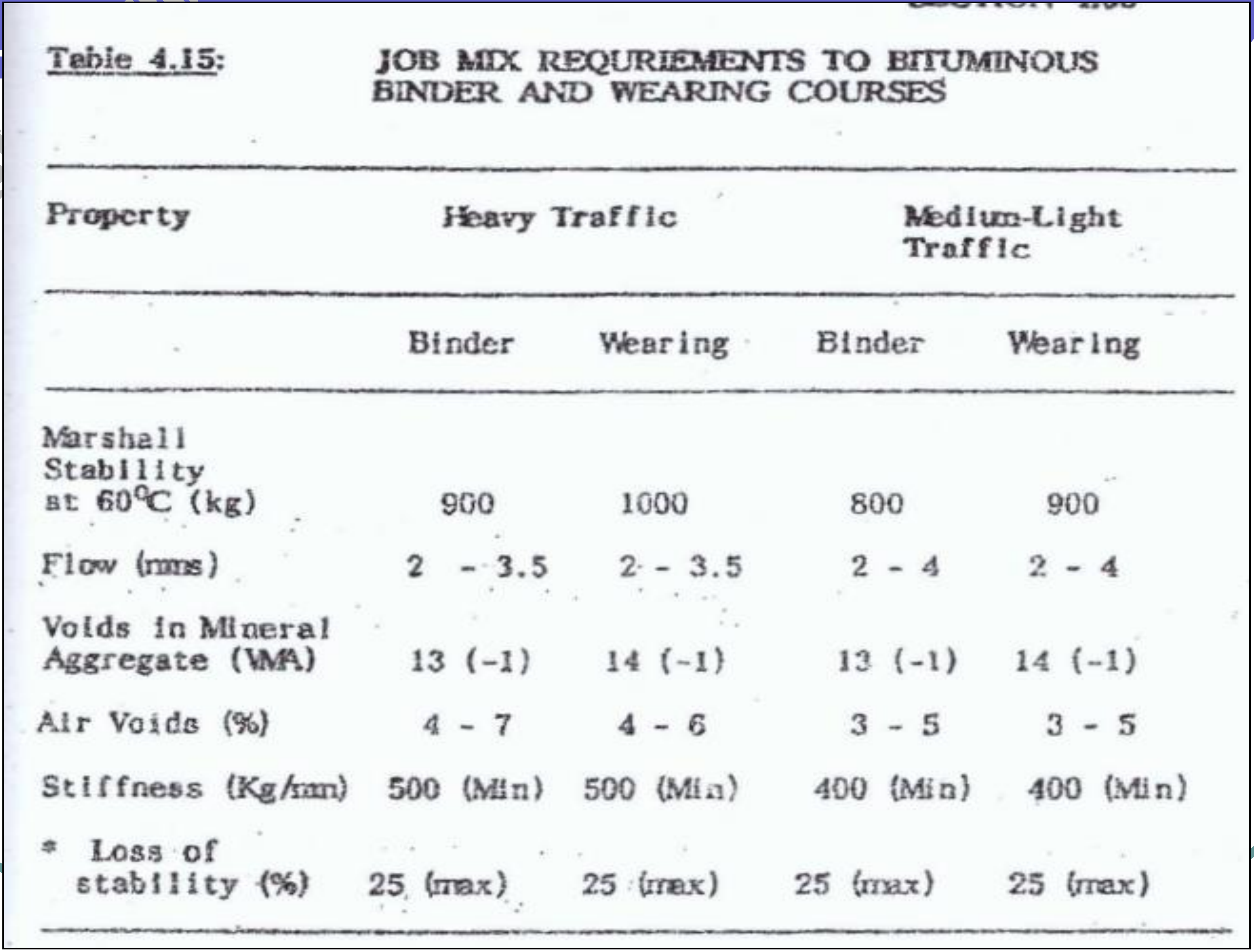


Table 4.15: JOB MIX REQURIEMENTS TO BITUMINOUS BINDER AND WEARING COURSES

Property	Heavy Traffic		Medium-Light Traffic	
	Binder	Wearing	Binder	Wearing
Marshall Stability at 60°C (kg)	900	1000	800	900
Flow (mms)	2 - 3.5	2 - 3.5	2 - 4	2 - 4
Voids in Mineral Aggregate (VMA)	13 (-1)	14 (-1)	13 (-1)	14 (-1)
Air Voids (%)	4 - 7	4 - 6	3 - 5	3 - 5
Stiffness (Kg/mm)	500 (Min)	500 (Min)	400 (Min)	400 (Min)
* Loss of stability (%)	25 (max)	25 (max)	25 (max)	25 (max)

Jordanian National Building council

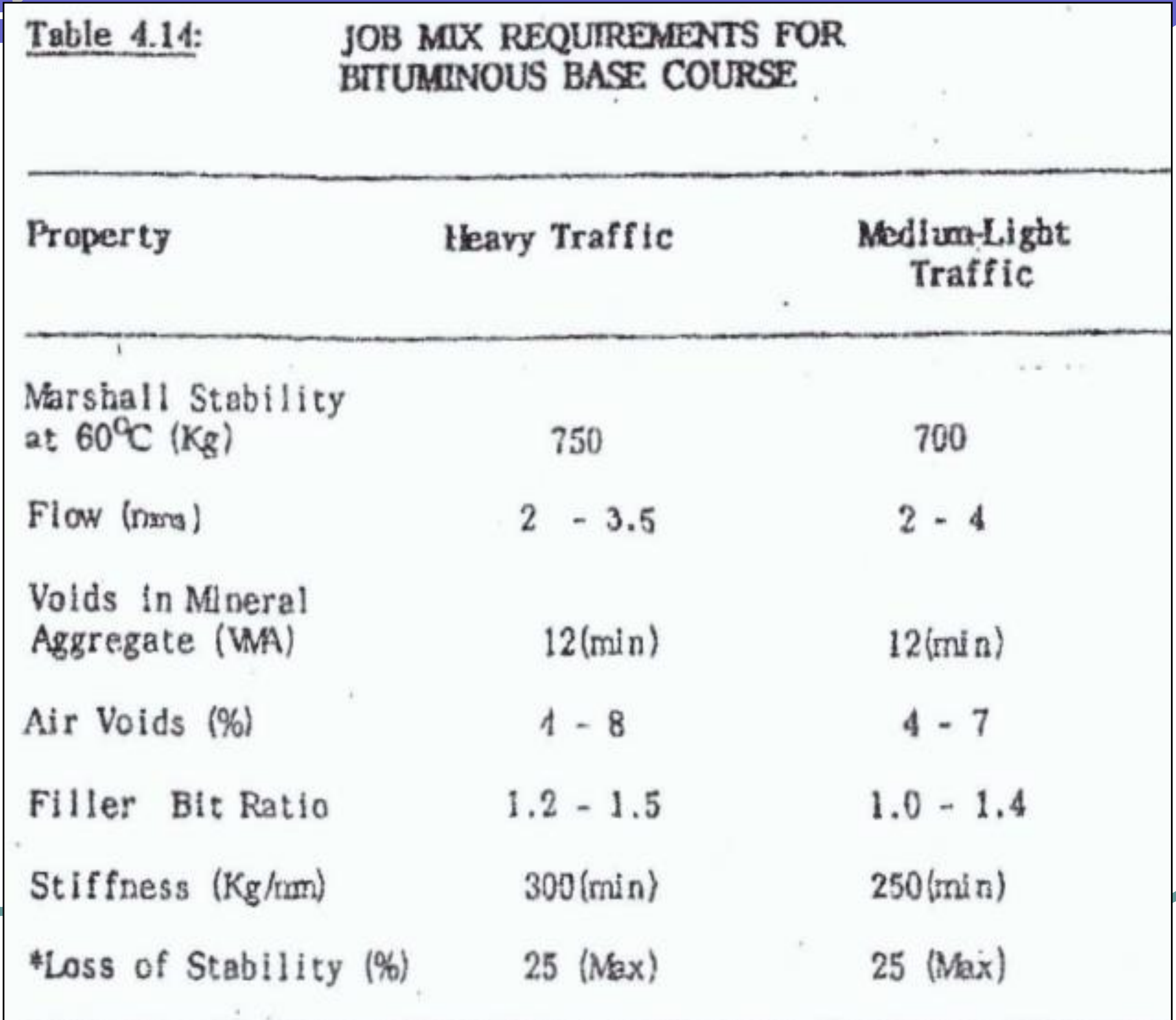


Table 4.14: JOB MIX REQUIREMENTS FOR BITUMINOUS BASE COURSE

Property	Heavy Traffic	Medium-Light Traffic
Marshall Stability at 60°C (Kg)	750	700
Flow (mm)	2 - 3.5	2 - 4
Voids in Mineral Aggregate (VMA)	12(min)	12(min)
Air Voids (%)	4 - 8	4 - 7
Filler Bit Ratio	1.2 - 1.5	1.0 - 1.4
Stiffness (Kg/mm)	300(min)	250(min)
*Loss of Stability (%)	25 (Max)	25 (Max)

Pavement Materials & Design (110401466/2104011466)
Flexible Pavement Thickness Design / AASHTO Method

Instructor:

Prof. TALEB M. AL-ROUSAN

Source:

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

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

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

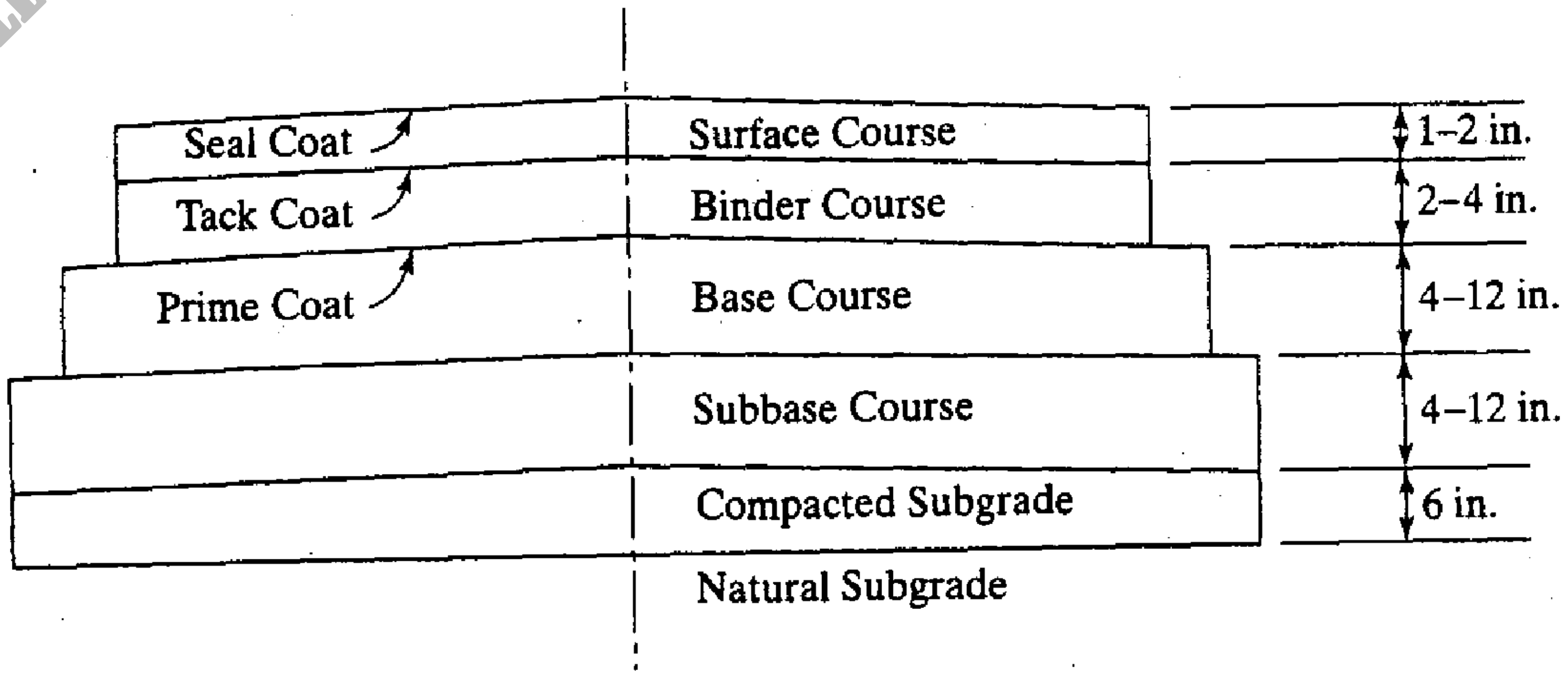


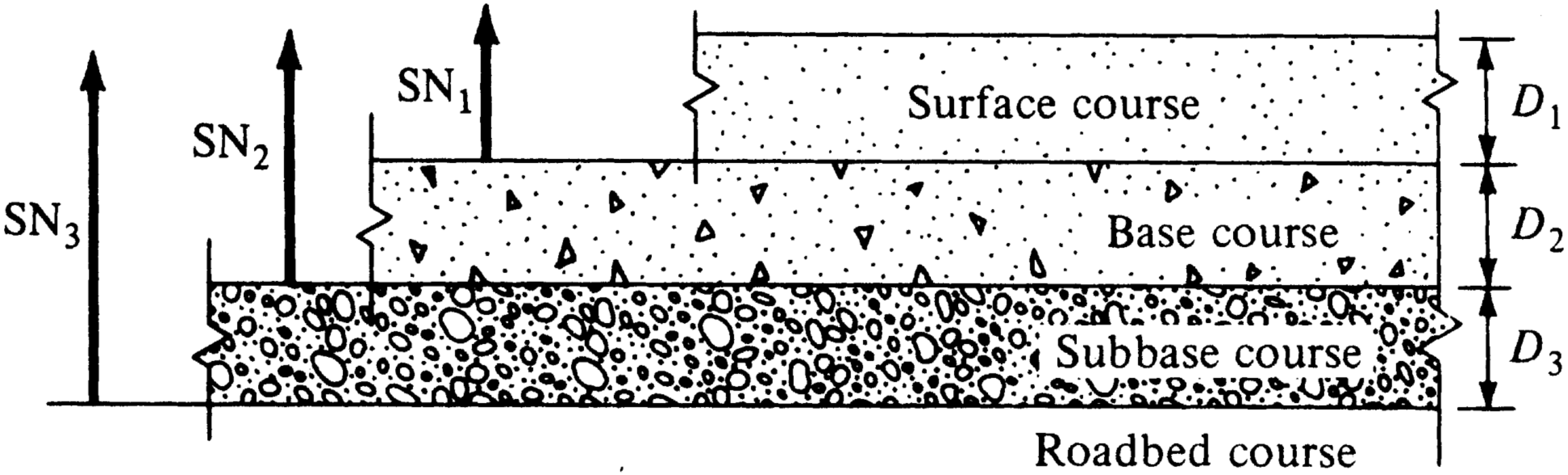
FIGURE 1.2

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

Pavement Structure Design/Goal

- The goal of structural design is to determine The number, material composition and thickness of the different layers within a pavement structure required to accommodate a given loading regime.

- This includes the surface course as well as any underlying base or subbase layers



Pavement Structure Design

Structural design for asphalt pavement (flexible) is mainly concerned with determining:

- Appropriate layer thickness.
- Appropriate layer composition.
- Calculations are chiefly concerned with traffic loading stresses.

Structural design for rigid pavement is mainly concerned with determining:

- The appropriate slab thickness based on traffic loads.
- Underlying material properties.
- Joint design.

Pavement Structure Design

Experience

For example, local governments often specify city streets to be designed using a given cross section (e.g., 100 mm (4 inches) of HMA over 150 mm (6 inches) of crushed stone) because they have found that this cross section has produced adequate pavements in the past.

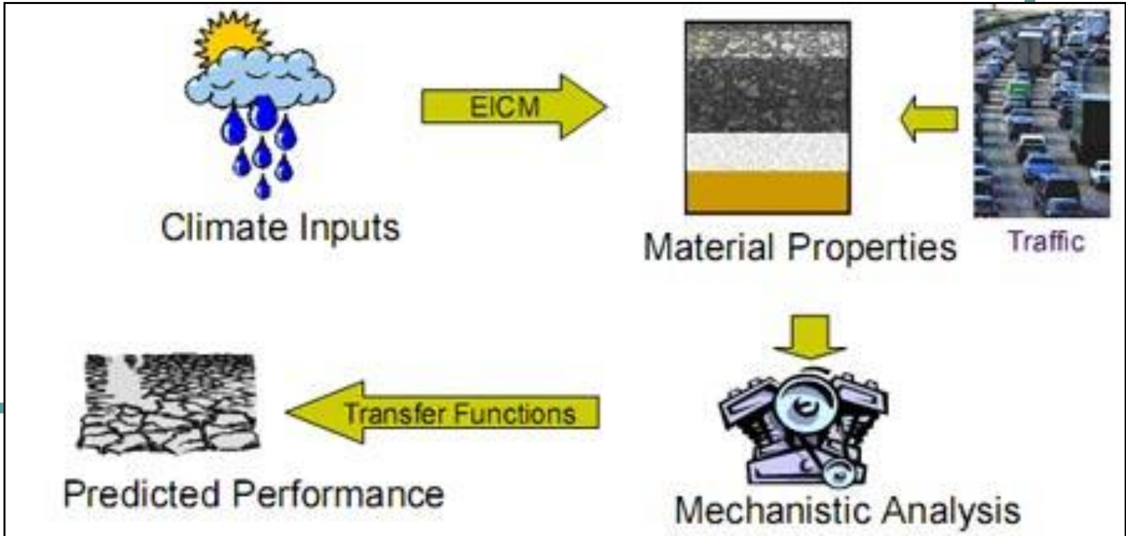
Empirical

- Based on the results of experiments or experience (e.g statistical models from road tests)
- This means that the relationship between design inputs (e.g., loads, materials, layer configurations and environment) and pavement failure were arrived at through experience, experimentation or a combination of both.
- For example
- California Bearing Ratio Method
- American Association of State Highway and Transportation Officials (AASHTO 1993) Method

Pavement Structure Design

Mechanistic- Empirical

- The phenomena are the stresses, strains and deflections within a pavement structure,
- The physical causes are the loads and material properties of the pavement structure.
- The relationship between these phenomena and their physical causes is typically described using a Empirical -based mathematical model
- For example
- AASHTO Mechanistic-Empirical pavement design (AASHTOWare Pavement ME Design)



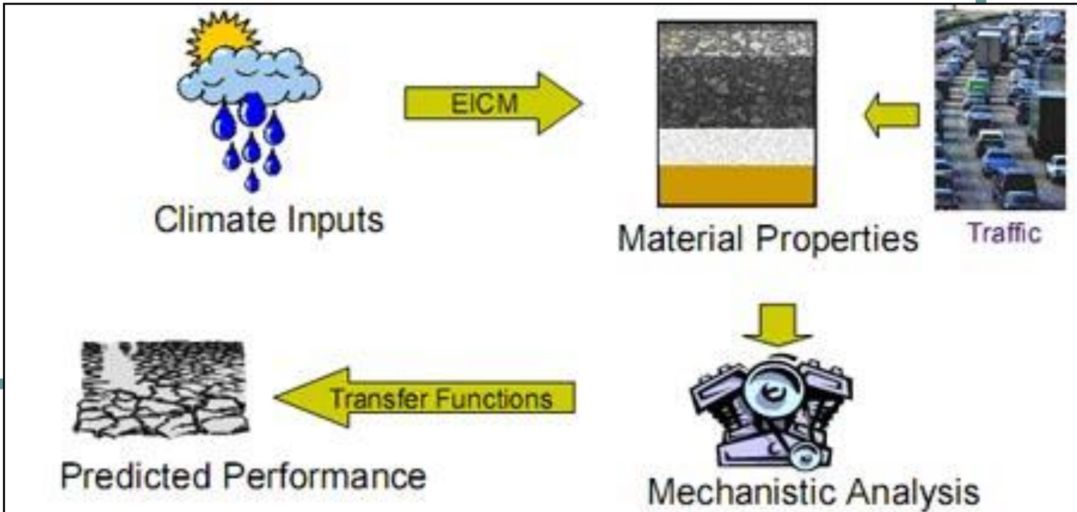
Pavement Structure Design

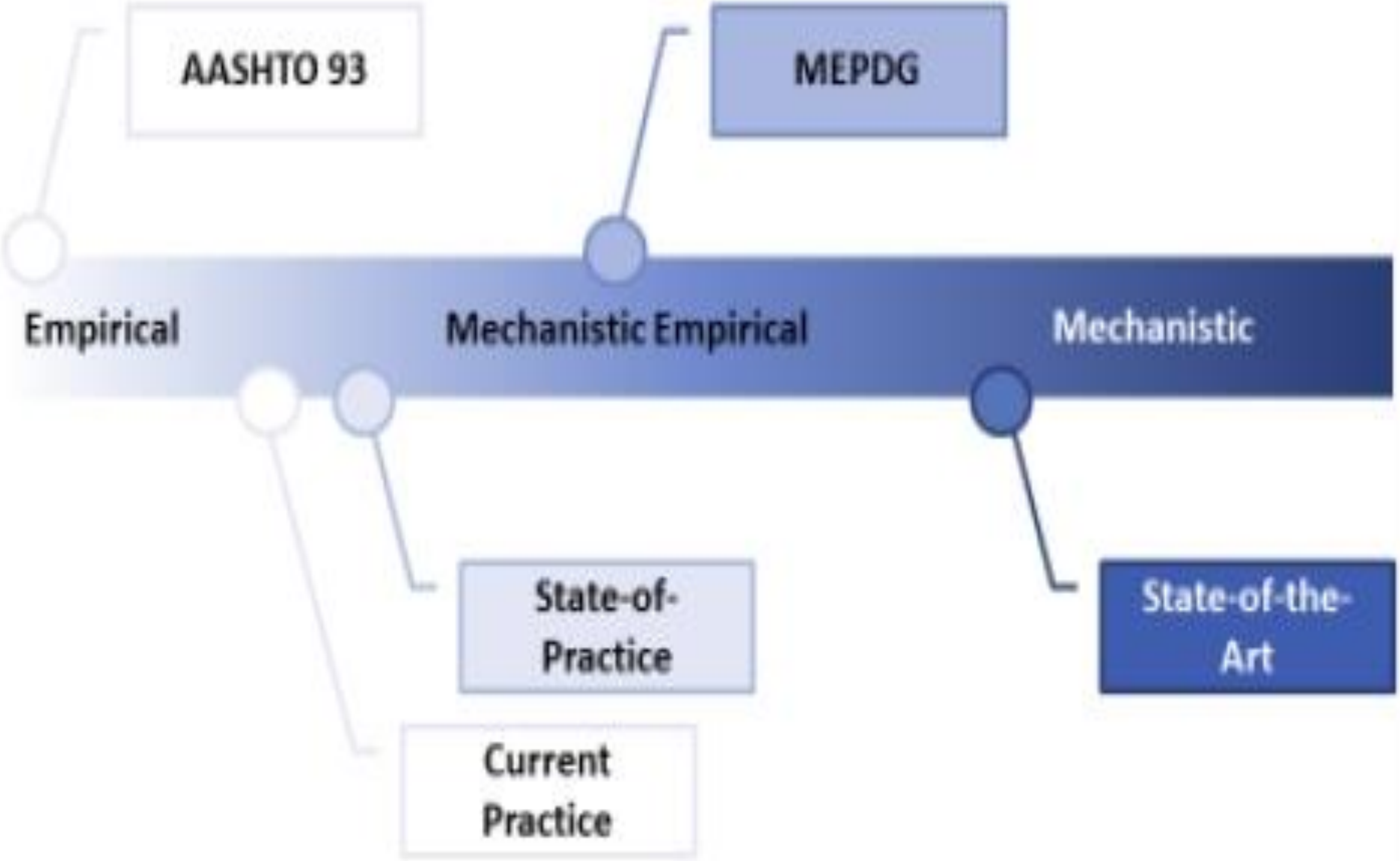
Mechanistic

The phenomena are the stresses, strains and deflections within a pavement structure,

The physical causes are the loads and material properties of the pavement structure.

The relationship between these phenomena and their physical causes is typically described using a Mechanics-based mathematical model




AASHTO 93
MEPDG
Empirical
Mechanistic Empirical
Mechanistic
State-of-Practice
State-of-the-Art
Current Practice

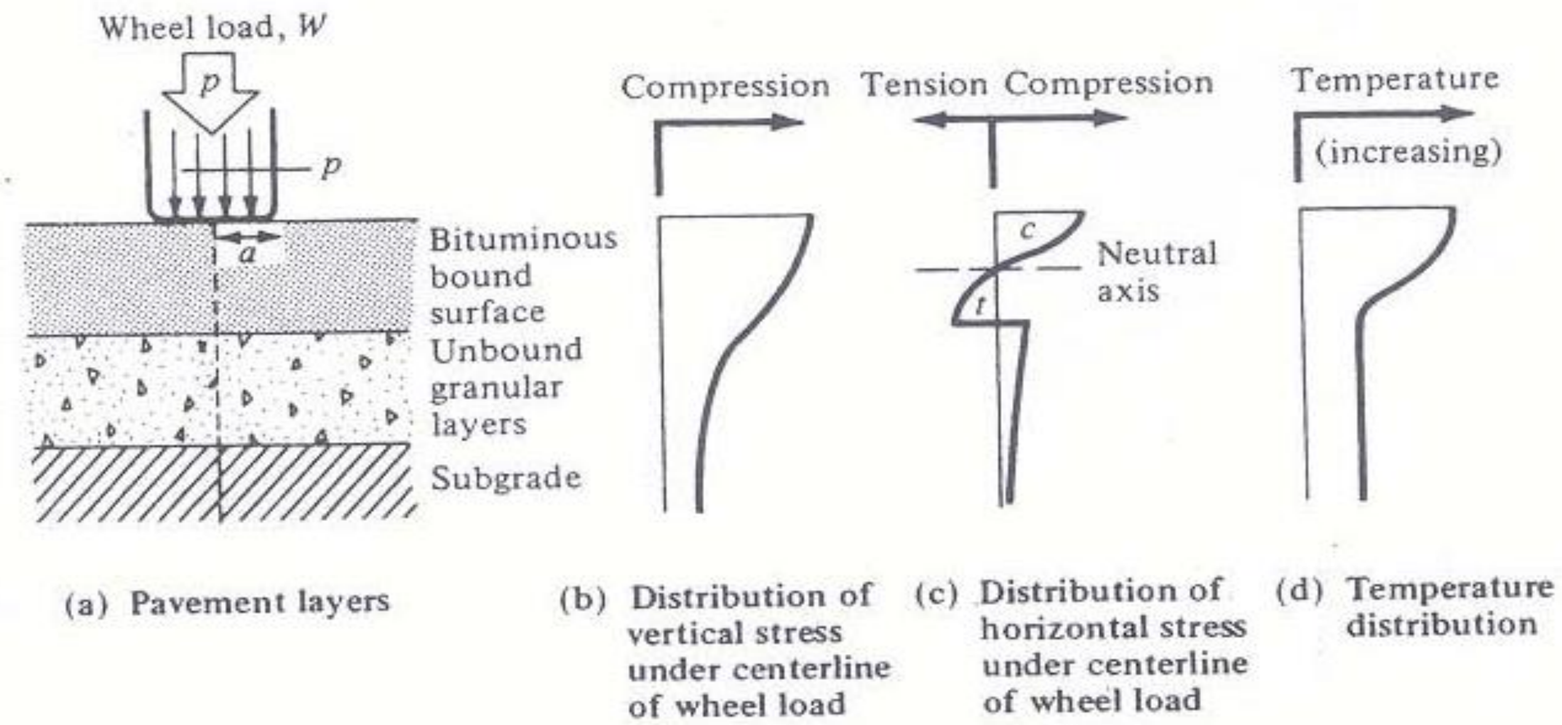
Principles of Flexible Pavement Design

- 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 in 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



(a) Pavement layers

(b) Distribution of vertical stress under centerline of wheel load

(c) Distribution of horizontal stress under centerline of wheel load

(d) Temperature distribution

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).

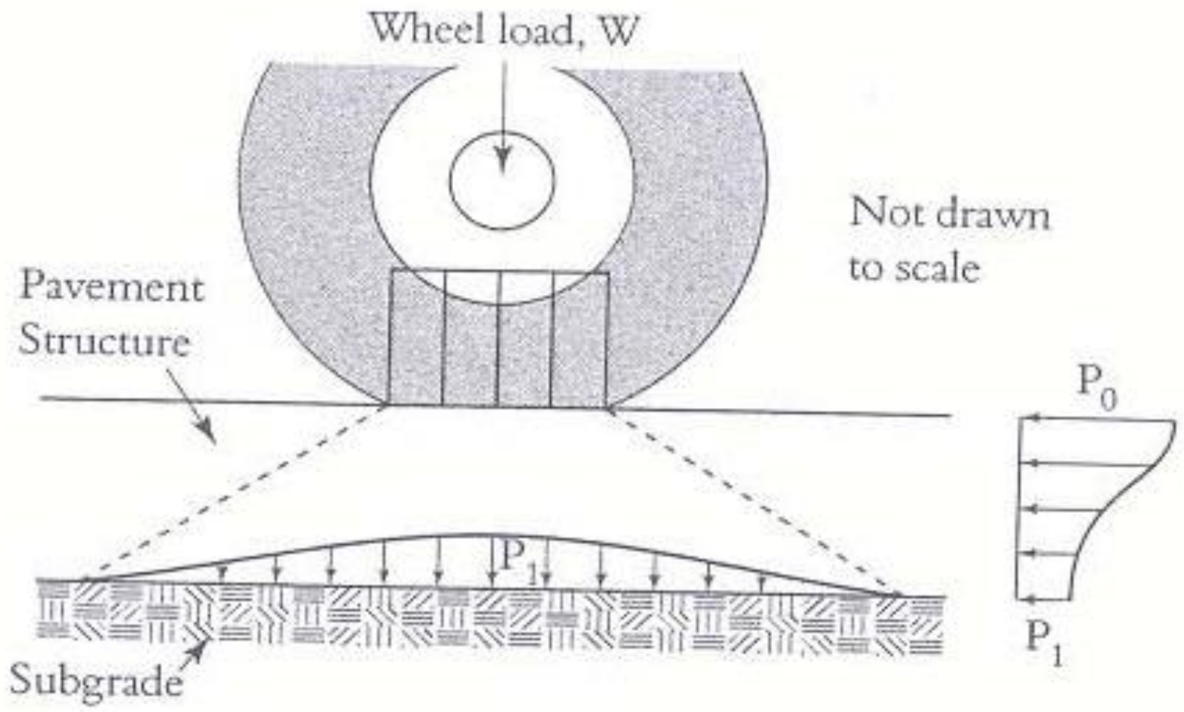
Material Characteristics

- 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



(a) Stress distribution within different components of the pavement

(b) General form of stress reduction

Figure 20.3 Soread of Wheel Load Pressure Through Pavement Structure

Figure 20.4 Tensile and compressive stresses in pavement structure

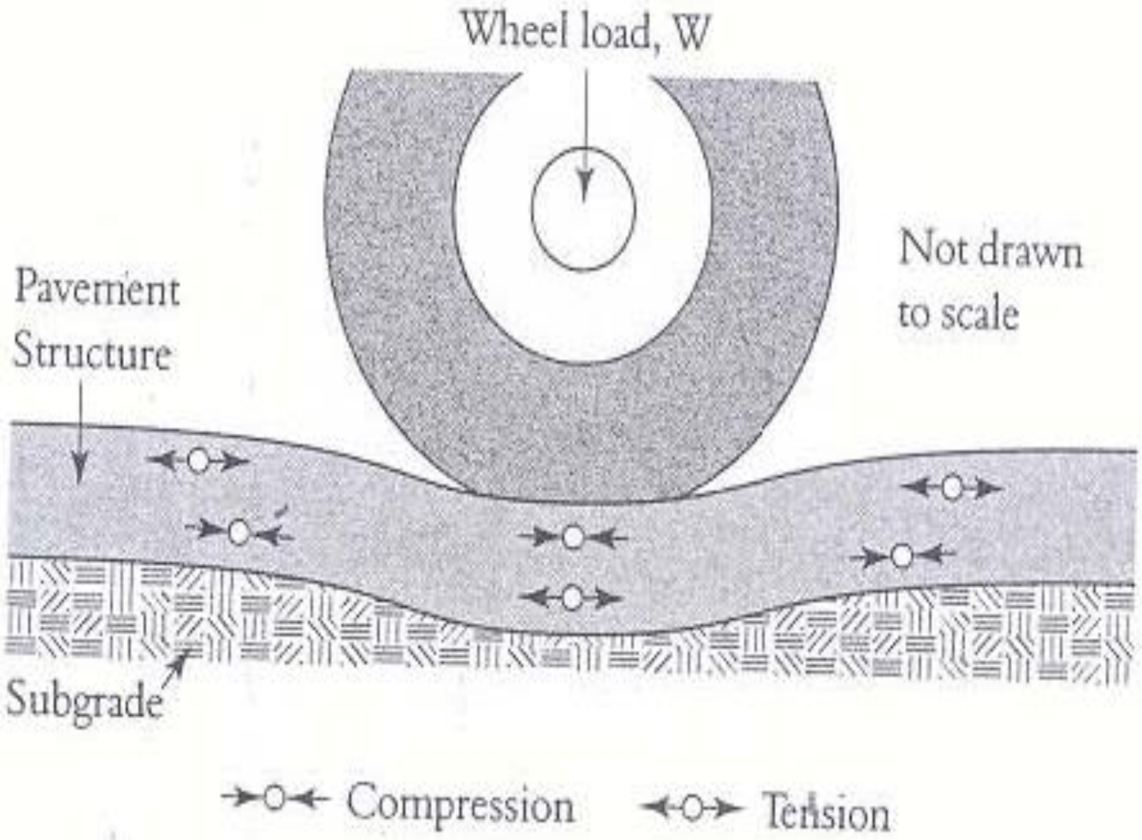
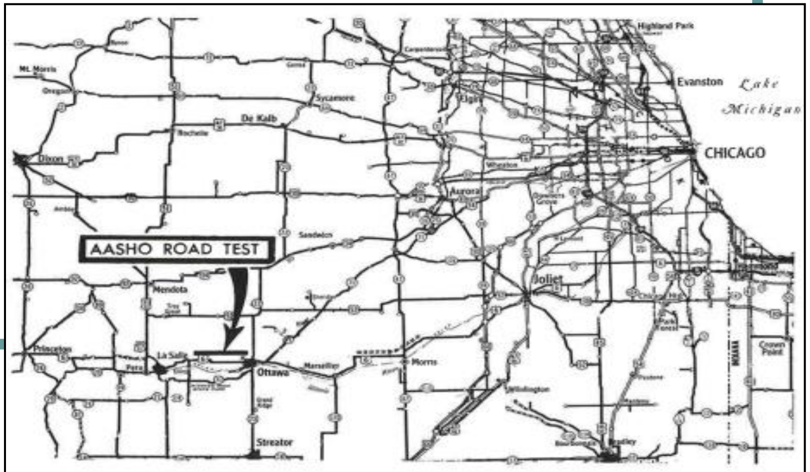


Figure 20.4 Schematic of Tensile and Compressive Stresses in Pavement Structure

AASHTO 1993 Design Method

- Based on the results of AASHTO road test in late 1950’s conducted on Ottawa, Illinois.
- It is an effort that was carried out with the cooperation of all states and several industry groups.
- The AASHO Road Test, a $27 million (1960 dollars) investment and the largest road experiment of its time
- The information obtained from the AASHO Road Test was crucial in advancing knowledge of:
  - Pavement structural design,
  - Pavement performance,
  - Load equivalencies,
  - Climate effects.



AASHTO 1993 Method

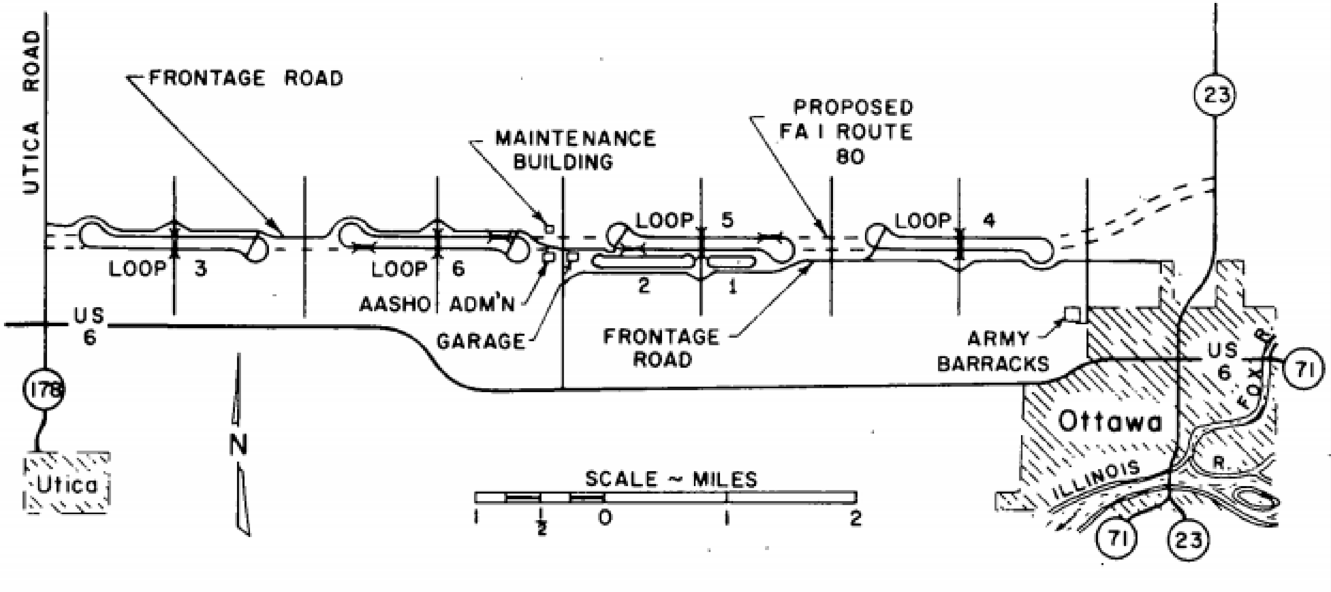


Figure 2. Layout of AASHO Road Test.

- Many types of test section were prepared and tested.
- Rigid & flexible.
- Short span bridges.
- 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).

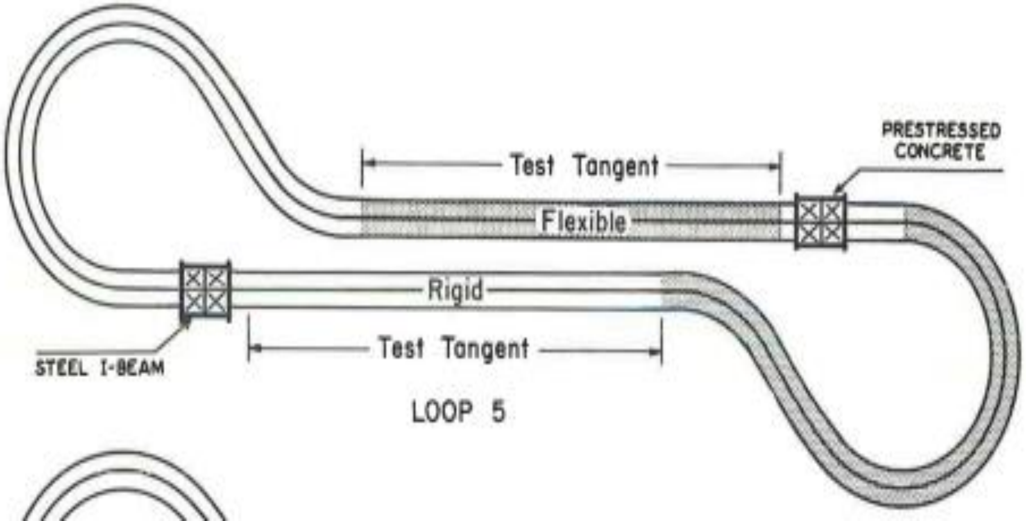
AASHTO 1993 Method/ Test Sections

The pavement test sections consisted of

- Two small loops
- Four larger ones with each being a four-lane divided highway.

The tangent sections consisted of:

- a successive set of pavement lengths of different designs, each length being at least 100 feet.



AASHTO 1993 Method/ Test Conditions & Materials

- **Test Conditions:**
  - One rainfall zone
  - One temperature zone
  - One subgrade (A-6/ A-7-6 [Clay])

Test Materials:

- One asphalt layer
  - ¾” surface course
  - 1” binder course
- One PCC layer
- Four base materials
- Main experiment
  - Well-graded crushed limestone
- Special studies
  - Well-graded uncrushed gravel
  - Bituminous-treated base (special studies)
  - Cement-treated base

AASHTO 1993 Method/ Traffic

Test traffic consisting of:

- Single-axle vehicles
- loads ranging from 2,000 to 30,000 pounds
- Tandem-axle vehicles
- loads ranging from 24,000 to 48,000 pounds
- Traffic were driven over the test sections until several thousand load repetitions had been made.

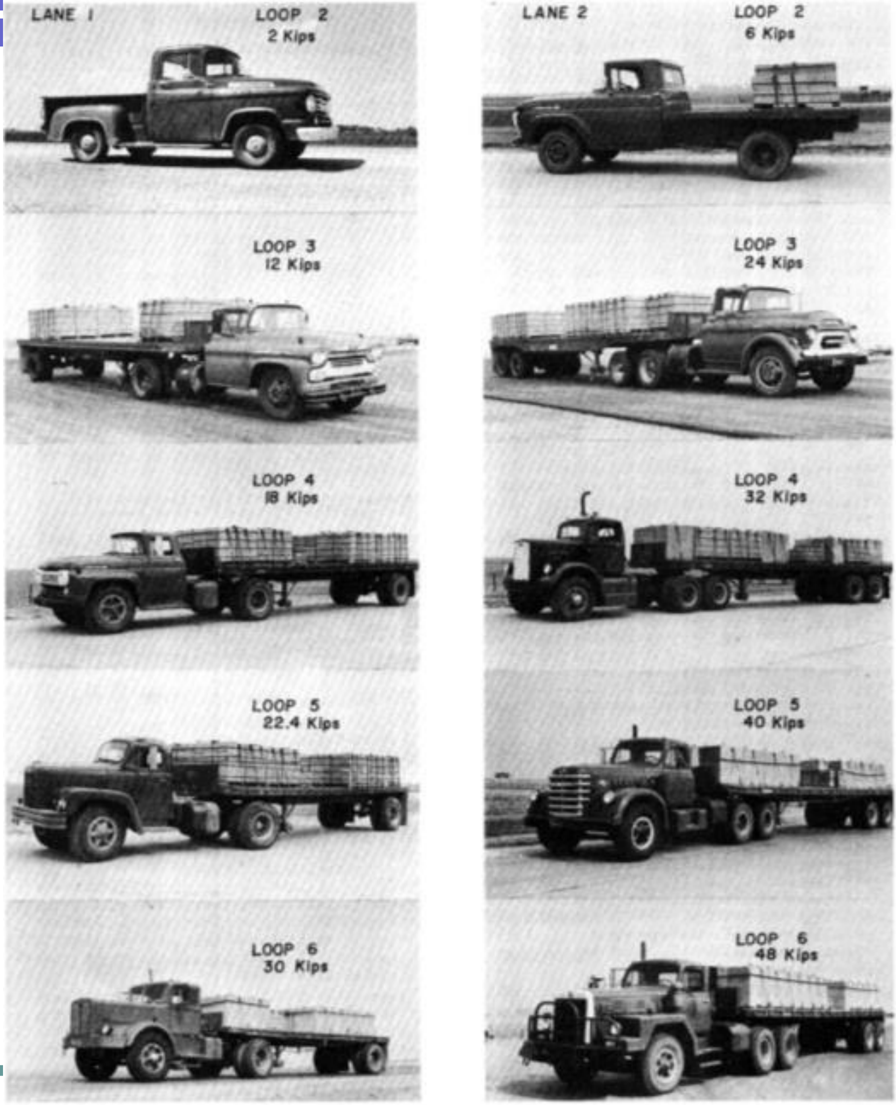


FIGURE 3 AASHO Road Test truck traffic.

