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دفتر

رصفات

(المادة كاملة)

إعداد : رند الشوبكي

Pavement Materials & Design (110401466/2104011466)
Pavement Types

Instructor:

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Pavement Definition

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- 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 (ديمومة) 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

يوجد عدة مفاهيم لمعنى الرصفات وهي كالاتي :-

التعريف العام :- هو مسار مجهز من صنع الانسان على الارض الطبيعية بحيث يستعمله الانسان او الحيوان

* تعريفها من ناحية civil eng :- فهي تعني ديمومة وبكون العرف منها تقليل load وبالغالب يكون فيها مرونة بحيث تتحمل loads الموجودة عليها

* تعريف اخر :- هو اتحاد طبقتين فأكثر لنقل load وتوزيعه على Pavement الموجود تحته وتحمل stress إلى ان يحي عليها

* مجموعة من طبقات بتوزيع stress من خلال الطبقة من يوصل السطح من غير ما يصير هبوط بالاساسات ، بفضل الطبقات حتى اضمن ان stress الواصل للطبقة ما ينتج عنه هبوط

Pavement Types

المرنة

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.

أنواع Pavement

1. Flexible :- كلمة bituminous هي مواد بيتومنية
وهي نوعين الاسفلت وقطران [Tar]
سموها Flexible لانه بصير فيها انحناء deflects

2. Rigid :- بتكون صلبة (concrete)
[Portland cement]

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.

Pavement وظائف

1. تقليل stress] رح ينتج عنه strain [الواصل حتى توزع وتخفف من قيمته

2. سهولة وصول بين نقطتين تحت أي ظرف جوي

3. طريق معبد بشكل جيد بكون طريق ناعم ومريح، الطريق إذا كانت سيئة ممكن تسبب أضرار غير مبرر

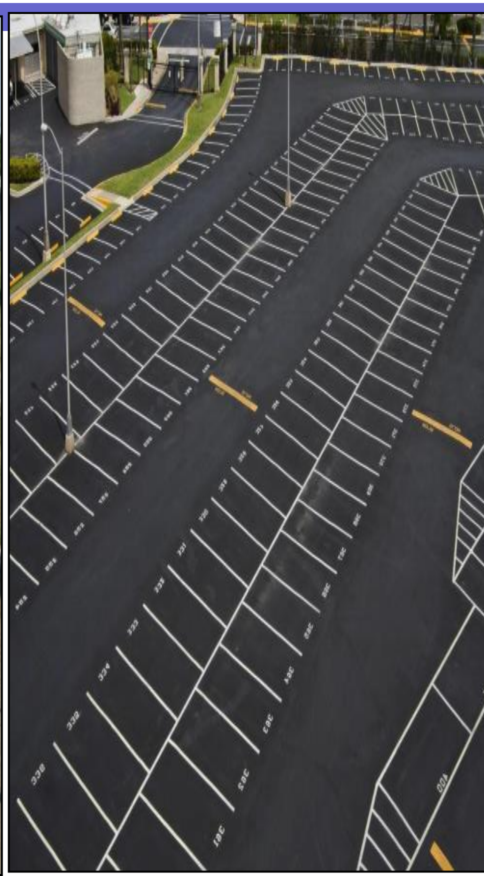
4. ما يعمل طريق إزعاج او يطلع غبرة لانه بأثر على بيئة ويكون ذو جمالية + نقطة 5

5. مراعاة القيمة الاقتصادية

Classification of pavements by Function

توظيف الرصفات

Highway pavement



Parking lots pavements

Airport pavements

Ports and Heavy industrial pavements

مناطق محيطة بالموانئ

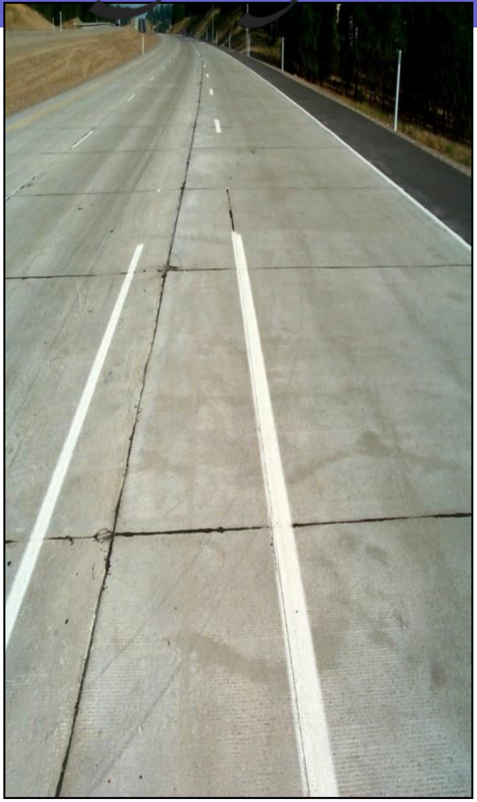
Classification of Pavements by Structure

نوعية الستركتشر

Gravel (unpaved) pavements

غير آمنة

Flexible pavements (asphalt concrete)



Rigid (concrete) pavement

Composite pavements

Flexible Rigid

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.**

شروط Pavement

1- يكون فيها سماكة كافية : بحيث تضمن انه ال stress الي
رح يوصل سطح sub-grad يعمل strain مناسب كل ما كبرت
سماكة كل ما كان stress الواصل لل sub اقل

2- ان تكون طبقات strong عشان تتحمل كل loads اللي عليها

3- لازم يكون في شوية خشونة عشان الاحتكاك

4- صح ذكرنا انه في خشونة ولكن لا يعني خشونة عالية
ف لازم يكون في نعومة عشان يكون مريح

5- ما يطلع غبرة

6- لا يسمح بدخول الماء ، وحدة من مميزات الاسفلت انها مادة
عازلة ، إذا دخل ماء رح يضعف طبقات التحت

7- تصميم المواصفات لعمر طويل وبصيانة اقل

8- يفضل انه الشارع ما يطلع ازعاج

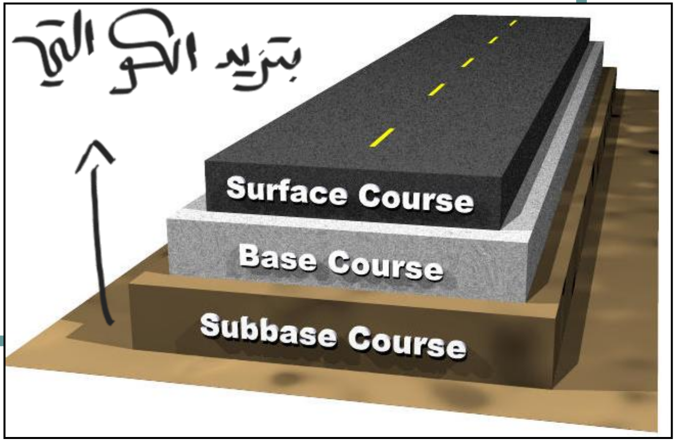
Flexible Pavement Types

استعملنا فيها الاسفلت

1. Conventional flexible pavements, discussed in detail. الاكثر شيوعًا
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.



* المواد ذات المواصفات العالية بتكون موجودة بالأعلى

وكل ما نزلنا لتحت سمحوا باستخدام مواد ذات مواصفات اقل

← بطبقات الموجودة فوق استخدمنا كوالتي اعلى عشان

بكون عليها stress عالي بينما تحت بكون stress اقل فما عندي

مشكلة يكون عندي ماتيريال كوالتي اقل

← إذا كان عندي مواد كوالتي اقل قريبة من موقع بقدر استفيد منها

فبتوفر تكاليف النقل

* local materials :- هي ماتيريال بتكون ارخص كلفة وارخص

نقلاً

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

بعض الطبقات مش شرط
تكون موجودة (حسب الحالة نفسها)