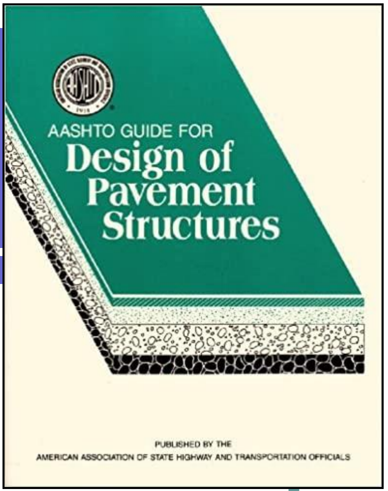
AASHTO Method/ Introduction

- 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 1993 Method/ Versions

- 1961 (Interim Guide)
- 1972
- 1986
  - Refined material characterization
  - Version included in Huang (1993)
- 1993
  - More on rehabilitation
  - More consistency between flexible, rigid designs
- 2002 (Current version)
  - Mechanistic-empirical approach (AASHTO ME) [Under development]

AASHTO Design Method/ Design Considerations



AASHTO GUIDE FOR
Design of
Pavement
Structures

PUBLISHED BY THE
AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

- 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 equipment (objective).

Pavement Serviceability Concept

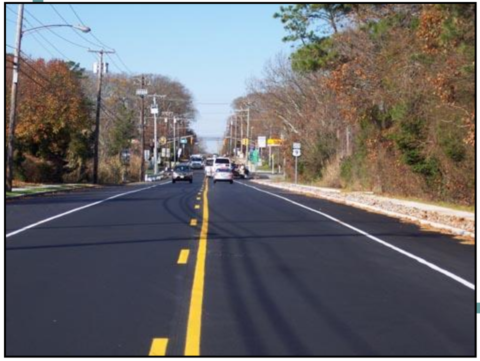
- It involves the measurement of the behavior of the pavement under traffic and its ability to serve traffic at some instance during its life.
- The evaluation is systematic but subjective.
- Evaluated by rating of the riding surface by individuals who travel over it.
- Can be evaluated also by means 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].

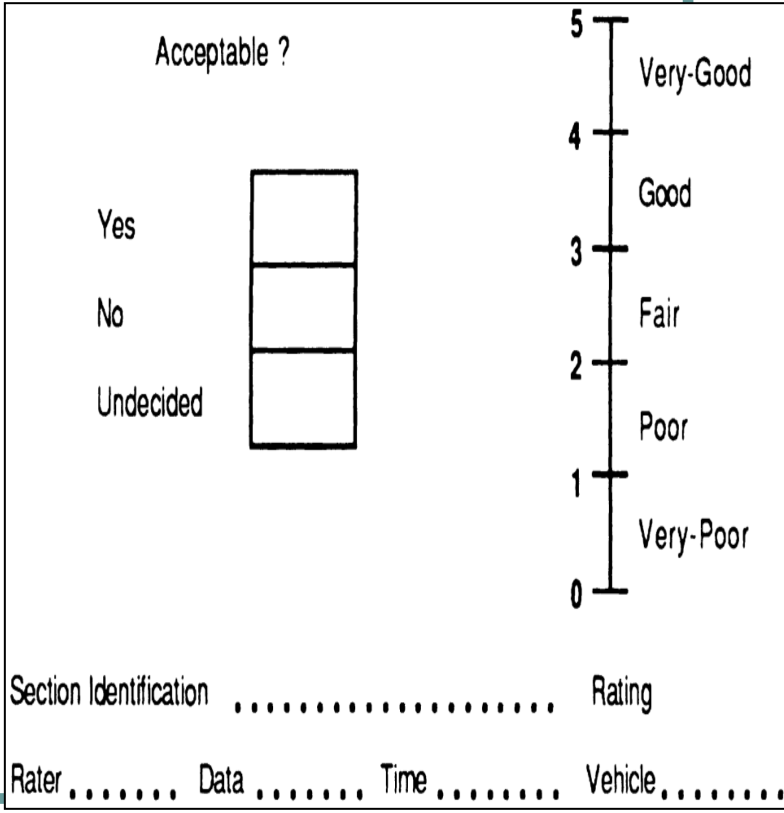
Pavement Roughness

- Pavement roughness is generally defined as:
    - An expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle (and thus the user).
    - Roughness is also referred to as “smoothness” although both terms refer to the same pavement qualities.
- Roughness is an important pavement characteristic because it affects:
    - Ride quality.
    - Vehicle delay costs.
    - Fuel consumption.
    - Maintenance costs.
- The World Bank found road roughness to be a primary factor in the analyses and trade-offs involving road quality vs. user cost (UMTRI, 1998[1]).

Present serviceability Index (PSI)

- The **PSI** is just a measure of the current overall rating of a section of highway based upon visual observation
- **PSI** ranges from
  - 5 (means excellent conditions)
  - 0 (essentially impassable)





Acceptable ?

Yes ☐

No ☐

Undecided ☐

5

Very-Good

4

Good

3

Fair

2

Poor

1

Very-Poor

0

Section Identification .... Rating

Rater .... Data .... Time .... Vehicle ....

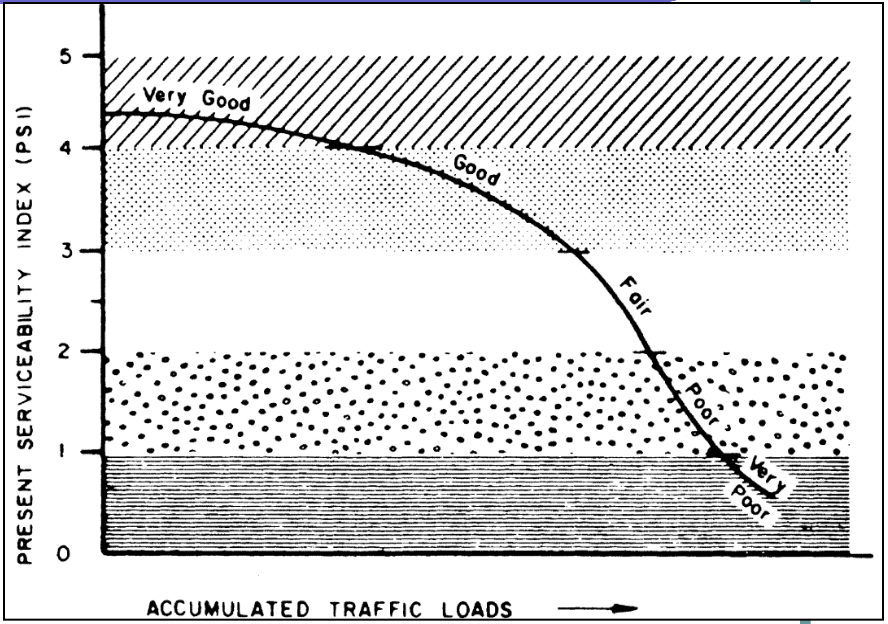
Serviceability

- 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].

Present serviceability Index (PSI)

Two serviceability indices are used in the design procedure:

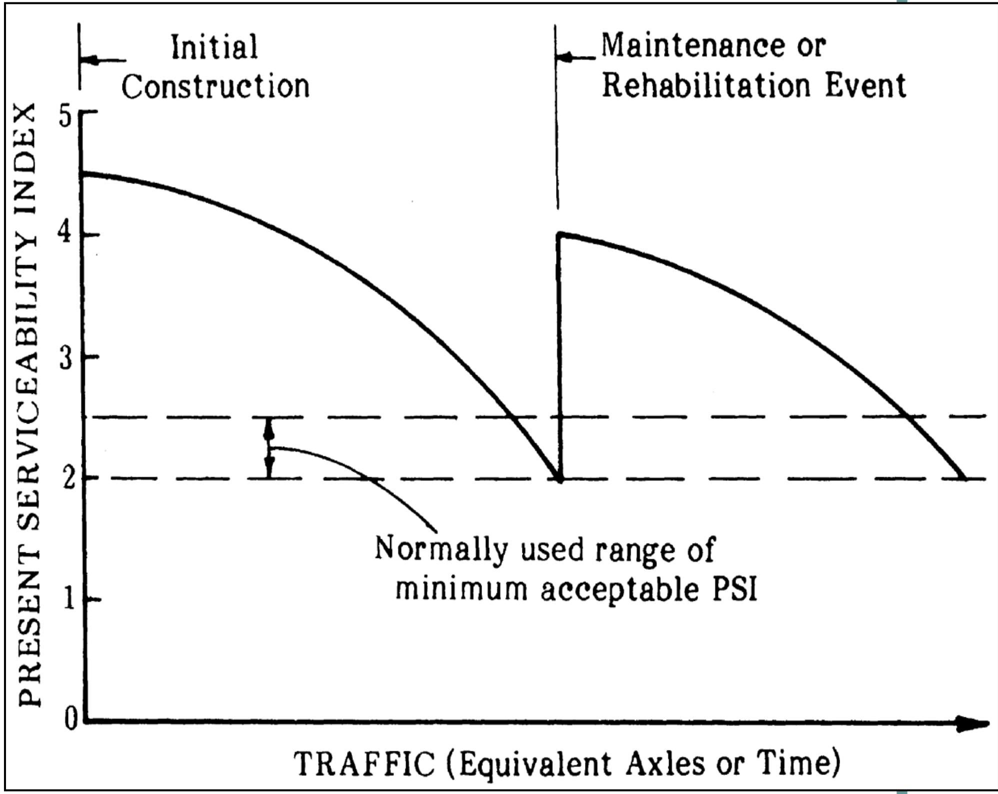
- The initial serviceability index (Pi)
  - is the serviceability index immediately after the construction of the pavement
  - AASHTO road test, a value of 4.2 was used for Pi for flexible pavements.
  - AASHTO recommends that each agency determine more reliable levels for Pi based on existing conditions.



Present serviceability Index (PSI)

The terminal serviceability index (Pt)

- is the minimum acceptable value before resurfacing or reconstruction is necessary
- Recommended values for the terminal serviceability index are:
    - 2.5 or 3.0 for major highways
    - 2.0 for highways with a lower classification.
    - 1.5 In cases where economic constraints restrict capital expenditures for construction or the performance period may be reduced.



After reaching the P_t, a maintenance/ rehabilitation is needed

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 Load

- Loads, the vehicle forces exerted on the pavement (e.g., by trucks, heavy machinery, airplanes), can be characterized by the following parameters:
  - Tire loads.
  - Axle and tire configurations.
  - Repetition of loads.
  - Distribution of traffic across the pavement.
  - Vehicle speed.

Traffic Load/ Tire and Axle Configuration

Single tire

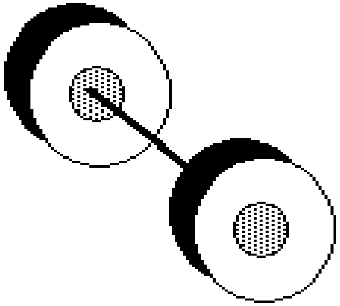
Dual tire

Single Axle

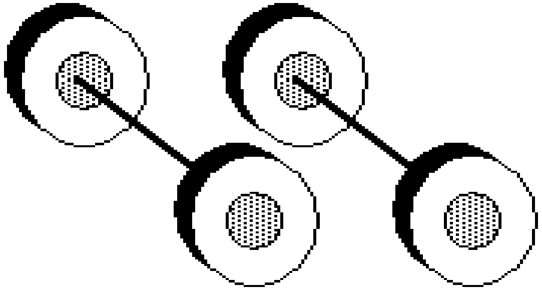
Tandem Axle

Tridem Axle

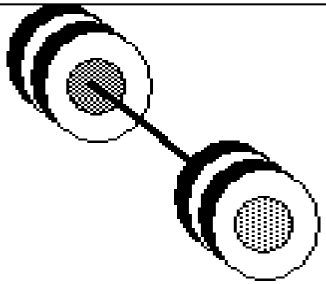
Traffic Load/ Tire and Axle Configuration



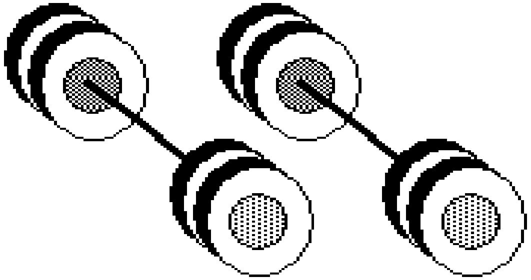
Single Axle with Single Tires



Tandem Axles with Single Tires

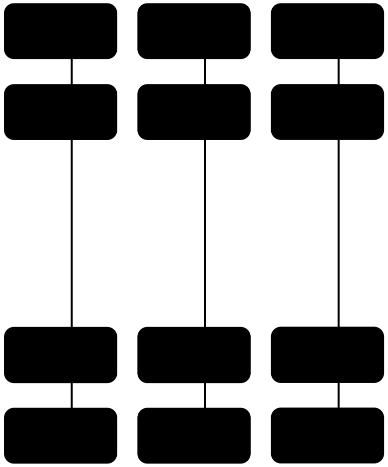


Single Axle with Dual Tires



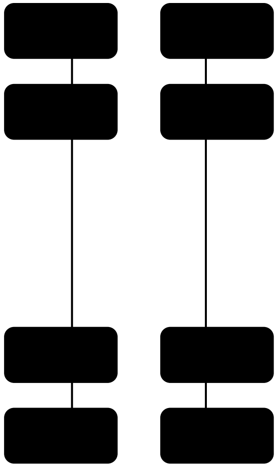
Tandem Axles with Dual Tires

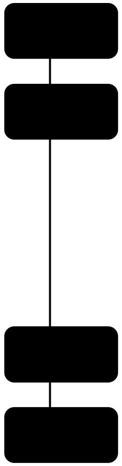
Axle & Wheel Configurations



Tridem Axles with Dual Tires

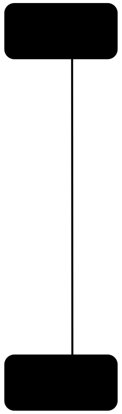
Tandem Axles with Dual Tires



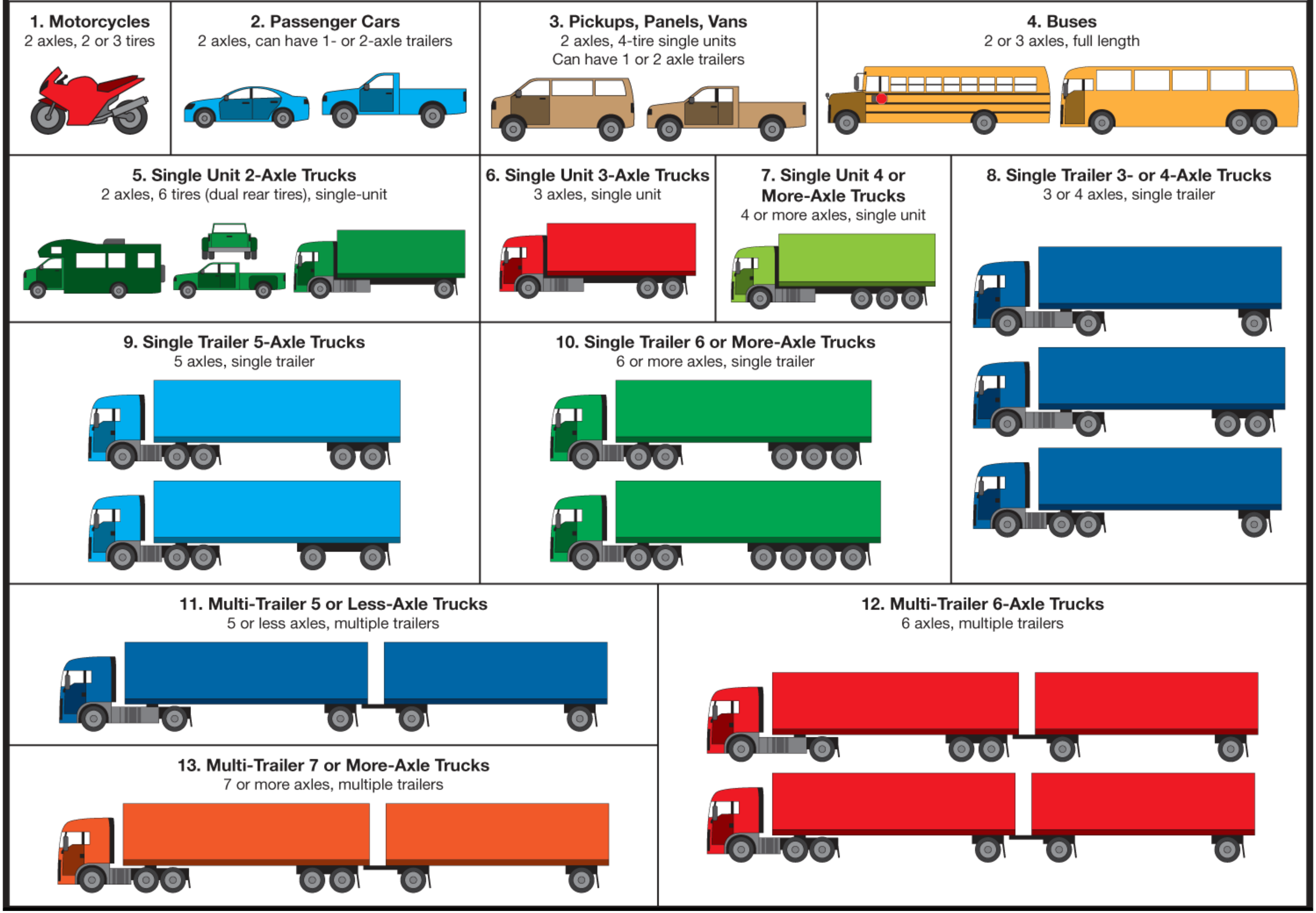


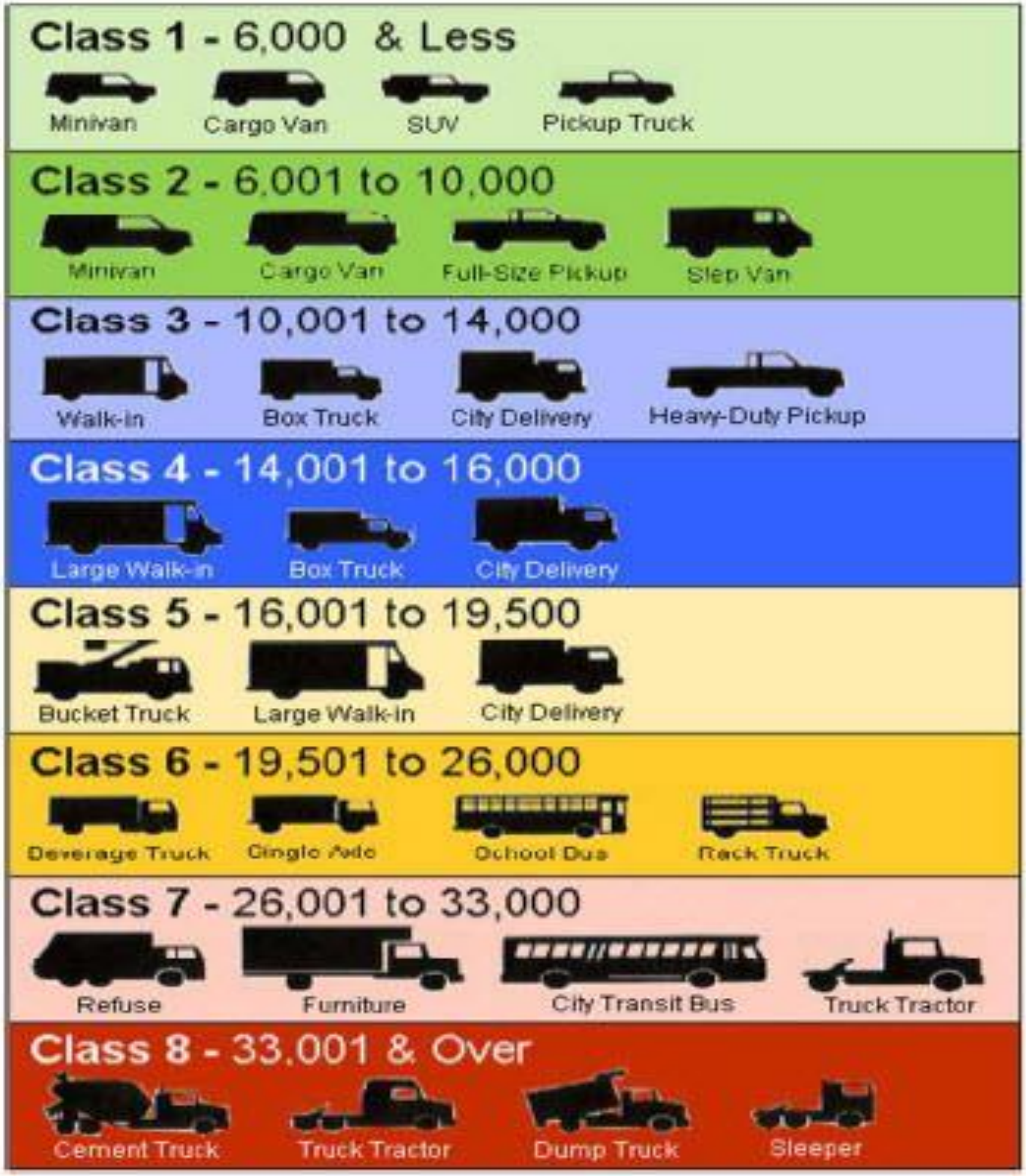
Single Axle with Dual Tires

Single Axle with Single Tire



FHWA Vehicle Classifications





Class 1 - 6,000 & Less

Minivan, Cargo Van, SUV, Pickup Truck

Class 2 - 6,001 to 10,000

Minivan, Cargo Van, Full-Size Pickup, Step Van

Class 3 - 10,001 to 14,000

Walk-in, Box Truck, City Delivery, Heavy-Duty Pickup

Class 4 - 14,001 to 16,000

Large Walk-in, Box Truck, City Delivery

Class 5 - 16,001 to 19,500

Bucket Truck, Large Walk-in, City Delivery

Class 6 - 19,501 to 26,000

Beverage Truck, Single Axle, School Bus, Rack Truck

Class 7 - 26,001 to 33,000

Refuse, Furniture, City Transit Bus, Truck Tractor

Class 8 - 33,001 & Over

Cement Truck, Truck Tractor, Dump Truck, Sleeper

Repetition of Wheel Load

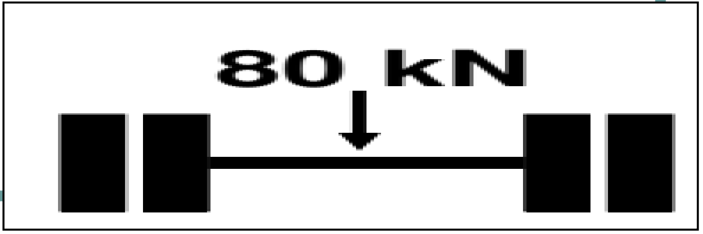
- Although it is not too difficult to determine the wheel and axle loads for an individual vehicle.
  - it becomes quite complicated to determine the number and types of wheel/axle loads that a particular pavement will be subject to over its entire design life.
  - Furthermore, it is not the wheel load but rather the damage to the pavement caused by the wheel load that is of primary concern.

Repetition of Wheel Load Cont.

- There are currently two basic methods for characterizing wheel load repetitions:
  - Equivalent single axle loads (ESALs).
    - This approach converts wheel loads of various magnitudes and repetitions (“mixed traffic”) to an equivalent number of “standard” or “equivalent” loads.
  - Load spectra.
    - This approach characterizes loads directly by number of axles, configuration and weight.
    - It does not involve conversion to equivalent values.
    - Structural design calculations using load spectra are generally more complex than those using ESALs.
  - Both approaches use the same type and quality of data but the load spectra approach has the potential to be more accurate in its load characterization.

Traffic Load Determination

- The traffic load is determined in terms of
  - the number of repetitions of an 18,000-lb (80 kilonewtons (kN)) single-axle load applied to the pavement on two sets of dual tires.
  - This is usually referred to as the Equivalent Single-Axle Load (ESAL)

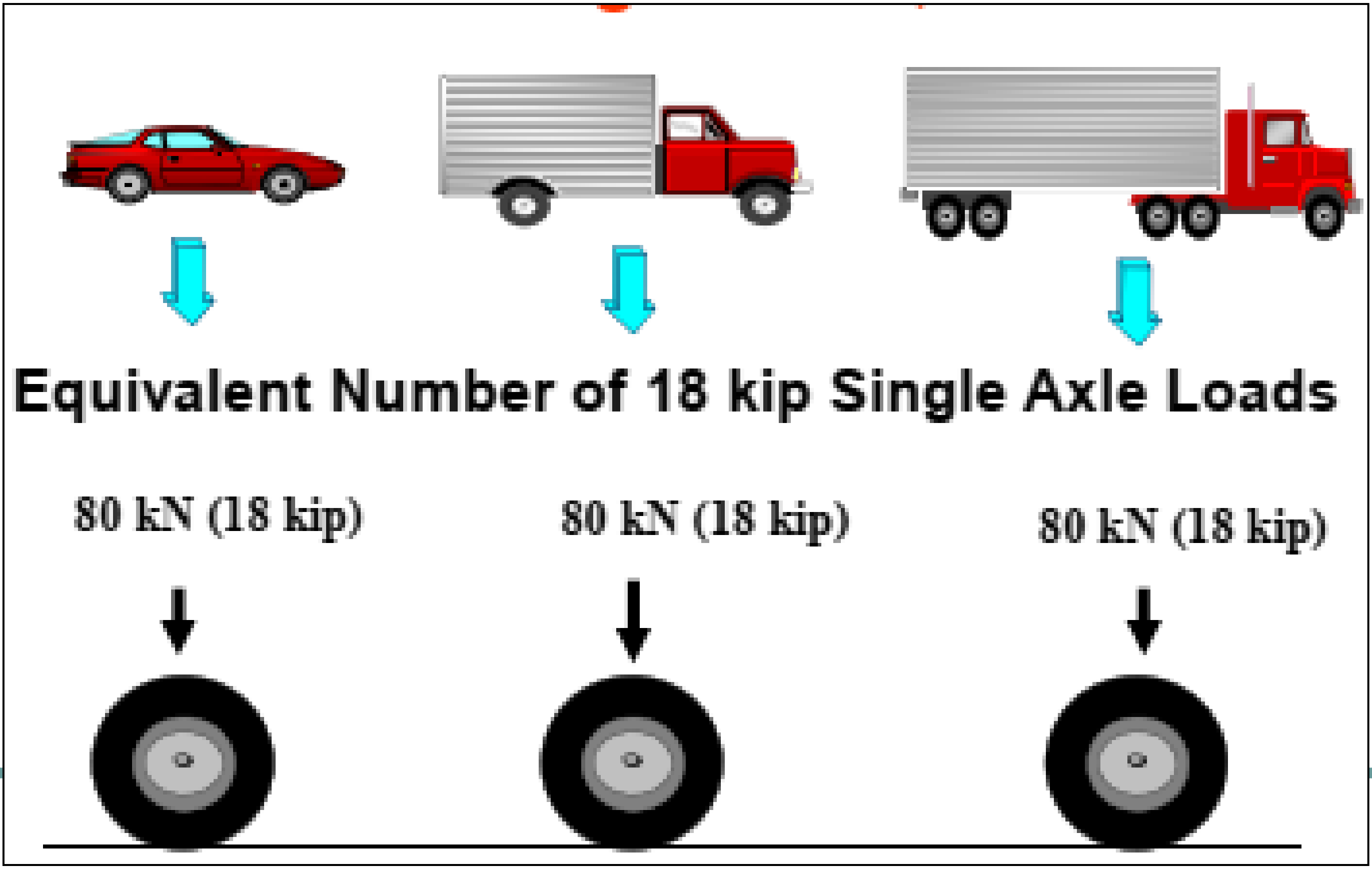


Traffic Load Determination

- Convert wheel loads of various magnitudes and repetitions ("mixed traffic") to an equivalent number of "standard" or "equivalent" loads based on the amount the damage they do to the pavement.
- Standard Axle Load (SAL)
  - A single axle with dual tires that has a weight of 18,000 lb (80 KN)
    - Selected based on the results of experiments that have shown that the effect of any load on the performance of a pavement can be represented in terms of the number of single applications of an 18,000-lb single axle (ESALs)
- 1 ESAL = Damage caused by one 18,000 lb single axle load

Traffic Load Determination

- The load is convert using Load equivalency factors (LEFs)



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

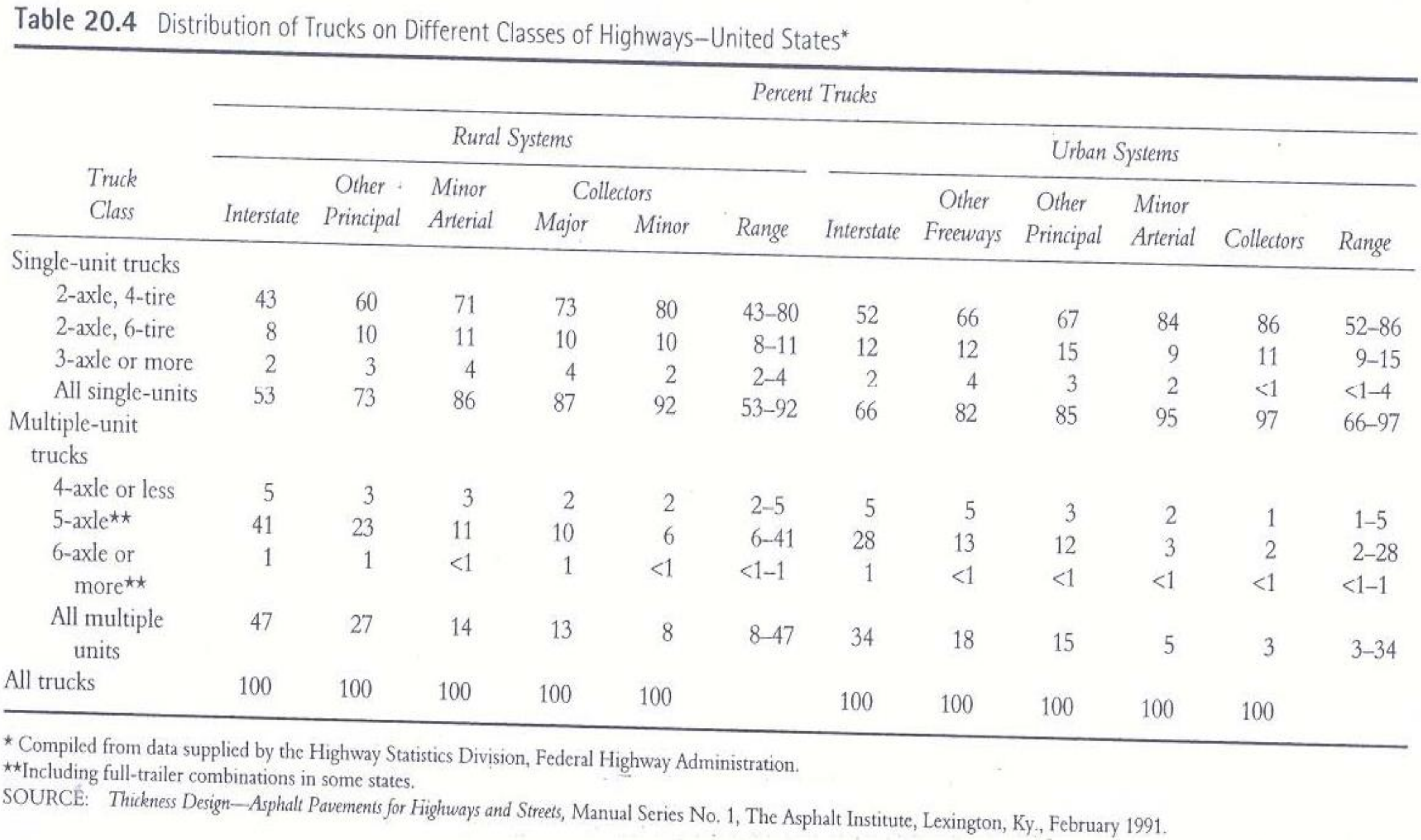


Table 20.4 Distribution of Trucks on Different Classes of Highways—United States*

Truck Class	Percent Trucks											
	Rural Systems						*Urban Systems*					
		Other	*Minor*	*Collectors*				*Other*	*Other*	*Minor*		
	Interstate	*Principal*	*Arterial*	*Major*	*Minor*	*Range*	*Interstate*	*Freeways*	*Principal*	*Arterial*	*Collectors*	*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	

* 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).

Load Equivalency Factors (LEF)

The LEFs depends on:

- The type of pavements
- Pavement thickness or structural capacity (SN)
- The terminal conditions at which the pavement is considered failed (Pt)

LEFs can be determined using :

- Equation
- Table (Handouts)

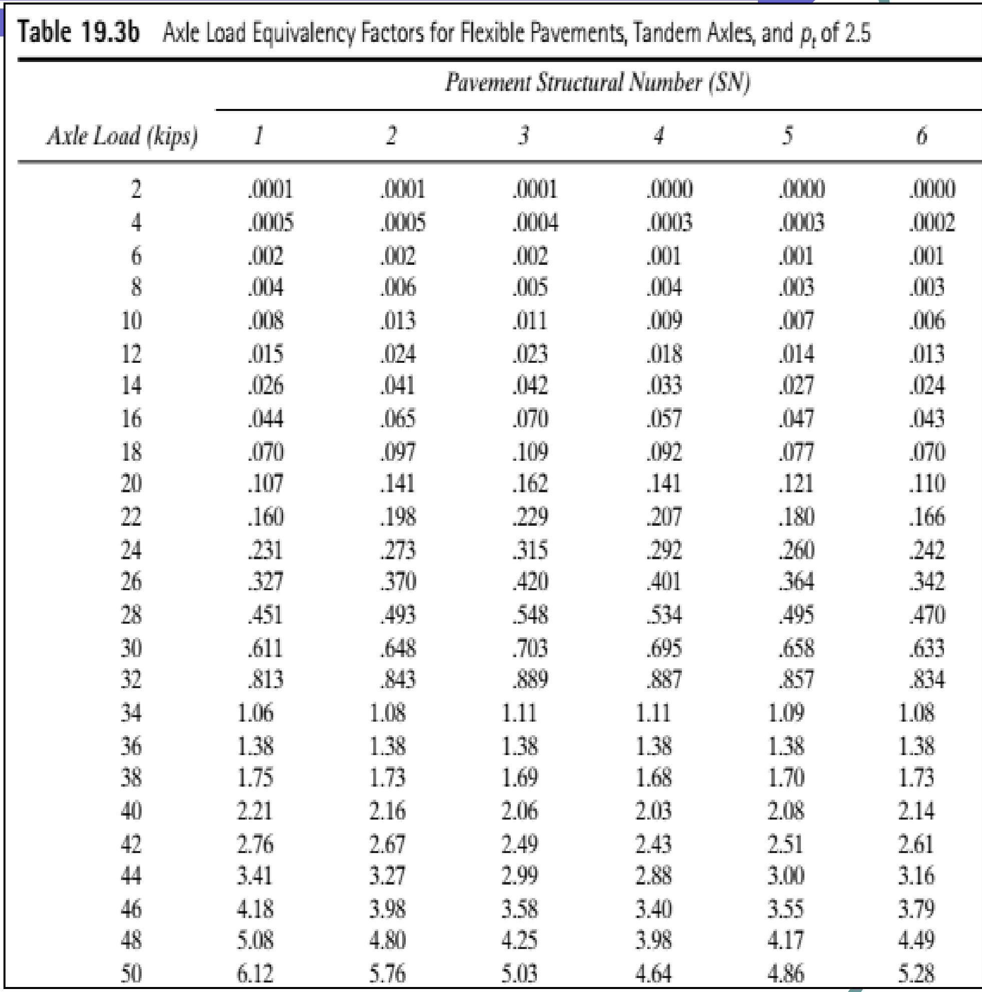


Table 19.3b Axle Load Equivalency Factors for Flexible Pavements, Tandem Axles, and p_t of 2.5

	Pavement Structural Number (SN)					
Axle Load (kips)	*1*	*2*	*3*	*4*	*5*	*6*
2	.0001	.0001	.0001	.0000	.0000	.0000
4	.0005	.0005	.0004	.0003	.0003	.0002
6	.002	.002	.002	.001	.001	.001
8	.004	.006	.005	.004	.003	.003
10	.008	.013	.011	.009	.007	.006
12	.015	.024	.023	.018	.014	.013
14	.026	.041	.042	.033	.027	.024
16	.044	.065	.070	.057	.047	.043
18	.070	.097	.109	.092	.077	.070
20	.107	.141	.162	.141	.121	.110
22	.160	.198	.229	.207	.180	.166
24	.231	.273	.315	.292	.260	.242
26	.327	.370	.420	.401	.364	.342
28	.451	.493	.548	.534	.495	.470
30	.611	.648	.703	.695	.658	.633
32	.813	.843	.889	.887	.857	.834
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14
42	2.76	2.67	2.49	2.43	2.51	2.61
44	3.41	3.27	2.99	2.88	3.00	3.16
46	4.18	3.98	3.58	3.40	3.55	3.79
48	5.08	4.80	4.25	3.98	4.17	4.49
50	6.12	5.76	5.03	4.64	4.86	5.28

- Determine the LEFs for the following the following axle loads,
  - **SN = 5** and **Pt = 2.5, Single axle** (10,000 lb/axle)

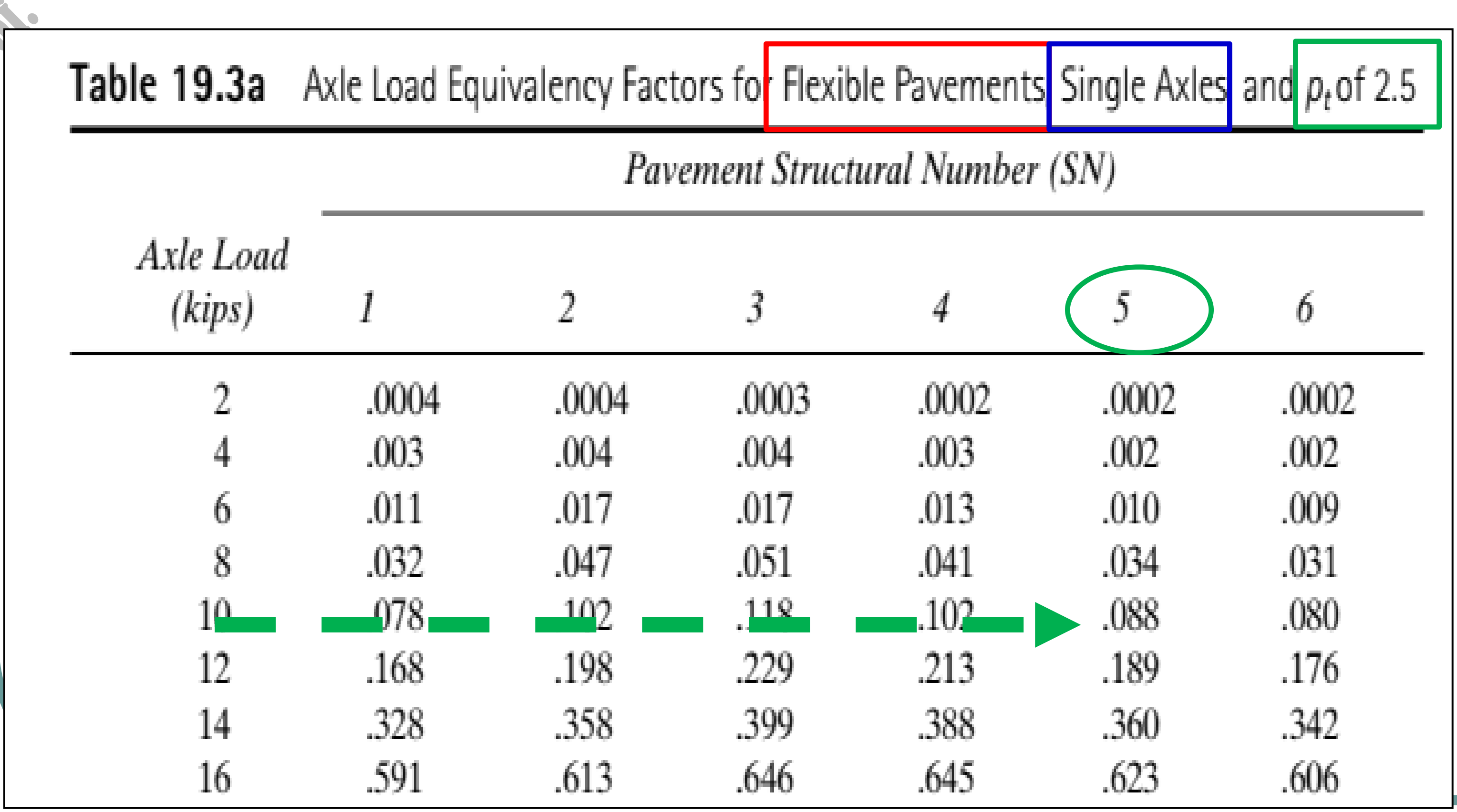


Table 19.3a Axle Load Equivalency Factors for Flexible Pavements Single Axles and p_t of 2.5

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591	.613	.646	.645	.623	.606

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

	Truck Factors											
	Rural Systems						*Urban Systems*					
		Other	*Minor*	*Collectors*				*Other*	*Other*	*Minor*		
Vehicle Type	*Interstate*	*Principal*	*Arterial*	*Major*	*Minor*	*Range*	*Interstate*	*Freeways*	*Principal*	*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.

(FEi): Load equivalency factor for vehicle category

- If the axle load is unknown,
  - The equivalent 18,000-lb load can also be determined from the vehicle type, if the axle load is unknown, by using a truck factor (T_f) for that vehicle type.

$$Truck\ factor(Tf) = \frac{\sum(Number\ of\ axles \times LEFs\ for\ each\ axle)}{Number\ of\ vehicles}$$

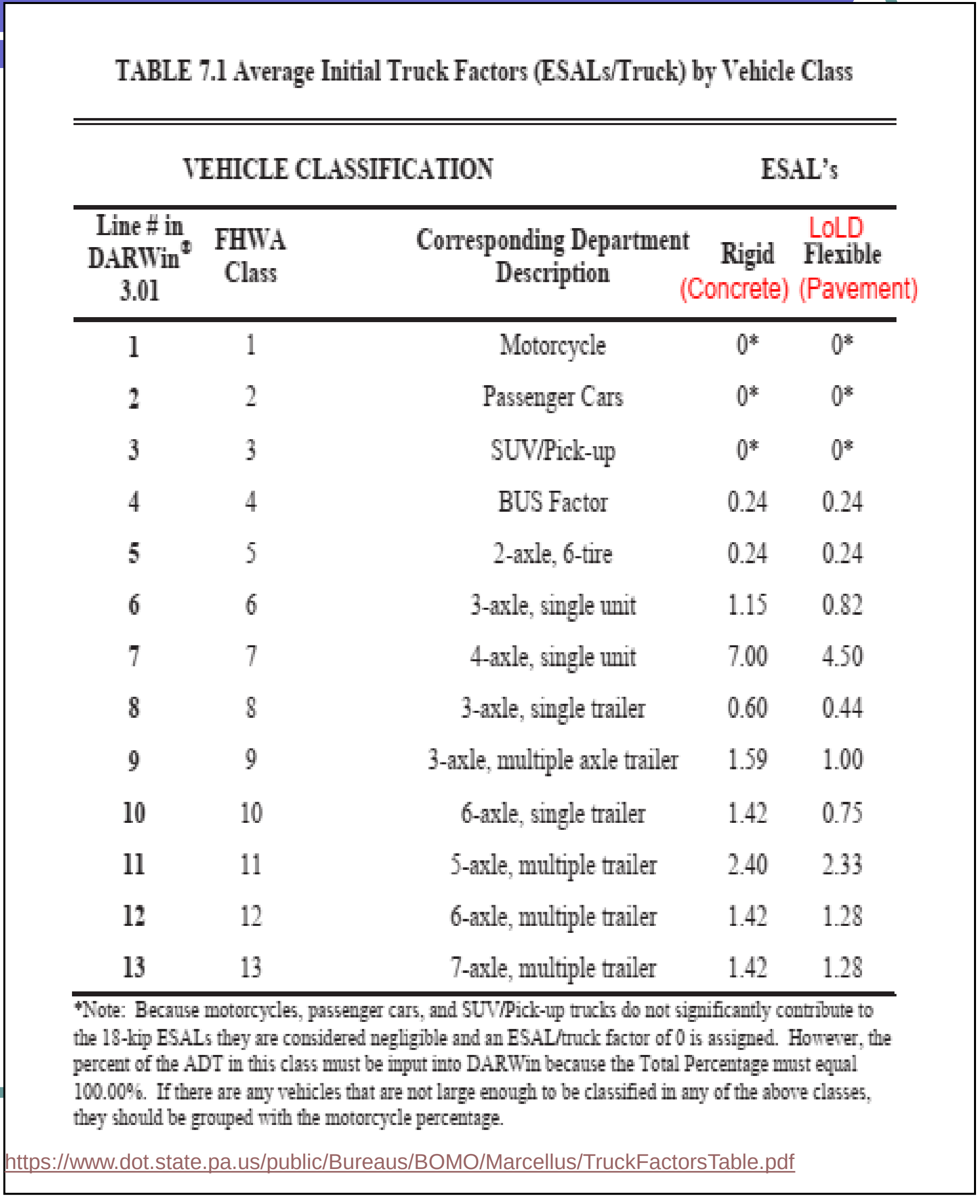


TABLE 7.1 Average Initial Truck Factors (ESALs/Truck) by Vehicle Class

VEHICLE CLASSIFICATION			ESAL's	
Line # in DARWin® 3.01	FHWA Class	Corresponding Department Description	Rigid (Concrete)	LoLD Flexible (Pavement)
1	1	Motorcycle	0*	0*
2	2	Passenger Cars	0*	0*
3	3	SUV/Pick-up	0*	0*
4	4	BUS Factor	0.24	0.24
5	5	2-axle, 6-tire	0.24	0.24
6	6	3-axle, single unit	1.15	0.82
7	7	4-axle, single unit	7.00	4.50
8	8	3-axle, single trailer	0.60	0.44
9	9	3-axle, multiple axle trailer	1.59	1.00
10	10	6-axle, single trailer	1.42	0.75
11	11	5-axle, multiple trailer	2.40	2.33
12	12	6-axle, multiple trailer	1.42	1.28
13	13	7-axle, multiple trailer	1.42	1.28

*Note: Because motorcycles, passenger cars, and SUV/Pick-up trucks do not significantly contribute to the 18-kip ESALs they are considered negligible and an ESAL/truck factor of 0 is assigned. However, the percent of the ADT in this class must be input into DARWin because the Total Percentage must equal 100.00%. If there are any vehicles that are not large enough to be classified in any of the above classes, they should be grouped with the motorcycle percentage.

https://www.dot.state.pa.us/public/Bureaus/BOMO/Marcellus/TruckFactorsTable.pdf

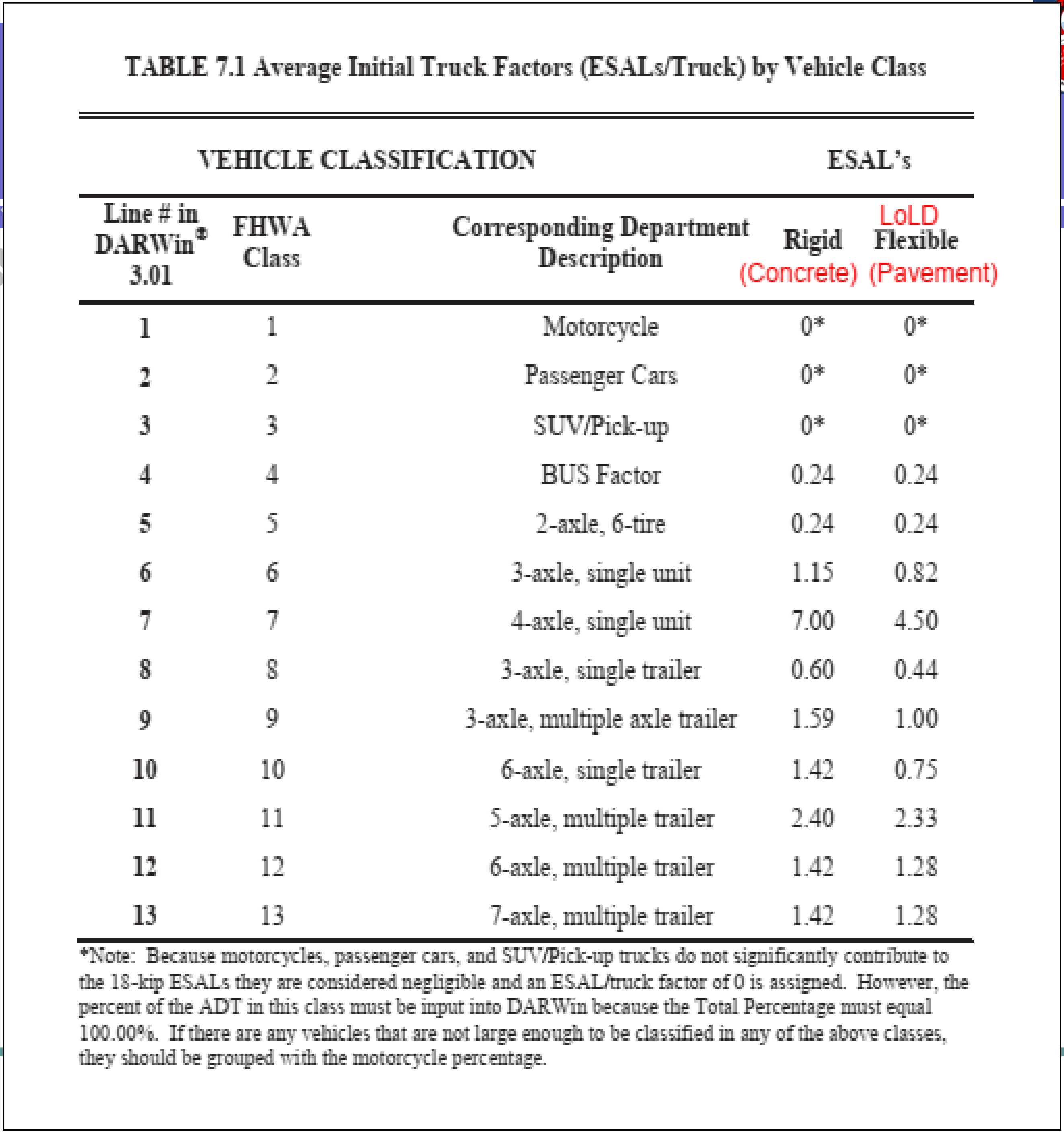


TABLE 7.1 Average Initial Truck Factors (ESALs/Truck) by Vehicle Class

VEHICLE CLASSIFICATION			ESAL's	
Line # in DARWin® 3.01	FHWA Class	Corresponding Department Description	Rigid (Concrete)	LoLD Flexible (Pavement)
1	1	Motorcycle	0*	0*
2	2	Passenger Cars	0*	0*
3	3	SUV/Pick-up	0*	0*
4	4	BUS Factor	0.24	0.24
5	5	2-axle, 6-tire	0.24	0.24
6	6	3-axle, single unit	1.15	0.82
7	7	4-axle, single unit	7.00	4.50
8	8	3-axle, single trailer	0.60	0.44
9	9	3-axle, multiple axle trailer	1.59	1.00
10	10	6-axle, single trailer	1.42	0.75
11	11	5-axle, multiple trailer	2.40	2.33
12	12	6-axle, multiple trailer	1.42	1.28
13	13	7-axle, multiple trailer	1.42	1.28

*Note: Because motorcycles, passenger cars, and SUV/Pick-up trucks do not significantly contribute to the 18-kip ESALs they are considered negligible and an ESAL/truck factor of 0 is assigned. However, the percent of the ADT in this class must be input into DARWin because the Total Percentage must equal 100.00%. If there are any vehicles that are not large enough to be classified in any of the above classes, they should be grouped with the motorcycle percentage.

Truck Factor Example

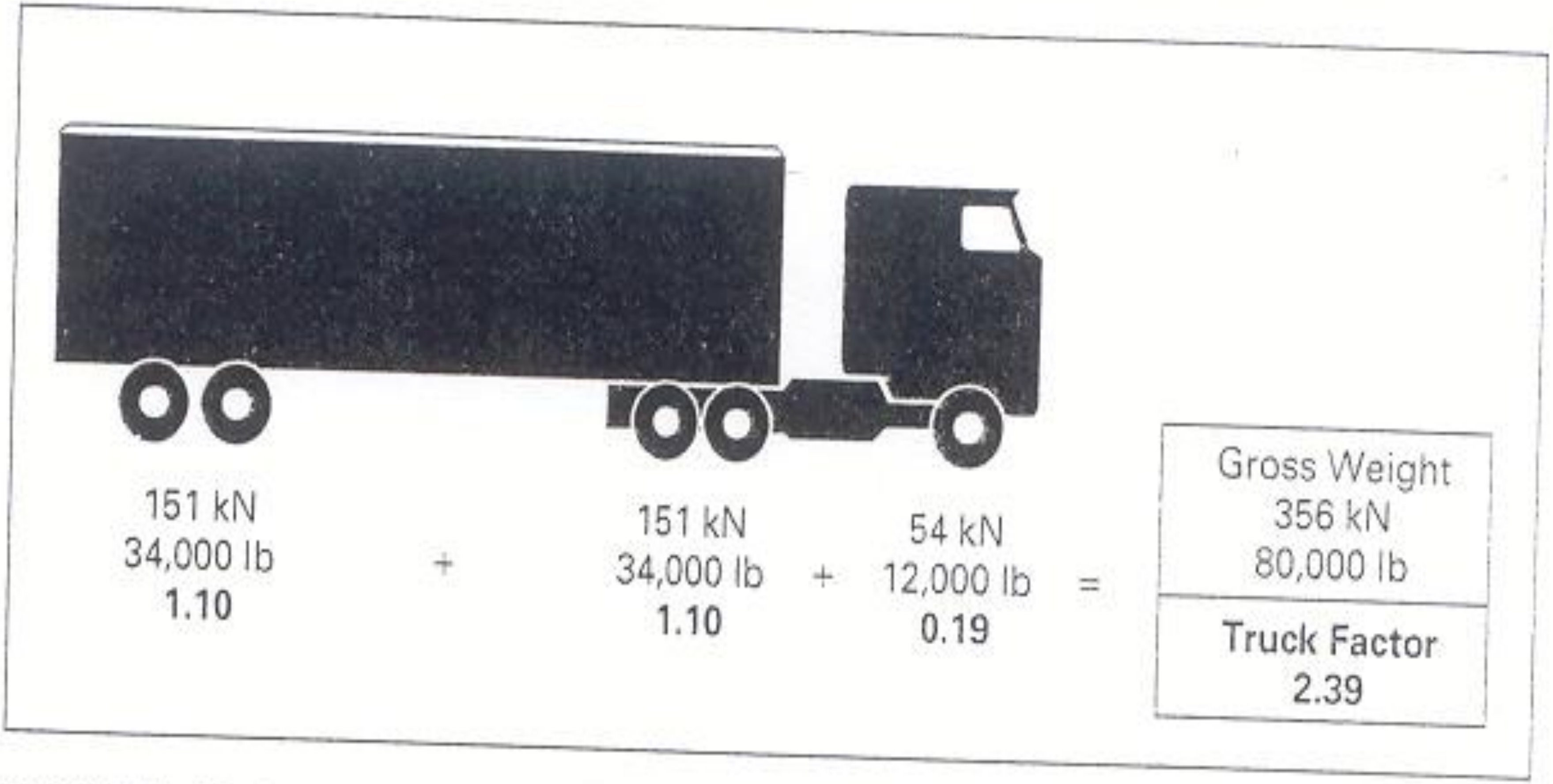


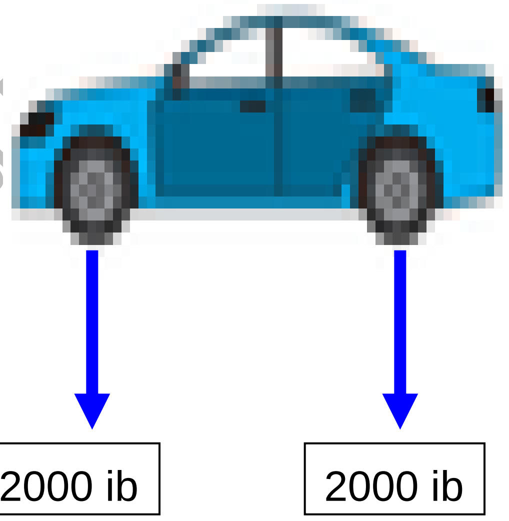
FIGURE 16-8 Load-equivalency factors and the truck factor for a single-tractor semitrailer truck. (Courtesy the Asphalt Institute.)

Example

- Determine the Truck factor for the following the following vehicle mix and axle loads
  - Passenger cars (2000 lb/axle)
  - 2-axle single-unit trucks (6000 lb/axle)
  - 3-axle single-unit trucks (10,000 lb/axle)

Assume SN = 5 and $P_t = 2.5$

Passenger cars 2000 lb/axle)



LEF for single axle = 0.0002

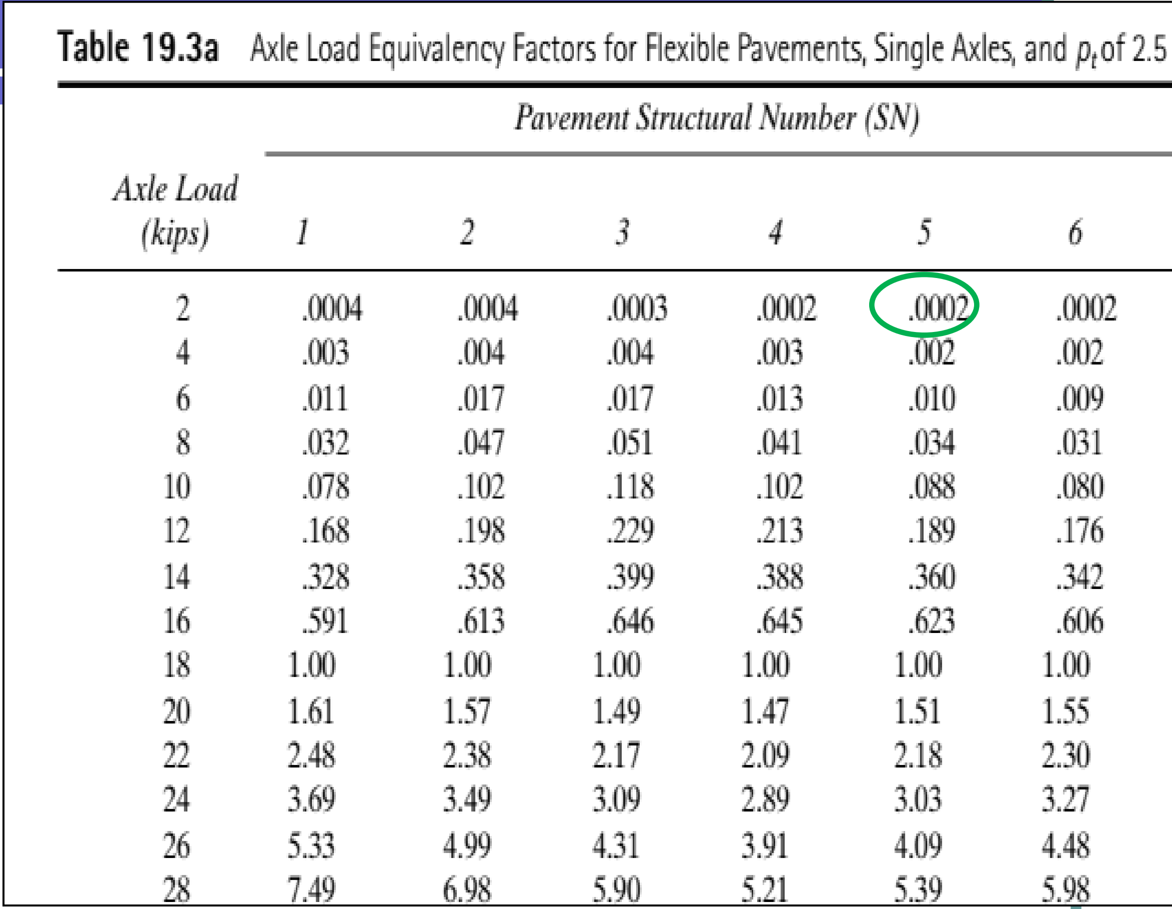
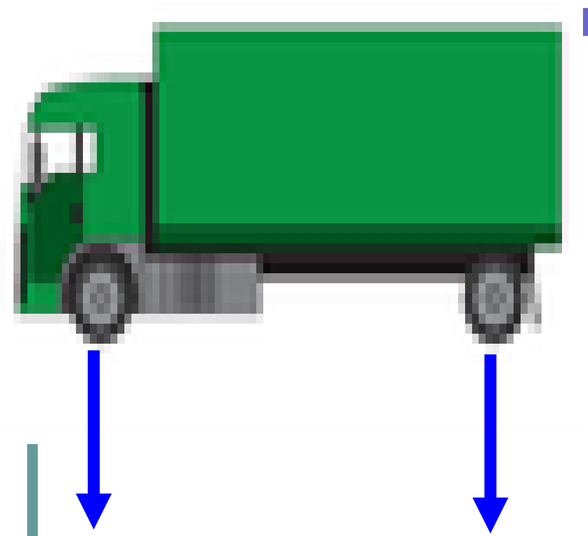


Table 19.3a Axle Load Equivalency Factors for Flexible Pavements, Single Axles, and p_t of 2.5

	Pavement Structural Number (SN)					
Axle Load (kips)	*1*	*2*	*3*	*4*	*5*	*6*
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591	.613	.646	.645	.623	.606
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.57	1.49	1.47	1.51	1.55
22	2.48	2.38	2.17	2.09	2.18	2.30
24	3.69	3.49	3.09	2.89	3.03	3.27
26	5.33	4.99	4.31	3.91	4.09	4.48
28	7.49	6.98	5.90	5.21	5.39	5.98

$$\text{Truck factor } (Tf) = \frac{\Sigma(\text{Number of axles} \times \text{LEFs for each axle})}{\text{Number of vehicles}} = \frac{\Sigma(2\times 0.002)}{1} = 0.004 \text{ per vehicle}$$

2-axle single-unit trucks (6000 lb/axle)



6,000 ib

6,000 ib

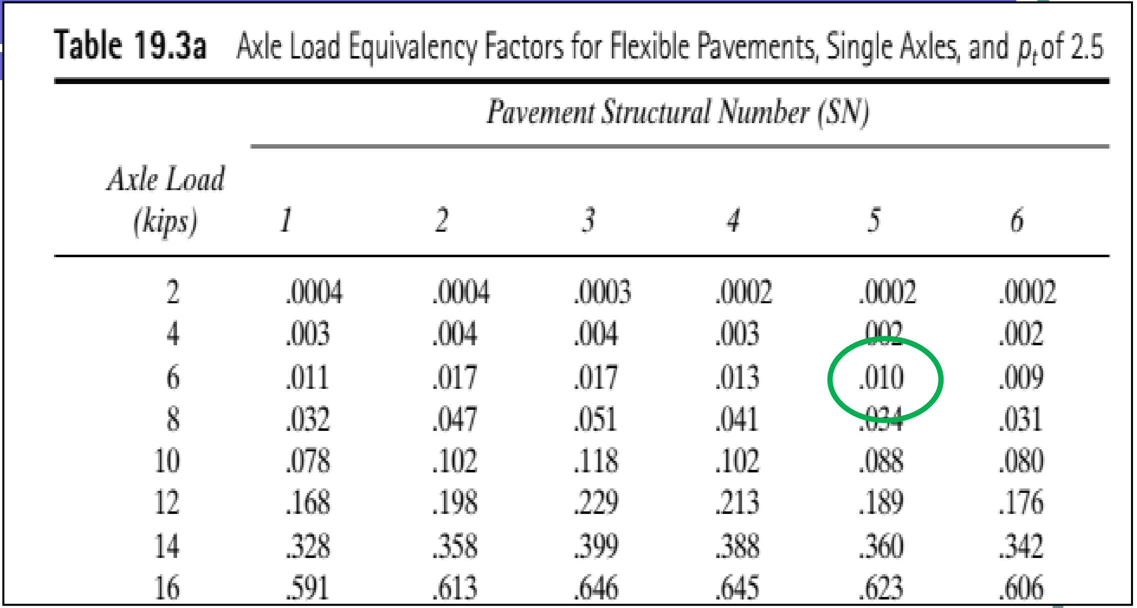
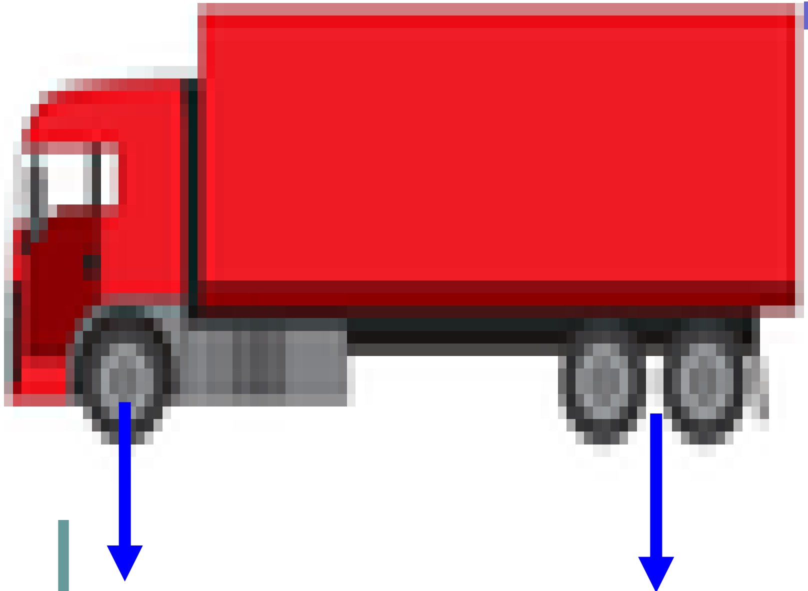


Table 19.3a Axle Load Equivalency Factors for Flexible Pavements, Single Axles, and p_t of 2.5

Axle Load (kips)	*Pavement Structural Number (SN)* 1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591	.613	.646	.645	.623	.606

$$Truck\ factor(Tf) = \frac{\Sigma(Number\ of\ axles \times LEFs\ for\ each\ axle)}{Number\ of\ vehicles} = \frac{\Sigma(2\times0.01)}{1} = 0.02\ per\ vehicle$$

3-axle single-unit trucks (10,000 lb/axle)



10,000 ib

22,000 ib

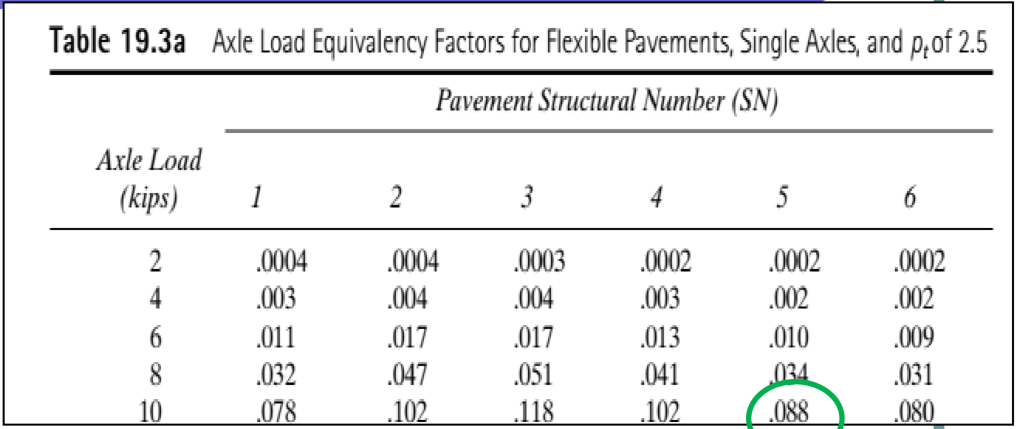


Table 19.3a Axle Load Equivalency Factors for Flexible Pavements, Single Axles, and p_t of 2.5

Axle Load (kips)	Pavement Structural Number (SN) 1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080

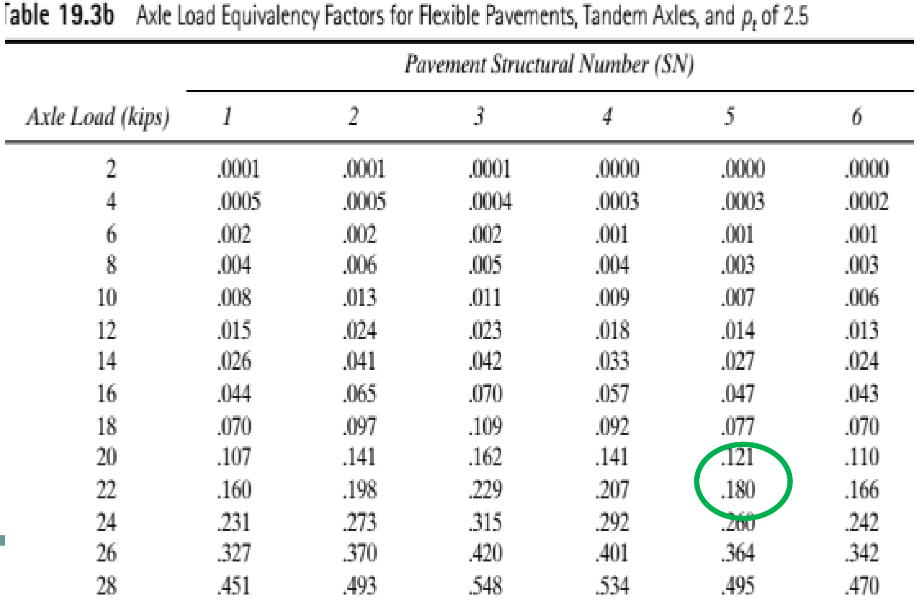
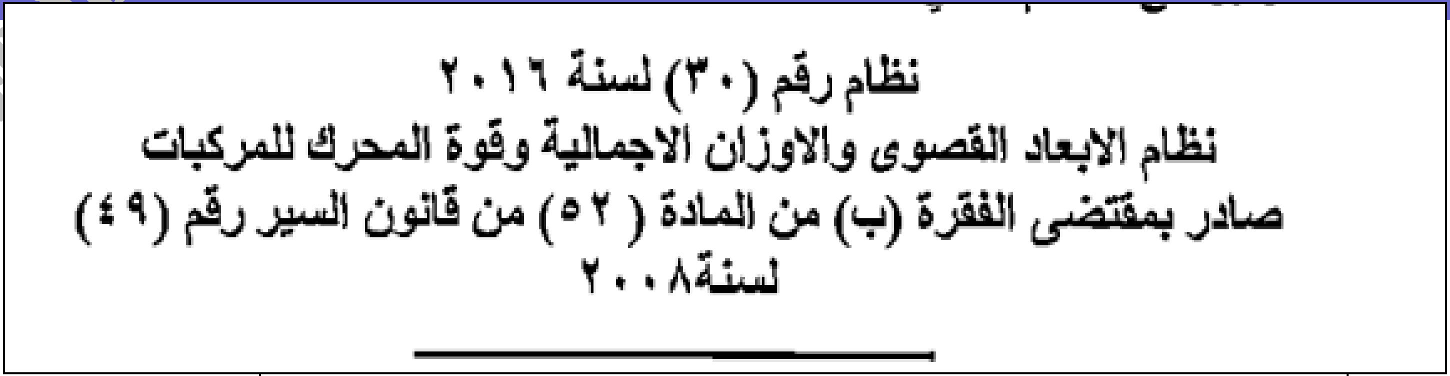


Table 19.3b Axle Load Equivalency Factors for Flexible Pavements, Tandem Axles, and p_t of 2.5

Axle Load (kips)	Pavement Structural Number (SN) 1	2	3	4	5	6
2	.0001	.0001	.0001	.0000	.0000	.0000
4	.0005	.0005	.0004	.0003	.0003	.0002
6	.002	.002	.002	.001	.001	.001
8	.004	.006	.005	.004	.003	.003
10	.008	.013	.011	.009	.007	.006
12	.015	.024	.023	.018	.014	.013
14	.026	.041	.042	.033	.027	.024
16	.044	.065	.070	.057	.047	.043
18	.070	.097	.109	.092	.077	.070
20	.107	.141	.162	.141	.121	.110
22	.160	.198	.229	.207	.180	.166
24	.231	.273	.315	.292	.260	.242
26	.327	.370	.420	.401	.364	.342
28	.451	.493	.548	.534	.495	.470

$$Truck\ factor(\mathrm{Tf}\ ) = = \frac{\Sigma_{(1\times 0.088+1*0.18\ )}}{1} = 0.\ 264\ per\ vehicle$$

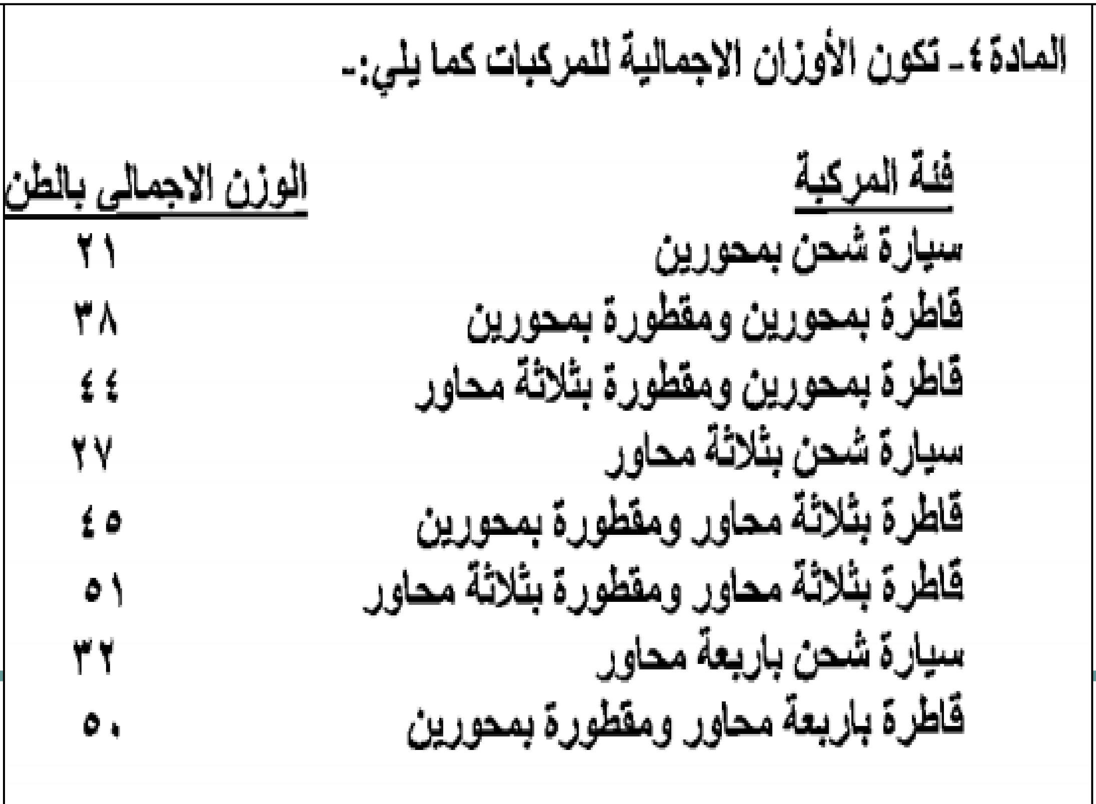
Specified Maximum Gross Weight For Trucks



نظام رقم (٣٠) لسنة ٢٠١٦

نظام الابعاد القصوى والاوزان الاجمالية وقوة المحرك للمركبات

صادر بمقتضى الفقرة (ب) من المادة (٥٢) من قانون السير رقم (٤٩)
لسنة٢٠٠٨



المادة ٤ـ تكون الأوزان الاجمالية للمركبات كما يلي:-

فئة المركبة	الوزن الاجمالى بالطن
سيارة شحن بمحورين	٢١
قاطرة بمحورين ومقطورة بمحورين	٣٨
قاطرة بمحورين ومقطورة بثلاثة محاور	٤٤
سيارة شحن بثلاثة محاور	٢٧
قاطرة بثلاثة محاور ومقطورة بمحورين	٤٥
قاطرة بثلاثة محاور ومقطورة بثلاثة محاور	٥١
سيارة شحن باربعة محاور	٣٢
قاطرة باربعة محاور ومقطورة بمحورين	٥٠

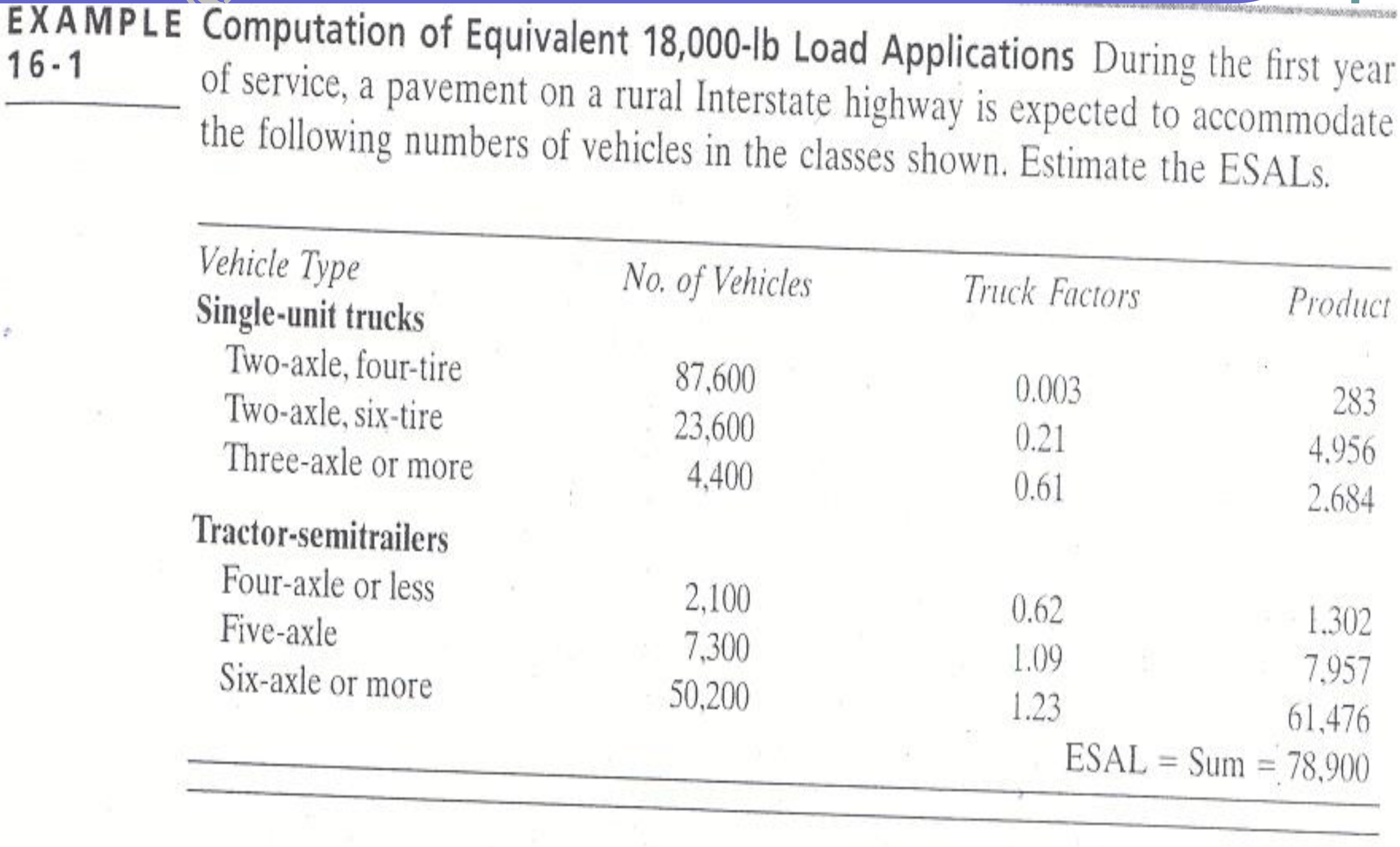
Traffic Analysis Cont.

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

The traffic to be used for design is the average traffic during the design period, so the initial traffic must be multiplied by a growth factor

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

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

j: Rate of growth.

t: Design period (yrs).