- 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

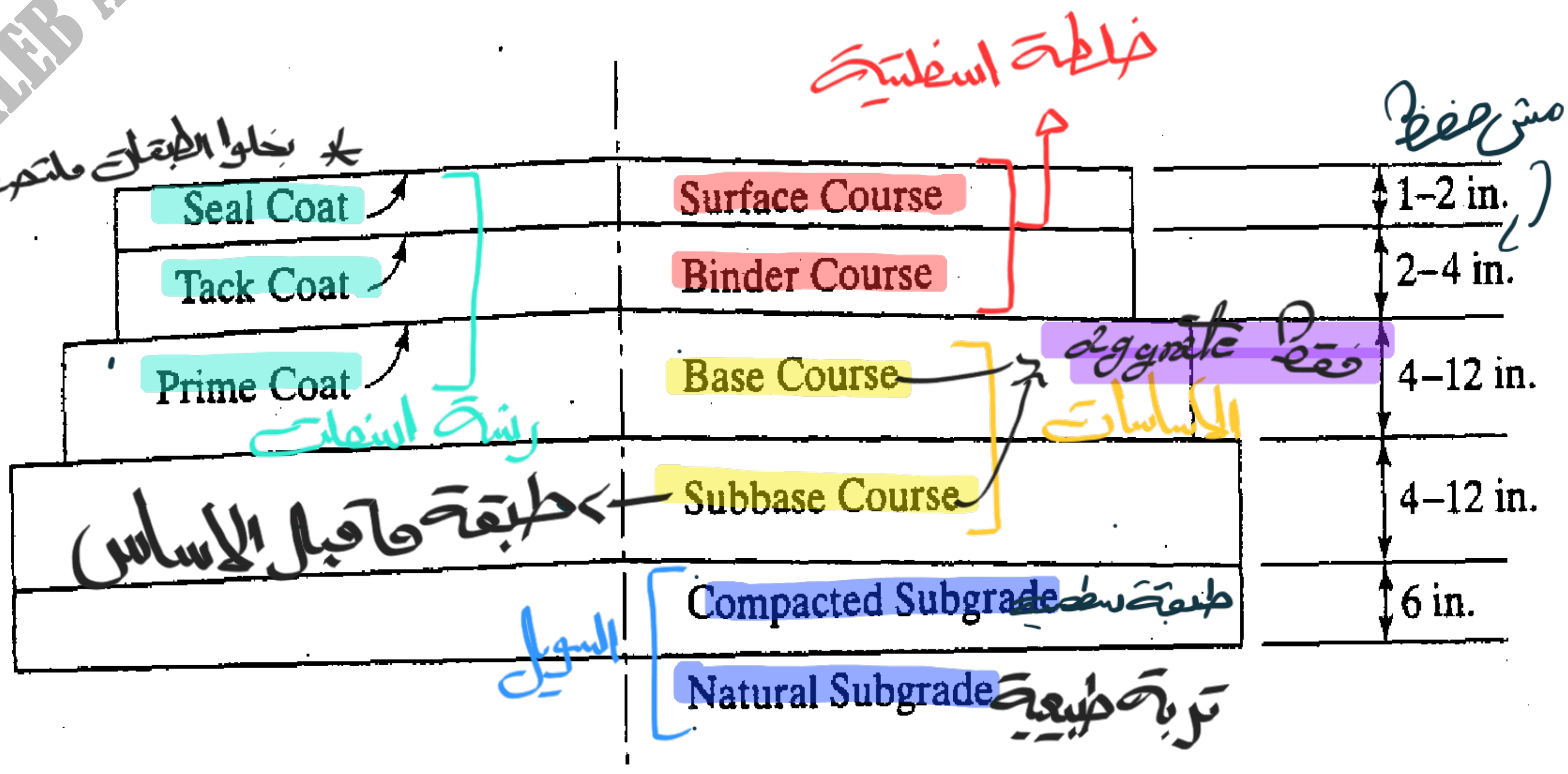


FIGURE 1.2 •

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

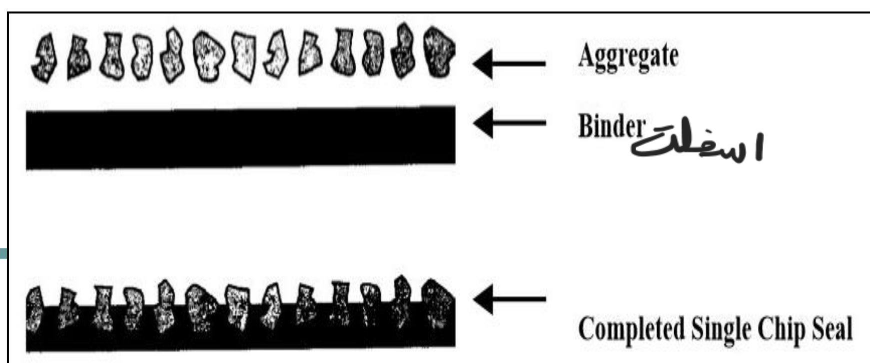
Conventional Flexible Pavements Cont./ Seal Coat (Chip seal)

- 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.

هي عبارة عن رشة اسفلت مضاف اليها

- 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.

Fine agg



شرح seal coat

هي طبقة اسفلت (طبقة معالجة اسفلتية سطحية) ورقيقة والهدف منها الاتي :-

1- عازلة للماء ، يعني لو عندي طريق في crack فممكن استخدم seal

2- إذا استخدم seal coat على طبقة قديمة فبتعمل إعادة حيوية

3- لما خشونة الشارع تتأكل بحيث عندي انزلاقات فبهاي حالة بستخدم seal coat

4- بتحسن الرؤية الليلية [بكون لون افتح] بحيث بنرش اسفلت ونضع فوقه aggregate

← seal coat هي surface treatment

لازم agg ينرش بطريقة منتظمة uniform

← إذا Pavement وضع سطح جيد فما في داعي لطبقة seal coat

Conventional Flexible Pavements Cont./ Surface Course

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- 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.

شرح طبقة surface course

* عندي اسم اخر للطبقة ← Wearing course

H.M.A: Hot max asphalt [خلطات اسفلتية ساخنة]
بتجهز بخلاطات مركزية

* اعلى stress بكون على الطبقة السطحية لذلك في شروط

1- لازم تكون صلبة بحيث تتحمل load [قساوة]

2- يكون سطحها ناعم ولكن ما يكون في انزلاقات

3- تكون عازلة [يجب ان تكون طبقة الاسفلت مرصوصة كويس]
لانه إذا نزلت ماء رح تضعف الطبقة إلي تحت

* إذا كان عندي مشكلة بالشروط المذكورة رح نستخدم seal coat
بس إذا الخلطات جديدة فما بستخدم seal coat

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:

مهمة

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.

شرح طبقة "Binder"

* العالم اخر Asphalt base course

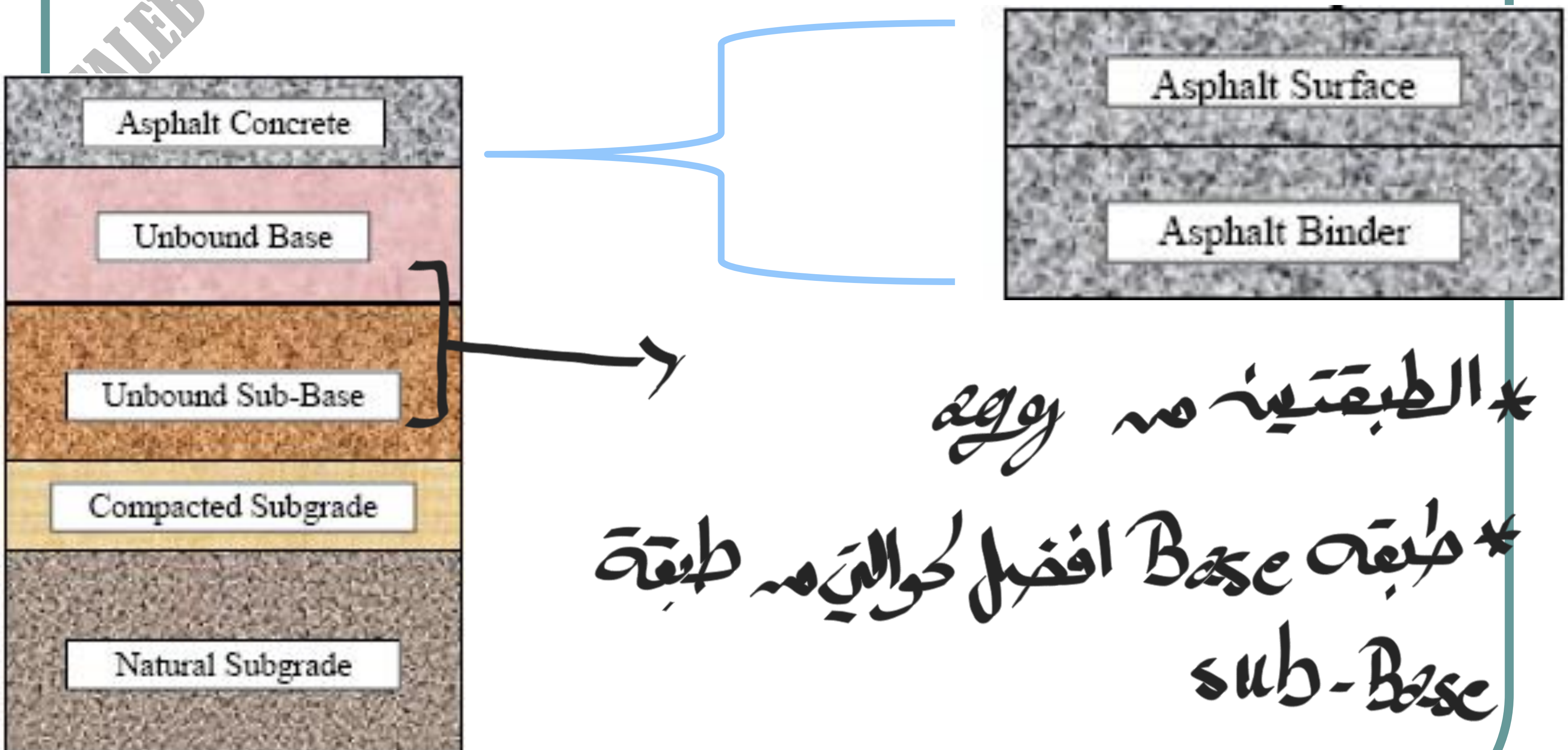
← هي الطبقة التي تقع اسفل surface ويوجد اسباب لاستخدامها :-

1- إذا بعد ما عملت ديزاين سماكة كانت مثلاً cm15_10 هون هاي سماكة نعتبرها كبيرة (حسب معدات) فهون رح نعمل طبقتين فبصير الطبقة التحت هي Binder والعلوية wearing

← إذا سماكة طبقة الاسفلت كونكريت اكثر من "3 بنعمل طبقتين

2- عند binder و wearing الهم كل وحدة مواصفات خاصة فمثلاً بـ binder بسمحوا استخدم agg الكبر فهون رح استخدم اسفلت اقل فبوفر تكلفة وبكون مواصفات اقل بشوي

Conventional Flexible Pavement Layers



* الطبقتين من agg

* طبقة Base افضل لحوالي من طبقة sub-Base

* unbound: هي طبقة agg مرشوشة ماء ومدحولة فقط

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.

Tack coat :- رشة اسفلت خفيفة

(1)

يوجد للاسفلت انواع في اسفلت سمنت العادي وفي

اسفلت إذا بخلطه مع ماء بمواصفات معينة بصير اسمه
(2) emulsion وفكرته انه هو اسفلت سمنت بنذوبه بماء
عشان نخلي سائل

← لجعل اسفلت سائل عندي طريقتين إما تذويبه من خلال
خلطه بماء أو من خلال حرارة العالية أو ممكن نخلطه
مع مادة بترولية و بصير اسمه cutback asphalt (3)

Tack coat بكون emulsion

ويستخدم حتى اضمن يكون في bond ما بين binder وطبقة العلوية
(wearing) او ممكن بين binder و binder

← يعني طبقة اسفلت فوق طبقة اسفلت بنستخدم

Tack ومرات بس يكون عندي composite هون برضه بنستخدم
Tack للارضية كونكريت بتكون)

Prime coat :- بكون اسفلت مذاب بمادة بترولية

وذكرا انها low viscosity :: بدي يله يكون لزوجته قليلة ؛ لأنه

طبقة Base course فيها فراغات ومسامات فبدي الاسفلت

يفوت جوا فهو على الاغلب يلصق طبقة base مع طبقة binder

← زي ما حكينا بكون low viscosity مشان في فراغات

ب base فبدي اسفلت يعبي فراغات

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.

Base course :- الطبقة التي تلي مباشرة طبقة surface
او طبقة Binder

← agg التي نستعملها هي غالبًا بتكون موجودة بالموقع يعني
حسب الكسارة شو بتطلع :
* crushed stone هو ناتج الكسارة

* crushed slage هو خبث الحديد بحيث بإمكانك
تطحنه وتستخدمه مع الاسمنت وتصنع slage cement
وممكن نفسه تستخدمه كـ agg

: بتقدر تستخدم اي واحد فيهم او ممكن تستخدم اي
مواد ثانية

Subbase course :- طبقة ما تحت الاساس ، مشان اوفر
شوي فعملنا طبقتين بحيث طبقة base course كوالتي
الها اعلى وطبقة ثانية بكوالتي اقل

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.

* Subgrade :- ممكن نحكي الأرض الطبيعية [soil]

← مكينا انه الطبقة الاولى بنعمل الها دمل وبنرصها

وبنرشها بالماء لنثبت الطبقة السطحية

∴ دائمًا الطبقة السطحية تتحرك وتتقلب وتترش بالماء وإذا كانت ماتريال الخاصة فيها سيئة فـ يتم استبدالها بماتريال افضل

هيك بنكون ظلحنا الطبقات الخاصة

بـ Conventional Flexible pavement

Full-Depth Asphalt Pavements

يصب الاسفلت مباشرة على subgrade

- 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.

الفرق بين النوع السابق وبين Full depth انو ب full ماعندي base ولا subbase بكون مباشرة اسفلت [wearing and binder] يعني agg غير موجود فوق ال subgrade بكون بعدها اسفلت حسب السماكات

سبب استخدام نوع Full depth:-

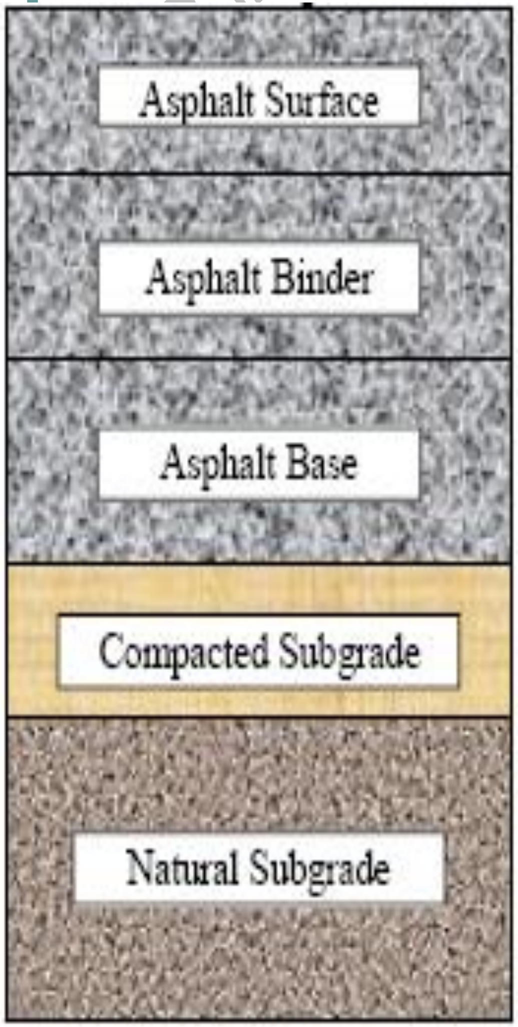
1- تحمل load عالي

2- مرات بكون ماتيريال غير متوفرة مثل agg

نقطة 3 + نقطة 4 رح نحكي عنهم لقدام

سلبيات تكلفة عالية

Full-Depth Asphalt Cross Section



ارقام غير دقيقة ←

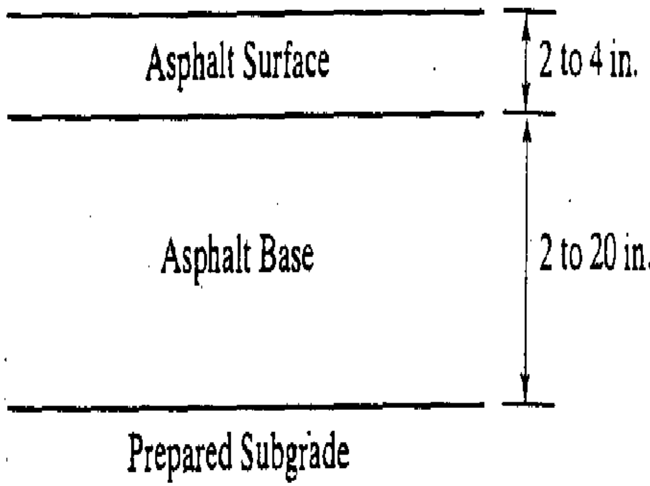


FIGURE 1.3

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.

1- الطبقة السطحية [اسفلت كونكريت] لو صار فيها cracks
رح تنزل على crack الـ base و base عبارة عن agg وكل ما زادت
رطوبته بصير ضعيف فميزة انه عندي طبقة اسفلت سميكة
وتحتها subgrade ف صعب شوي انه تدخل له

2- وهي نفسها نقطة 3 سابقا وهي كالاتي: طبقة base او
subbase بوخذ وقت وجهد و ممكن تأخير لانه ممكن
إذا جا رمي شتاء فلازم تستنى تنشف بينما اسفلت بكون
اسرع ولو اجا شتاء ما رح يكون في تأخير مباشرة بس
بوقف الشتا تاني يوم بتم اكمال العمل : بـ Full ما عندي
base فالشغل بكون اسرع

3- اسرع وبكون بسماكة معينة

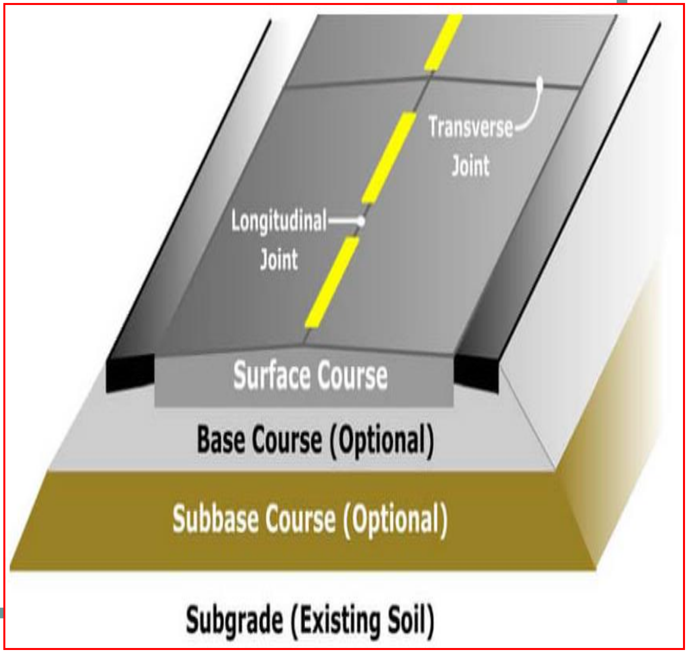
4- عندي بالمادة ستركتشر رح تكون كلها اسفلت كونكريت فبكون اسهل

5- بسبب السماكة العالية فهي لا تتأثر بالرطوبة

6- بتحمي طبقة subgrade انه يوصلها ماء وتضعفها

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 :- هي افضل من باقي الانواع ولكن تكلفة عالية وهو عبارة عن Portland cement conc

مش دايمًا بستخدموا base او subbase تحتها

ومن الجدير بالذكر انه Rigid تنفذ كـ slab يعني قطع

للتذكير :- الكوالتي الخاصة بالمتيريال لـ base و subbase بتكون اعلى بكثير من كوالتي ماتيريال sub grade

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).

* ممكن نحط concrete pavement مباشرة على subgrade او نحطها على طبقة فوق subgrade بكون base او subbase

* إذا كان في طبقة base او subbase تحت concrete فرح يعطيني ميزة اضافية وهي كالاتي :-

5- لما نعمل طبقة base corse بكون كثير الارضية ممتازة لنشتغل عليها

1- عشان يوصل بين كل سلاب و سلاب بكون في قضبان حديد جزء منهم بكون داخل ب سلاب الاولى وجزء ب سلاب ثانية بس بينهم فواصل هاد فاصل رح نعبي بمادة مانعة الماء تدخل وقابلة للانضغاط مثل سليكون , اسفلت واحد من عيوب rigid المشهورة انه هاي joint بتروح فبصير ماء تدخل على طبقات التحت فإذا كنت ماء subgrade فهو ضعيف وبنفس حالة لو فرضنا سطح كونكريت صار في crack فبنزل crack ويسمح بدخول ماء ومع وقت وضغط بتصير مواد الموجودة تحت تطلع على السطح فبصير تحت فراغ

:

pumping :- خروج ماتيريل الخامة بـ base او subgrade بطلعها من crack او من joint

1- وجود طبقة base برفعلي Pavement بحيث ما يوصل ماء بسهولة

2- بس يوصل تربة ماء وتتجمد نحجم بزيد فتنتفخ التربة وبعدها بذوب جليد فبرفع رطوبة بشكل كبير وهاد بضعفها ويحركة عليها او زيادة load بتطلع برا فهاد بنسمي frost action

ف وجود طبقة زي base بكون وزن زيادة على التربة فبتقلل من الانتفاخ متوقع صورة

3- اعتبرنا انه رفع الطبقة عن منسوب الماء

Rigid Pavement Cross Section

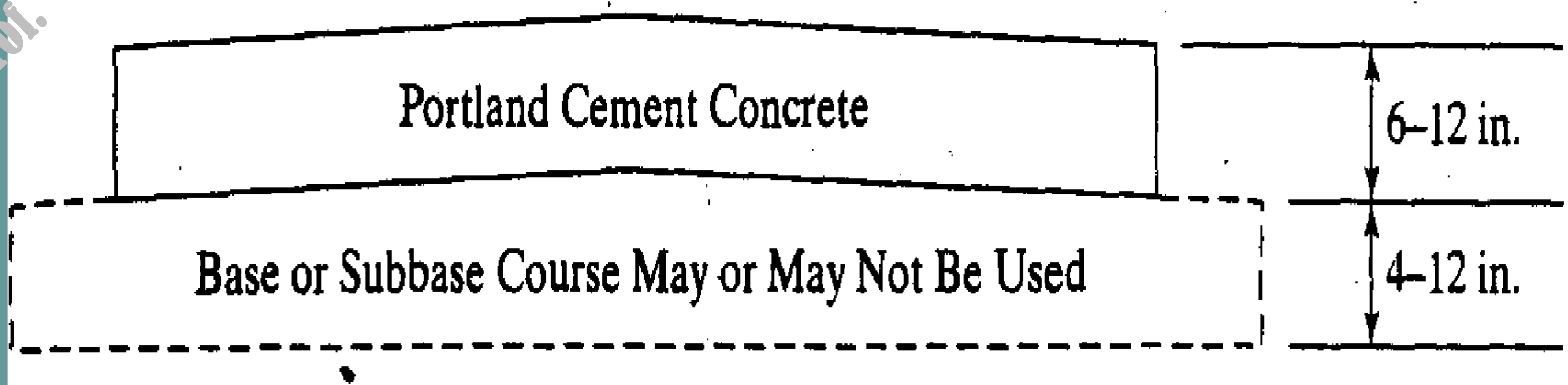


FIGURE 1.4

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

Types of Rigid Pavements 16/7

حفظ بترتيب الاحرف

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.