Growth Factors

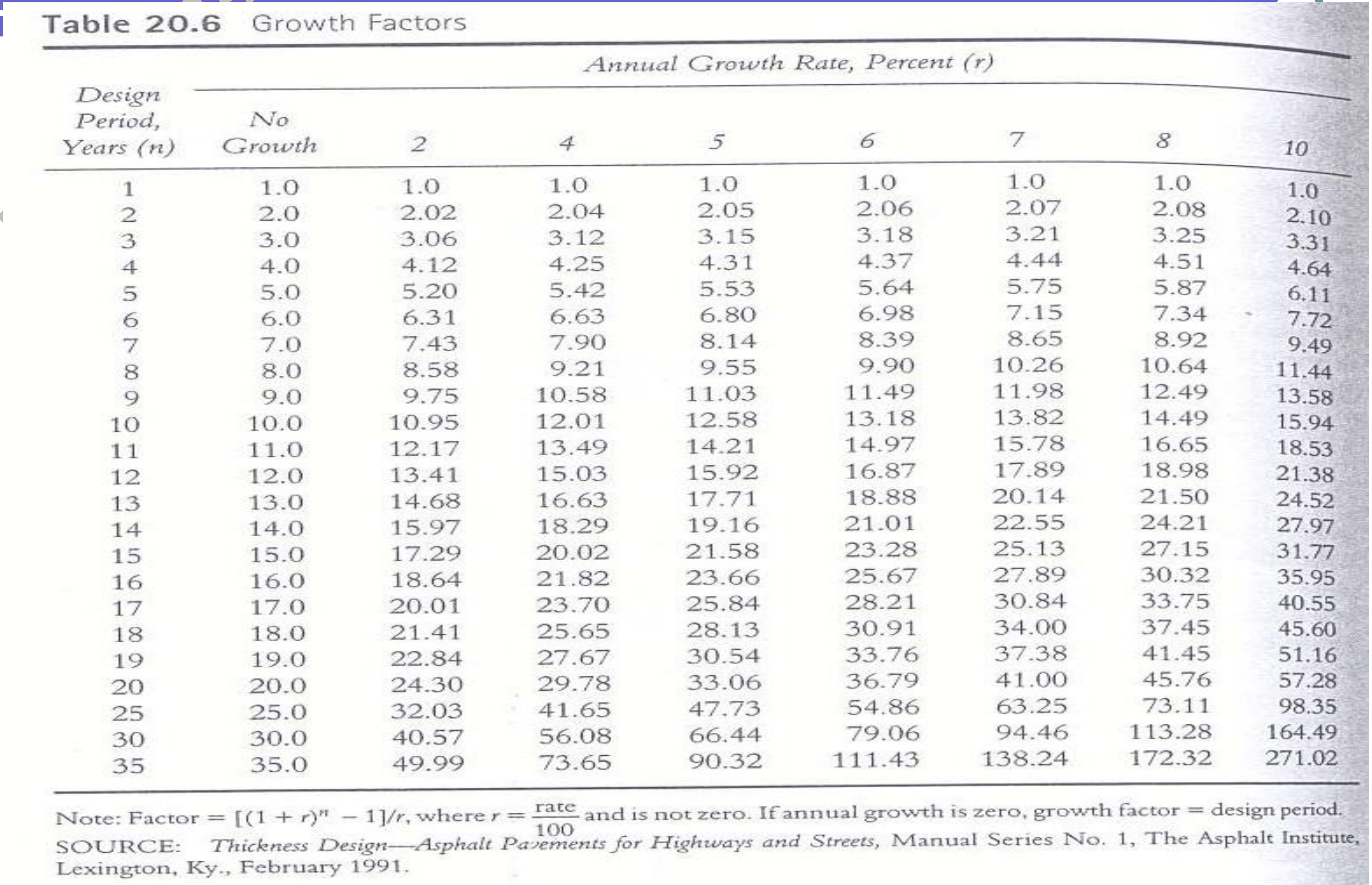


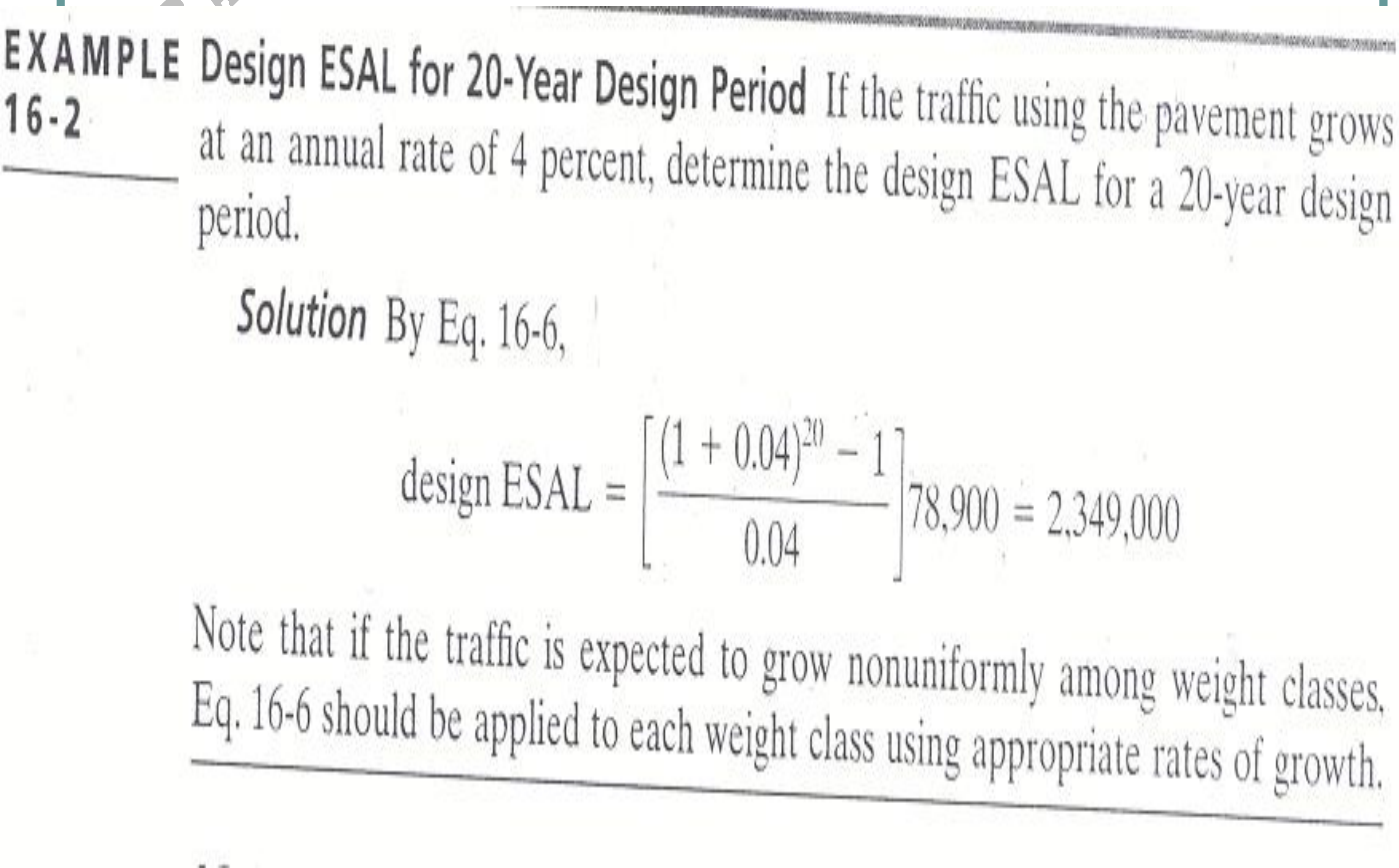
Table 20.6 Growth Factors

Design Period, Years (*n*)	No Growth	*Annual Growth Rate, Percent (r)* 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.

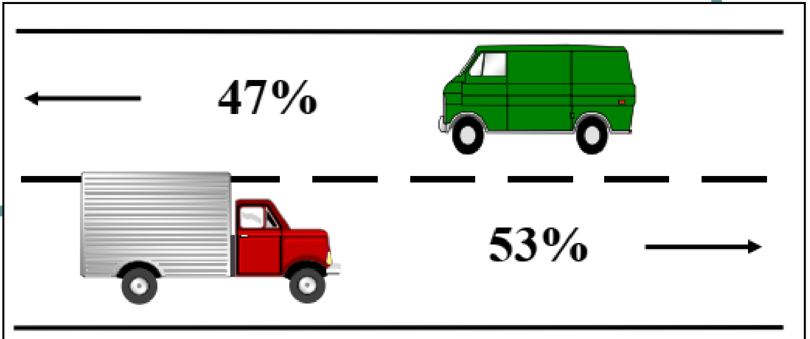
Total ESAL Calculation Cont.

- 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).

Design Lane factor (Fd)

- $F_d = D \times L$
  - (D): is the directional distribution factor
  - (L): L is the lane distribution factor
- D: represent Percentage of trucks traffic traveling in one direction.
- D usually assumed to be 0.5 unless the traffic in two directions is different.

Design for worst case!!



Lane Distribution Factor (L)

- Design lane:
  - Lane expected to receive the severe service
- For two-lane highways,
  - The lane in each direction is the design lane, so the lane distribution factor is 100%
- For multilane highways,
  - The design lane is the outside lane

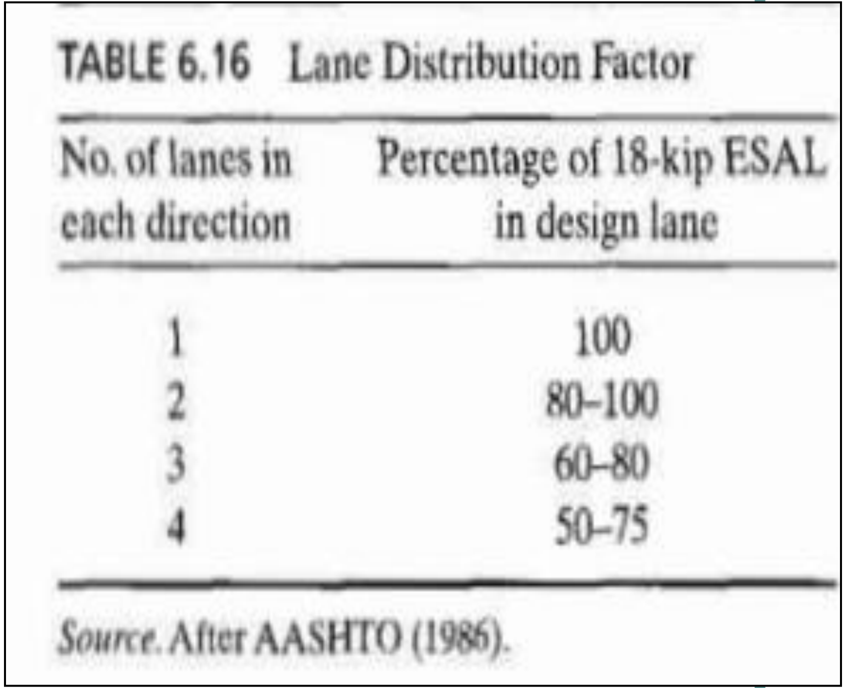


TABLE 6.16 Lane Distribution Factor

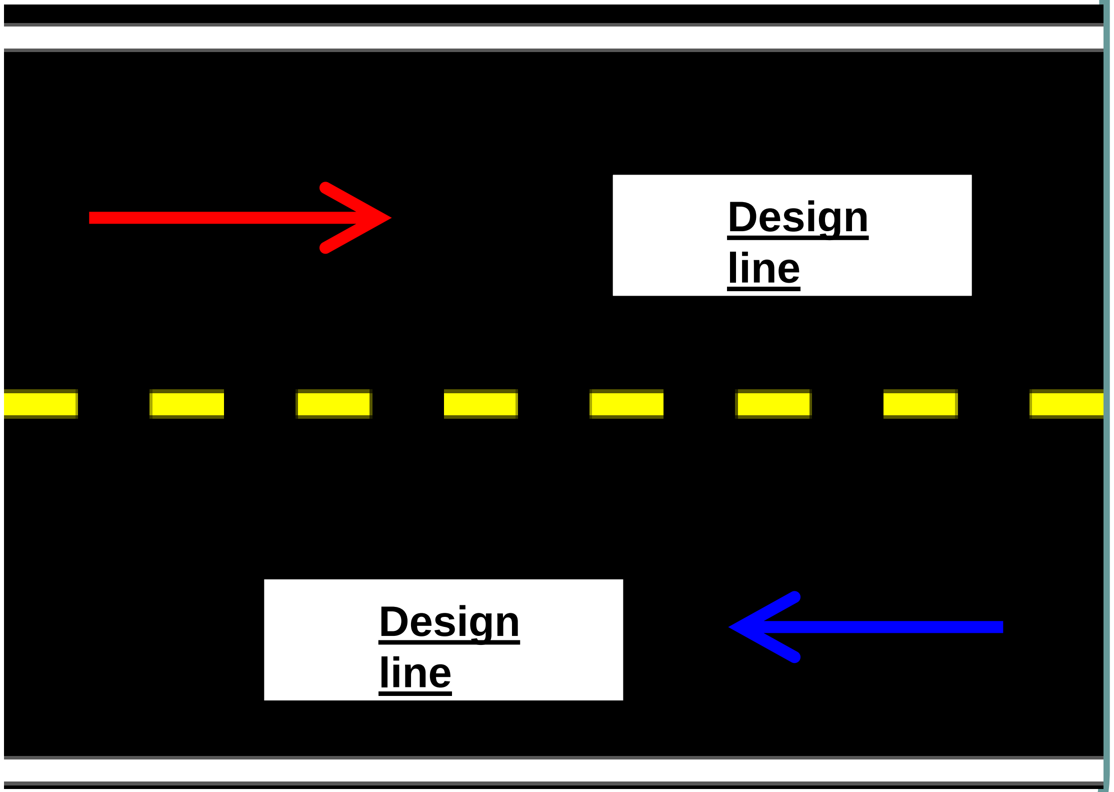
No. of lanes in each direction	Percentage of 18-kip ESAL in design lane
1	100
2	80–100
3	60–80
4	50–75

Source. After AASHTO (1986).

Design for worst case!!

Lane Distribution

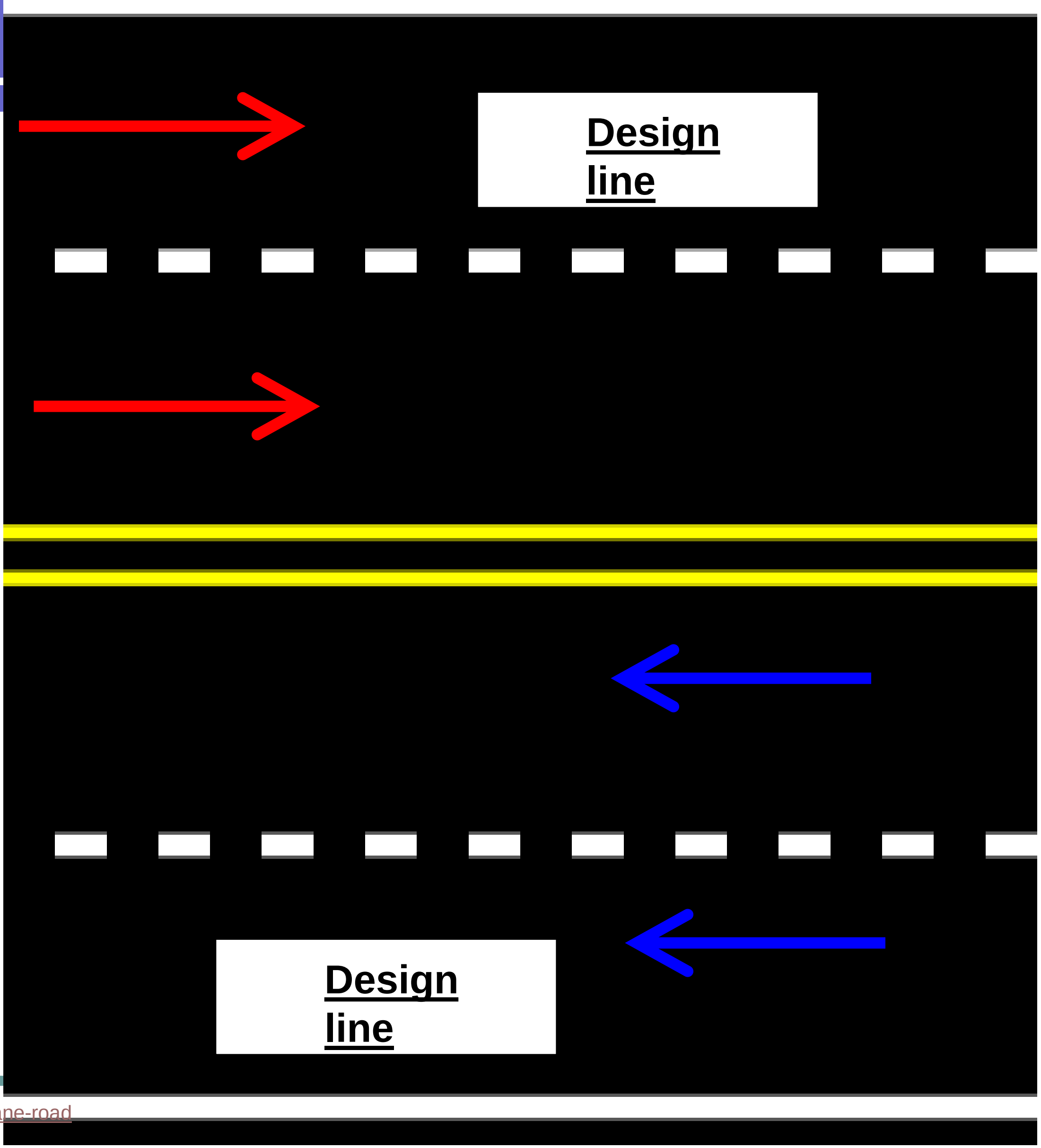
- For two-lane highways,
  - The lane in each direction is the design lane, so the lane distribution factor is 100%
  - Design lane: Lane expected to receive the severe service



https://english.stackexchange.com/questions/270607/what-is-meant-by-a-two-lane-road

Lane Distribution Factor (L)

- For Multilane highways,
  - The design lane is the outside lane
  - Design lane: Lane expected to receive the severe service



https://english.stackexchange.com/questions/270607/what-is-meant-by-a-two-lane-road

Table 20.7 for Percentage of Total Truck Traffic on Design Lane

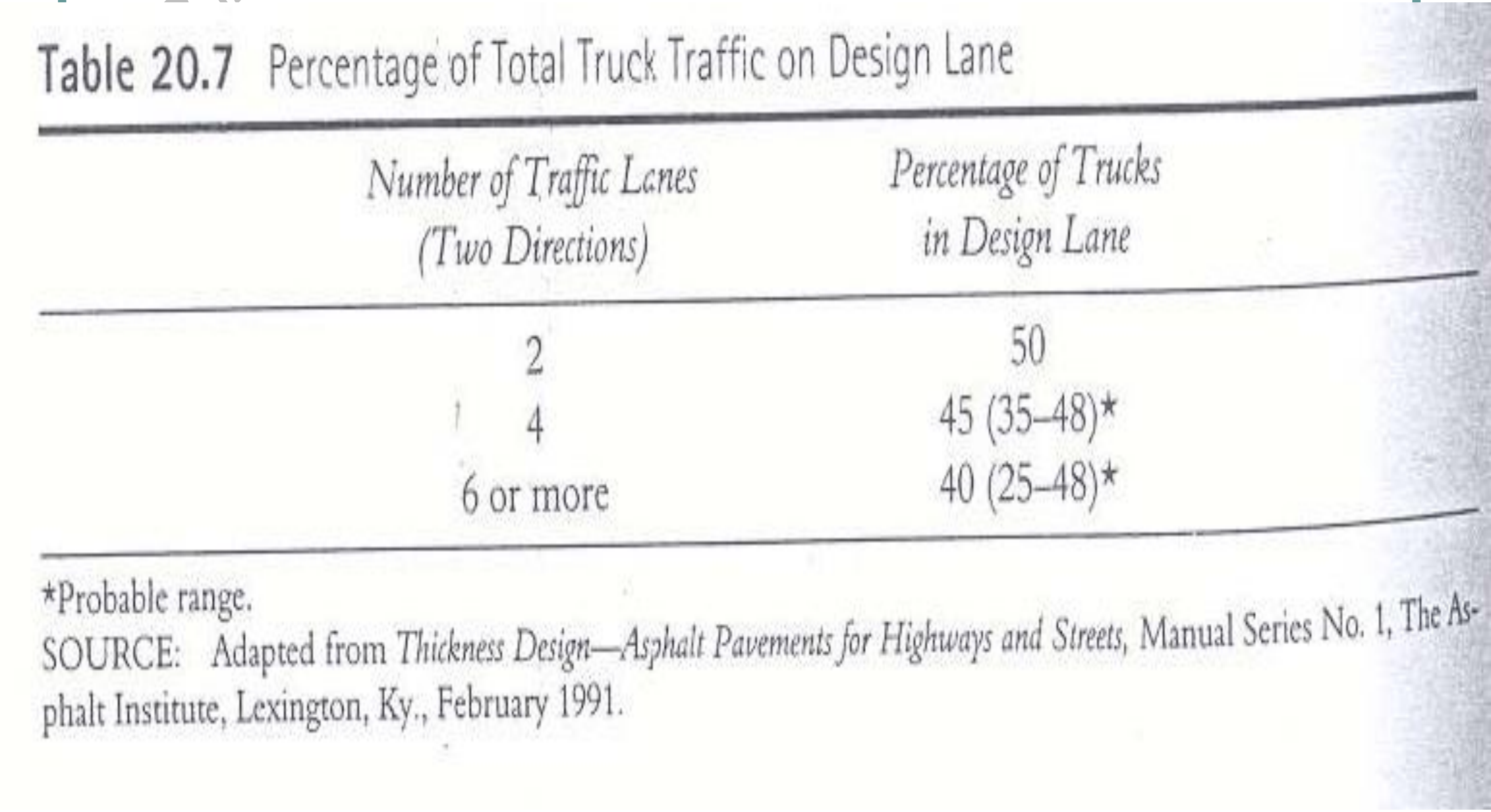


Table 20.7 Percentage of Total Truck Traffic on Design Lane

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

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

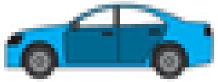
from i =1 to n

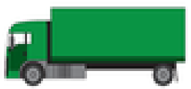
n= number of truck categories

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

<u>Solution</u>

- 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

- 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.

Total ESAL Calculation for mixed traffic

Vehicle Category, FHWA Classification	ESAL for Vehicle Category						
	AADT	T	G_{rn}	F_d	T_f (/ vehicle)		ESAL
Passenger Cars and small trucks						365	
2axle, 4tire vans motorhomes, etc							
2-axle 6 tire single units							
3 axle single unit							
4 axle single unit							
4-or-less-axle multi unit							
5 axle multi unit							
6-or-more-axle double unit							
5-axle or less, multi-unit							
6-axle, multi-unit							
7-or-more-axle, multi-unit							
Total ESAL							0.00E+00

Roadbed Soils (Subgrade Materials)

- AASHTO 1993 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.
- There are several factors that affect the resilient modulus of a soil include: Moisture content, Stress levels, Freeze-thaw cycles.

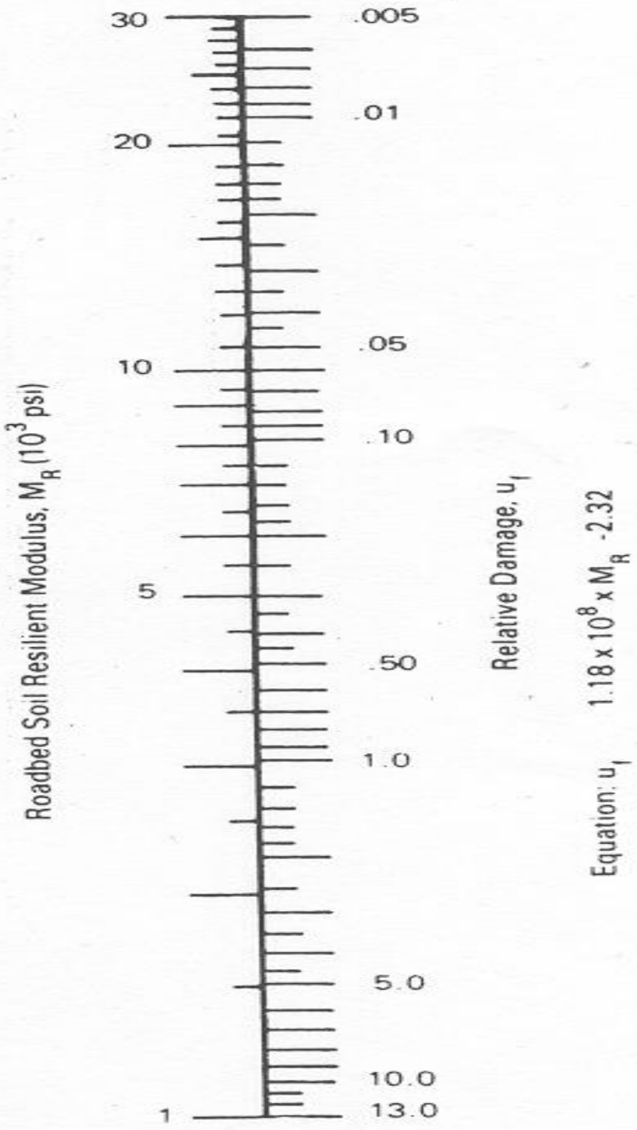
Roadbed Soils (Subgrade Materials)

- Since the seasonal variation of resilient modulus is quite complex, the selection of a single resilient modulus value for use in design can be quite complex.
- 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.)

Determination of Effective Roadbed Soil Resilient Modulus

- **Step 1:**
  - Develop a relationship between
    - Resilient modulus
    - Subgrade moisture content
  - For example :
    - at 25% moisture content, Mr is 9500 Psi

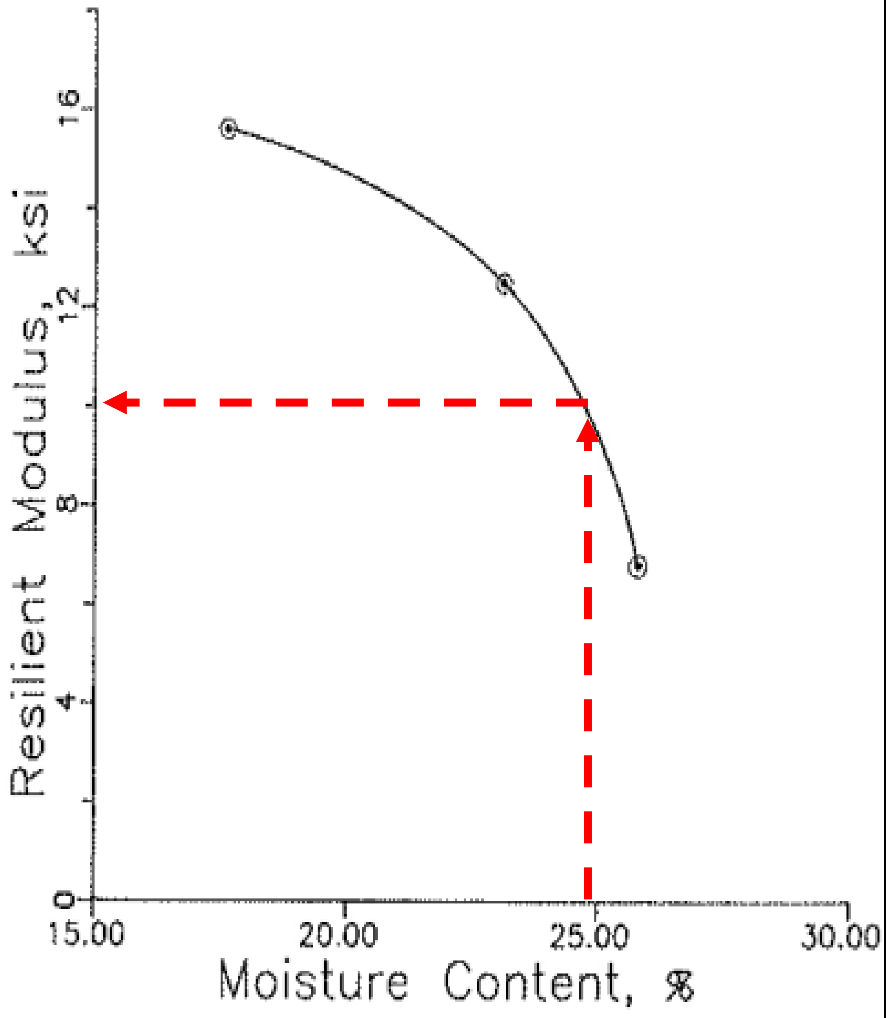


FIGURE 12 Moisture content-resilient modulus relationship for soil used in example.

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Determination of Effective Roadbed Soil Resilient Modulus

- **Step 2:**

Estimate the seasonal variation in moisture content.

- There is no standard approach for making this estimate.
- A practical approach might be to sample a similar subgrade.
- For this example it is assumed that moisture contents were determined four times during the year on a similar subgrade soil from a nearby pavement.
- For example:
- in March the water content was 25%

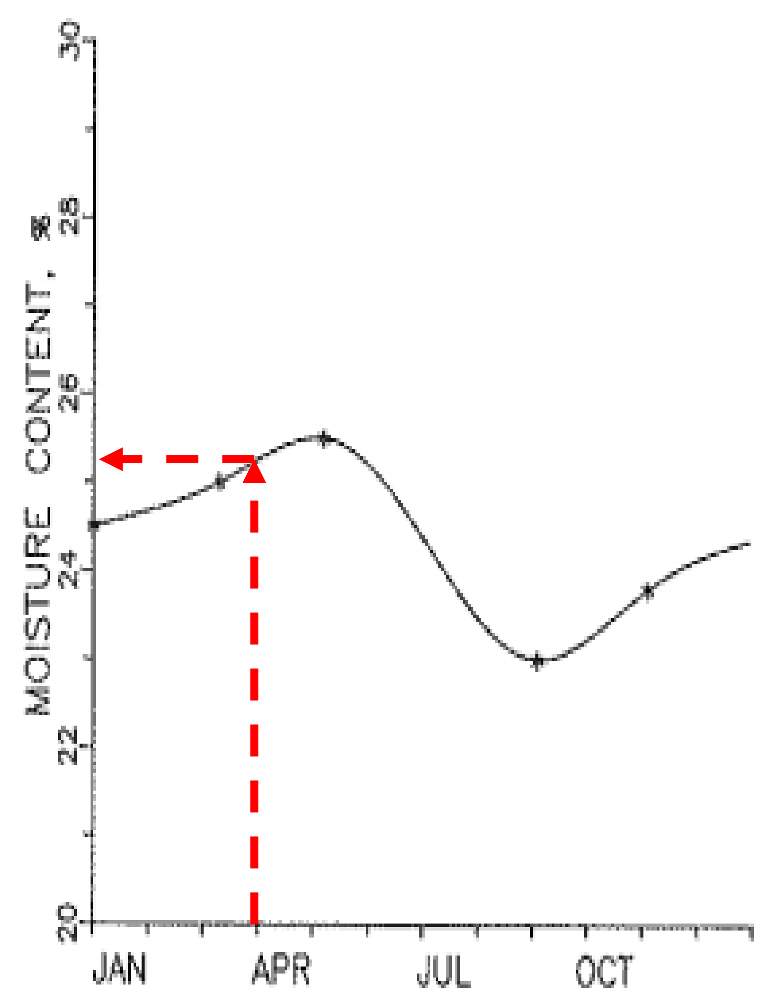

FIGURE 13 Seasonal moisture variation used in example.

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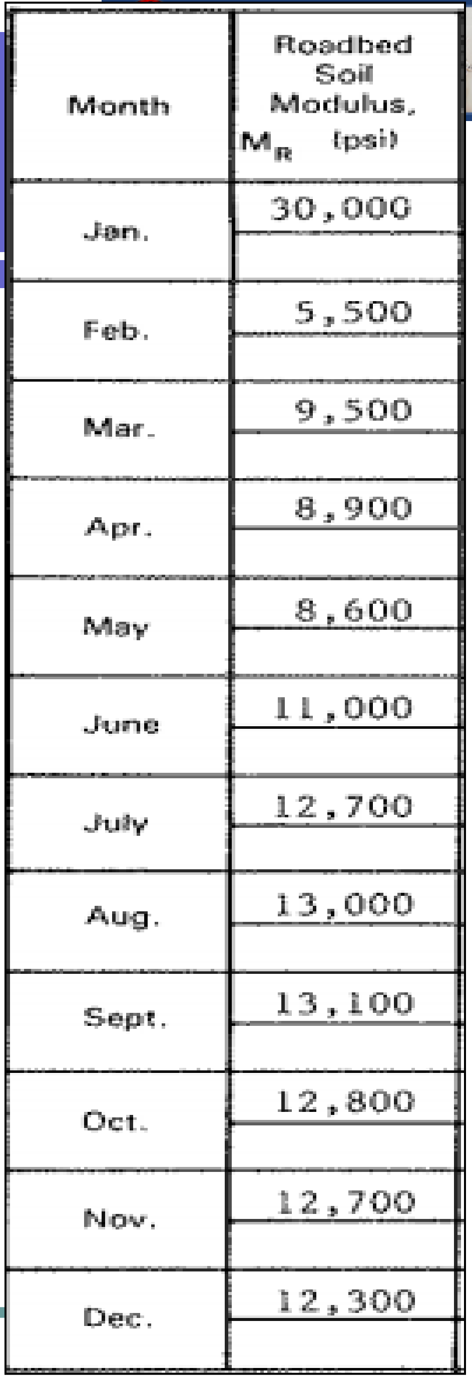
Determination of Effective Roadbed Soil Resilient Modulus

- **Step 3:**
  - Determine the monthly (or bimonthly) resilient modulus
    - Use data collected in step 1 and step 2
    - For example:
      - March has water content of 25 % (step 2), which is correspond to 9,500 Mr (step 1)



Month	Roadbed Soil Modulus, M_R (psi)
Jan.	30,000
Feb.	5,500
Mar.	9,500
Apr.	8,900
May	8,600
June	11,000
July	12,700
Aug.	13,000
Sept.	13,100
Oct.	12,800
Nov.	12,700
Dec.	12,300

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Determination of Effective Roadbed Soil Resilient Modulus

- **Step 4:**

  - Select a relative damage factor for each resilient modulus (U_f)
  - $U_f = 1.18 \times 10^8 \times Mr^{-2.32}$
  - For the frozen subgrade (January),
    - The resilient modulus would be high resulting in a low relative damage
      - For practical purposes, a damage value of 0.0 is assigned

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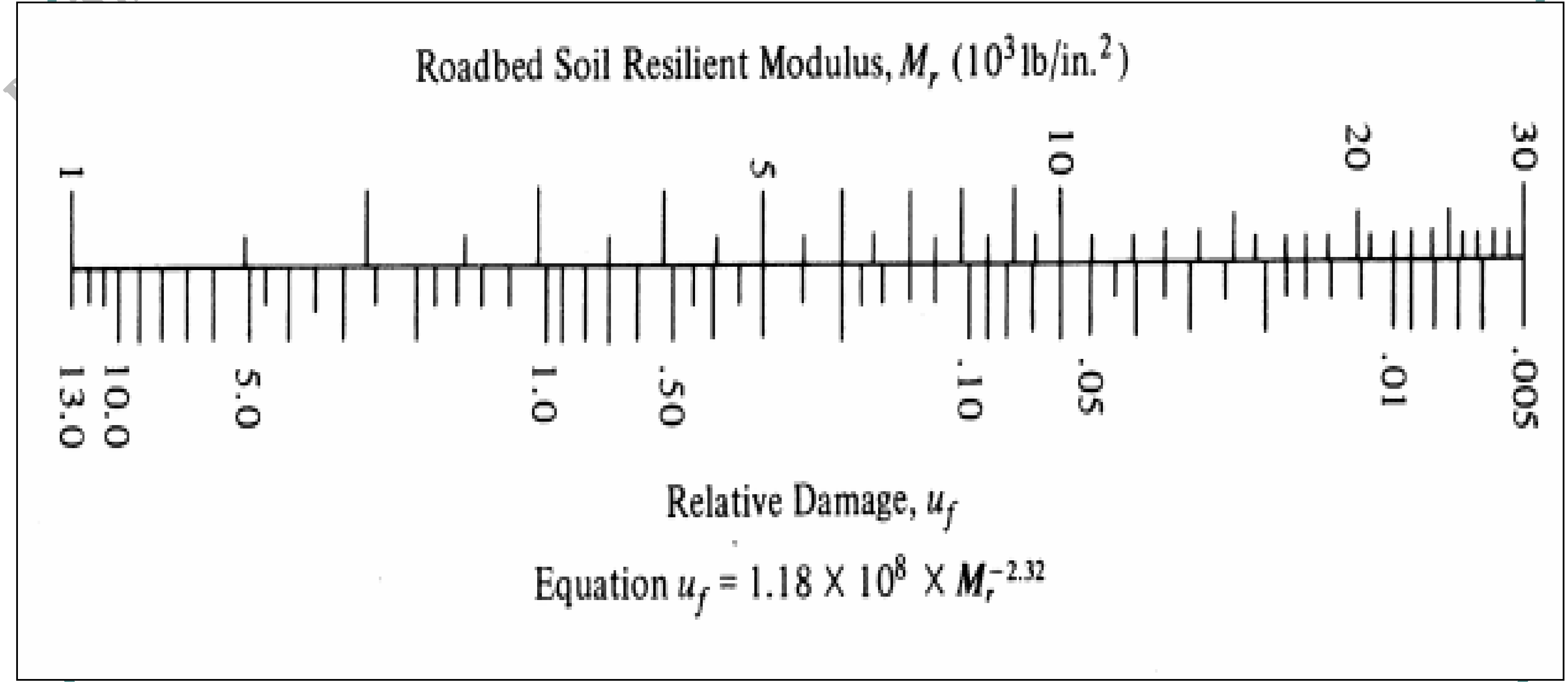
Determination of Effective Roadbed Soil Resilient Modulus

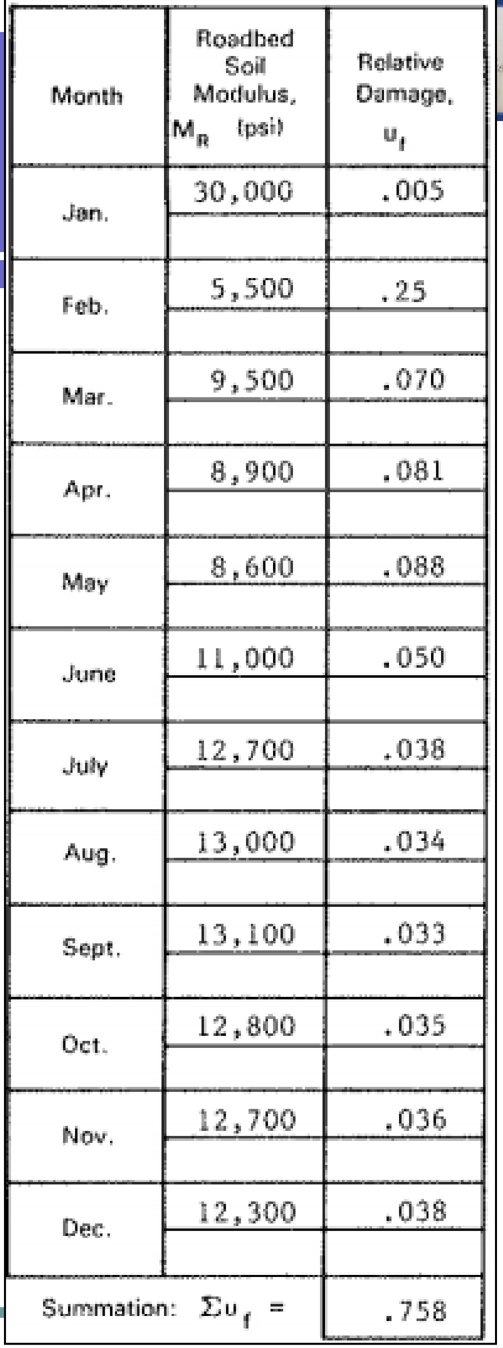


Determination of Effective Roadbed Soil Resilient Modulus

- **Step 5:**
  - Determine the average U_f for all months

- $$\overline{U_f} = \frac{\sum_{i=1}^{N} U_f}{n}$$
  - n is number of months (12)

$$\overline{U_f} = \frac{0.758}{12} = 0.063$$



Month	Roadbed Soil Modulus, M_R (psi)	Relative Damage, u_f
Jan.	30,000	.005
Feb.	5,500	.25
Mar.	9,500	.070
Apr.	8,900	.081
May	8,600	.088
June	11,000	.050
July	12,700	.038
Aug.	13,000	.034
Sept.	13,100	.033
Oct.	12,800	.035
Nov.	12,700	.036
Dec.	12,300	.038
Summation: Σu_f =		.758

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Determination of Effective Roadbed Soil Resilient Modulus

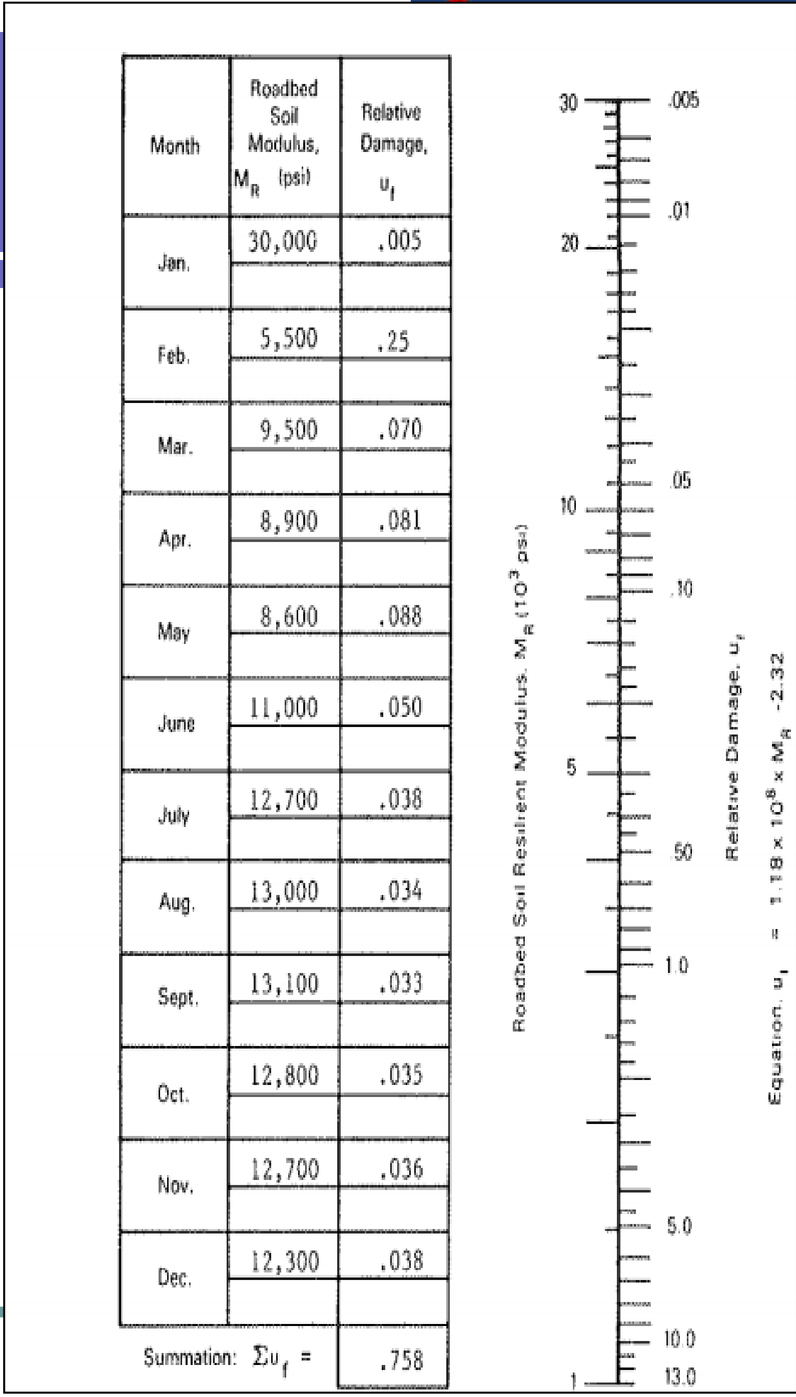
Step 6.

- Determine the effective Mr using average $\overline{U_f}$

- $$\text{Effective } Mr = 10^{\left[\frac{\log\left[\frac{\overline{U_f}}{1.18\times10^{8}}\right]}{-2.32}\right]}$$

- For example:

  - at $\overline{U_f}$ of 0.063 ….
    Effective Mr =9,900 Psi



Month	Roadbed Soil Modulus, M_R (psi)	Relative Damage, u_f
Jan.	30,000	.005
Feb.	5,500	.25
Mar.	9,500	.070
Apr.	8,900	.081
May	8,600	.088
June	11,000	.050
July	12,700	.038
Aug.	13,000	.034
Sept.	13,100	.033
Oct.	12,800	.035
Nov.	12,700	.036
Dec.	12,300	.038
Summation: Σu_f =		.758

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Example

- The table show the roadbed soil resilient modulus *Mr* for each month estimated from laboratory results correlating *Mr* with moisture content.