أنواع Rigid Pavements

1- JPCP :- ما تحتوي على حديد تسليح بكون خرسانة فقط

← كلما استعملت حديد في Pavement يعطيني مجال ابعد المسافة ما بين Joints

:- هي النوع الأول عندي المسافة بين Joints قليلة يعني عندي Joints أكثر

2- JRCP :- لما نحكي Joints يعني فيها Joint بكون تسليح كل سلاب لحال، يعني كل سلاب الها حديد تسليح لحال

3- CRCP :- بكون تسليح مستمر ولا تحتوي على Joint وهي الأكثر ديمومة

4- PCP :- يحتوي على Joint وهو أقل عدد Joint

يفضل يكون عندي بين مسربين فاصل طولي لتجنب crack

عشان انقل load بين السلاب د longitudinal
بحط Ties

وممكن استخدم Dowels او agg بحيث
انتقال load يكون من خلالها

بال Joint plane : ممكن يكون فيها Dowels وممكن
لاء

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

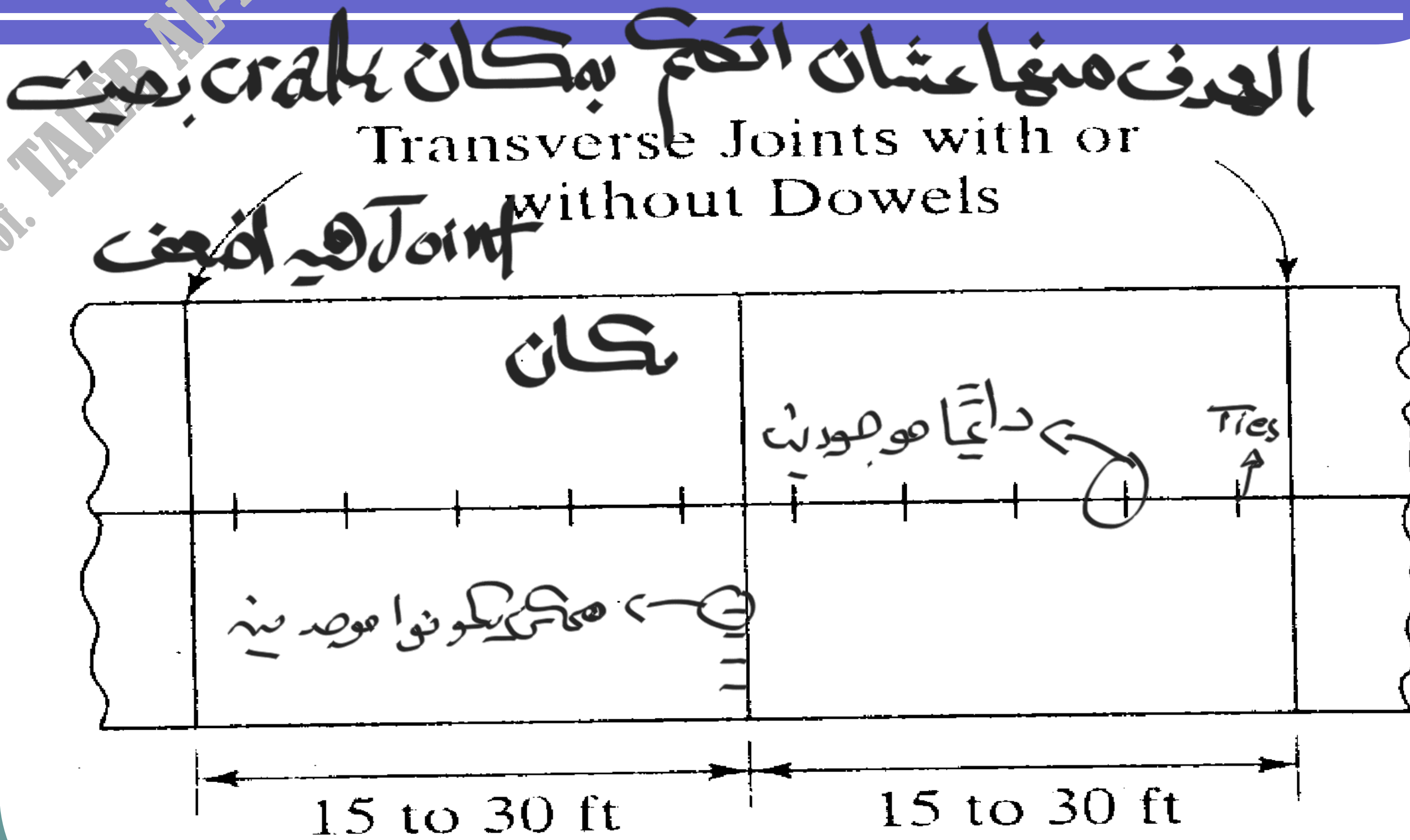
المسافة بين الفواصل قريبة ١

مش شرط وجود Dowels 2

مسافة بين Joint من 30 - 15 وهي غير ثابتة وحسب مواصفات 3

دايما Ties في longitudinal عرضي ٤

JPCP


الهدف منها عشان اتحكم بمكان crak بحيث
Transverse Joints with or without Dowels
Joint هي اضعف
مكان
دائما موجودة
Ties
هون ممكن يكونوا موجودين
15 to 30 ft
15 to 30 ft

(a) JPCP

JPCP

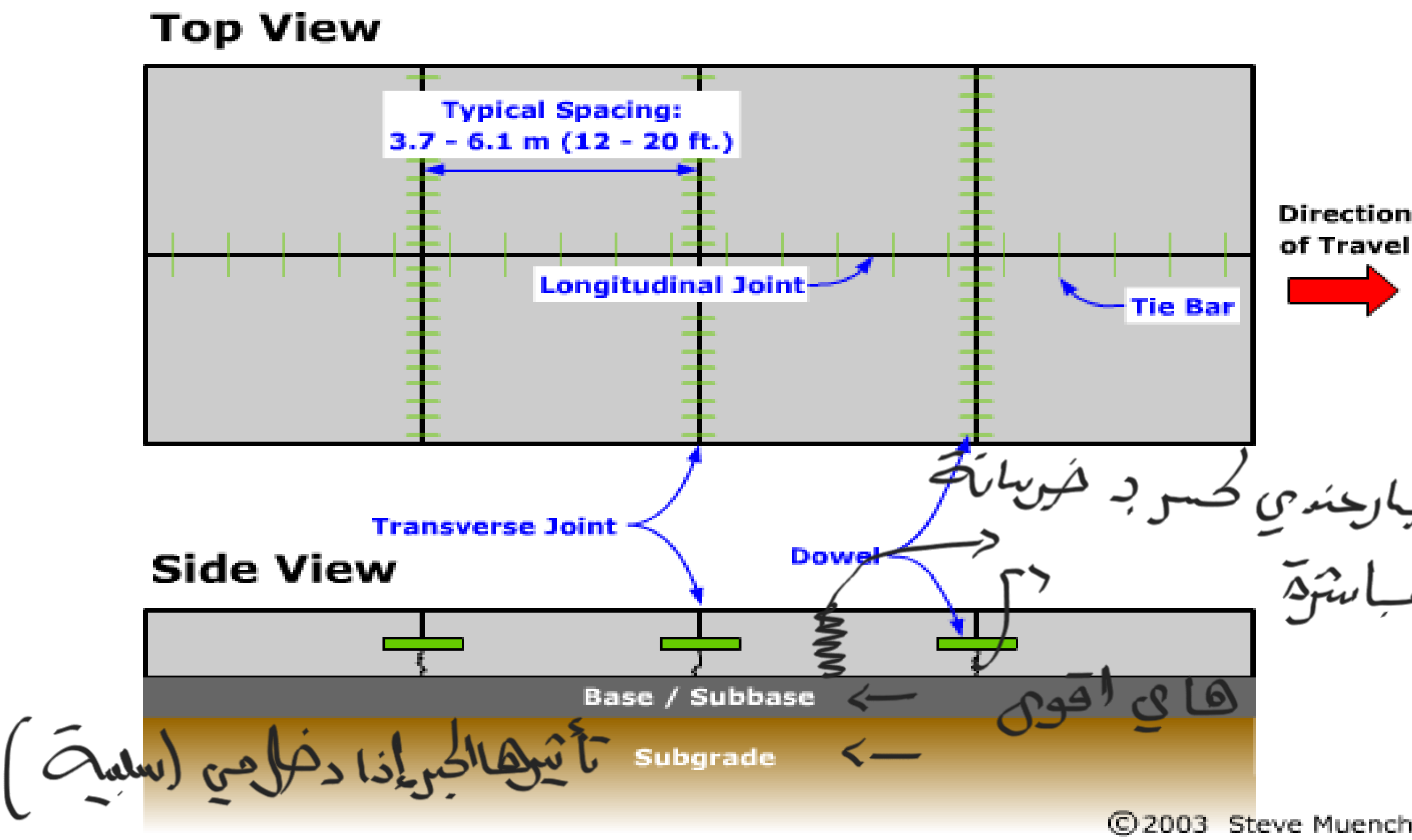


Figure 2.39: Jointed Plain Concrete Pavement (JPCP)

Jointed Reinforced Concrete Pavements (JRCP).

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

JRCP

تحتوي على فواصل وعلى reinforcement وهي تساعدني على
اوسع مسافة بين Joint

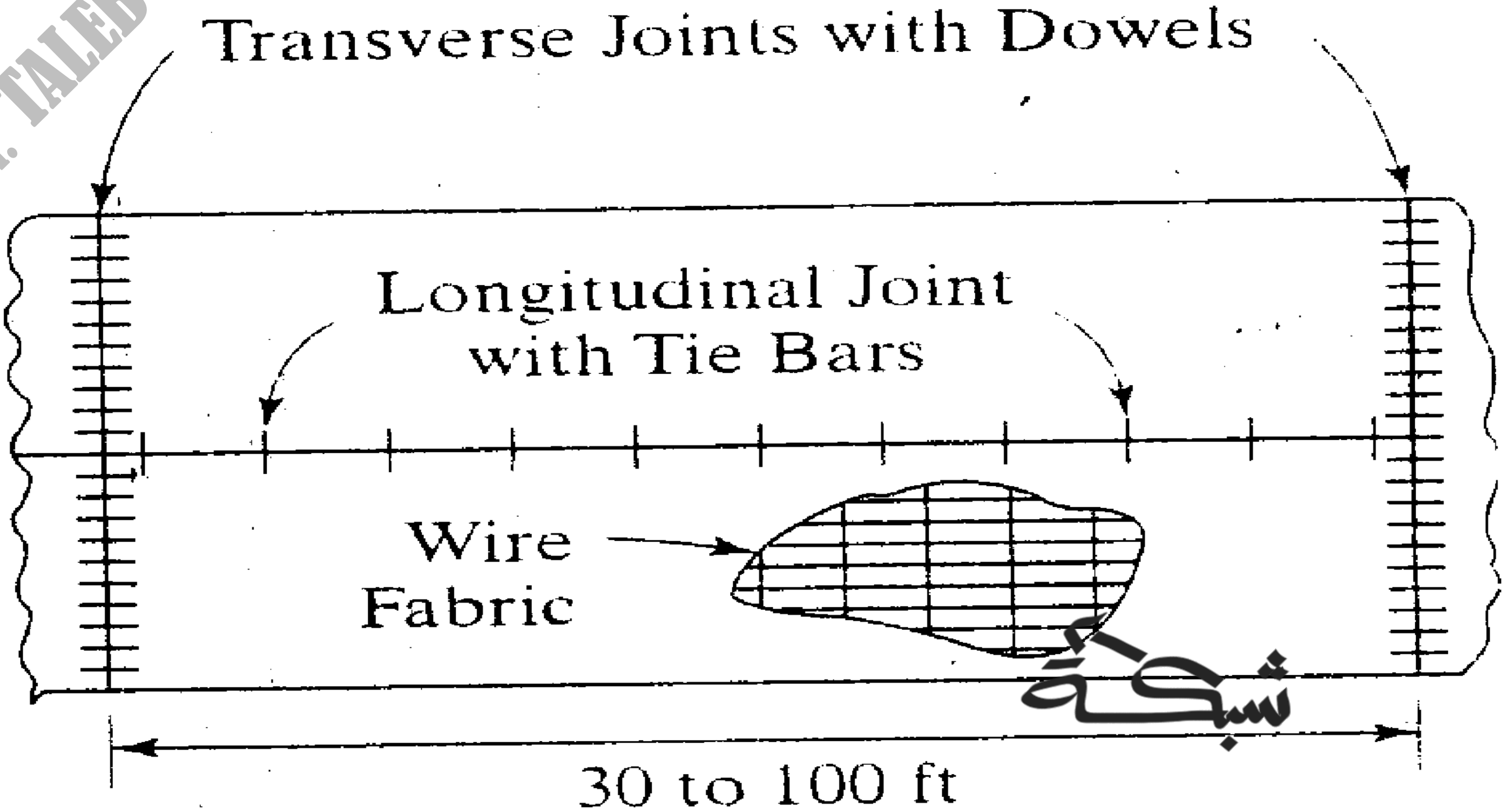
والهدف من وجود الحديد ليس لجعلها تتحمل زيادة
ونحن على الاغلب هو اوسع spacing بين Joint

لازم يكون عنا Dowels

* كلما زودت الحديد حتزيد المسافة بين spacing

-> وجود الحديد بالكونكريت بخلي متماسك فهو
بحافظ على seafty

JRCP



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

(b) JRCP

JRCP

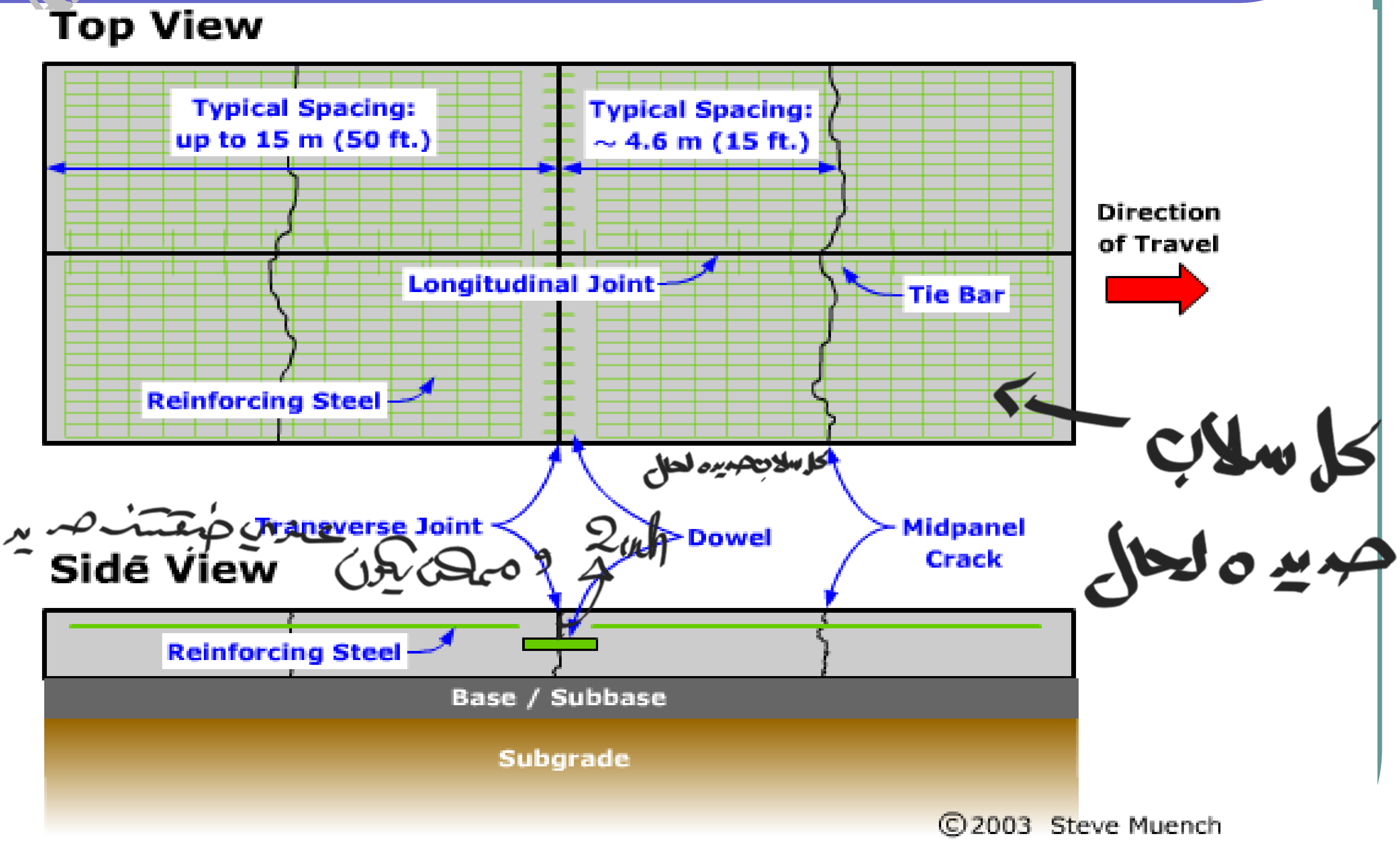


Figure 2.40: Jointed Reinforced Concrete Pavement (JRCP)

Continuous Reinforced Concrete pavements (CRCP).

هادا افضل نوع

- 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

*حكينا انها لا تحتوي على Joint

* ممكن يصير عندي فاصل في حال انشغلت فرضًا يوم وبعد بيوم كملت شغل

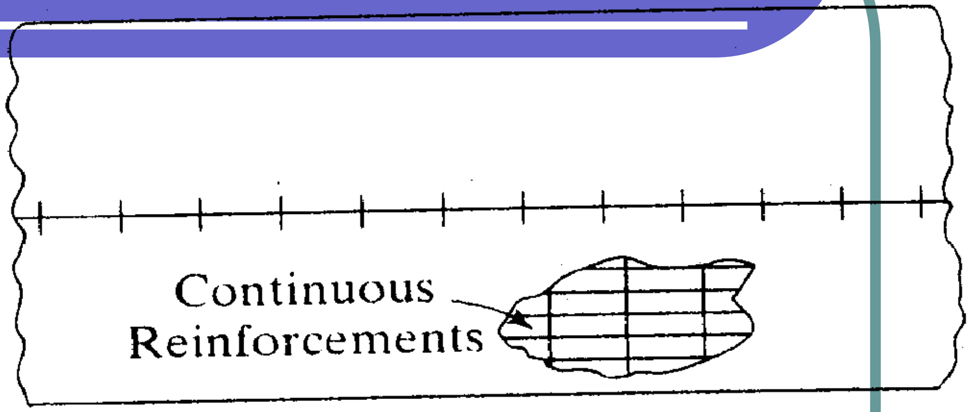
* كونه هاد النوع لا يحتوي على Joint فهو أفضل نوع ، لأنه أضعف نقطة هي عند Joint