- Determine
  - The effective resilient modulus of the subgrade

Month	Roadbed (Mr) (ib / in)
January	22000
February	22000
March	5500
April	5000
May	5000
June	8000
July	8000
August	8000
September	8500
October	8500
November	6000
December	22000

Example 3/ Solution

Month	Roadbed (Mr) (ib / in)	Relative damage (U_f)
January	22000	0.010
February	22000	0.010
March	5500	0.248
April	5000	0.309
May	5000	0.309
June	8000	0.104
July	8000	0.104
August	8000	0.104
September	8500	0.090
October	8500	0.090
November	6000	0.203
December	22000	0.010

Summation of relative damage	1.591
Average U_f	0.133
Effective Mr	7203

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.***
  - convert the actual thickness of the **subbase** to an equivalent Structure Number (SN)
  - Higher *a*3 coefficient indicate better subbase materials .

- 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.***
  - convert the actual thickness of the **base** to an equivalent Structure Number (SN)
  - Higher *a*3 coefficient indicate better base materials .

- 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.***
  - a_1 relates to Dense grade asphalt concrete surface course with its resilient modulus at 68°F

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 (**a_1**)
- **16.14** : Bituminous treated base (**a_2**)
- **16.15** : Granular base (**a_2**)
- **16.16** : Granular subbase (**a_3**)
- **16.17** : Cement treated bases (**a_2**).

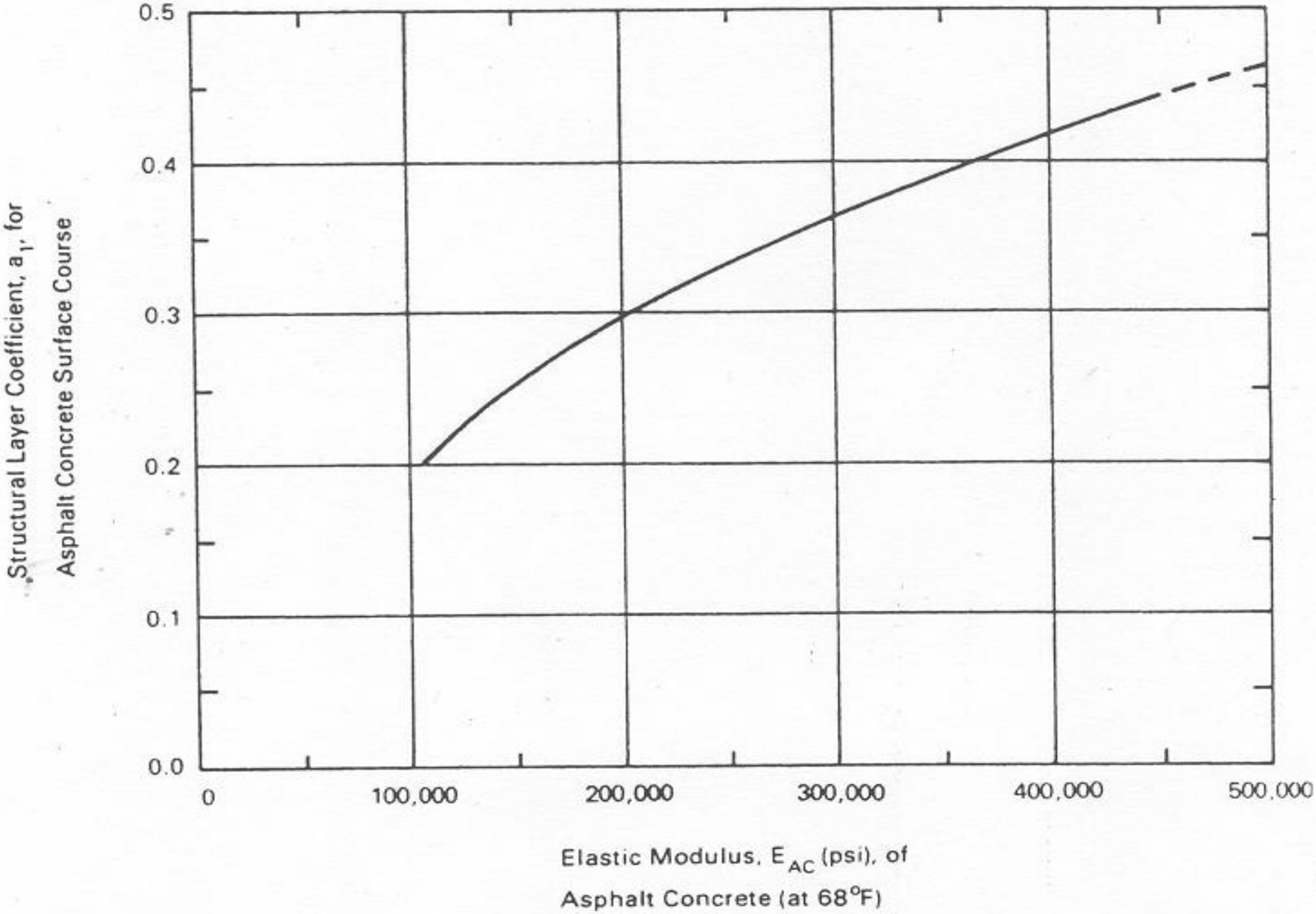
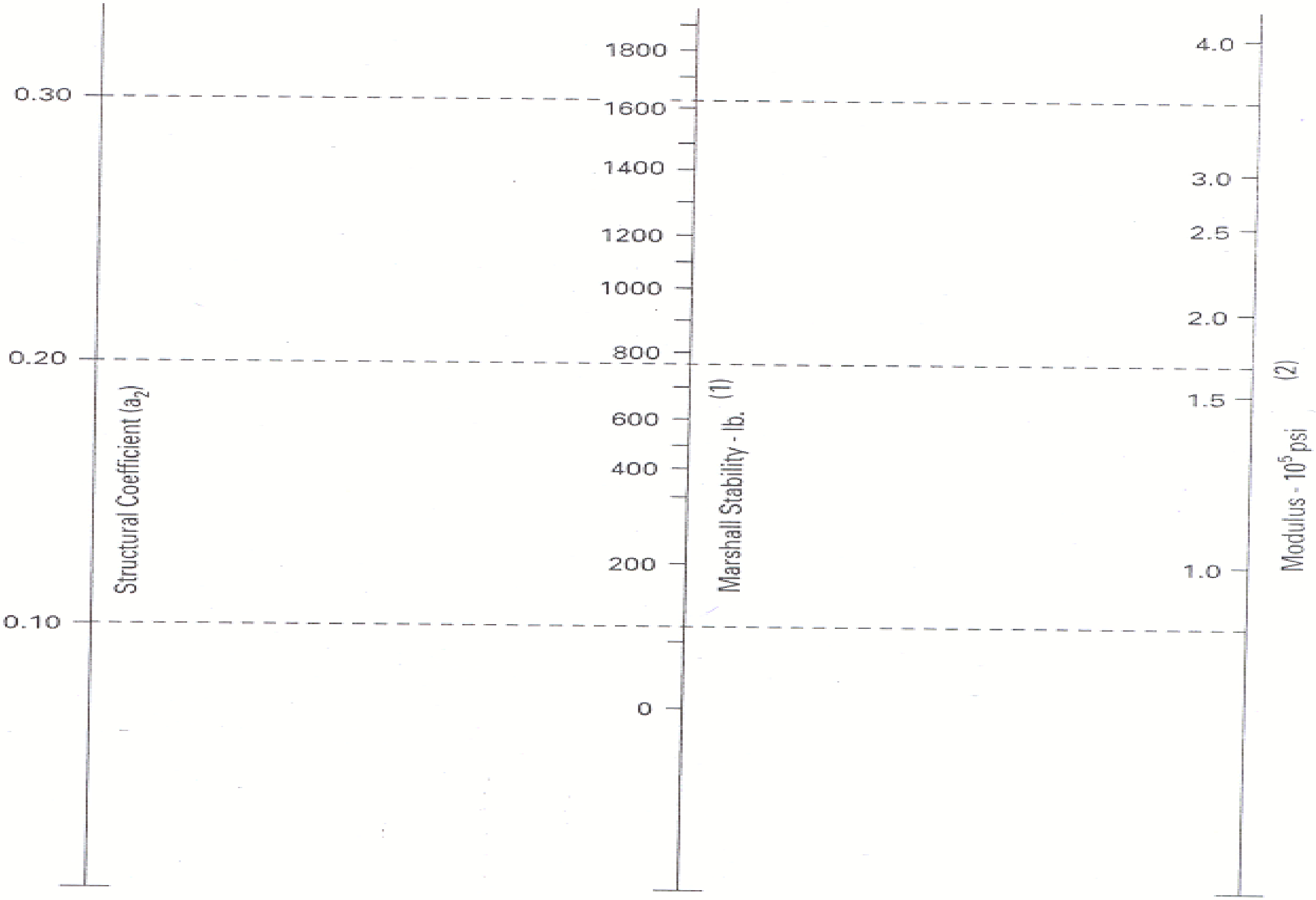
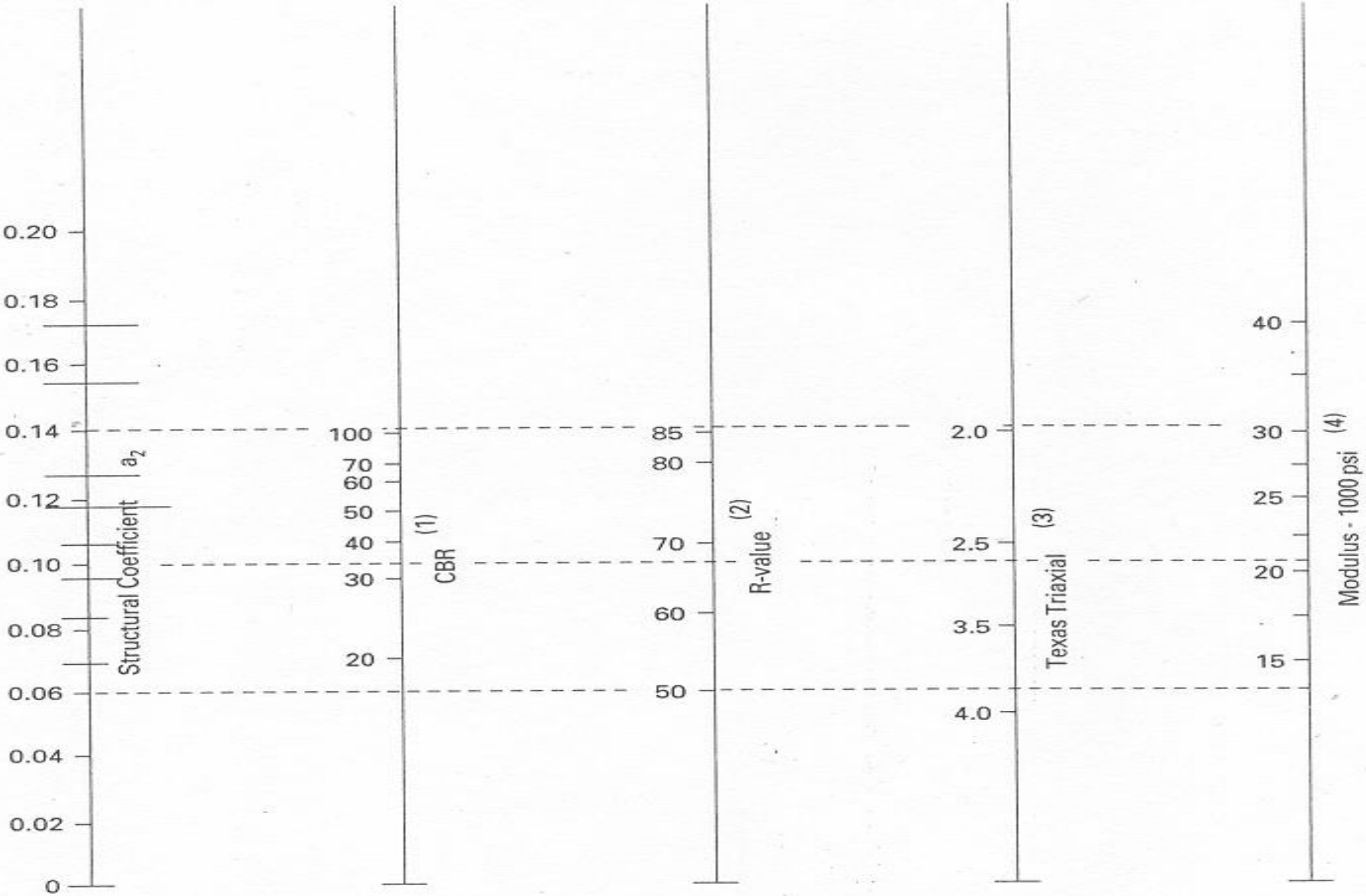


FIGURE 16-13 Chart for estimating structural layer coefficient of dense-graded asphalt concrete based on the elastic (resilient) modulus. (Courtesy American Association of State Highway and Transportation Officials.)



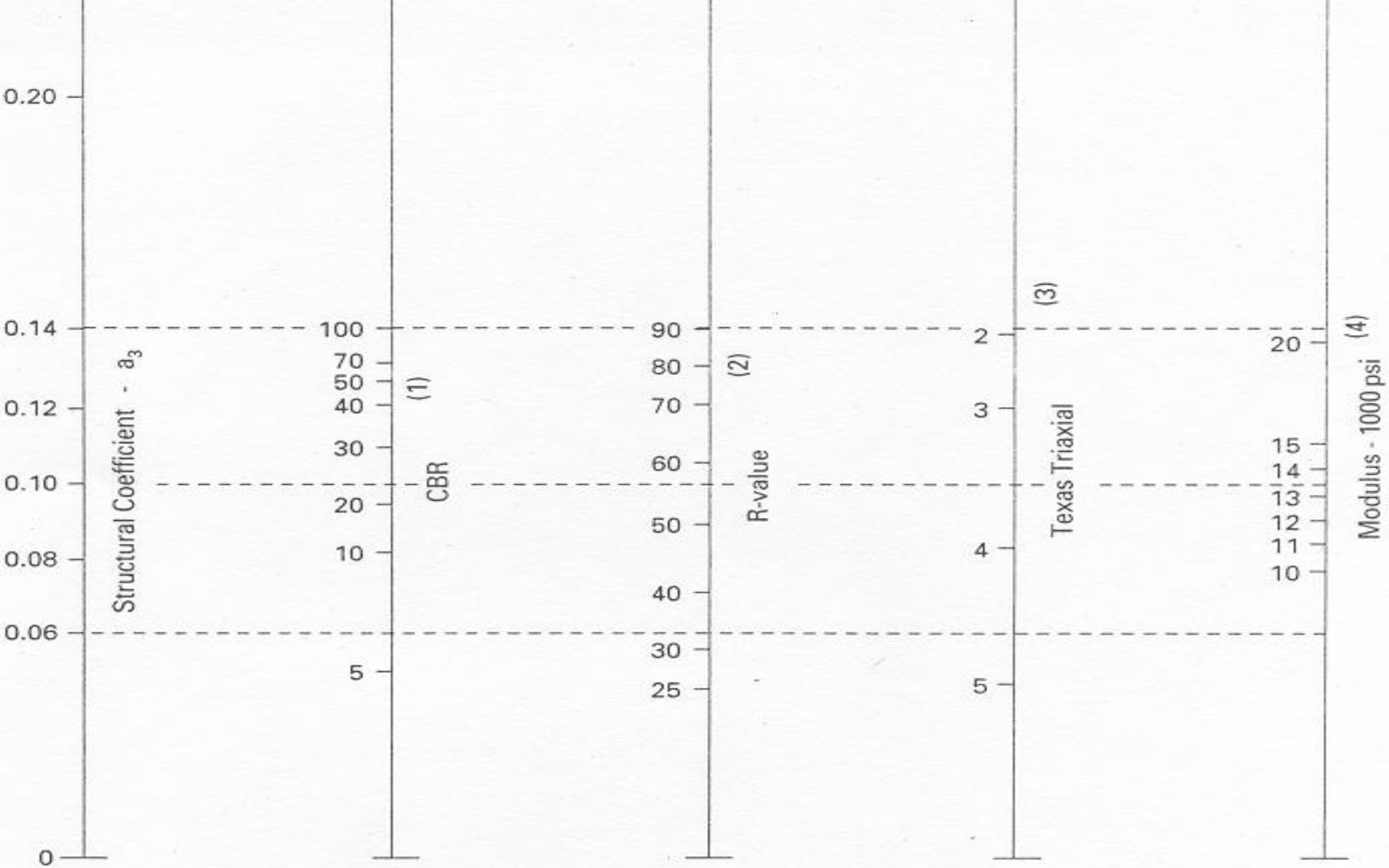
(1) Scale derived by correlation obtained from Illinois.
(2) Scale derived on NCHRP project (4).

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



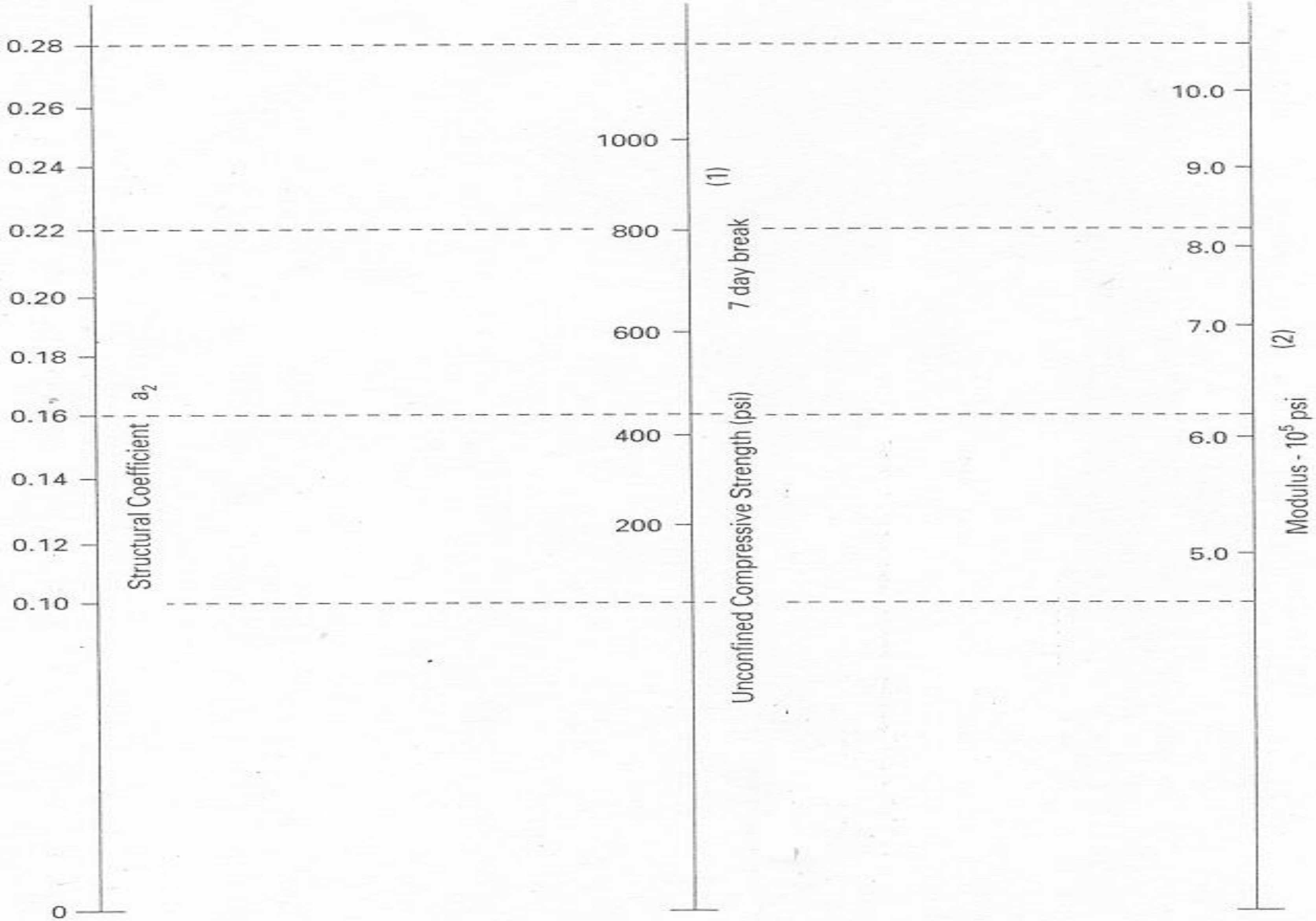
(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on NCHRP project *(4)*.

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

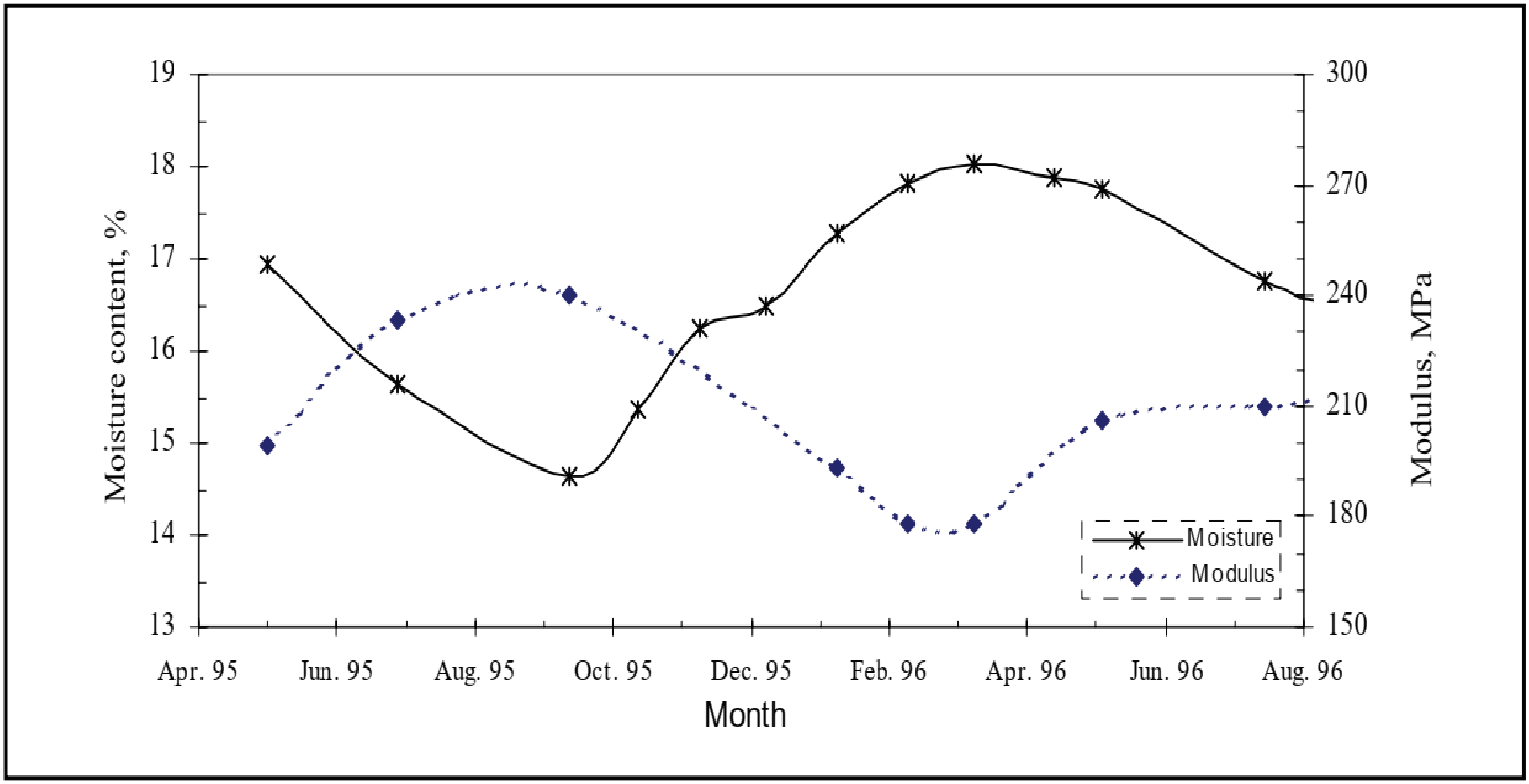
- Temperature and Rainfall are the two main environmental factors used in evaluating pavement performance in the AASHTO method.
- Effect of temperature includes:
    - Stresses induced by thermal action.
    - Changes in creep properties.
    - Effect of freezing and thawing on subgrade soil.
- Effect 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 cont.

- 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.
- 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.

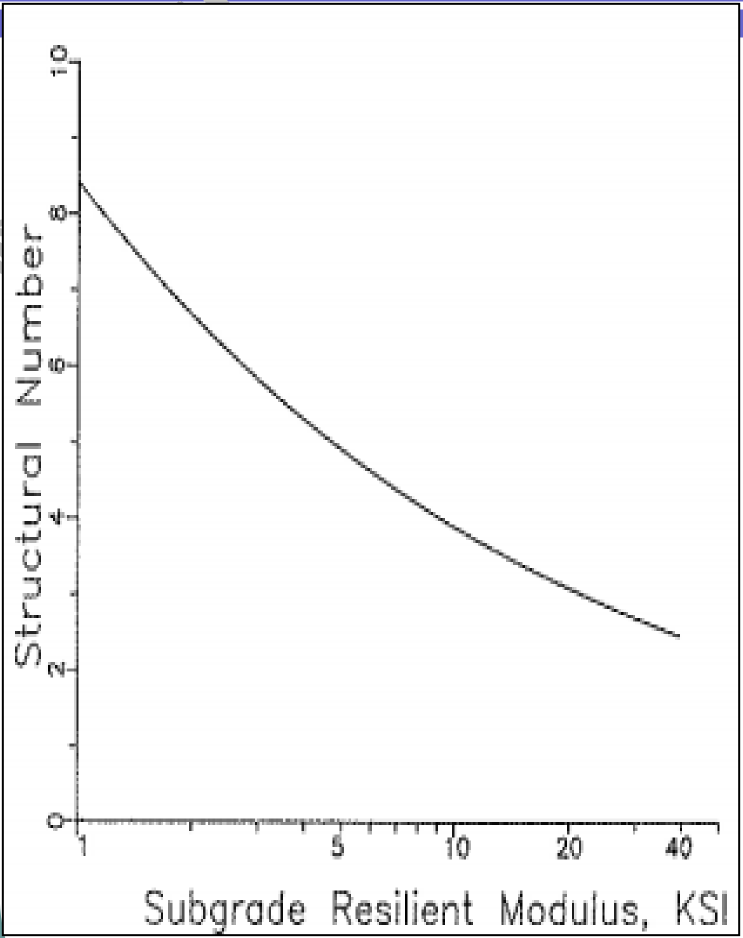
Subgrade Mr Seasonal Variation

Moisture content effects on Mr

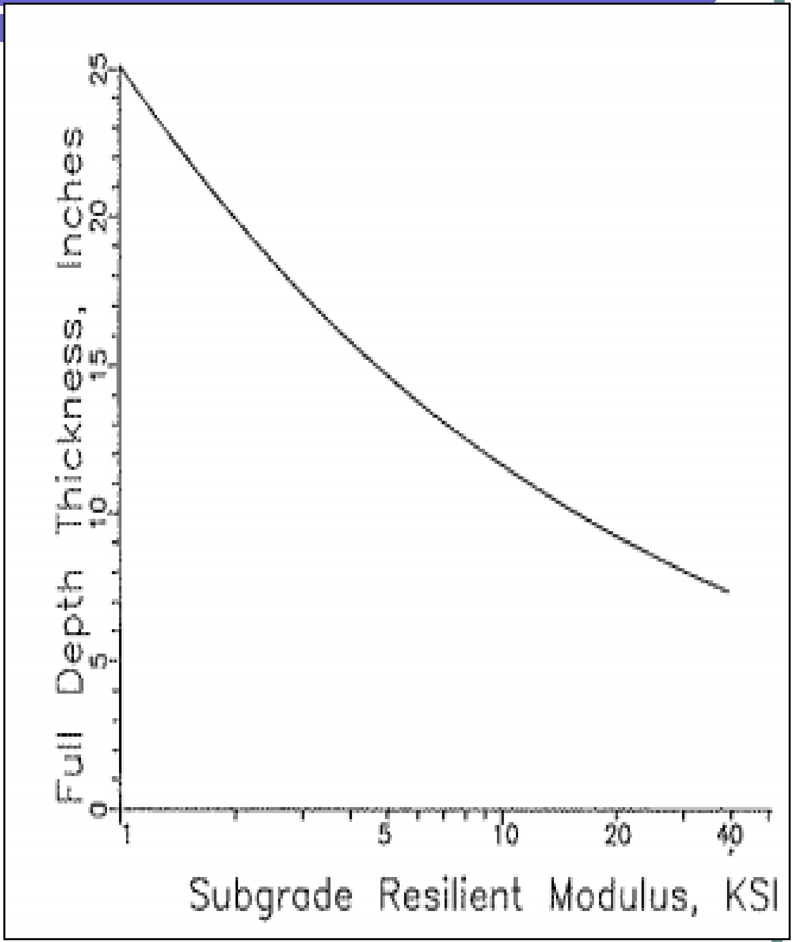


Roadbed Soils (Subgrade Material)

Effects of Mr on AASHTO 1993 Design



Effect of subgrade resilient modulus on design structural number



Effect of subgrade resilient modulus on design thickness

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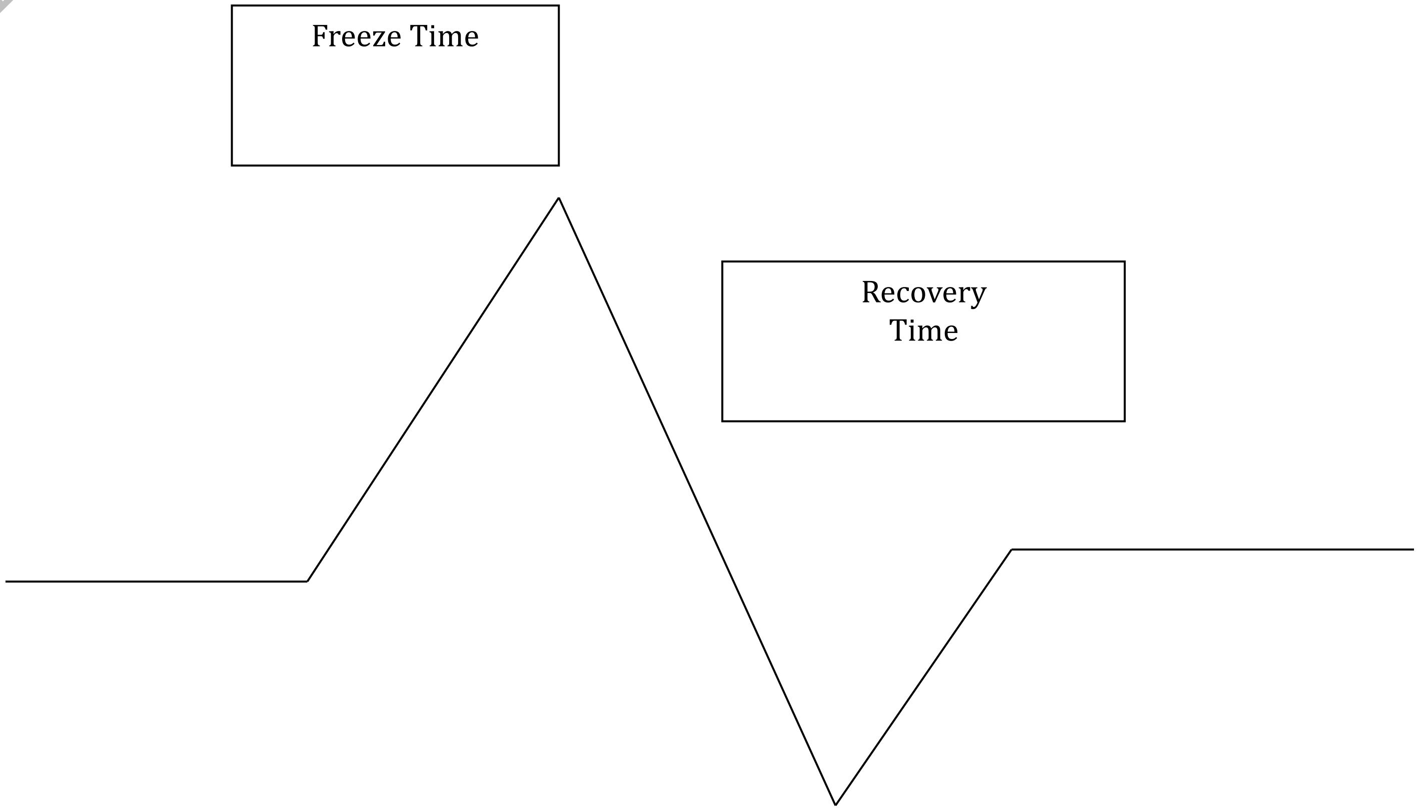
Subgrade Mr Seasonal Variation

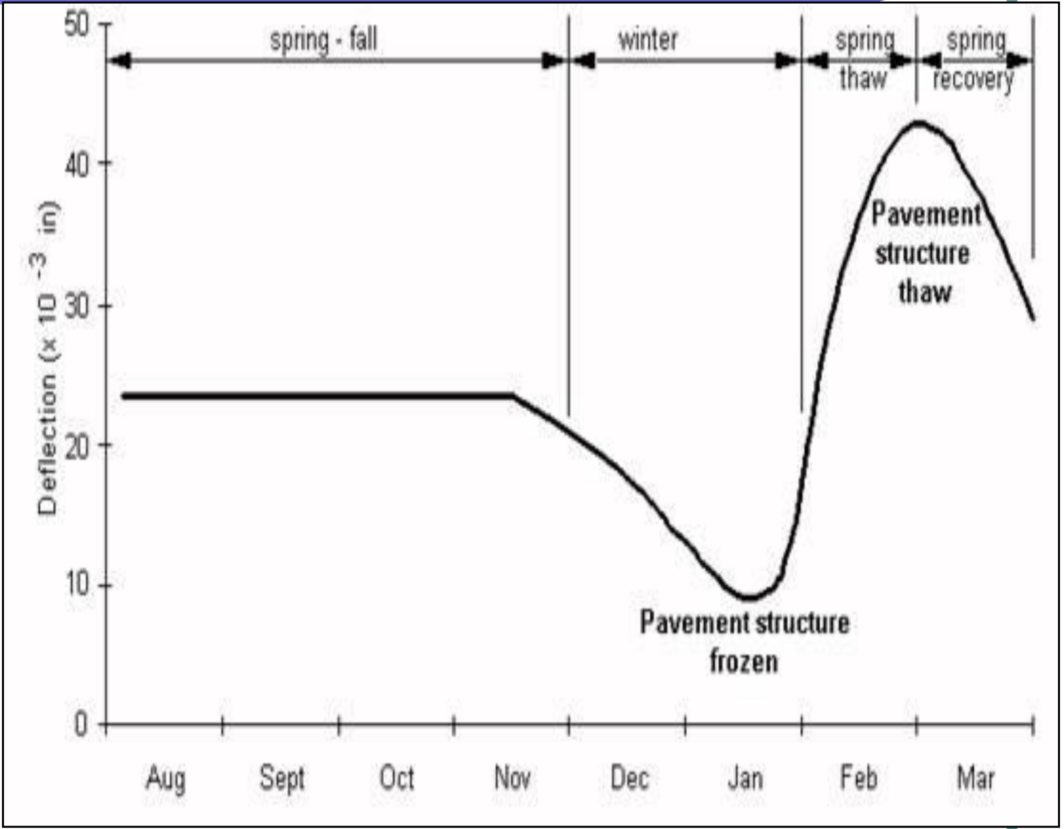


Freeze Time

Recovery Time

Frost Action in Soils

- During winter
  - Frost Heave : Distortion or expansion of the subgrade soil or base during freezing temperatures.
  - An upward movement of the subgrade resulting from the expansion of accumulated soil moisture as it freezes.
- 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).



Roadbed Soils (Subgrade Material)

Mr seasonal variation

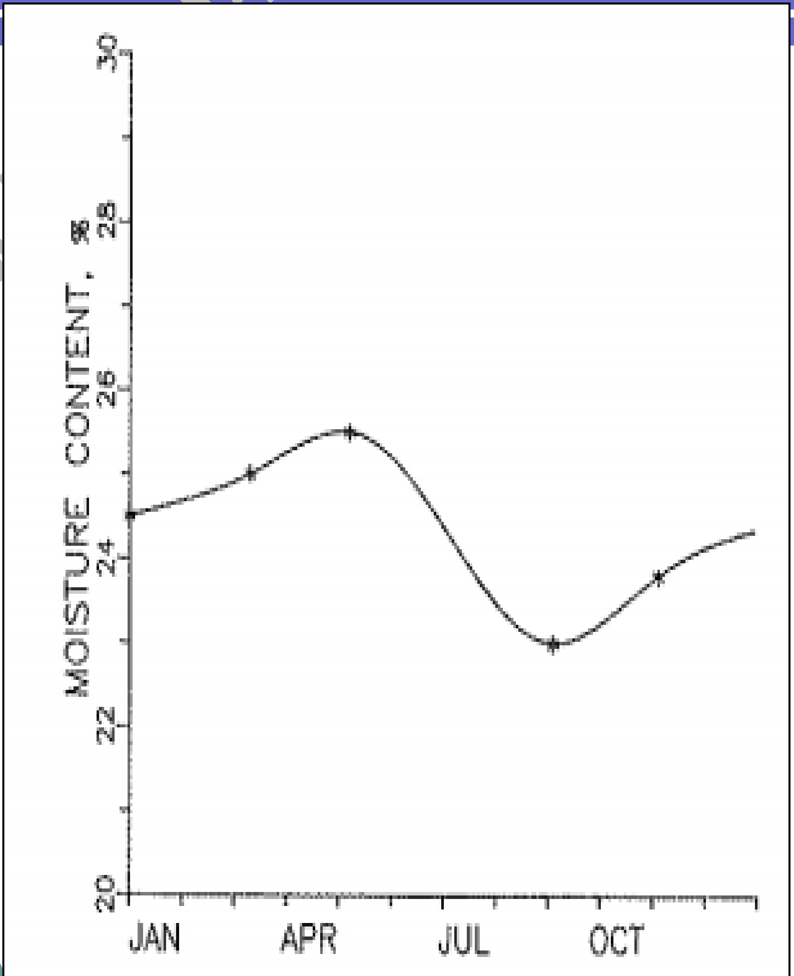


FIGURE 13 Seasonal moisture variation used in example.

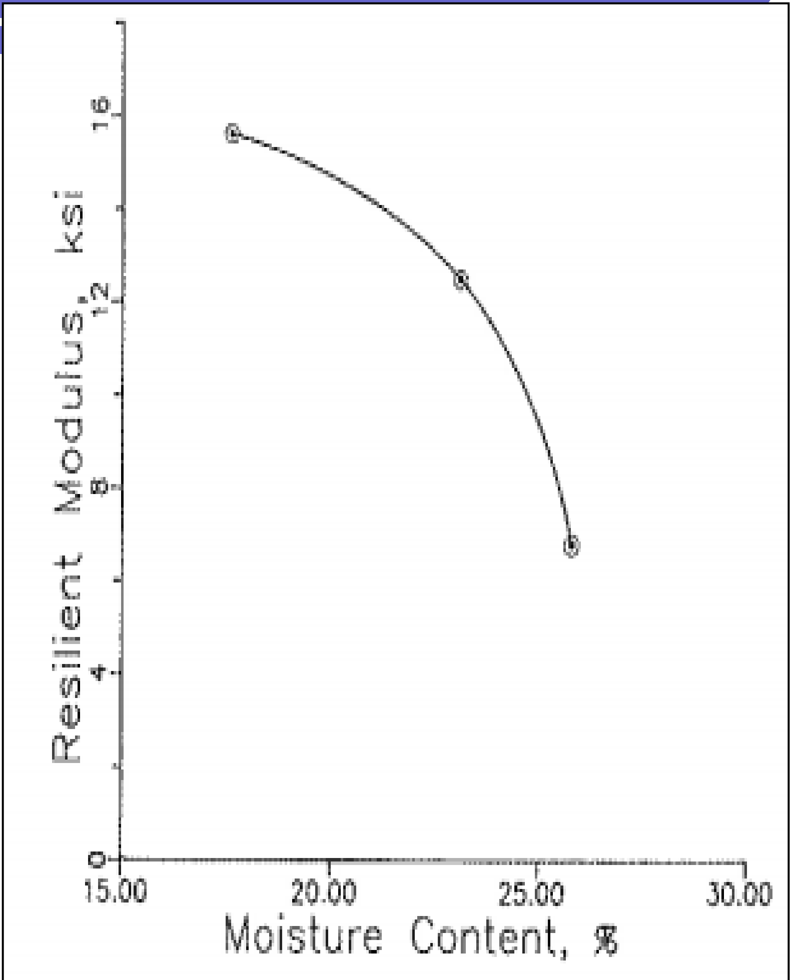


FIGURE 12 Moisture content-resilient modulus relationship for soil used in example.