* لانه في حديد تسليح ف على الاغلب بساعد انه يقلل سماكة

* بكون عندي traffic عالي

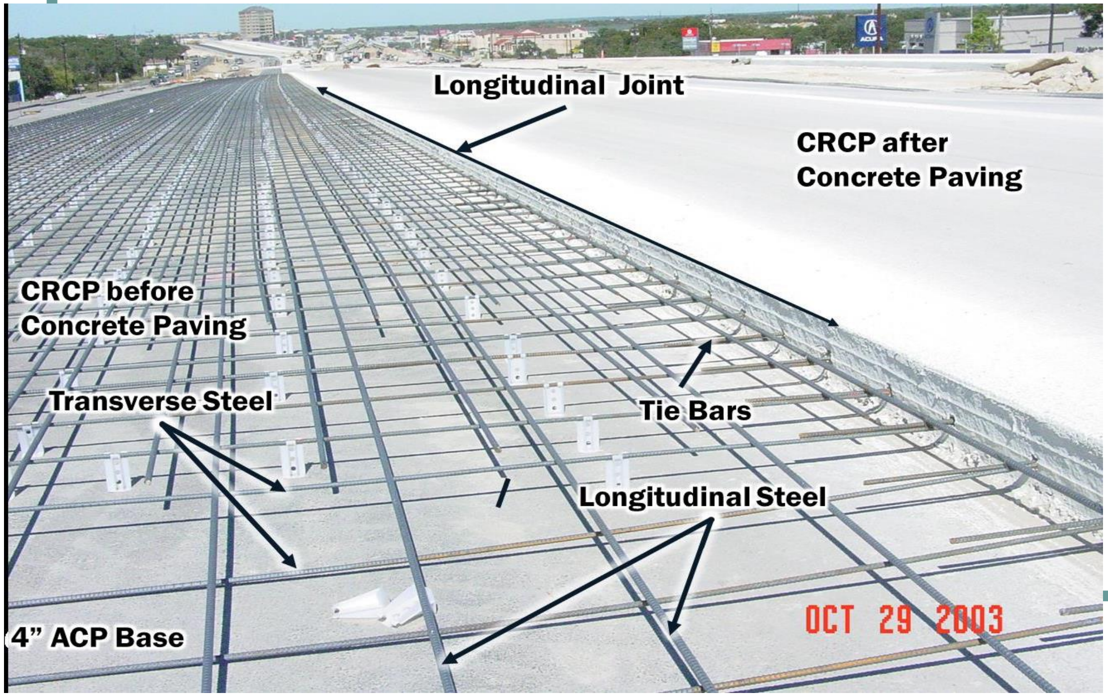
* العيوب ممكن يصير عندي تكسرات بالاطراف

CRCP



No Joints

(c) CRCP



CRCP

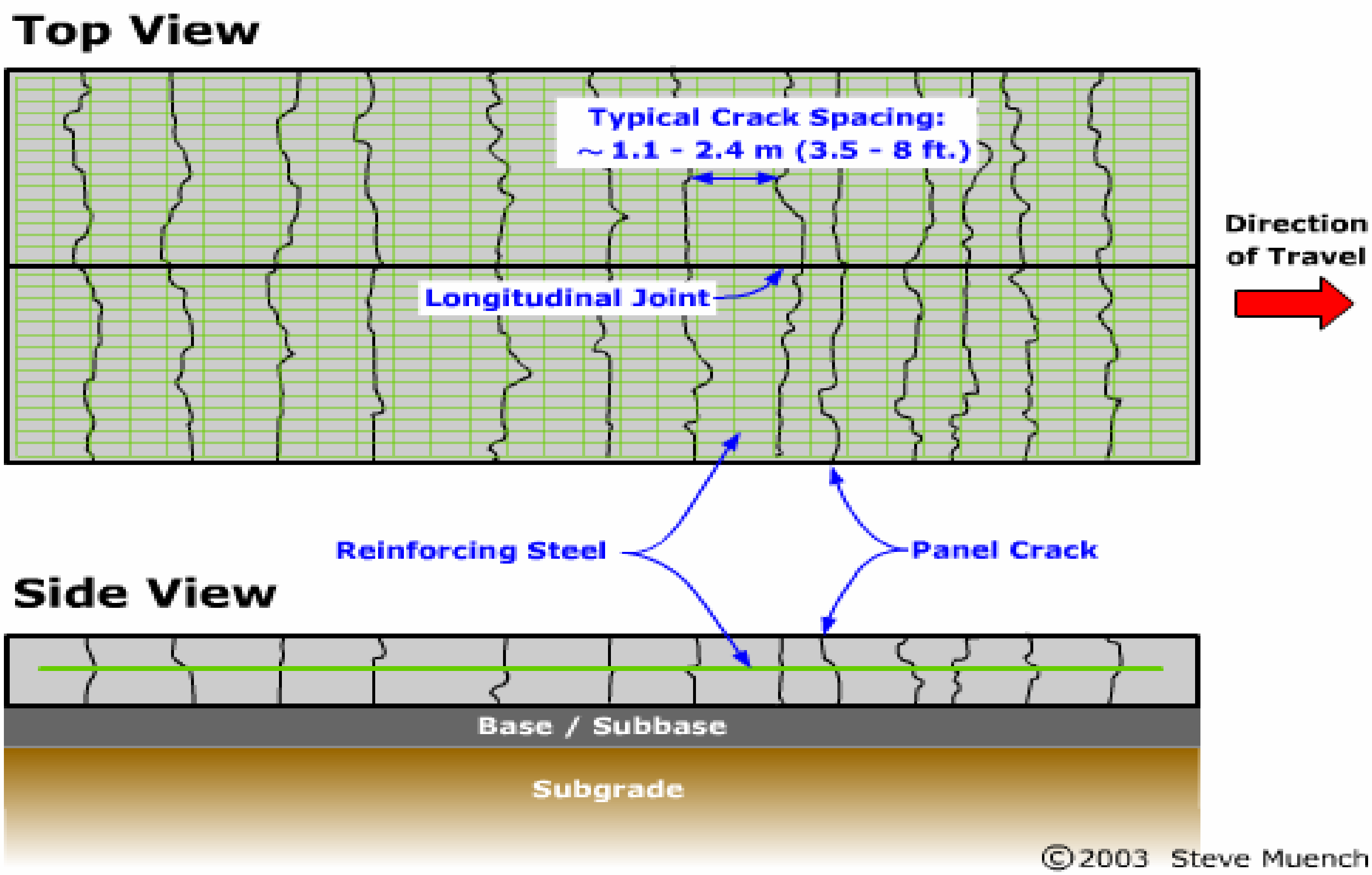


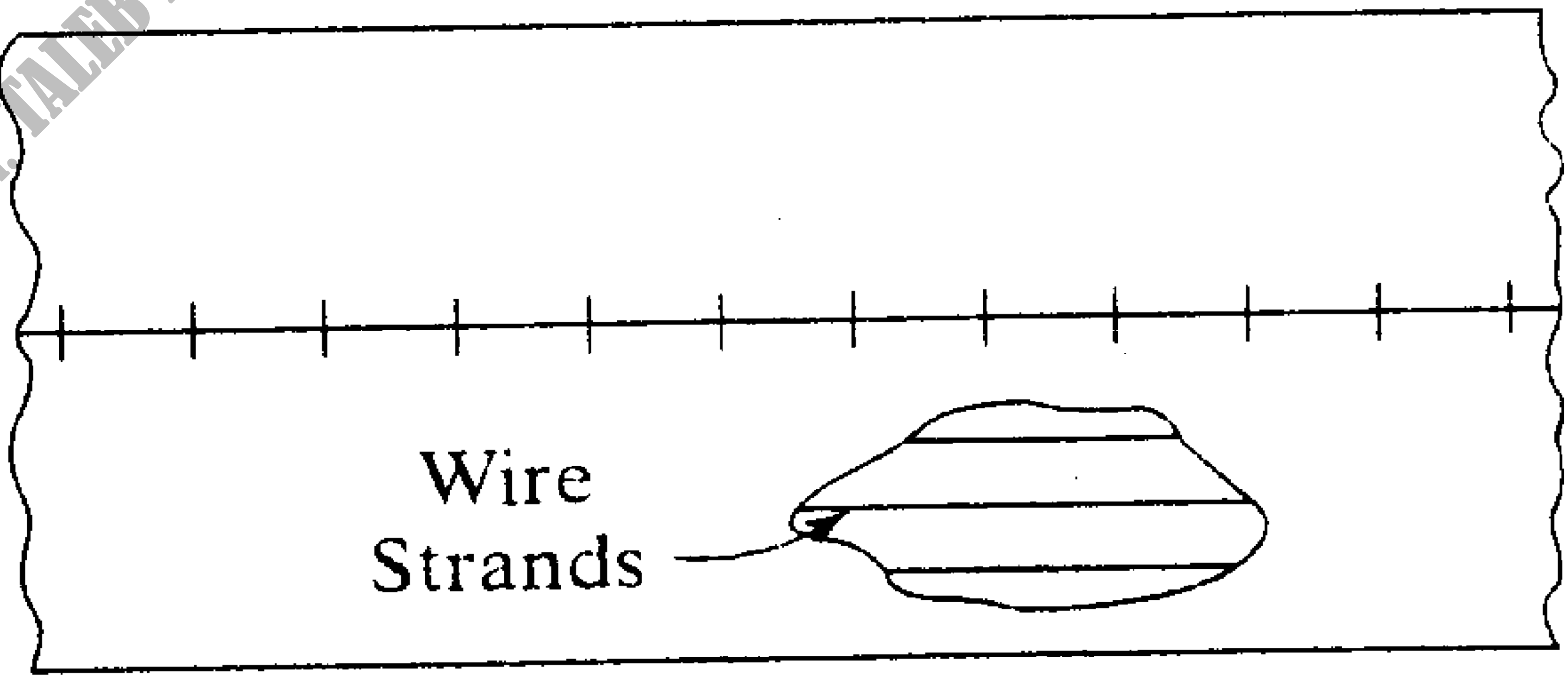
Figure 2.41: Continuously Reinforced Concrete Pavement (CRCP)

Prestressed Concrete Pavements (PCP)

بتزود قدرة

- 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

PCP

* بتزود قدرة ، لما تحط compretion زيادة ولا ما بتعرض
لـ tension هيك بتزود قدرة

* فيها transverse ولكن عدد قليل

* على الغالب بالمدرجات تستعمل لانها بتوفر سماكة

* نهاية أنواع Rigid Pavement

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. مشاكلها
- Most of the available are the rehabilitation of PCC using asphalt overlays.

عمل إعادة تأهيل الاسفلت

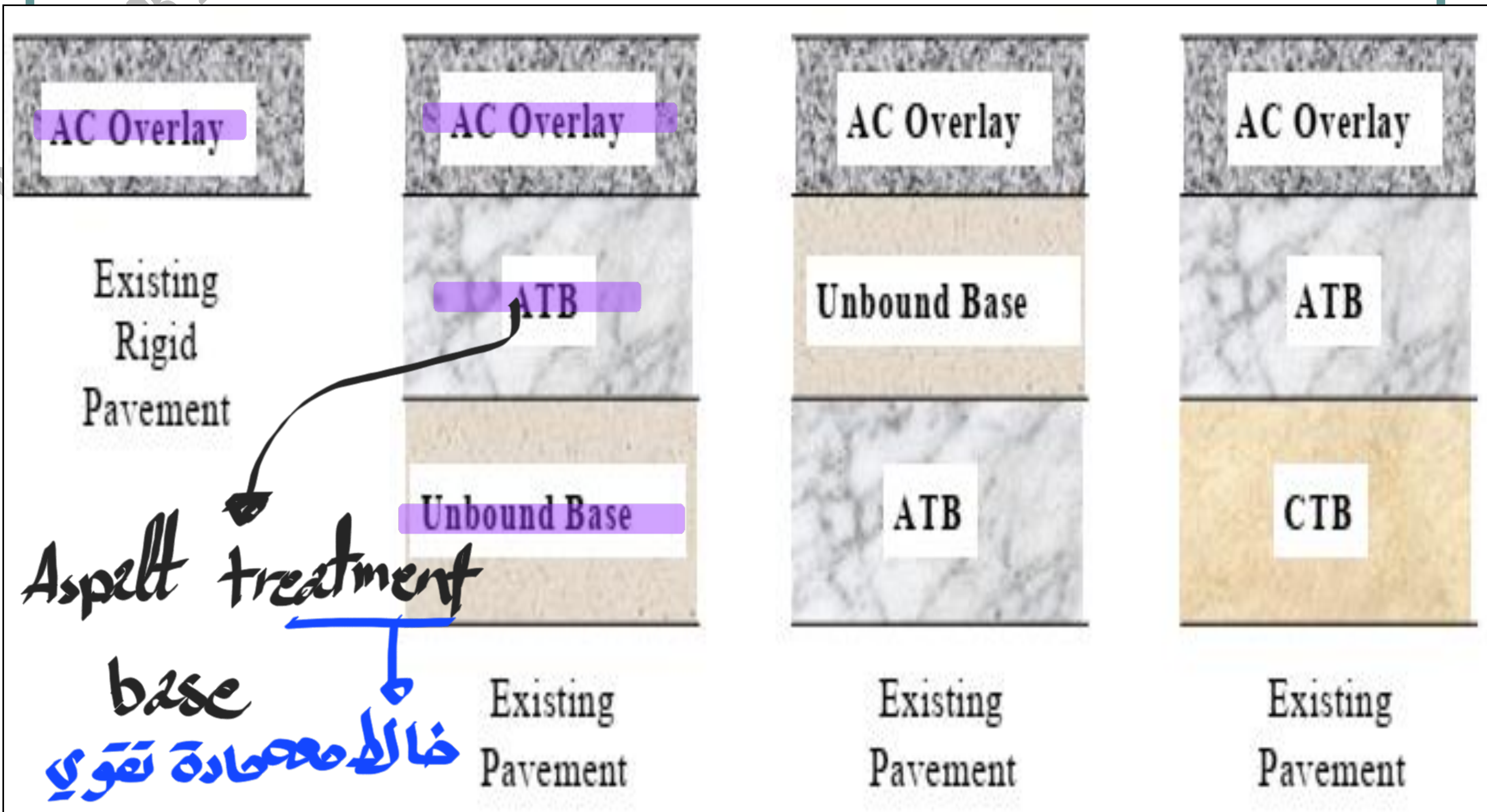
هوحلى الغالب كونكريت او Rigide و Flexible

* بكون الطبقة السفلية PCC وفوقيها طبقة اسفلت

* فمشكلتها انها غالية السعر

* اغلب الموجود هو Rigide قديم تم إعادة تأهيلها

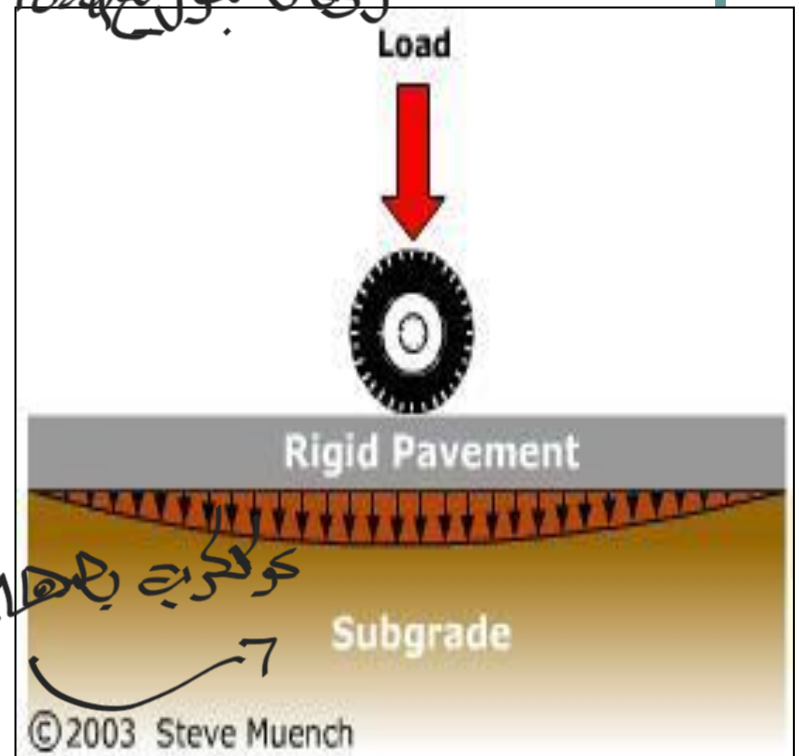
Typical Composite Pavement Sections



Rigid VS. Flexible pavement

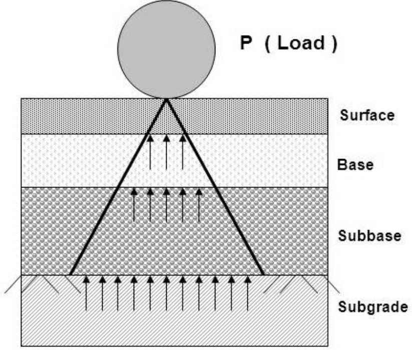
Load Distribution over the Subgrade

- 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.

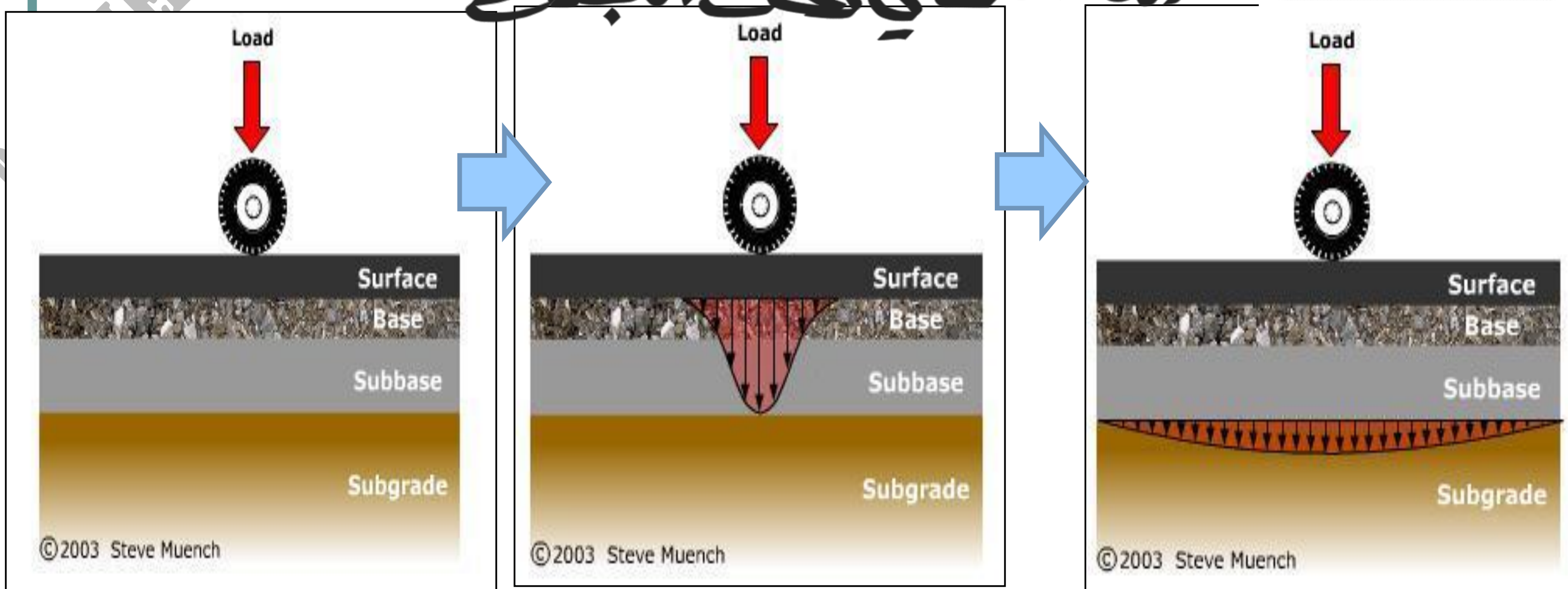


Rigid VS. Flexible pavement

Flexible Pavement Load Distribution



stress عالي تحت العجلات



- 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

كيف بوزعوا loads على sub grade :-

Rigid :- stiffness العالية ، اعطس area كبيرة
بحيث بروح للكونكريت بعدها لـ subgrade فـ
اعطاني Area عالية و stress اقل

Flexible :- stress عالي جداً تحت العجلات
والطبقة الاولية مارح توزعها الـ stress فهون بلش stress
توزع بزاوية وكل ما نزل لتحت اكثر بتصير Area
اكبر ، بحيث كل ما عليت الطبقات كل ما كان stress
الواصل subgrade اقل

Rigid VS. Flexible pavement

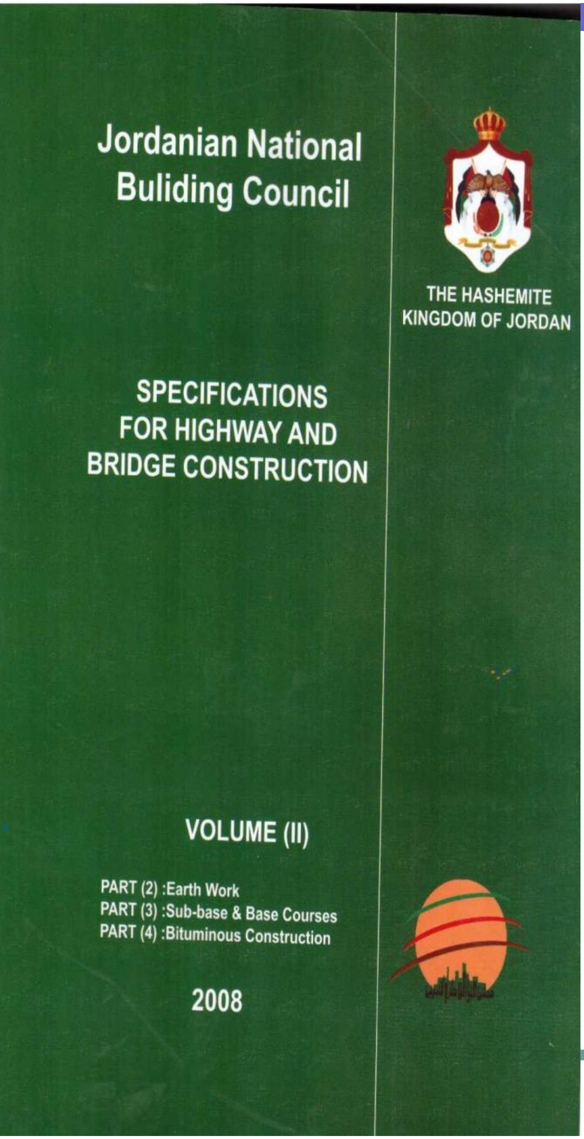
FLEXIBLE PAVEMENTS	RIGID PAVEMENTS
1. Grain to grain load transfer	1. Slab action takes place
2. Initial cost is low	2. Initial cost is high
3. Joints are not required	3. Joints are required
4. Durability is less	4. Durability is high
5. Good subgrade is required	5. Good subgrade Is not required
6. Temperature 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.