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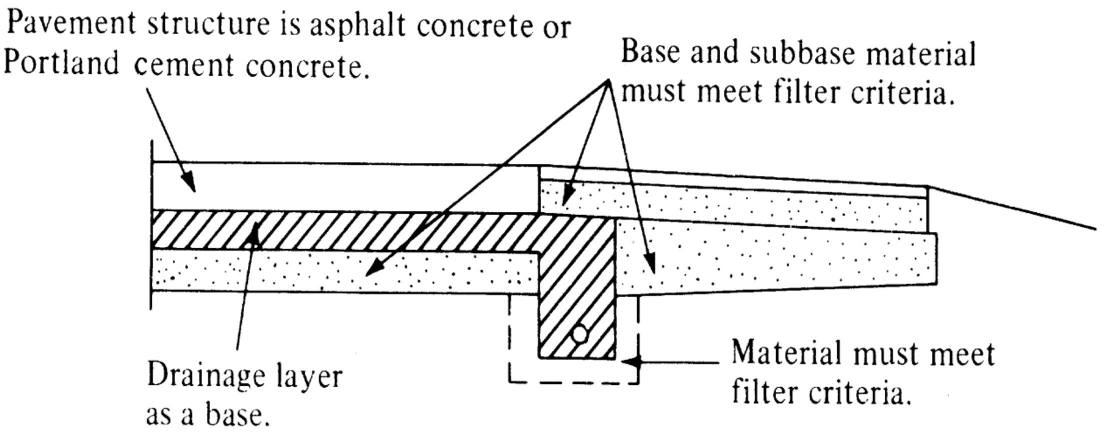
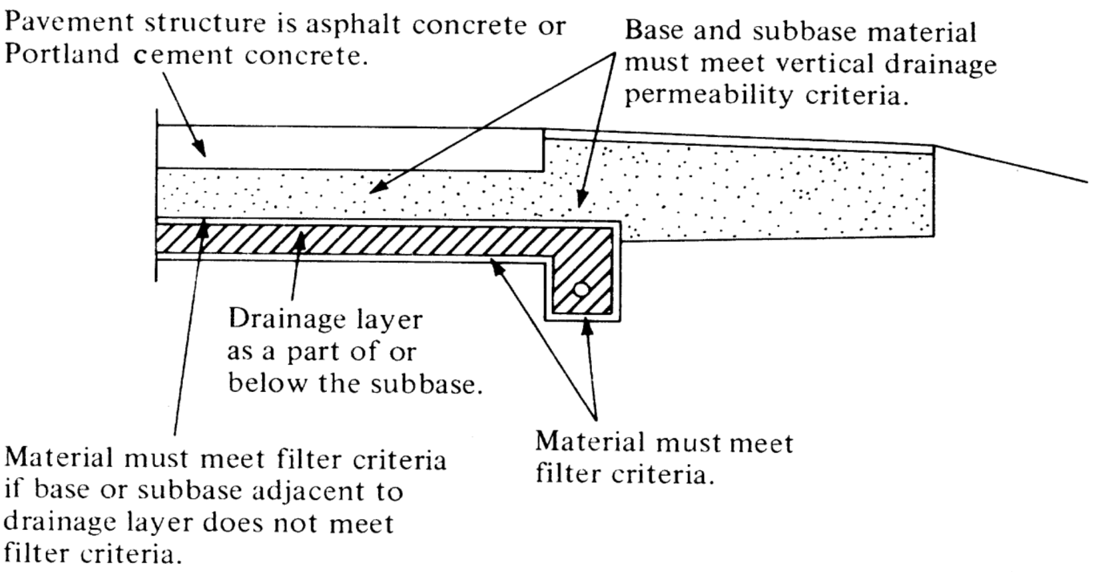
Drainage

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



(a) **Base is used as the drainage layer.**



(b) **Drainage layer is part of or below the subbase.**

Note: Filter fabrics may be used in lieu of filter material, soil, or aggregate, depending on economic considerations.

Drainage

- The coefficient of drainage 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 19.5*** below 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

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

* time required to drain base layer to 50% saturation

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.
- The reliability factor is comprised of two variables:
  - Z_R = standard normal deviate
  - S_o = combined standard error of the traffic and performance prediction.

Reliability

- The level of reliability to be used for design should increase with the increase of
  - The volume of traffic.
  - Difficulty of diverting traffic.
  - Public expectation of availability.

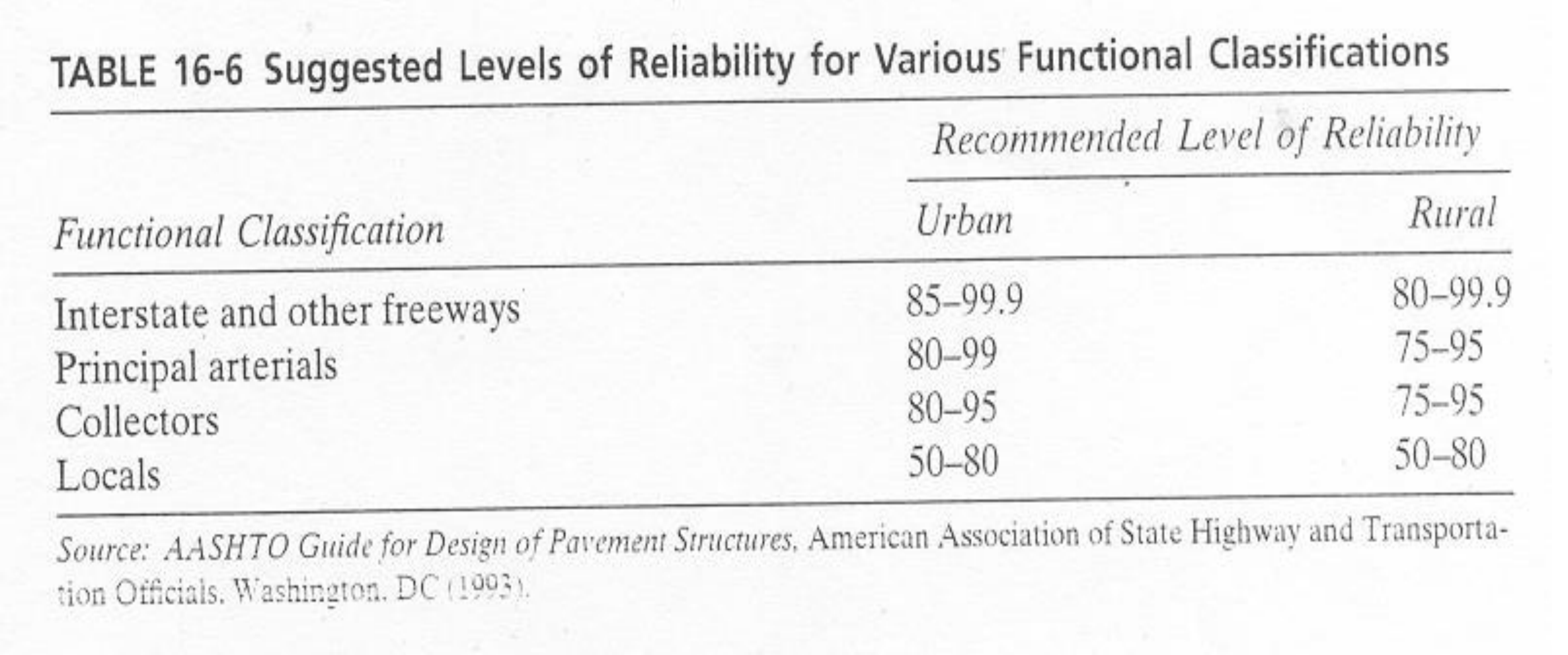


TABLE 16-6 Suggested Levels of Reliability for Various Functional Classifications

	Recommended Level of Reliability	
Functional Classification	*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

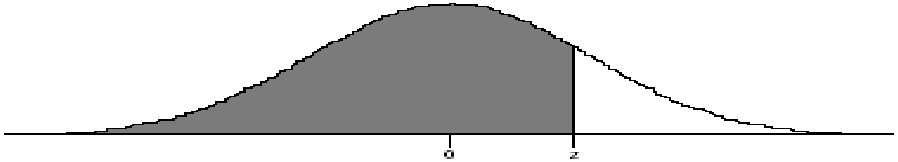
- ***So***: Overall standard deviation that accounts for standard deviation (or variation) in materials & construction, chance variation in traffic prediction, and normal variation in pavement performance.
- So = 0.45 for flexible pavement (0.40 - 0.50)
- So = 0.35 for rigid pavements (0.30 -0.40).
- 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.

Table 19.8 Standard Normal Deviation (Z_R) Values Corresponding to Selected Levels of Reliability

Reliability (R%)	*Standard Normal Deviation, Z_R*
50	−0.000
60	−0.253
70	−0.524
75	−0.674
80	−0.841
85	−1.037
90	−1.282
91	−1.340
92	−1.405
93	−1.476
94	−1.555
95	−1.645
96	−1.751
97	−1.881
98	−2.054
99	−2.327
99.9	−3.090
99.99	−3.750

SOURCE: Adapted with permission from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

The standard normal table value corresponding to a desired probability of exceedance level.



Normal Deviate z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-4.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-3.9	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-3.8	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-3.7	.0001	.0001	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-3.6	.0002	.0002	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.5	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002
-3.4	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
-3.3	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
-3.2	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
-3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
-3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
-2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
-2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
-2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
-2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
-2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
-2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
-2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
-2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
-2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
-2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
-1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
-1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
-1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
-1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
-1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
-1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
-1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
-1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
-1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
-1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
-.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
-.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
-.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
-.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
-.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
-.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
-.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483

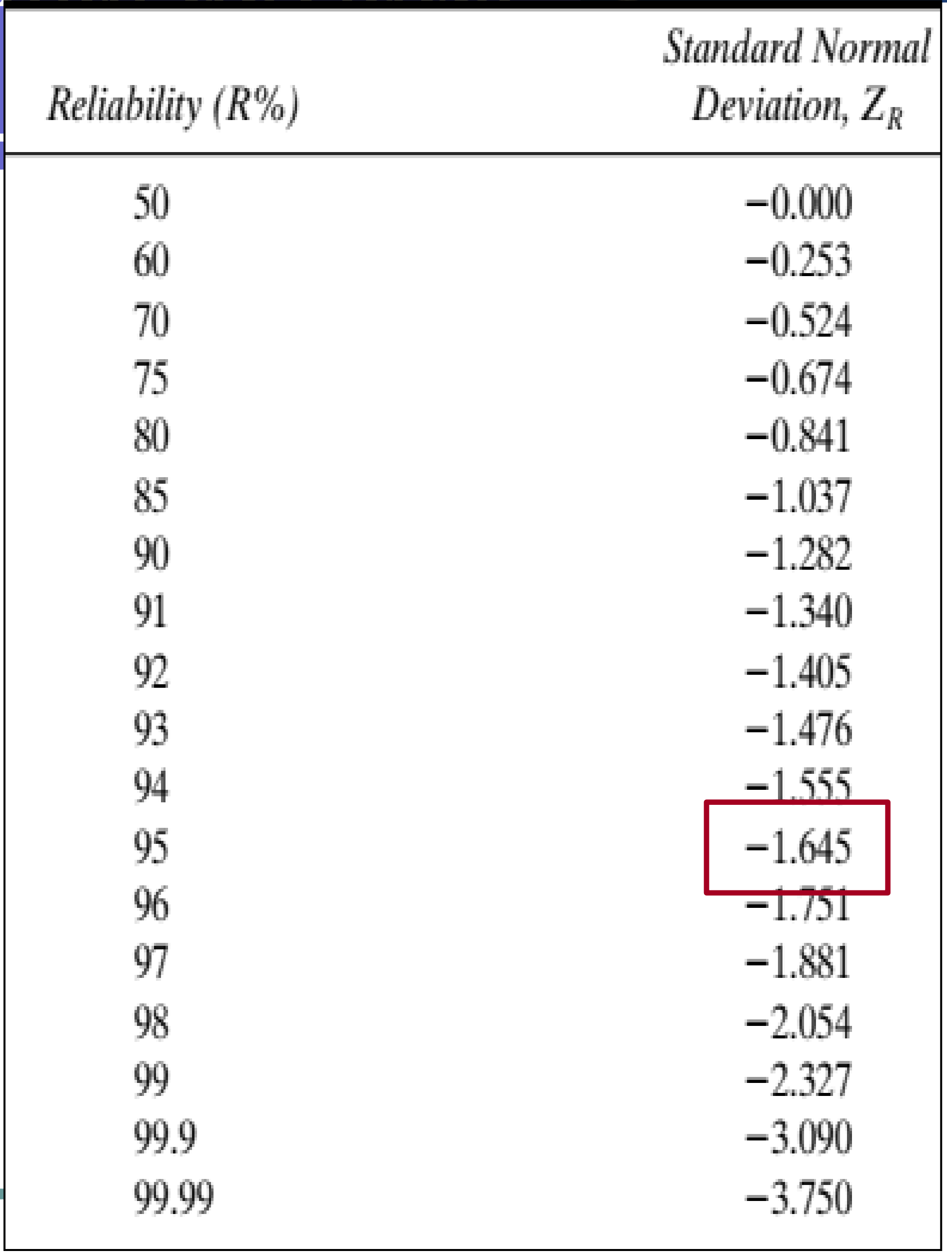
Z_R = standard normal deviate.

Example

A designer may specify that there should only be a 5 % chance that the design does not last a specified number of years (e.g., 20 years).

This is the same as stating that there should be a 95 % chance that the design does last the specified number of years (e.g., 20 years).

- Then,
  - the reliability is 95 % (100 % – 5 %)
  - The corresponding Z_R value is -1.645



Reliability (R%)	Standard Normal Deviation, Z_R
50	−0.000
60	−0.253
70	−0.524
75	−0.674
80	−0.841
85	−1.037
90	−1.282
91	−1.340
92	−1.405
93	−1.476
94	−1.555
95	−1.645
96	−1.751
97	−1.881
98	−2.054
99	−2.327
99.9	−3.090
99.99	−3.750

Structural Design Concept

- 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

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

where

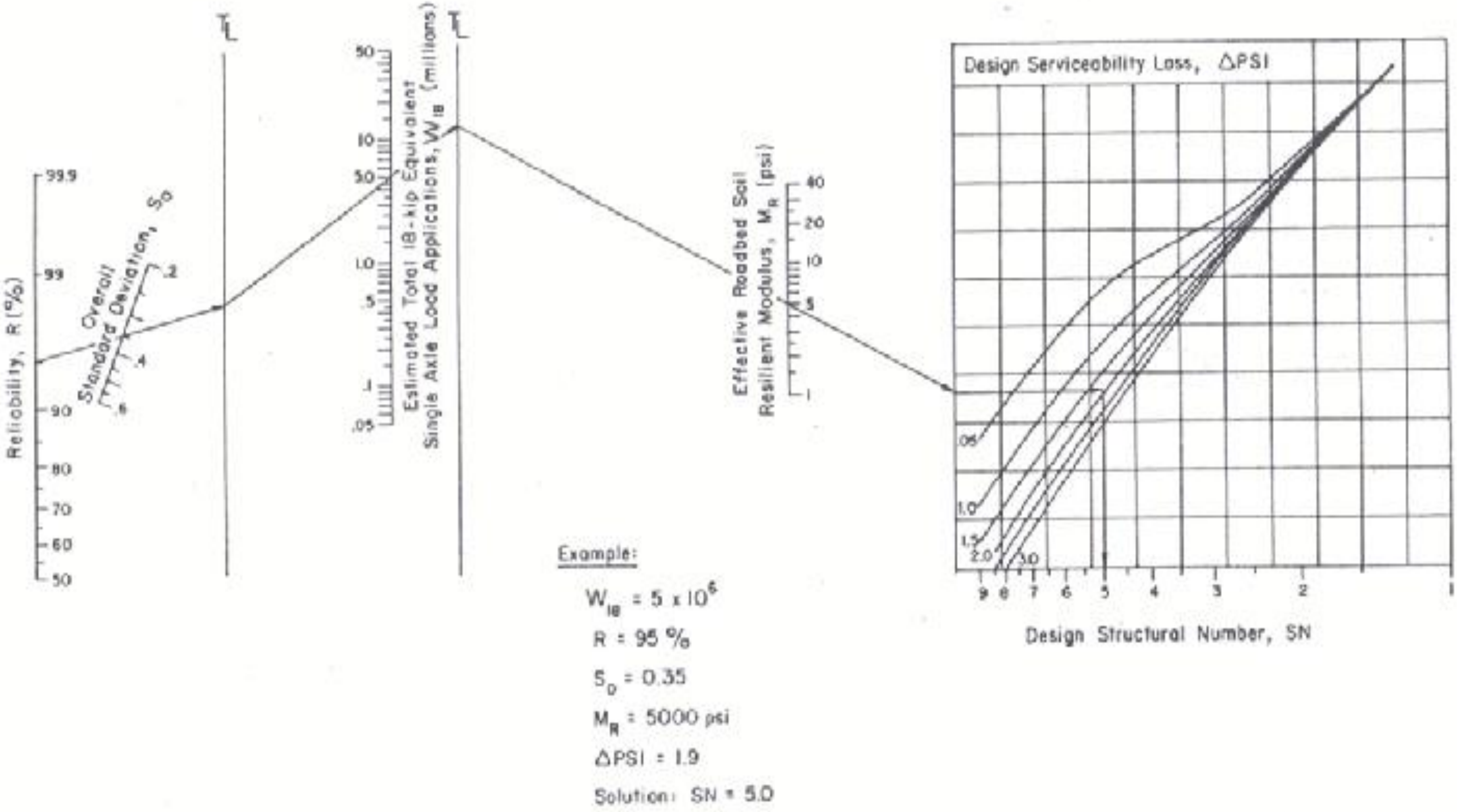
W_{18} = predicted number of 18,000-lb (80 kN) single-axle load applications
Z_R = standard normal deviation for a given reliability
S_o = overall standard deviation
SN = structural number indicative of the total pavement thickness
$\Delta\mathrm{PSI} = p_i - p_t$

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:

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



Example:

$W_{18} = 5 \times 10^6$

R = 95 %

$S_o = 0.35$

M_R = 5000 psi

ΔPSI = 1.9

Solution: SN = 5.0

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.

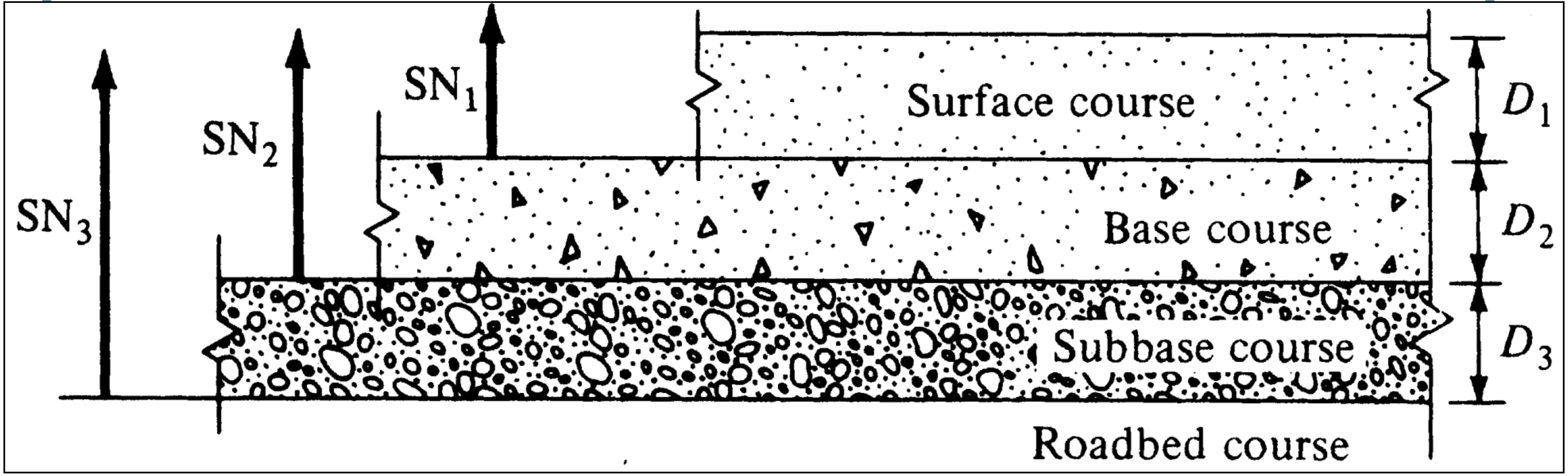
Structural Number (SN)

There are three type of **SN** :

SN1 = The structure number require to protect base layer

SN2 = The structure number require to protect subbase layers

SN3 = The structure number require to protect (roadbed) subgrade layer



Design steps

- ***Step -1:***

  - Determine the Structural Number (SN) for pavement layers

    - SN_1 = The structure number require to protect base layer
    - SN_2 = The structure number require to protect subbase layers
    - SN_3 = The structure number require to protect (roadbed) subgrade layer

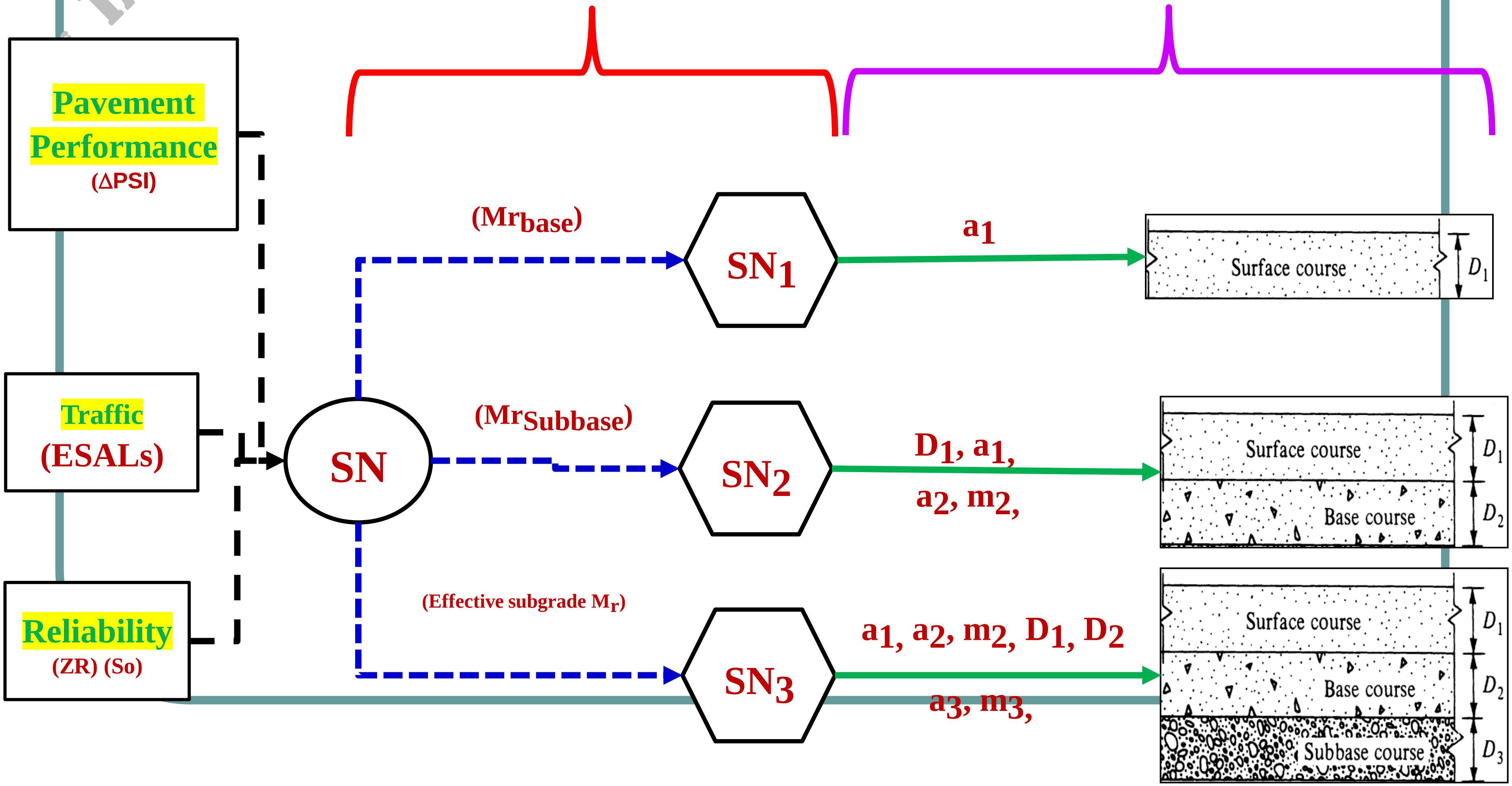
- ***Step -2 :***

  - Estimate the required layers thickness based on SNs values

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

Step-1 :SN determination

Step-2 :Thickness determination



Step -1:

Determination of Pavement Layers Structural Numbers (SNs)

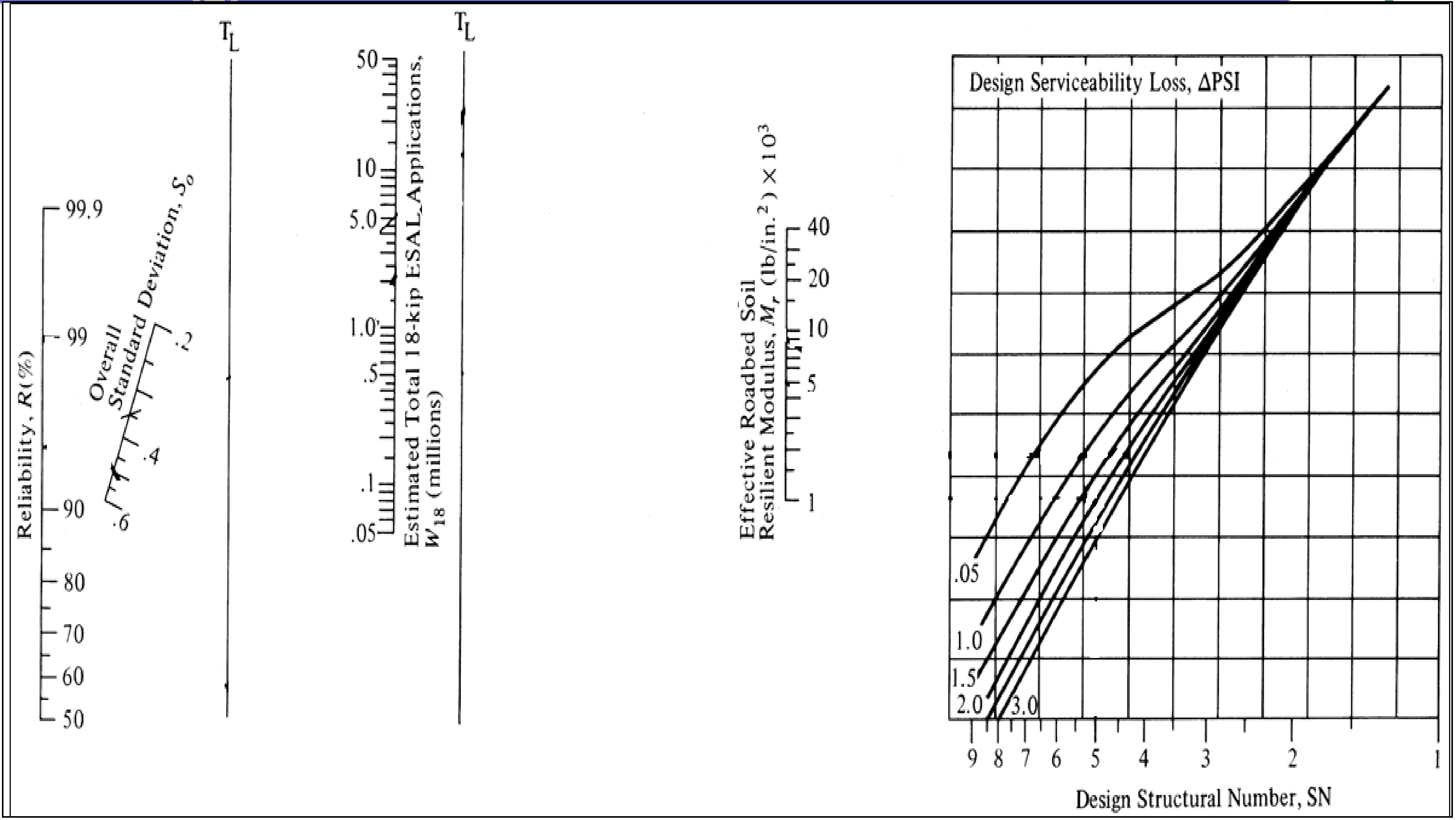
SN Determenation

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

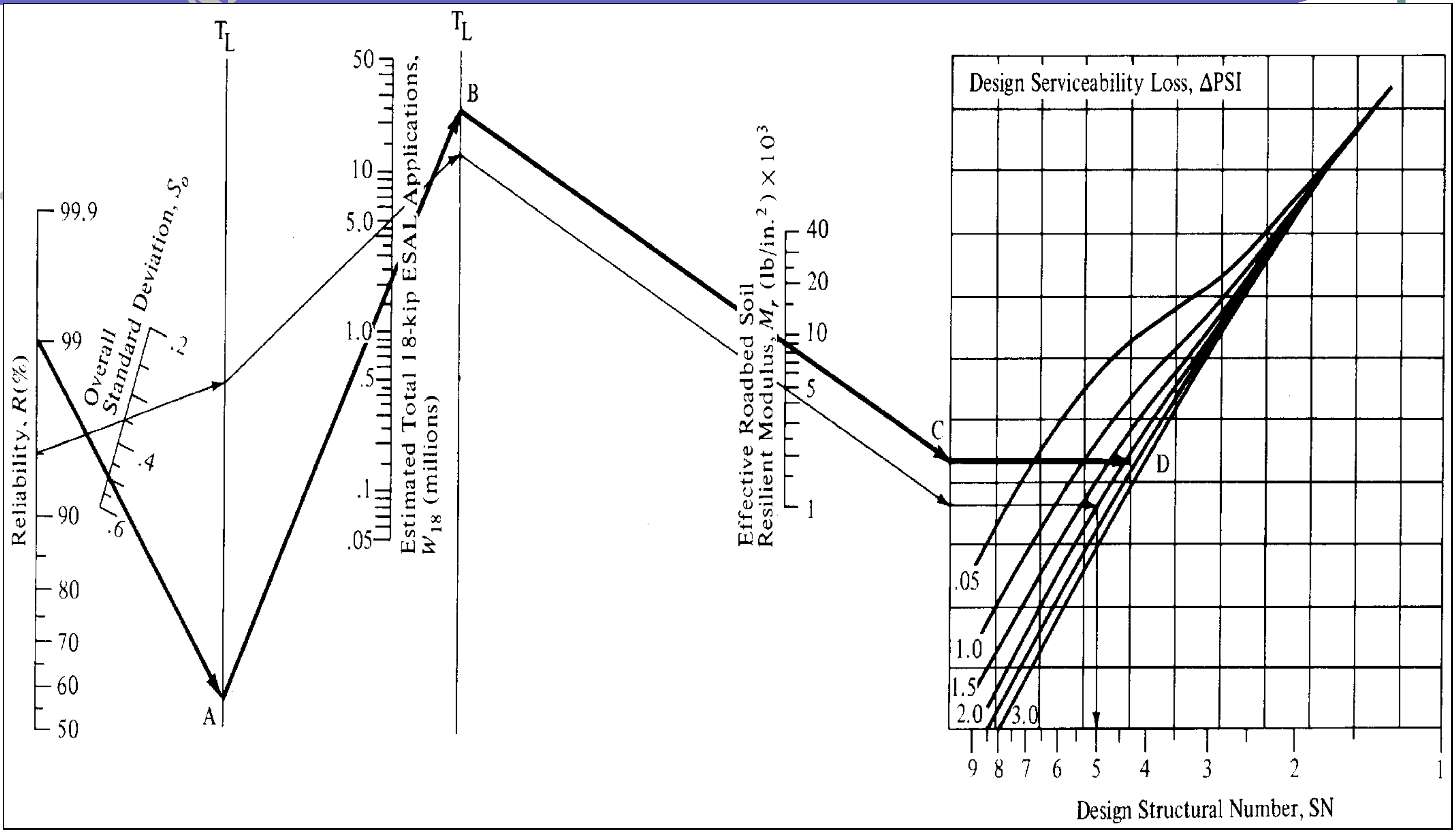
- W_{18} = predicted number of 18,000-lb (80 kN) single-axle load applications
- Z_R = standard normal deviation for a given reliability
- S_o = overall standard deviation
- SN = structural number indicative of the total pavement thickness

- $\Delta PSI = p_i - p_t$
- p_i = initial serviceability index
- p_t = terminal serviceability index
- Mr = resilient modulus for Base, subbase, and effective subgrade layers lb/in²

SN determenation/ Design Chart for flexible pavement (Nomograph solution)



SN determenation



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:

$$D_1 \geq \frac{SN_1}{a_1}$$

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”).

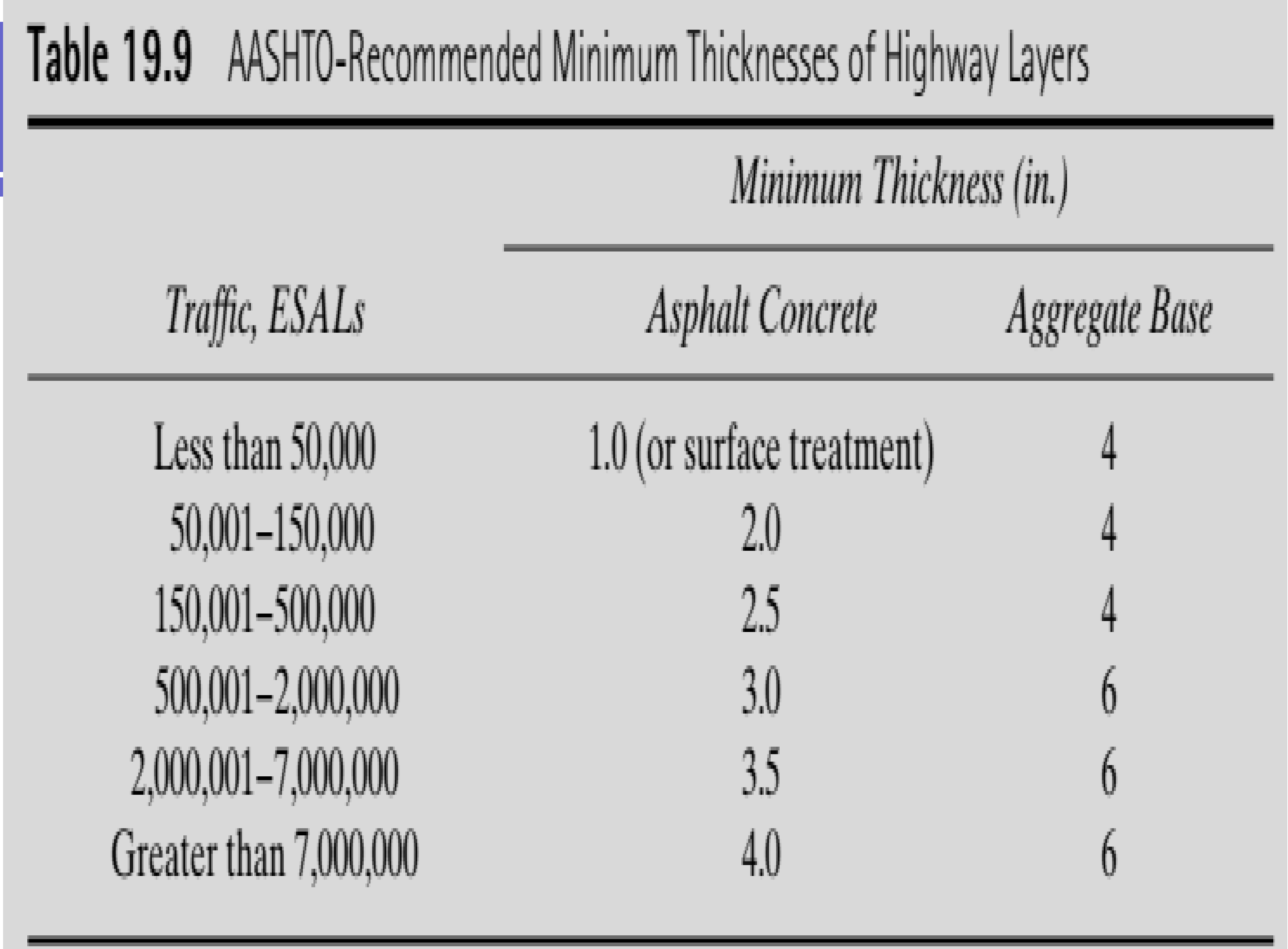


Table 19.9 AASHTO-Recommended Minimum Thicknesses of Highway Layers

	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

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:

$$D_2 \geq \frac{SN_2 - a_1 \times D_1^*}{a_2 m_2}$$

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

General Procedure for Selection Layer Thickness Cont.

- 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:

$$D_3 \geq \frac{SN_3 - a_1 \times D_1^{**} - a_2 \times D_2^{**}}{a_3 m_3}$$

2. The computed thickness (D_3) is also rounded up to the nearest one-half inch (D3*).

Example 1 (20.8 in text)

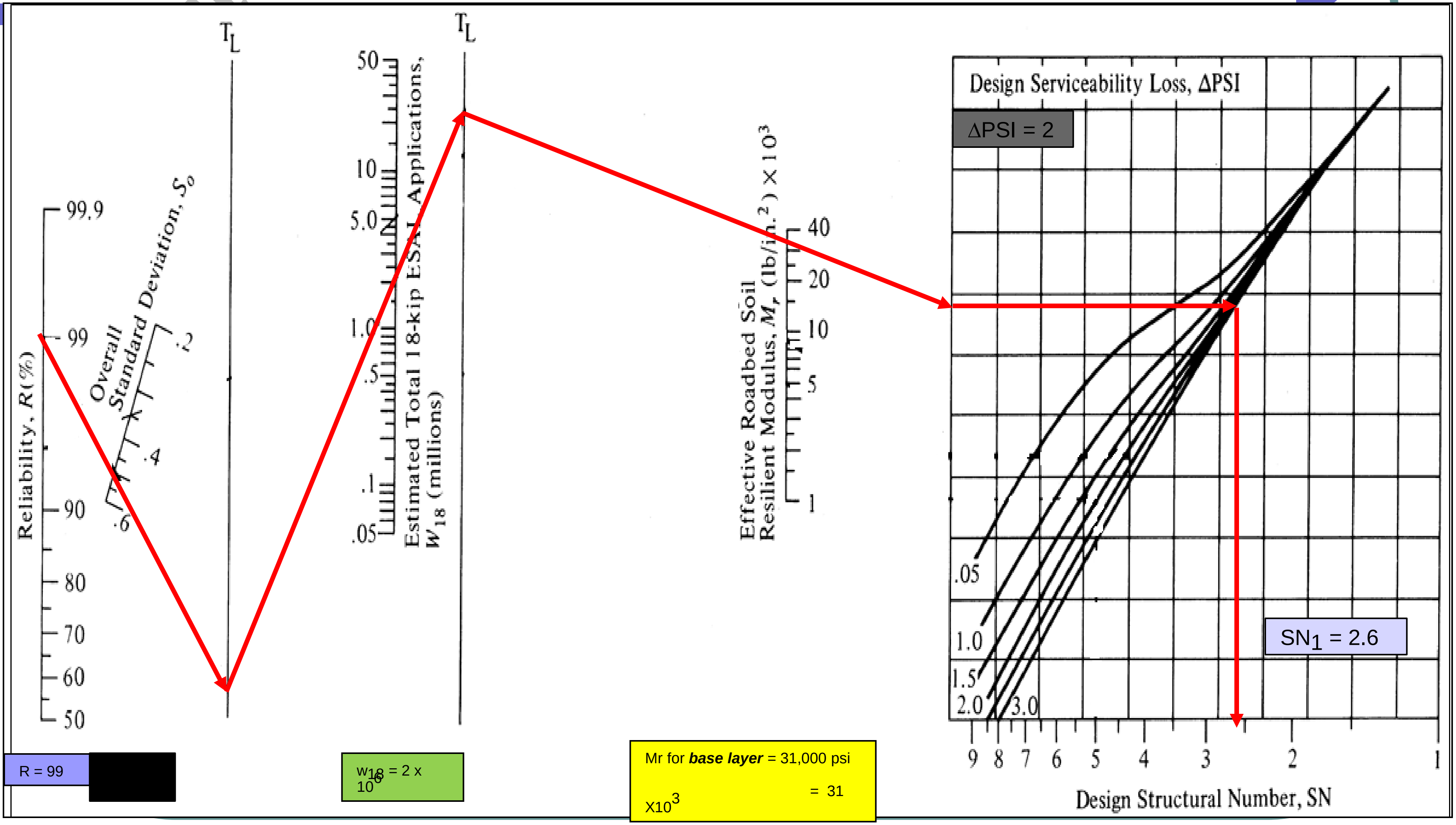
- A flexible pavement for an urban interstate highway.
- ESAL = 2x 10^6
- It takes about a week for water to be drained from within the pavement.
- The pavement structure will be exposed to moisture levels approaching saturation for 30% of time.
- Resilience modulus of asphalt concrete = 450,000 psi.
- 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

Determination of SN_1 (to protect base layer)



ΔPSI = 2

$SN_1 = 2.6$

R = 99 [redacted]

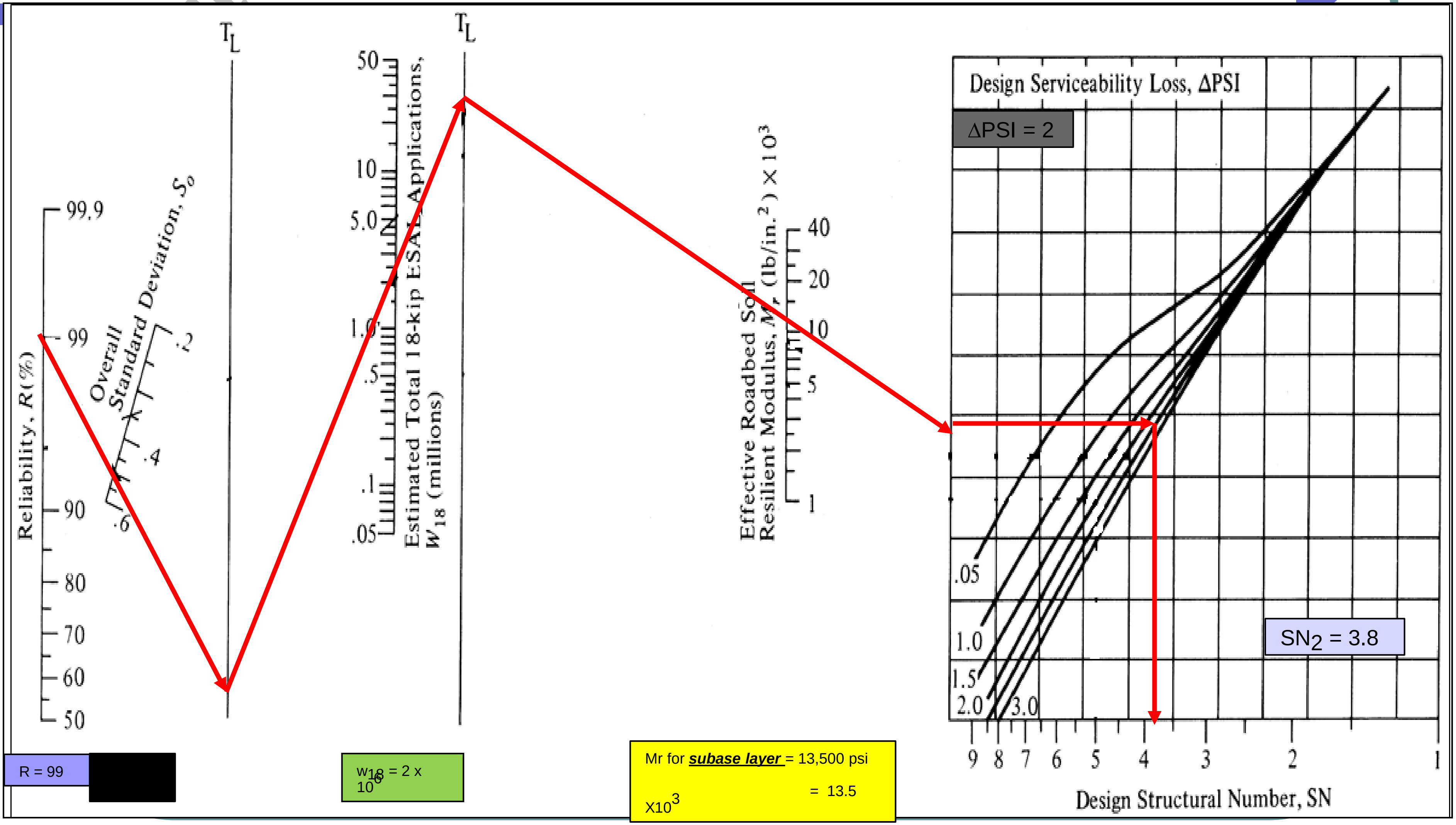
$w_{18} = 2 \times 10^6$

Mr for ***base layer*** = 31,000 psi = 31 X10^3

Follow the red line

Example 1 solution

Determination of SN_2 (to protect subase layer)



ΔPSI = 2

SN_2 = 3.8

R = 99 [redacted]

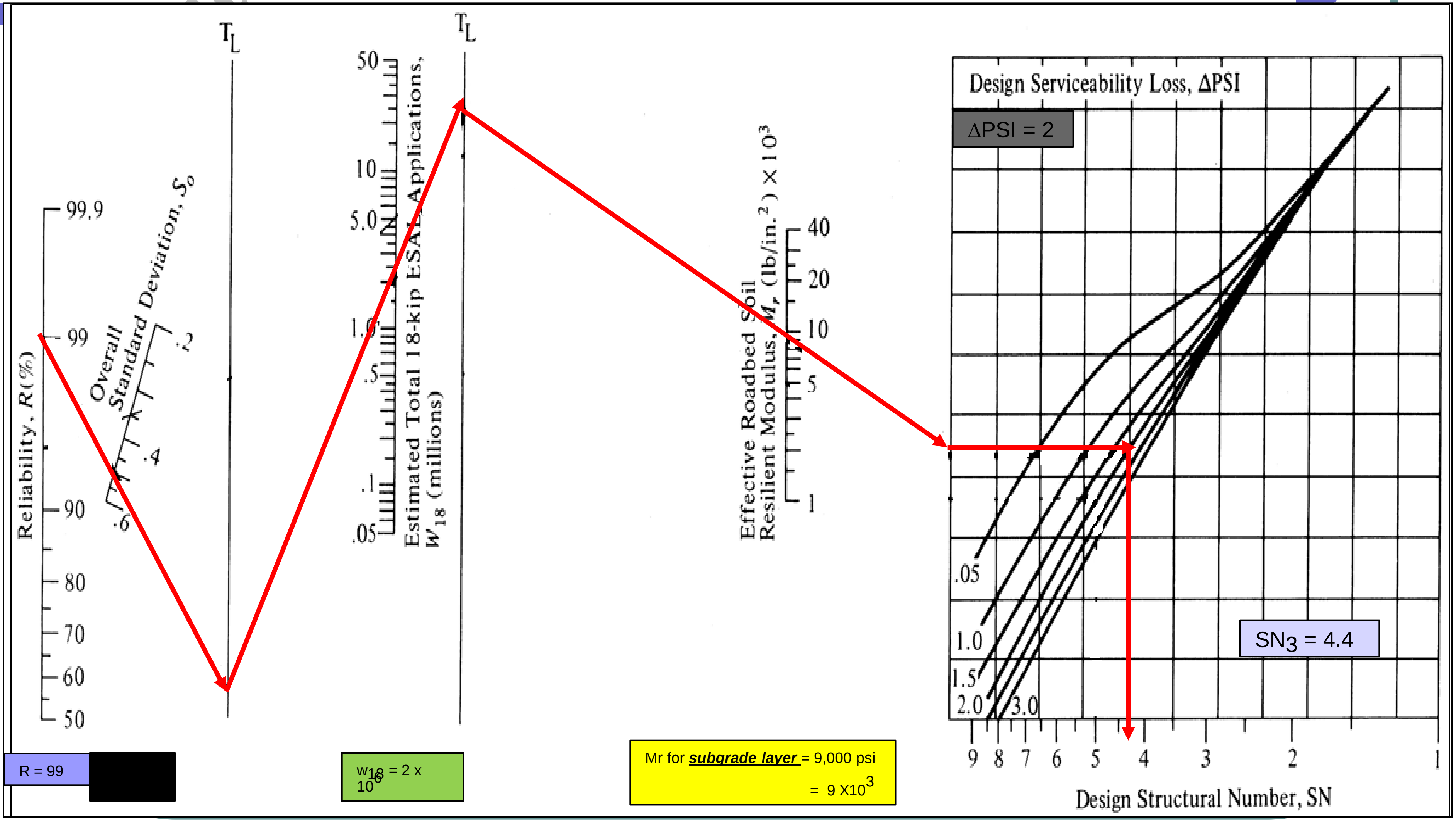
w_{18} = 2 x 10^6

Mr for ***subase layer*** = 13,500 psi = 13.5 X10^3

Follow the red line

Example 1 solution

Determination of SN$_3$ (to protect Subgrade layer



ΔPSI = 2

SN$_3$ = 4.4

R = 99 [redacted]

w_{18} = 2 x 10^6

Mr for ***subgrade layer*** = 9,000 psi = 9 X10^3

Follow the red line

Example 1 Solution

- Using E2 as Mr & Fig. 20.20

SN1 = 2.6

- $D_1 \geq \frac{SN_1}{a_1} = \frac{2.6}{0.44} = 5.9\ in$.... use 6 -in.

- Using E3 as Mr & Fig. 20.20

SN2 = 3.8

$$D_2 \geq \frac{SN_2 - a_1 \times D_1^*}{a_2 m_2} = \frac{3.8 - 0.44 \times 6.0}{0.14 \times 0.8} = 10.36$$

use D2”= 12 in (as per text book)or (10.5”)

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 (as per textbook)

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

Example 1 Solution

- Using subgrade Mr & Fig. 20.20

SN3 = 4.4

Alternatively (using D2” = 10.5)

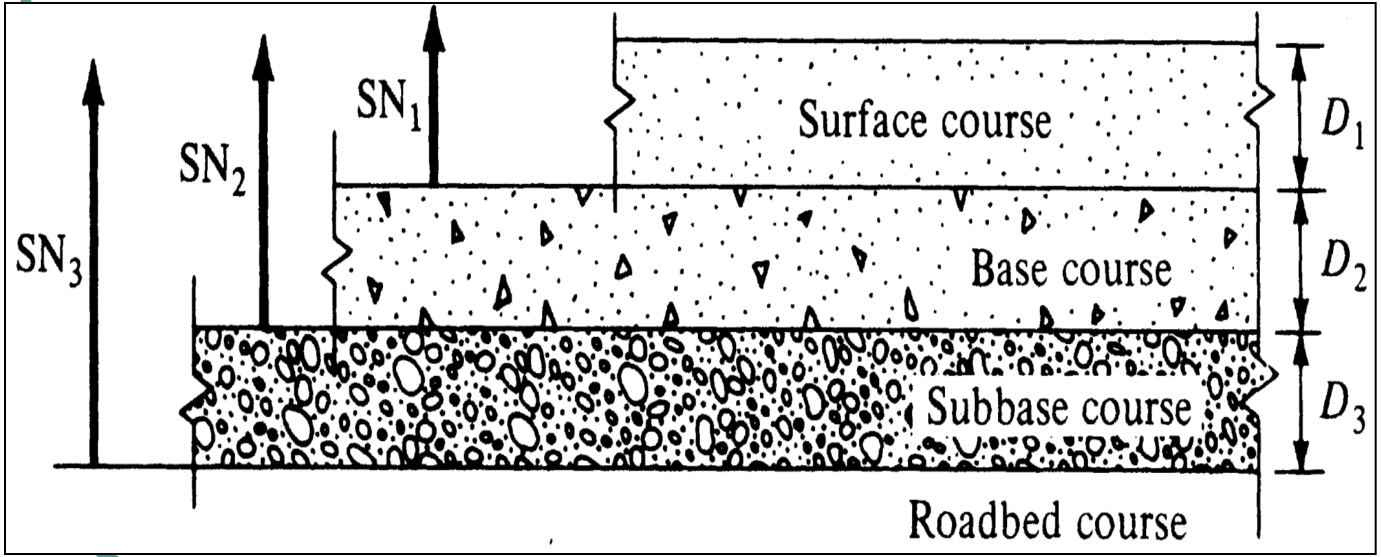
- $$D_3 \geq \frac{SN_3 - a_1 \times D_1^{**} - a_2 \times D_2^{**}}{a_3 m_3} = \frac{4.4 - 0.44 \times 6.0 - 0.14 \times 10.5}{0.1 \times 0.8} = \frac{.29}{0.08} = 3.625$$

Use D3”= 4 -in (as per textbook)

The pavement has a 6-in surface, an 10.5 -in base, and a 4-in subbase.

Example 1 Solution

- Report the selected values
- $D_1^{**} = 6\ in$
- $D_2^{**} = 10.5$ in
- $D_3 = 4$ in



6 in

10.5 in

4.0 in

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 -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- 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.

Pavement Materials & Design (110401466/2104011466)

Hot Mix Asphalt Production and Placement

Instructor:

Prof. TALEB M. AL-ROUSAN

HMA Manufacturing

HMA is produced in a plant that proportions, blends, and heats aggregate and asphalt to produce a HMA that conforms to job mix formula (JMF) requirements.

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.

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.

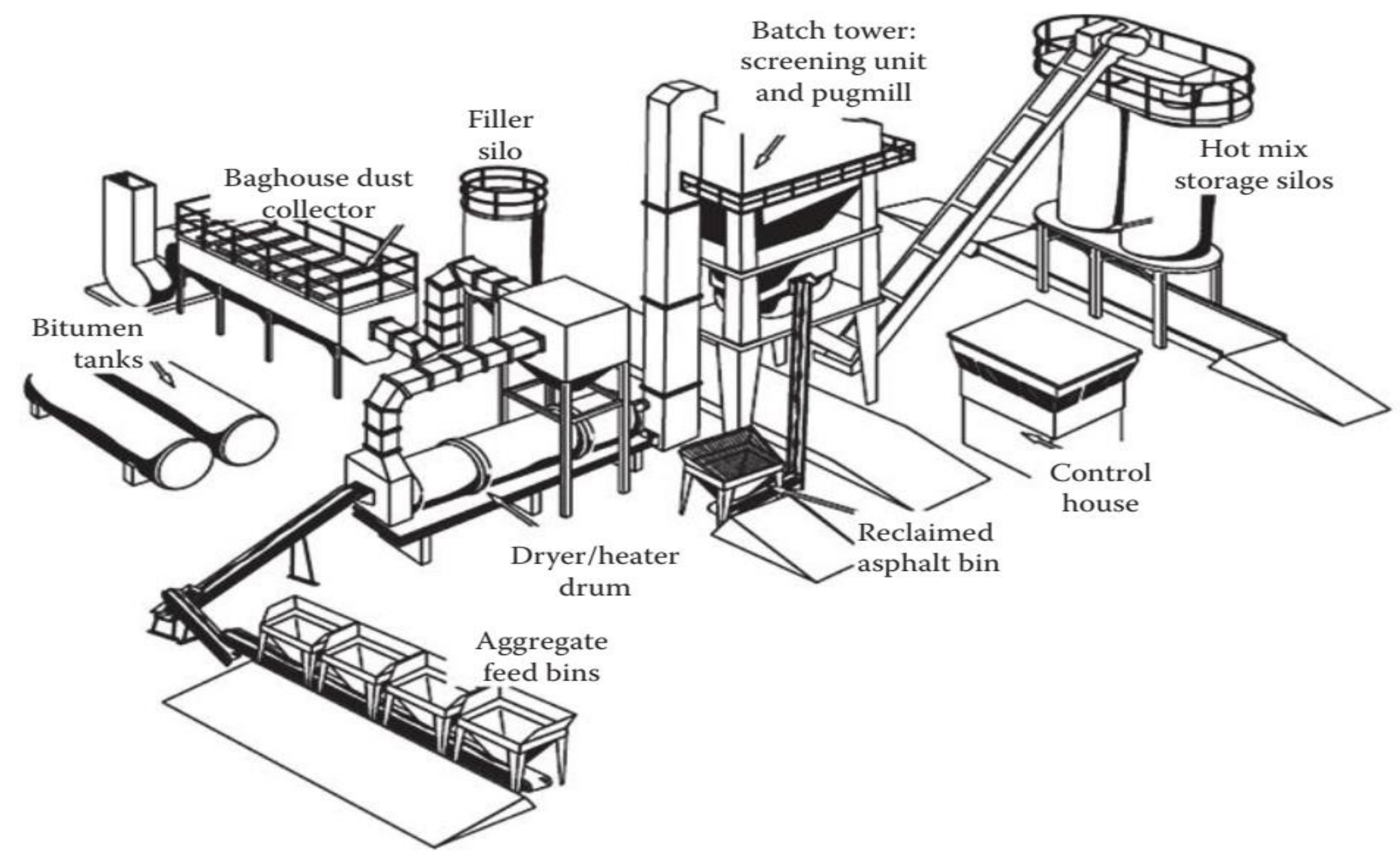
Types of Central Mixing Plants

- **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 material 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 discharges continuously into a surge silo, where it is temporarily stored and later loaded into trucks.*

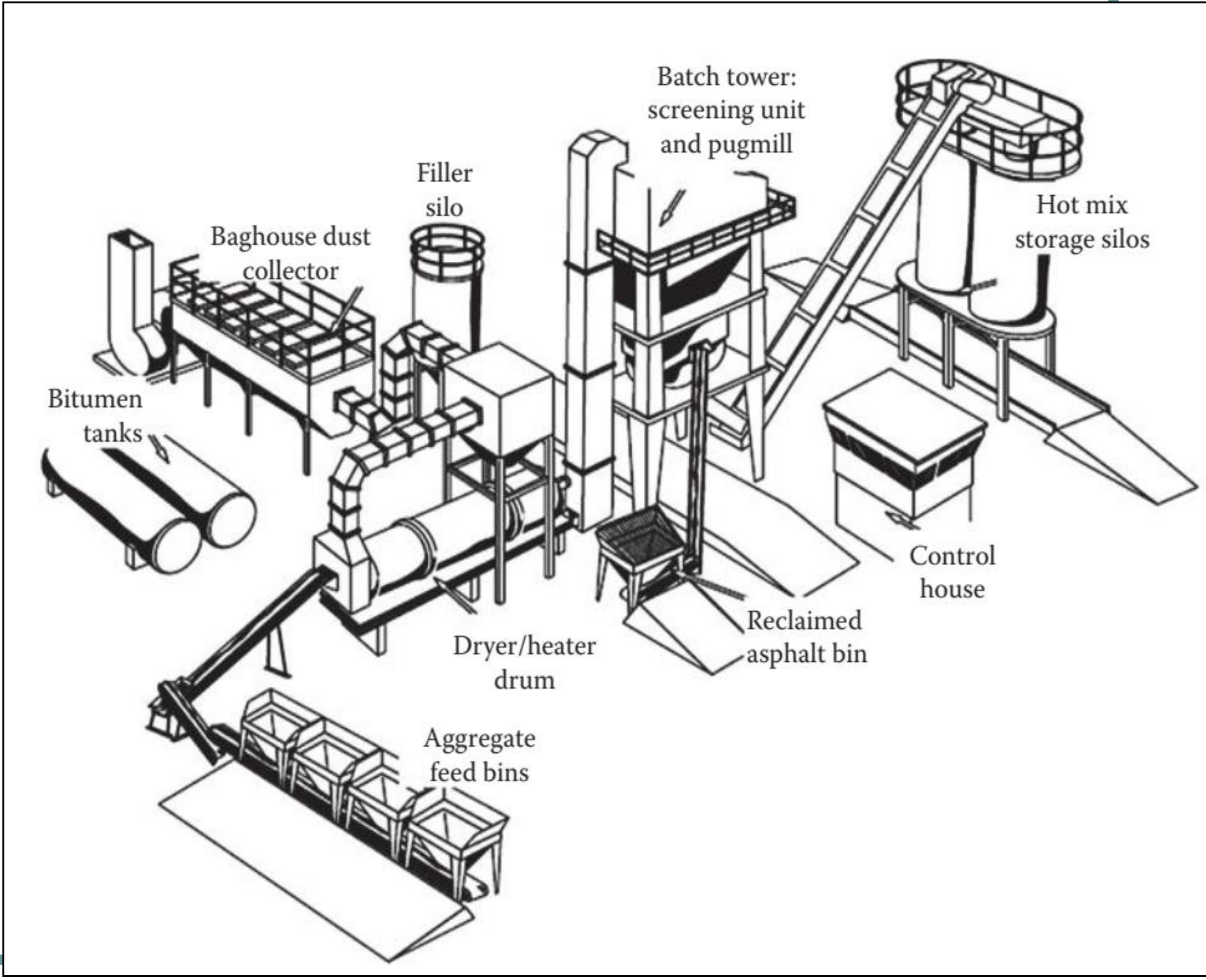
The choice of a batch or drum mix plant depends upon business factors such as purchase price, operating costs, production requirements and the need for flexibility in local markets; both can produce quality HMA.

Batch Plant


Batch tower: screening unit and pugmill
Filler silo
Baghouse dust collector
Hot mix storage silos
Bitumen tanks
Control house
Reclaimed asphalt bin
Dryer/heater drum
Aggregate feed bins

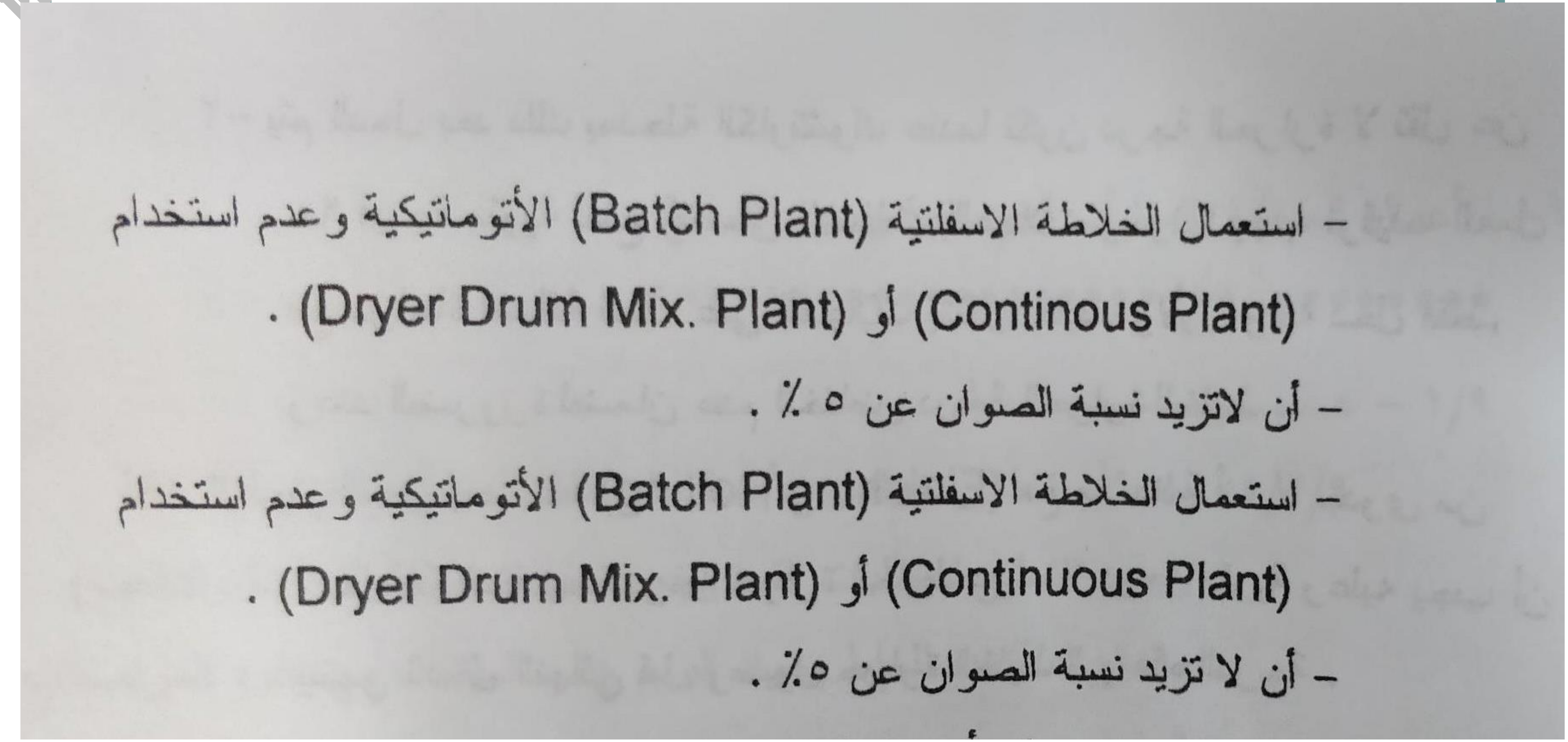
Drum Plant

Generally, offer higher production rates than batch plants for comparable cost. Each type of plant can produce the same types of HMA



Jordanian National Building Council

Specifications for highway and bridge construction



– استعمال الخلاطة الاسفلتية (Batch Plant) الأتوماتيكية وعدم استخدام
(Continous Plant) أو (Dryer Drum Mix. Plant) .

– أن لاتزيد نسبة الصوان عن ٥ ٪ .

– استعمال الخلاطة الاسفلتية (Batch Plant) الأتوماتيكية وعدم استخدام
(Continuous Plant) أو (Dryer Drum Mix. Plant) .

– أن لا تزيد نسبة الصوان عن ٥٪ .

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.

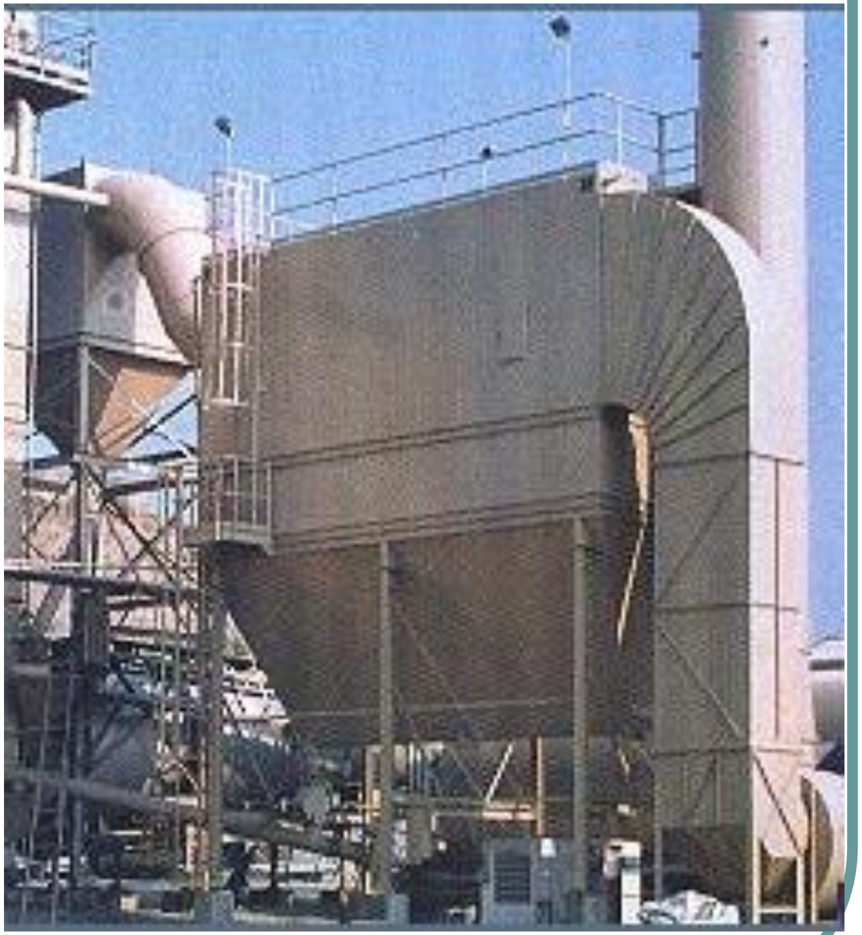
Cold Feed Bins

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

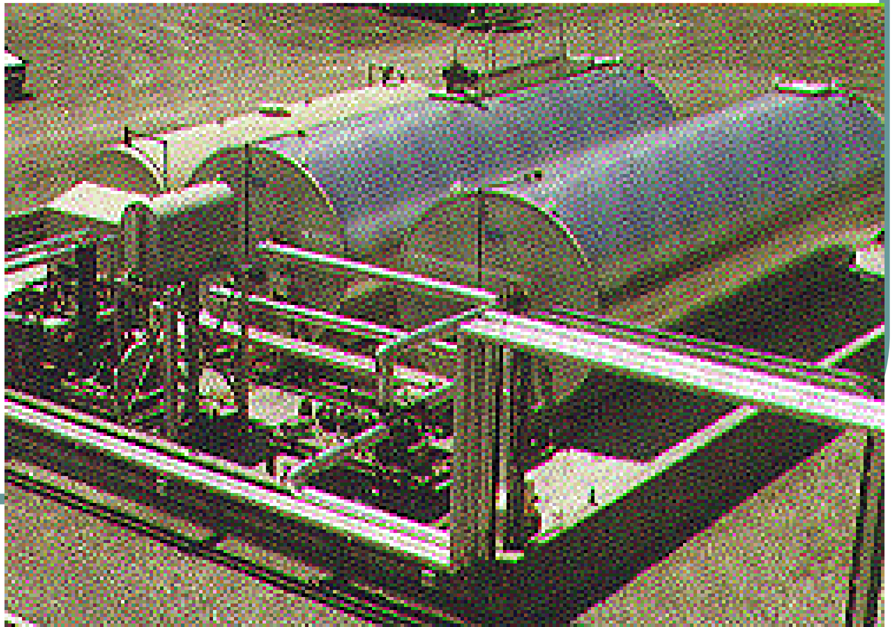
- Works with the drying system
- Eliminates dust from plant exhaust
- Two basic types:
  - Wet scrubber
  - Baghouse
    - Collected dust may be returned to drum if desired



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

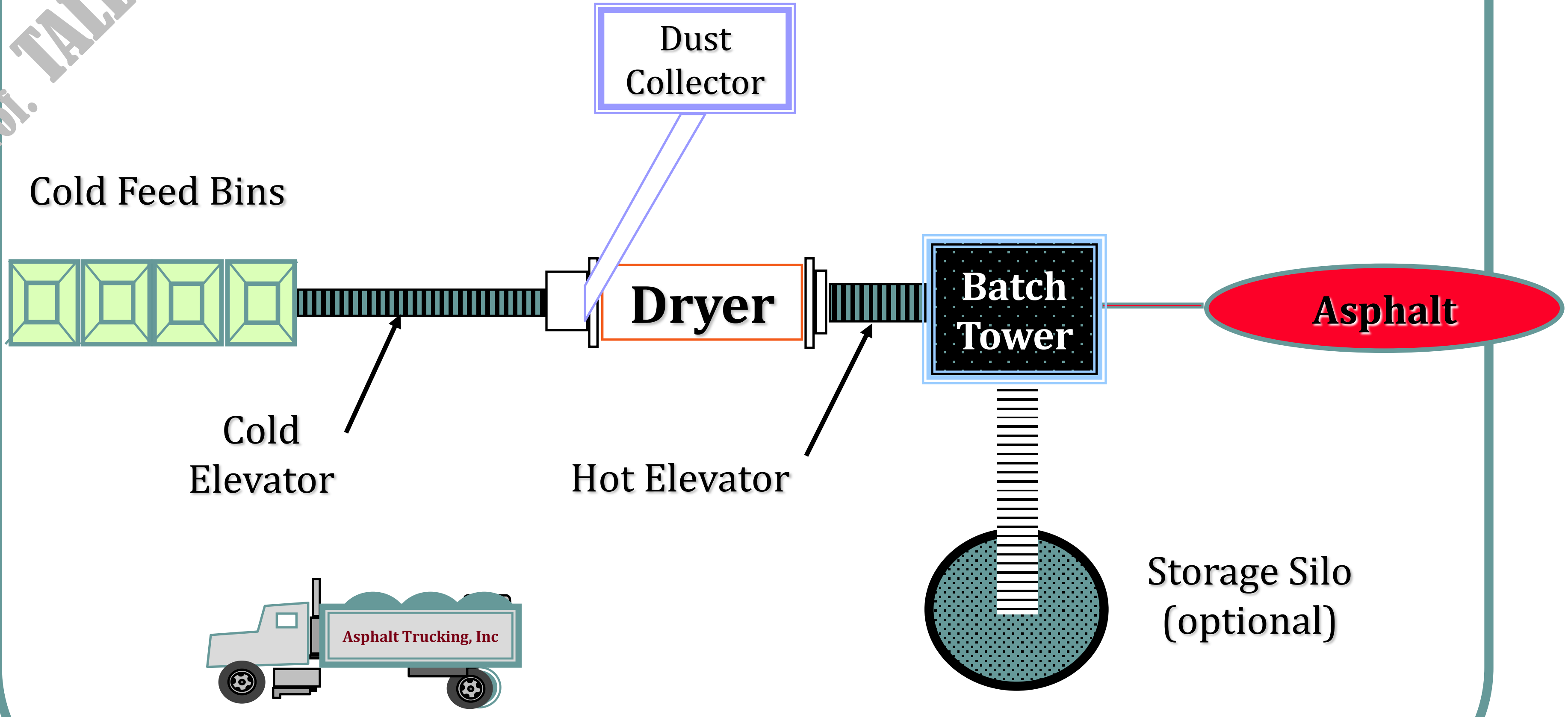
- Plant operations are monitored
  - Aggregate feed rate (s)
  - Asphalt feed
  - Burner control
- Truck loading

Batch Plant

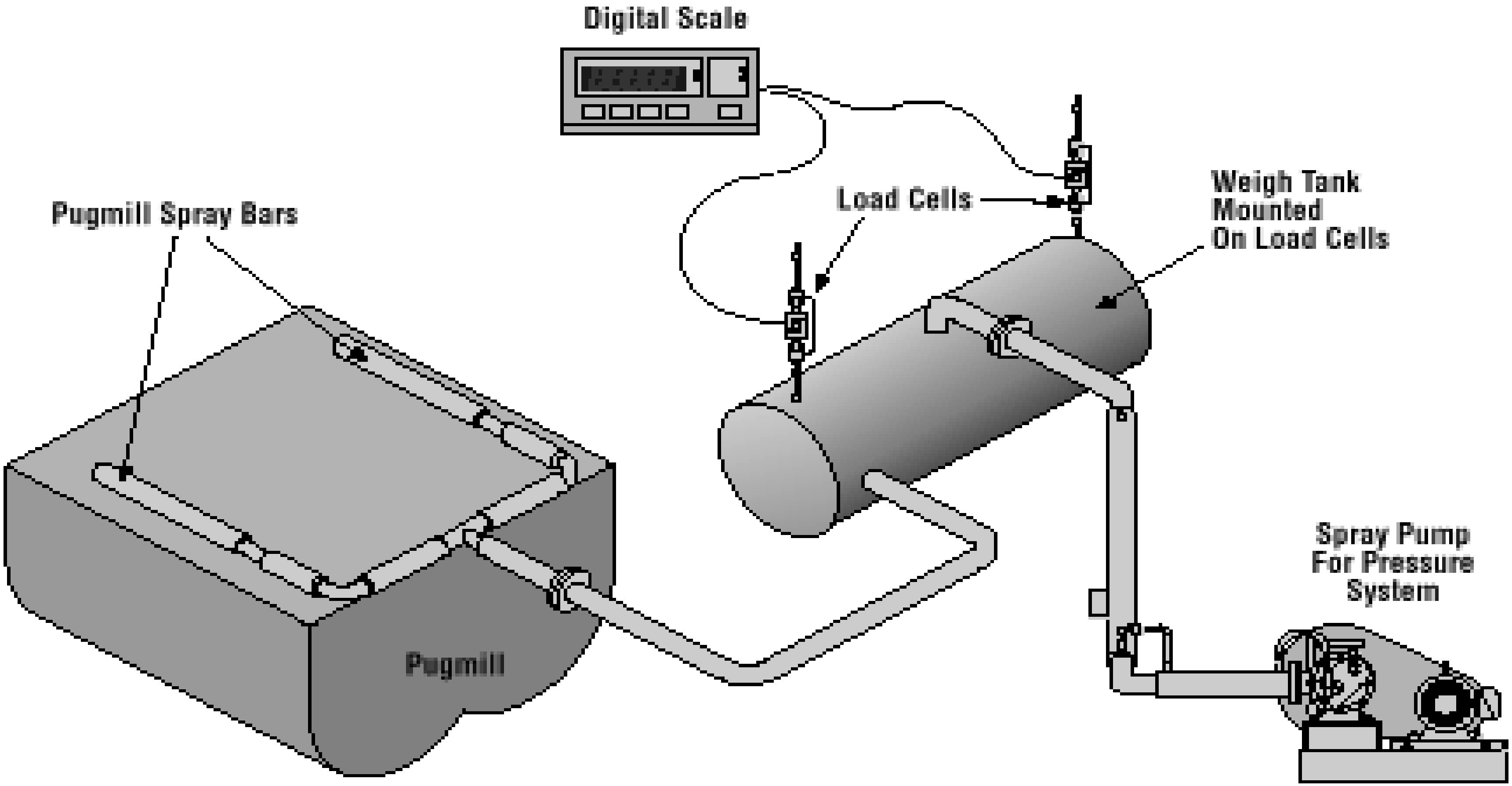
Batch Plants / Features

- 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



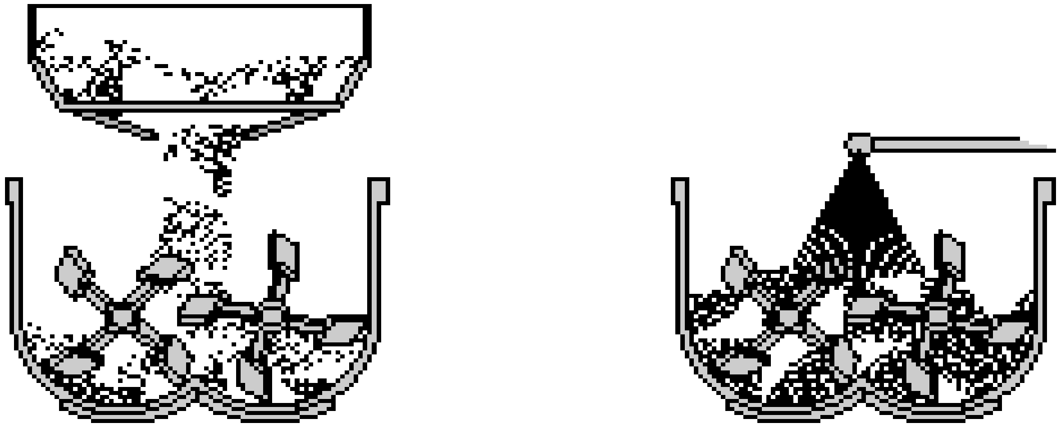
Batch Plant/ Asphalt Delivery System



Asphalt cement is weighed separately in a load cell-mounted weigh tank.

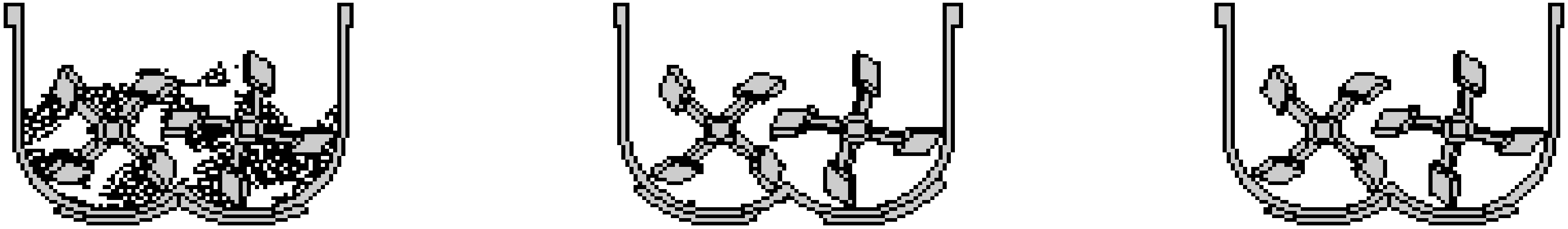
Figure 4.35 Asphalt Weighing and Delivery System in a Batch Plant (Courtesy of GenTec)

Batch Plant Typical Mixing Cycle



1. The gates of the weigh box are opened, and the aggregates empty into the pugmill.

2. The asphalt is discharged into the pugmill by a spraybar.



3. The aggregates and the asphalt are mixed.

4. The pugmill gate opens, and the finished mix is discharged.

5. The pugmill gate closes to receive the next batch.

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

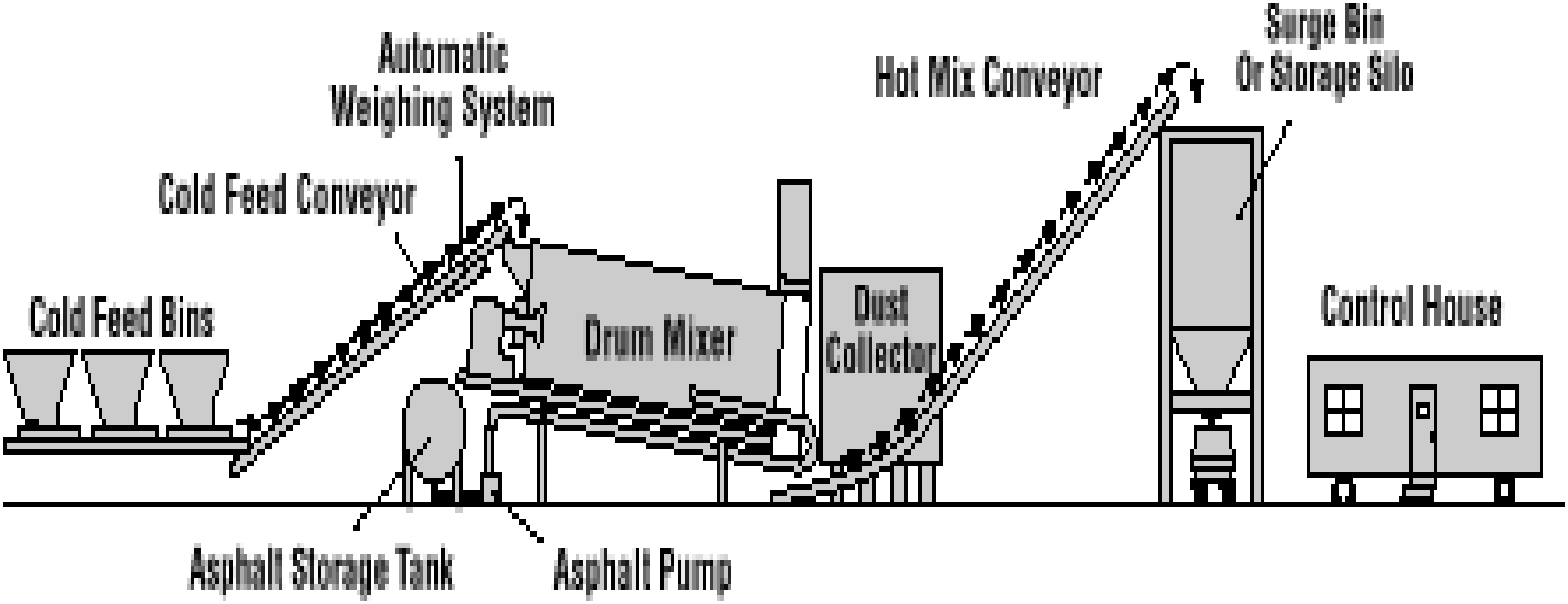


Figure 4.43 Basic Drum Mix Plant

Drum Plant-Knippa, Texas

Asphalt Mixtures Transport

- Mix transport involves everything required to convey HMA from a production facility to a paving site including truck loading, weighing and ticketing, hauling to the paving site, dumping of the mix into the paver or material transfer vehicle hopper, and truck return to the HMA production facility.

- Ideally, the goal of mix transport should be to maintain mix characteristics between the production facility and the paving site.

Asphalt Mixtures Transport

- **End dump Trucks**
  - End dump trucks unload their payload by raising the front end and letting the payload slide down the bottom of the bed and out the back through a tailgate .
  - They are the most popular transport vehicle type because they are plentiful, maneuverable and versatile.

Asphalt Mixtures Transport

- **Bottom dump (or belly dump) Trucks.**
  - Bottom dump trucks unload their payload by opening gates on the bottom of the bed.
  - Internal bed walls are sloped to direct the entire payload out through the opened gates. Discharge rates can be controlled by the degree of gate opening and the discharge is usually placed in an elongated pile, called a windrow, in front of the paver by driving the truck forward during discharge. Windrows require a special MTV to feed the HMA into the paver.

Asphalt Mixtures Transport

- **Live bottom (or flo-boy) Trucks.**
  - Live bottom dump trucks have a conveyor system at the bottom of their bed to unload their payload.
  - HMA is discharged out the back of the bed without raising the bed.
  - Live bottom trucks are more expensive to use and maintain because of the conveyor system but they also can reduce segregation problems and can eliminate some detrimental types of truck bed – paver contact (because the bed is not raised during discharge).

HMA Placement

Self Propelled Paving Machine

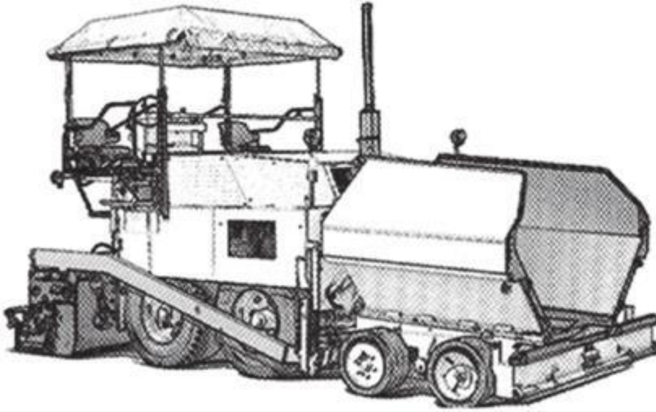
THE BASIC PRINCIPLE HAS NOT CHANGED MUCH

Asphalt Mixtures Laying/Paving

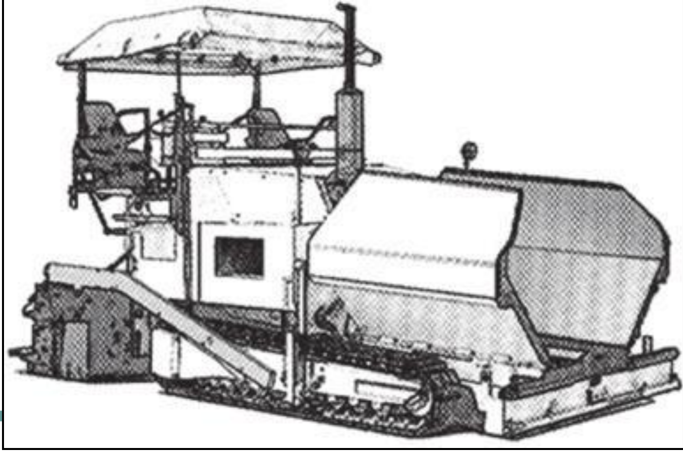
- Laying of the hot asphalt is carried out with special motorized units called pavers.
- Pavers are available in a wide variety of sizes capable of laying mats from as narrow as 1 m to up to 16 m wide.
- The minimum and the maximum range of paving width vary from one manufacturer's model to another.
- The pavers are distinguished from the type of their traction, and there are two types:

  The wheeled pavers

  The tracked pavers.



The wheeled pavers



The tracked pavers

Asphalt Mixtures Laying/Paving

This set of functions can be divided into two main systems:

1- Tractor

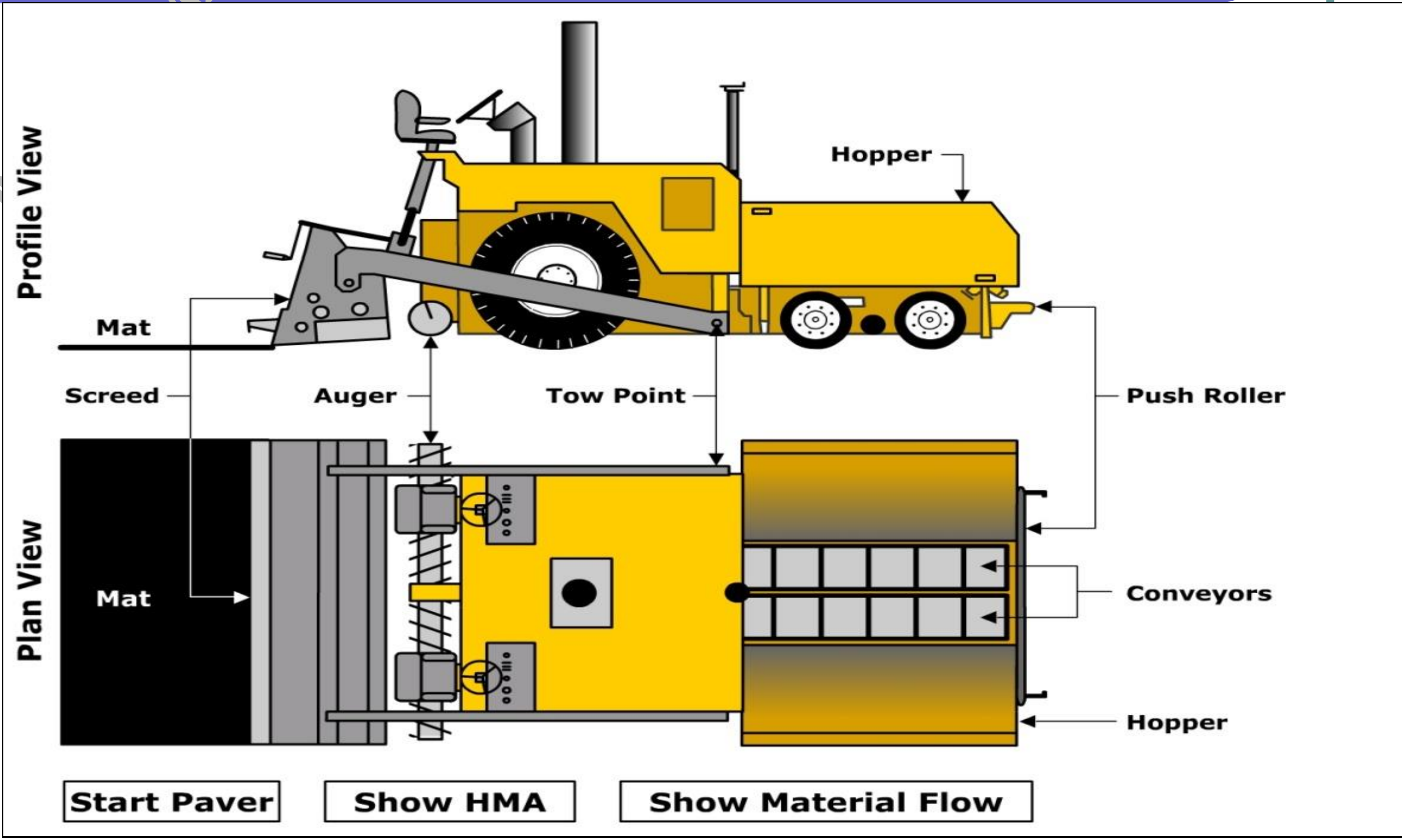
The tractor contains the material feed system, which accepts the HMA at the front of the paver, moves it to the rear and spreads it out to the desired width in preparation for screed leveling and compaction.

2- Screed

The most critical feature of the paver is the self-leveling screed unit, which determines the profile of the HMA being placed.

The screed takes the head of HMA from the material delivery system, strikes it off at the correct thickness and provides initial mat compaction.

Paver


Profile View
Hopper
Mat
Screed
Auger
Tow Point
Push Roller
Plan View
Mat
Conveyors
Hopper
Start Paver
Show HMA
Show Material Flow

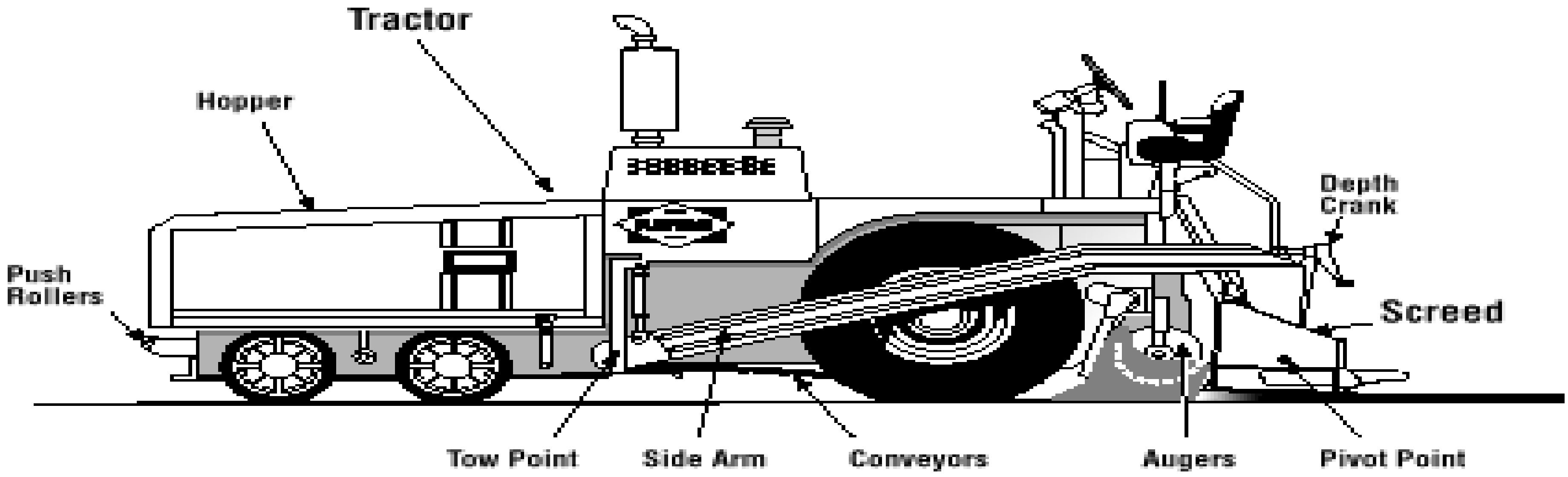
Paving Equipments

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

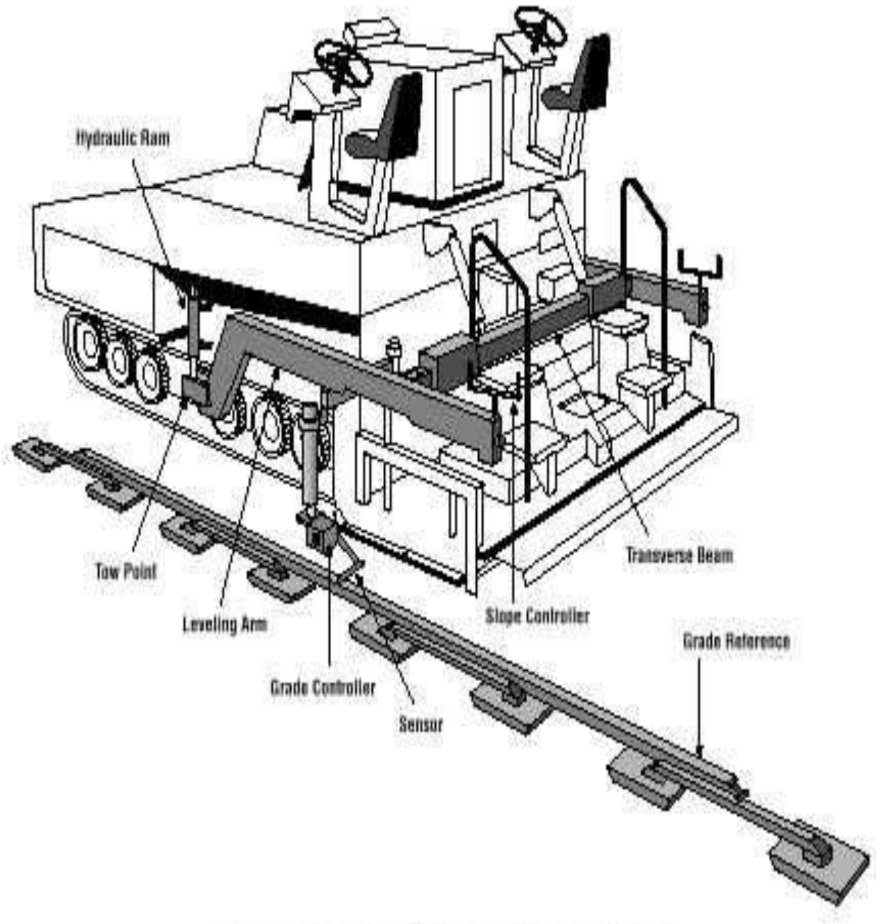


Figure 5.17 Automatic Screed Reference System

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.

Placement

- **Placement Considerations:**

  - **Lift thickness**
    - A “lift” refers to a layer of pavement as placed by the asphalt paver.
    - In order to avoid mat tearing (which generally shows up as a series of longitudinal streaks) a good rule-of-thumb is that the depth of the compacted lift should be at least twice the maximum aggregate size and three times the nominal maximum aggregate size
  - because it is prone to aggregate segregation and results in a slightly rough surface texture

Placement

- **Placement Considerations:**

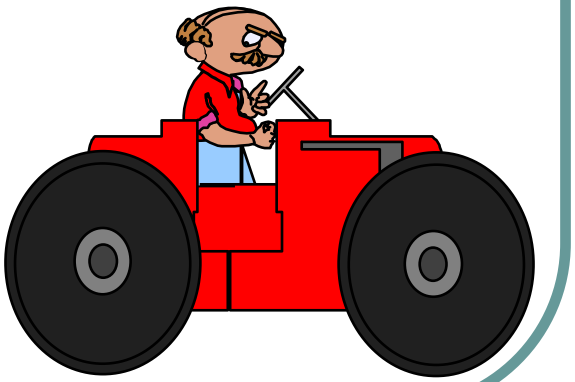
  - **Longitudinal joints**
    - The interface between two adjacent and parallel HMA mats.
    - Improperly constructed longitudinal joints can cause premature deterioration of multilane HMA pavements in the form of cracking and raveling.
  - **Handwork**
    - HMA can be placed by hand in situations where the paver cannot place it adequately.
    - This can often occur around utilities, around intersection corners and in other tight spaces. Hand-placing should be minimized because it is prone to aggregate segregation and results in a slightly rough surface texture.

Compaction

- The compaction of asphalt layers is possibly the most critical stage of asphalt works.
- It is needed to achieve proper and uniform compaction, which in turn ensures a better long-lasting performance.
- During compaction,
    - The coated aggregates are compressed, are re-oriented and take such positions that the distance between them becomes the smallest possible.
    - As a consequence, the air voids decrease, and the mixture density increases.
    - Because of aggregate re-orientation, the stability of the mix and the strength of the asphalt and of the pavement increase.

Compaction

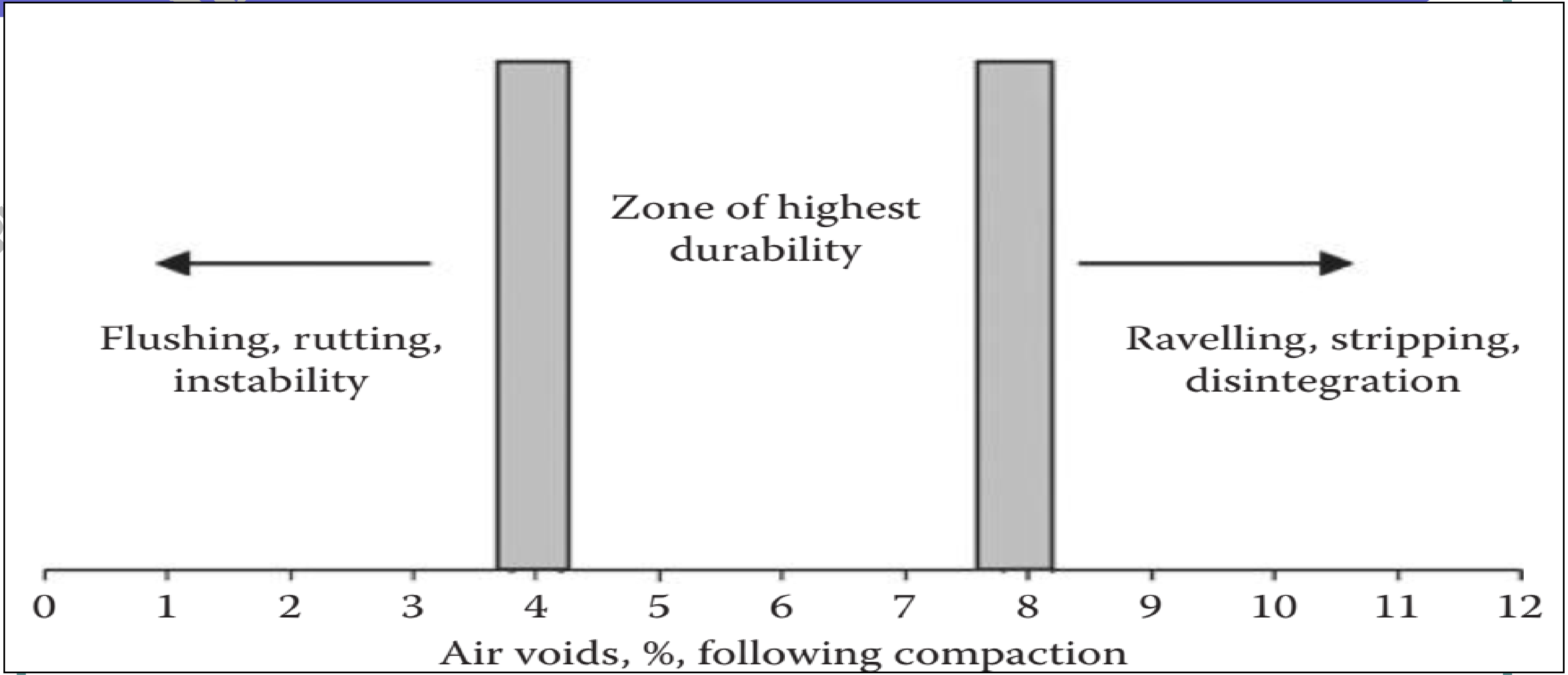
- Compaction is defined as : The process of compressing a material into a smaller volume while maintaining the same mass.
- Essential to good performance!
  - *To provide shear strength or resistance to rutting*
  - *To ensure the mixture is waterproof*
  - *To prevent excessive oxidation of the asphalt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



Compaction

- The aim during compaction is to achieve an optimum void content and at the same time to ensure a smooth surface.
- An asphalt concrete immediately after laying has a void content ranging from 15% to 20%, using conventional screeds.
- The task of the rollers is to reduce this content to approximately 8% or less.
- Air voids of less than 3.5% after compaction should be avoided, since rutting, flushing and instability of the mix will most certainly occur.

Compaction



The effect of air voids obtained during compaction on the durability of asphalt concrete layer

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 (or 2 times max agg. Size).*
  - *particularly important for gradations below maximum density line*
  - *0.5 in nom. Max size ➔ 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

Factors Affecting Compaction/ Aggregates

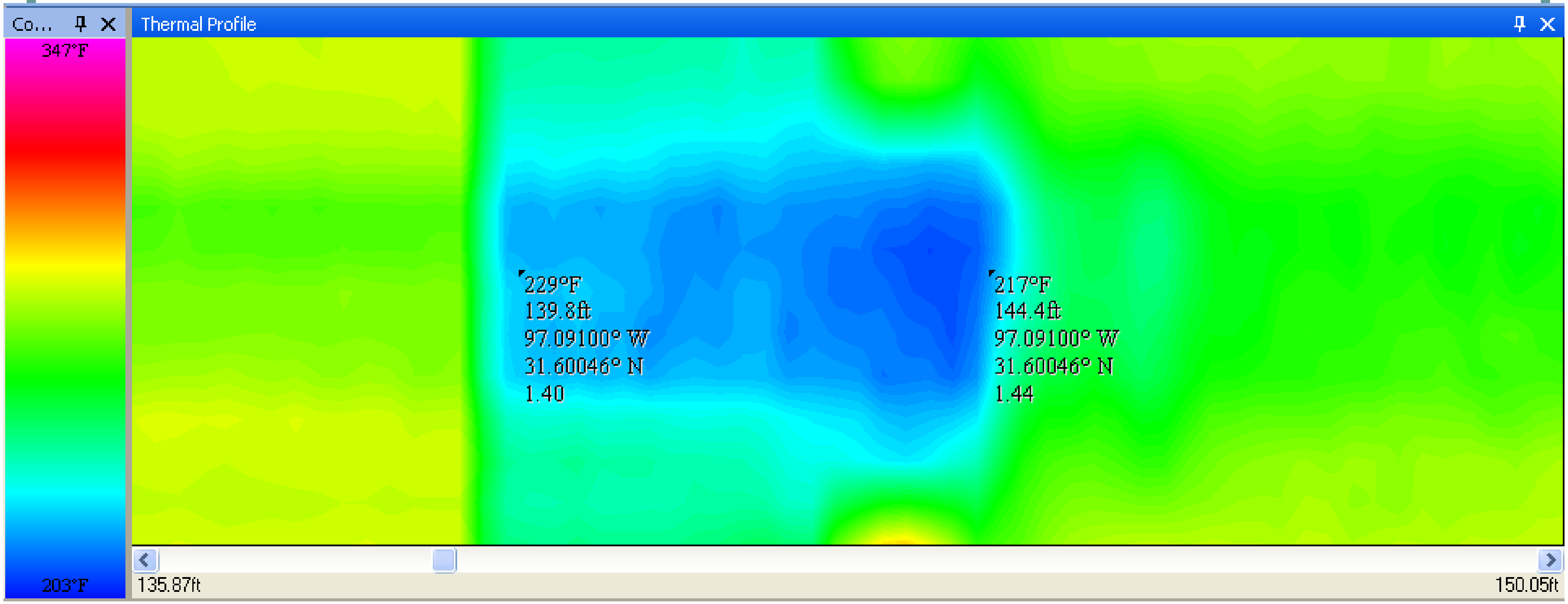
- Aggregates, with respect to their particle size distribution, shape and surface texture, directly affect the asphalt workability/compactibility
  - Open-graded mixtures have better workability and require a smaller compaction effort than dense-graded mixtures.
  - An increase of coarse aggregate content reduces the workability and increases the compaction effort.
  - When rounded and smooth-surfaced aggregates are contained in the mixture, its workability increases.
  - It is known that workability/compactibility is improved by the addition of natural sand or by the use of uncrushed aggregates instead of crushed aggregates.
    - High percentage of filler can have a negative impact on the asphalt workability/compatibility.

Factors Affecting Compaction/ Bitumen and Temperature

- The grade or type of bitumen and its quantity in the mixture are the major factors affecting asphalt compaction.
- The increase of bitumen content has, up to a point, a beneficial effect on the asphalt workability/compaction.
- when ‘hard’ bitumen is incorporated into the asphalt, the compaction at a given temperature is more ‘difficult’ than the one of asphalt containing ‘soft’ bitumen.
- To phase this problem, the asphalt produced with hard bitumen is compacted, and thus produced, at higher temperatures.
- The appropriate compaction temperature is determined by the viscosity/temperature relationship.
- As a general rule, compaction of asphalt with grade bitumen should never start when the mix temperature is less than 85 °C to 90 °C.

Factors Affecting Compaction/ Bitumen and Temperature

- A point that should also be noted is the uniformity of the temperature throughout the mass of the mixture.
- The non-uniformity of temperature affects the density of layer with respect to depth.



Temperature Is Critical

Factors Affecting Compaction/ Environmental Conditions and Layer Thickness

Environmental conditions

- Affecting compaction and the duration during which compaction should be completed.
- Low ambient temperatures and high wind speeds demand a shorter duration of compaction.

Layer thickness

- Affects the ease in achieving the desired degree of compaction.
- In general, the thicker the layer, the easier it is to achieve the desired compaction, since it retains its heat for a longer period (lower rate of heat loss).
- Layers with a thickness between 25 and 40 mm, if possible, should not be laid during cold winter months, or greater attention should be given to the duration of compaction, which should be as short as possible.

Factors Affecting Compaction/ Compaction Equipment

- Effective compaction is related to the type of **compaction equipment** used.
- The desired compaction is achieved by applying a certain number of passes of the rollers over the asphalt layer, known as compaction effort.
- The number of passes is always determined in situ and it depends on: *The asphalt type, thickness of layer, weather conditions and type and weight of roller*
- There are four types of rollers:
  - (a) static steel-wheel roller
  - (b) vibrating steel-wheel rollers
  - (c) pneumatic-tyre rollers
  - (d) combination rollers

Compaction Equipments

- Screed unit on paver
  - weight of screed
  - tamping/vibratory unit
- Rollers
  - Vibratory steel-wheeled
  - Static steel-wheeled
  - Pneumatic
  - Combination rollers

Compaction Equipments

Three-wheel static roller

Double-drum vibrating roller

Pneumatic-tyre roller

Combination roller

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

Compaction Procedure

To achieve proper and effective compaction of asphalt layers, the following points are recommended:

- Rolling should start as quickly as possible after asphalt has been laid
- Rolling consists of three consecutive phases:
  - The initial or breakdown rolling
    - Most of the compaction is achieved during breakdown rolling.
  - The intermediate rolling
    - Increases the density of the mix further and minimizes all surface pores.
  - The finish rolling
    - During finish rolling, all roller traces and other surface deficiencies are removed.
- Between the three phases, there should be no time delay.

Compaction Procedure

- The number of rollers required to be used is determined by the width of paving lane;
- A typical paving lane width of 3.5 to 3.75 m, usually two or more rollers are required.
- As for the width of the roller, it is usually chosen to be approximately equal to one-third of the width of the paving lane.
- Rolling always starts from the lowest point of the mat, in case of transverse slope.
- The roller moves twice over the same rolling path, by moving forwards and backwards; then, the roller changes rolling path (lane).
- The same applies to all subsequent rolling.
- When longitudinal joint is formed, rolling starts from the joint.
- The roller moves over the hot mat with approximately 200 mm of its drum overlapping the already compacted mat. This is known as hot-side rolling.

Compaction Procedure

- The length of the first and second rolling pass, and all subsequent passes, is mainly dependent on the thickness of the mat.
- Longer rolling lengths can be used on thick mats (more than 60 mm in thickness) in comparison to thin mats.
- Usually, an ideal length is between 30 and 40 m for a mat of asphalt concrete of 100 mm in thickness.
- During rolling, particularly at the start, the surface of cylinder or of the tires is sprayed with a small quantity of water to avoid mixture adhering to the surface of the cylinder or the tires.
- Rollers should move at low speeds.
  - Not higher than 5 km/h for static or vibrating rollers
  - Not higher than 8 km/h for rubber ones
- The selected speed should be retained constant throughout rolling.

Rolling Pattern

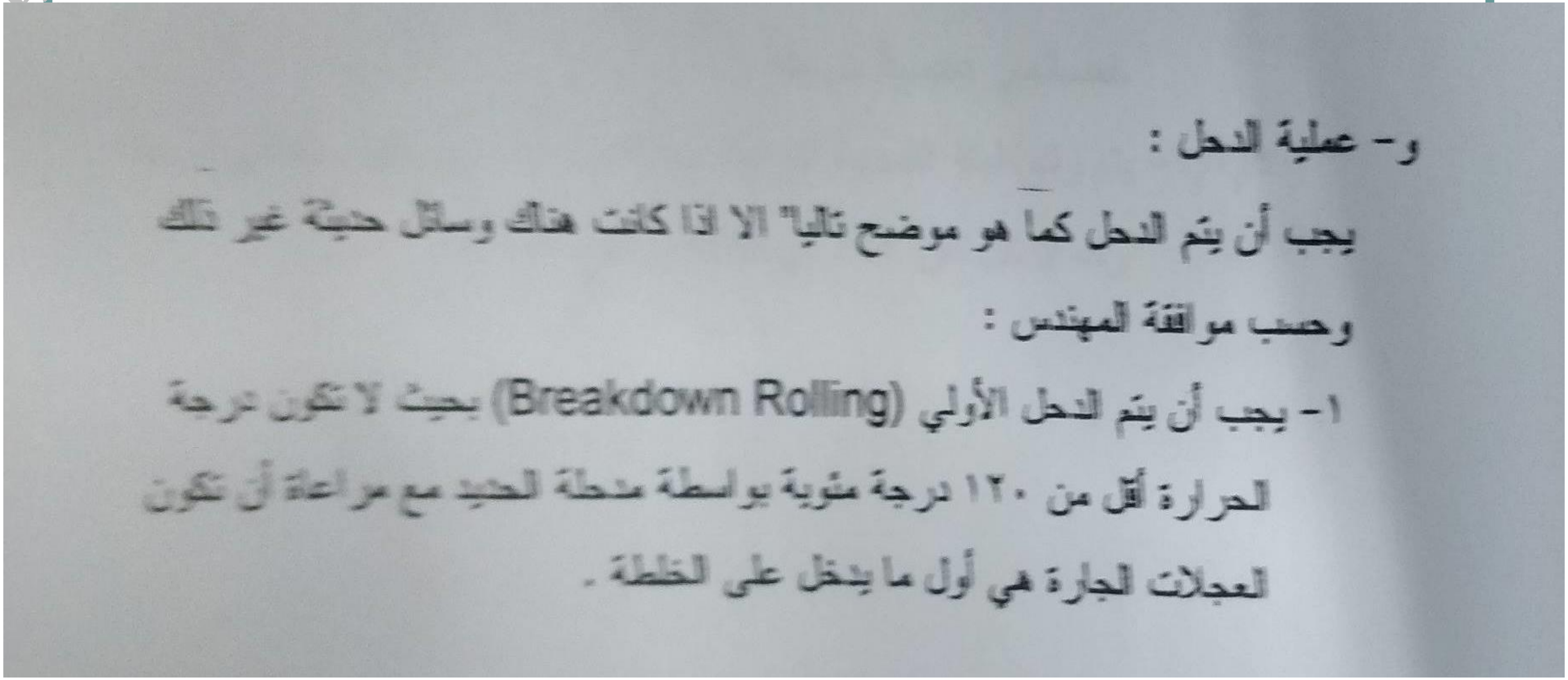
- Speed & lap pattern for each roller
- No. of passes for each roller
- Min. temperature by which each roller must complete pattern

IMPORTANT:

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

Jordanian National Building Council

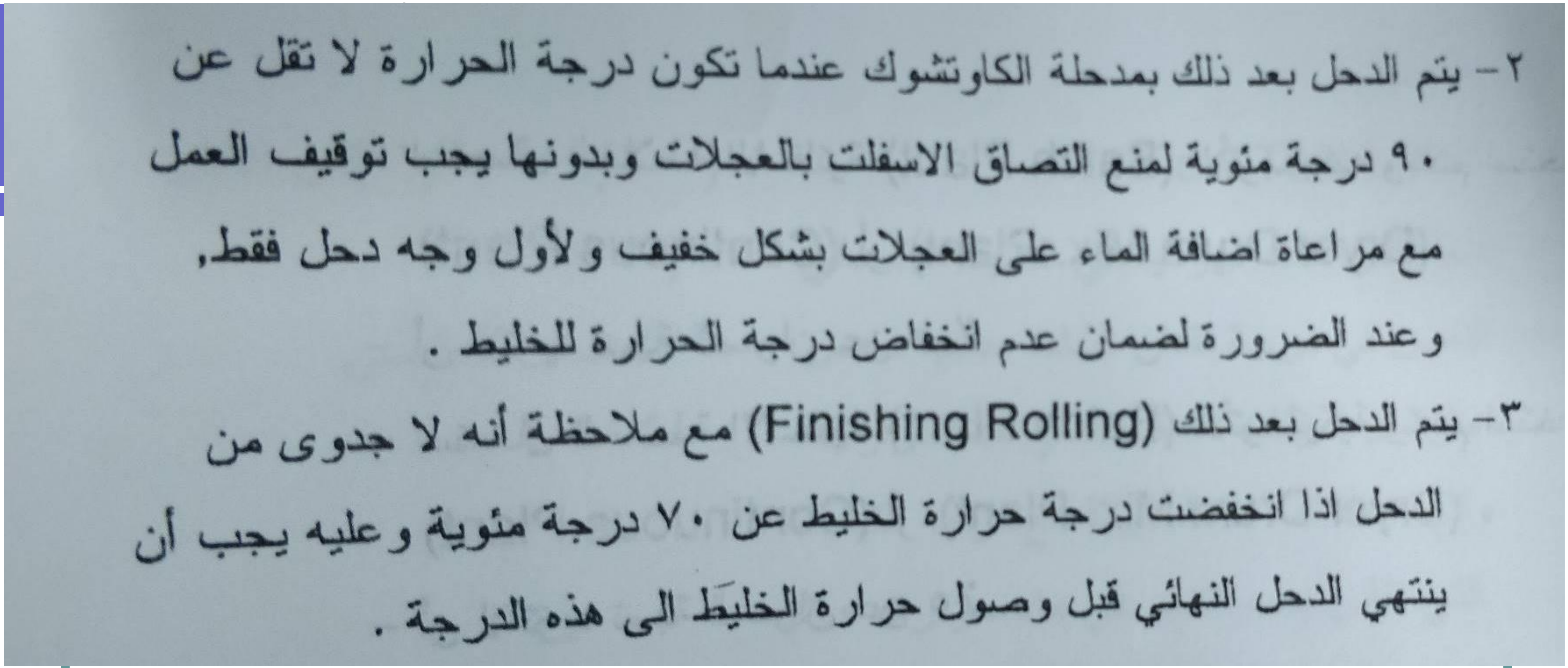
Specifications for highway and bridge construction



و- عملية الدحل :

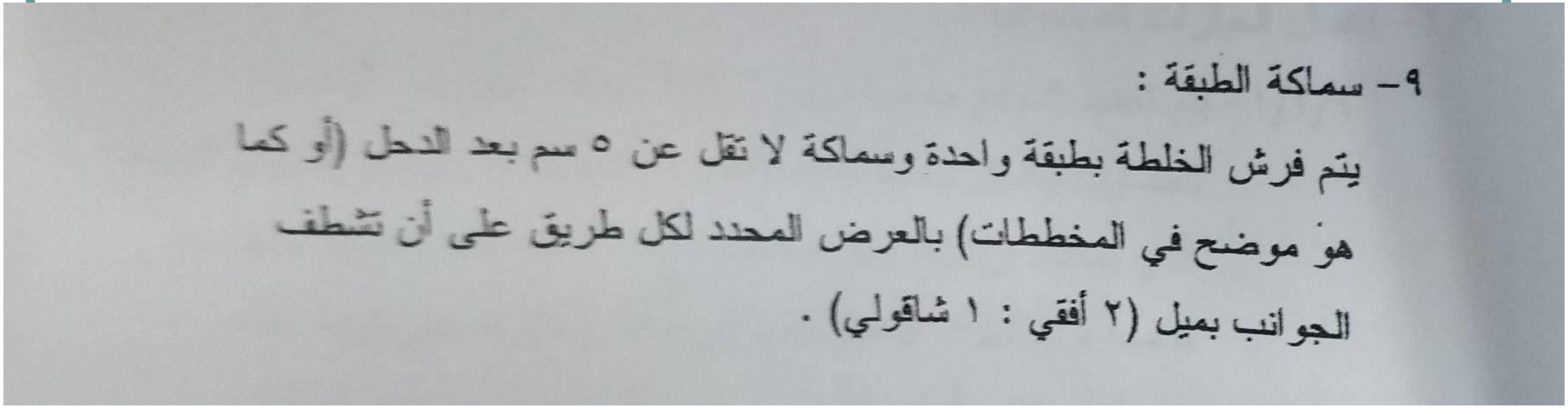
يجب أن يتم الدحل كما هو موضح تالياً" الا اذا كانت هناك وسائل حديثة غير ذلك وحسب موافقة المهندس :

١- يجب أن يتم الدحل الأولي (Breakdown Rolling) بحيث لا تكون درجة الحرارة أقل من ١٢٠ درجة مئوية بواسطة مدحلة الحديد مع مراعاة أن تكون العجلات الجارة هي أول ما يدخل على الخلطة .



٢- يتم الدحل بعد ذلك بمدحلة الكاوتشوك عندما تكون درجة الحرارة لا تقل عن ٩٠ درجة مئوية لمنع التصاق الاسفلت بالعجلات وبدونها يجب توقيف العمل مع مراعاة اضافة الماء على العجلات بشكل خفيف ولأول وجه دحل فقط، وعند الضرورة لضمان عدم انخفاض درجة الحرارة للخليط .

٣- يتم الدحل بعد ذلك (Finishing Rolling) مع ملاحظة أنه لا جدوى من الدحل اذا انخفضت درجة حرارة الخليط عن ٧٠ درجة مئوية وعليه يجب أن ينتهي الدحل النهائي قبل وصول حرارة الخليط الى هذه الدرجة .



٩- سماكة الطبقة :

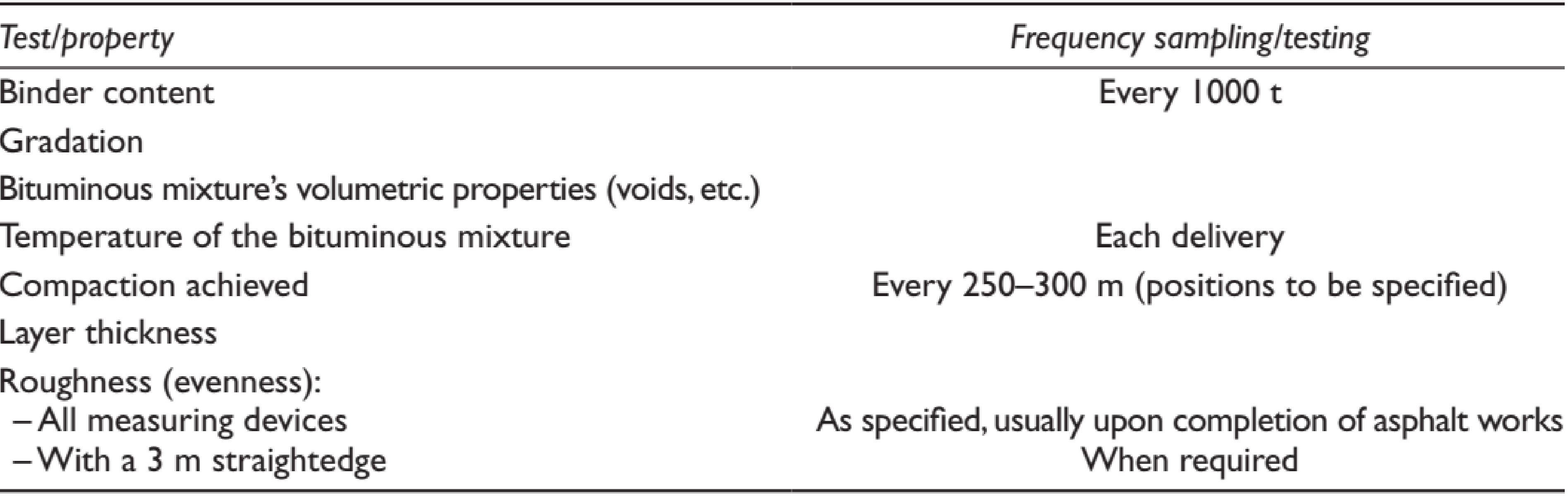
يتم فرش الخلطة بطبقة واحدة وسماكة لا تقل عن ٥ سم بعد الدحل (أو كما هو موضح في المخططات) بالعرض المحدد لكل طريق على أن تشطف الجوانب بميل (٢ أفقي : ١ شاقولي) .

Quality control of production and acceptance of asphalts mixtures

- Asphalt production control is necessary in order to ascertain that the produced asphalt complies with the mix formulation and to verify a good and stable mix plant operation.
- The acceptance of delivered and laid asphalt is usually based on the results obtained for the determination of:
  - Binder content
  - Aggregate gradation
  - Mixture volumetric properties (voids, VMA or VFA)
  - Asphalt temperature
  - Degree of compaction
  - Compacted layer evenness
  - Layer thickness

Quality control of production and acceptance of asphalts mixtures

- The frequency of sampling/testing is always determined in contract documents.
- Sampling/ testing frequencies that are usually used are given in table below.



Test/property	*Frequency sampling/testing*
Binder content	Every 1000 t
Gradation	
Bituminous mixture's volumetric properties (voids, etc.)	
Temperature of the bituminous mixture	Each delivery
Compaction achieved	Every 250–300 m (positions to be specified)
Layer thickness	
Roughness (evenness):	
– All measuring devices	As specified, usually upon completion of asphalt works
– With a 3 m straightedge	When required

Quality control of production and acceptance/ Binder Content

Binder content is determined using one of the following methods:

- Binder extraction method (Most common)
- Ignition method.
- Nuclear method.

In the first two methods,

- the remaining/recovered ‘clean’ aggregate is used for determining aggregate gradation and density;
- in the third method, only binder content determination can be carried out

Quality control of production and acceptance/ Aggregate Gradation & Volumetric properties

Aggregate gradation

- The determination of the aggregate gradation of the asphalt sampled from the site is carried out by sieving after extracting or burning the binder from the bituminous mixture.
- The aggregate gradation determined should be within the tolerance limits declared by the supplier or set by the relevant specification.

Volumetric properties of the asphalt

- The volumetric properties of the asphalt such as air voids, voids in the mineral aggregate and voids filled with bitumen are calculated from the compacted asphalt specimens obtained from the site.
- The volumetric properties determined should be within the tolerance limits declared by the supplier or set by the relevant specification.

Quality control of production and acceptance/ Temperature

Asphalt temperature

- The temperature of the asphalt arriving on site is a critical parameter for effective paving and compaction operations.
- For the acceptance of delivered product, the asphalt temperature is measured while the material is still in the arrived lorry.
- Infrared thermometers are not advised to be used since readings are very sensitive to wind and moisture conditions and will certainly give erroneous results

Quality control of production and acceptance/ Compaction

Compaction achieved

- The compaction achieved (degree of compaction) after completion of rolling should always be within the pre-determined tolerance range.
- The degree of compaction is:
  - **Percentage of TMD** (or “percent Rice”): the ratio of bulk density obtained on site over the bulk density obtained in the laboratory for the target mix, expressed in percentage.
  - **Percentage of a laboratory-determined density**.: The laboratory density is usually a density obtained during mix design.
  - **Percentage of a control strip density**: A control strip is a short pavement section that is compacted to the desired value under close scrutiny then used as the compaction standard for a particular job.

Quality control of production and acceptance/ Compaction

- The degree of compaction achieved by no means should be equal to 100%.
- For dense asphalt concrete: The targeted minimum degree of compaction on site is usually 95% and the maximum is 98%
- The bulk density achieved after completion of rolling is usually determined using:
  - Extracted cores
  - Nuclear devices
- Numerous researchers have stated that compaction is the greatest determining factor in dense graded pavement performance (Scherocman and Martenson, 1984[2]; Scherocman, 1984[3]; Geller, 1984[4]; Brown, 1984[5]; Bell et. al., 1984[6]; Hughes, 1984[7]; Hughes, 1989[8])
- Inadequate compaction results in a pavement with: decreased stiffness, reduced fatigue life, accelerated aging/decreased durability, rutting, raveling, and

Quality control of production and acceptance/ Layer Thickness

Layer thickness

- The thickness of the compacted layer is determined from cores, taken at specified locations, using a metal tape or rule, set of callipers, measurement jig or other device, capable of measuring specimen thicknesses.
- The thickness of the asphalt layer may also be determined by a non-destructive method using short-pulse radar

Checking Density With Nuclear Gauge

Extracting A Core

Quality control of production and acceptance/ Surface evenness

Surface irregularities and evenness (roughness)

- The irregularities and evenness (or roughness) of the surface(s) or of the surface course are measured for compliance within the specified limits, which is a prime determinant of quality in new construction of asphalt works.
- Measurements are taken normally after completion of asphalt works, although daily measurements are not uncommon

Quality control of production and acceptance/ Segregation

Segregation

- is a lack of homogeneity in the hot mix asphalt constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress(es)."