انعكاس شمس قليل

انعكاس شمس اكثر

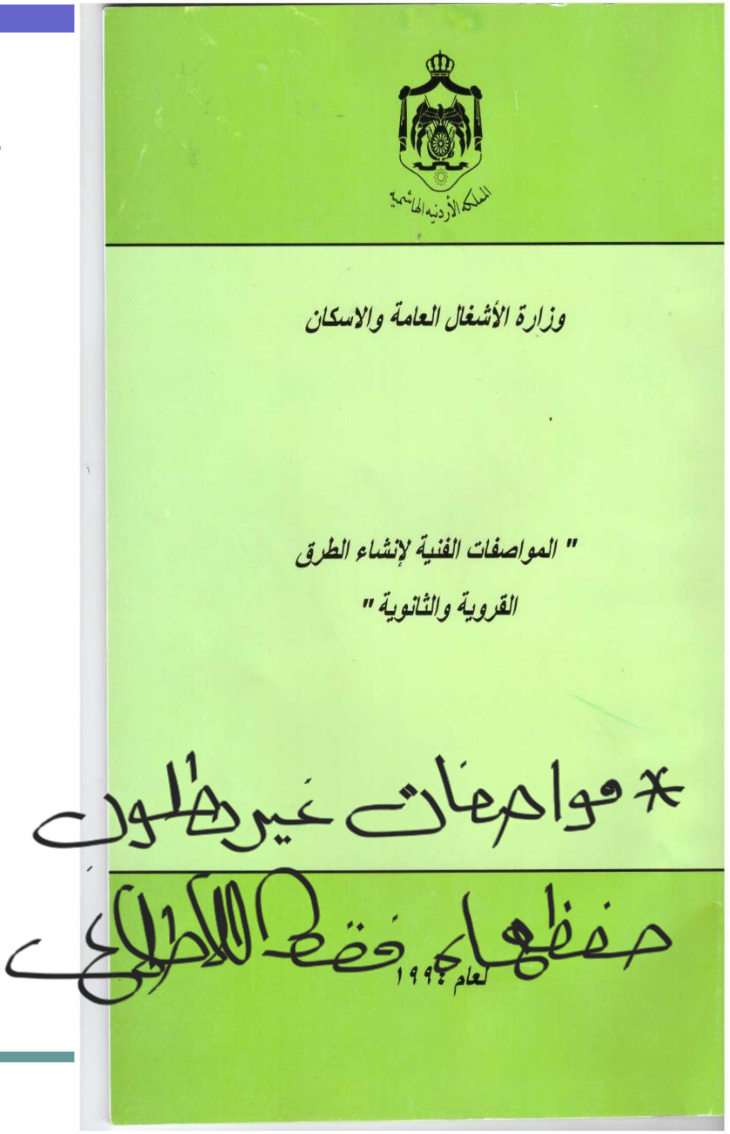
غالب هما عكس بعض

ممكن يكون في عندي سلاب	
اعلى تكلفة	ارخص
عندي Joint	ماعندي Joint
عمر اطول (ديمومة)	عمر اقصر
مش كثير مهم لانه اصلا السلاب	كثير بعتمد ا subgrade يكون في strength مناسبة
هون بكون تأثير كثير اوضح لكونه بحسب ماتيريل موجودة داخله	كونكريت رح يتأثر بالحرارة وممكن يصير في تقلصات
عمر span 30 years	عمر span 15 years
اقل الصيانة فيها	صيانة فيها مكلفة
الاسمنت بدك تستنى لينشف	مجرد ما طبيت الاسفلت بومه وبمشي
كونكريت لونه فاتح فبساعد على الرؤية	لون اسفلت اسود فبليل فما بكون في
طبقات اقل : سماكة اقل	طبقات اكثر : سماكة اكثر
	بعتمد على طبقة ال subgrade تكون strength الها جيدة
ثبات بعتمد على ال slab & Joint	ثبات هذه الطبقات بعتمد على تشابك بين particles / الاحتكاك و cohesion



Jordanian National Building council

Specifications for highway and bridge construction



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 .

أولاً: التعاريف :

****

١- الطرق الثانوية :

وهي الطرق التي تربط المدن بالقرى وتمر بأكثر من قرية باعتبارها طريقاً نافذاً.
ويمكن لهذه الطرق أن تصل بين الطرق الرئيسية مروراً بقرى أو مدن (غير مراكز المحافظات) .

٢- الطرق القروية :

وهي الطرق غير النافذة التي تتفرع 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 :

****

٥/١- 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 رقم (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 .

٥/٢- 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) :

Tack coat

****

٦/١- يجب أن يكون الاسفلت من نوع (MC-70) على أن يرش بمعدل(٠٫٧٥ -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

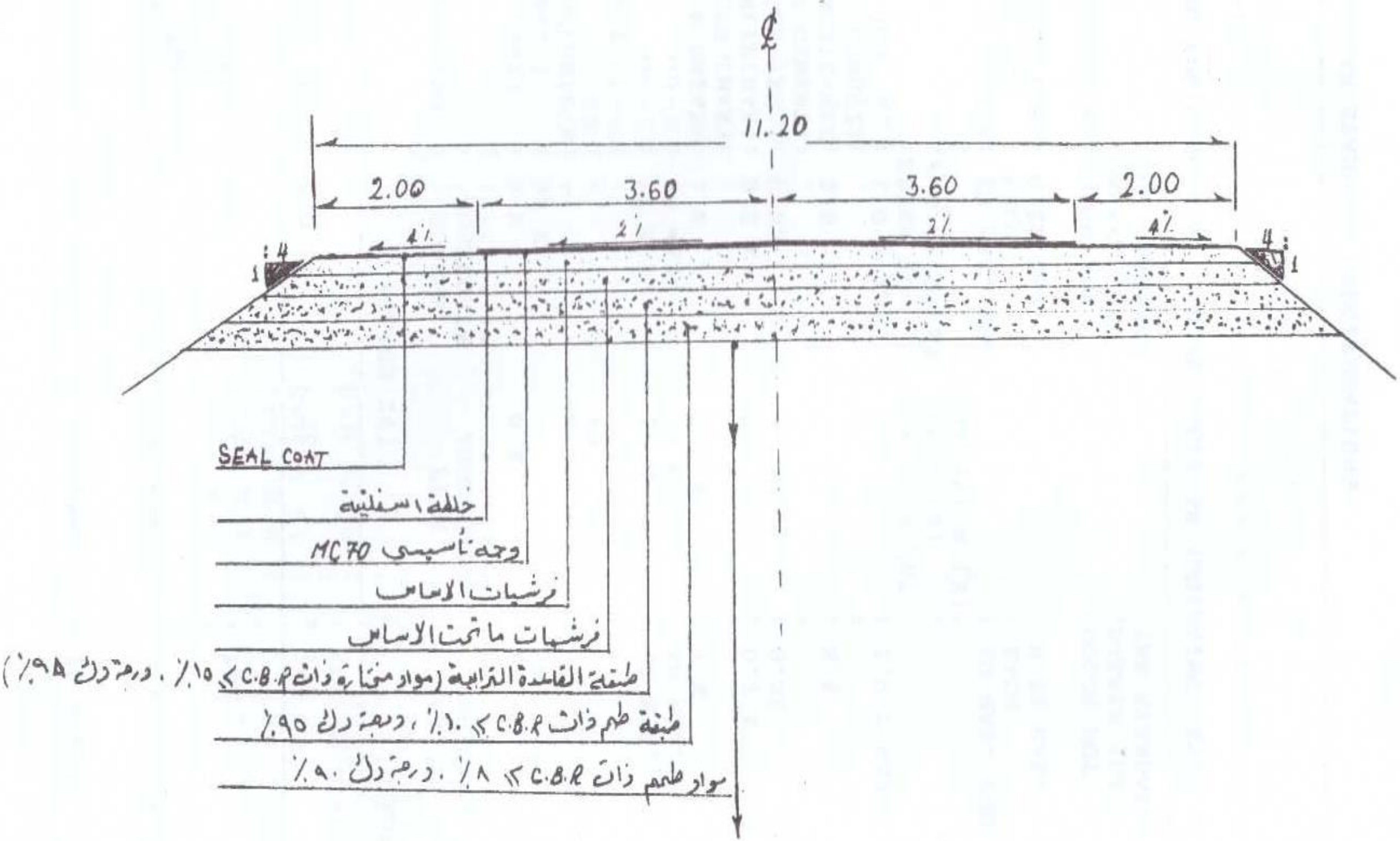
صف كمية الرش في اعلى ؟

Prime

٨/أ- الوجه اللاصق (Tack Coat) :

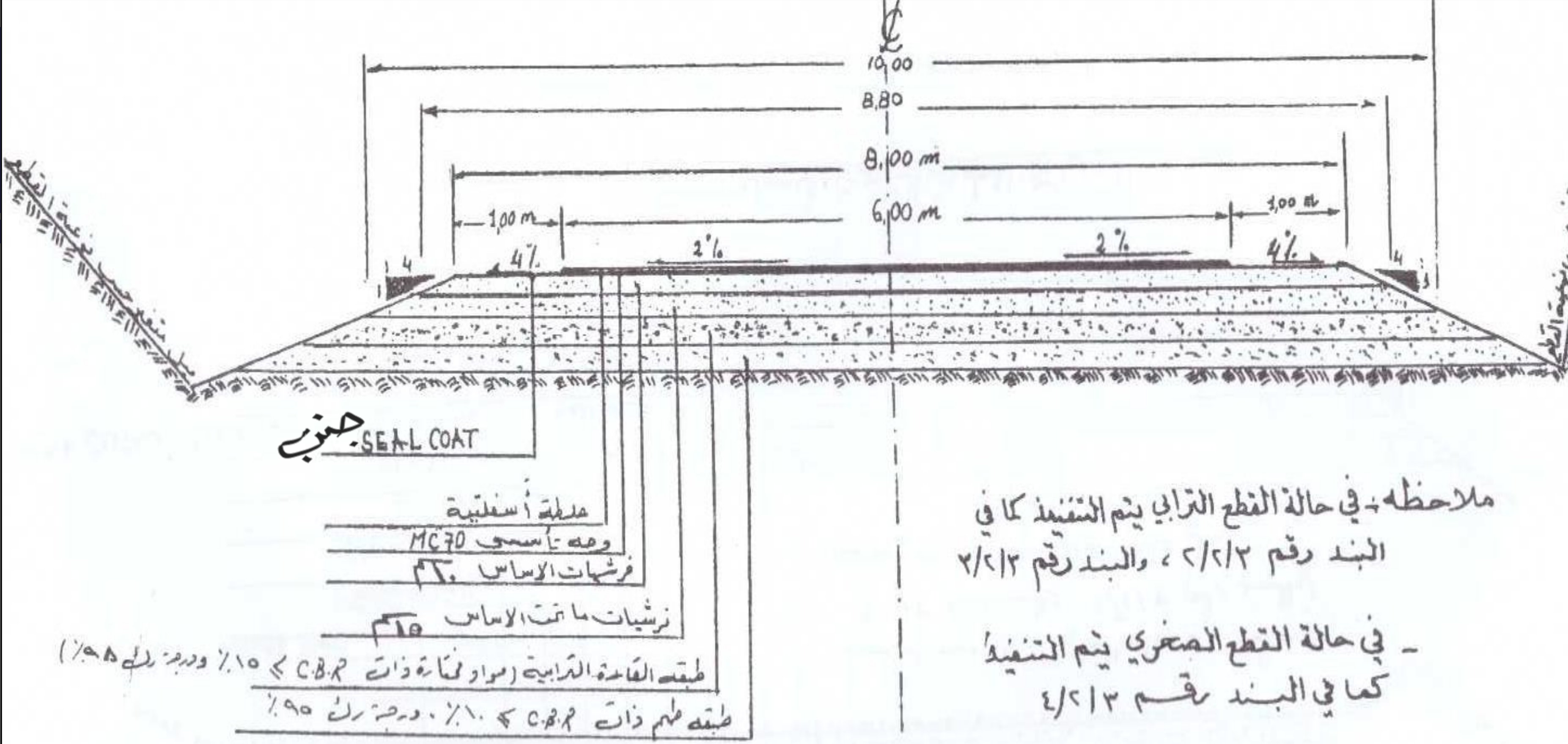
****

- تتم هذه الأعمال وفقاً" 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 جيداً" بواسطة الضاغطة الهوائية (الكمبريسور) قبل رش الوجه اللاصق ولا يدفع سعر لهذا العمل وانما يكون محملاً" 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 اعتماداً" على نوع مادة الوجه اللاصق وعلى نوع السطح المراد رشه وحسب تعليمات المهندس المشرف .
- تمنع حركة السير على الأسطح المرشوشة .
- تتم هذه الأعمال وفقاً" 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 .



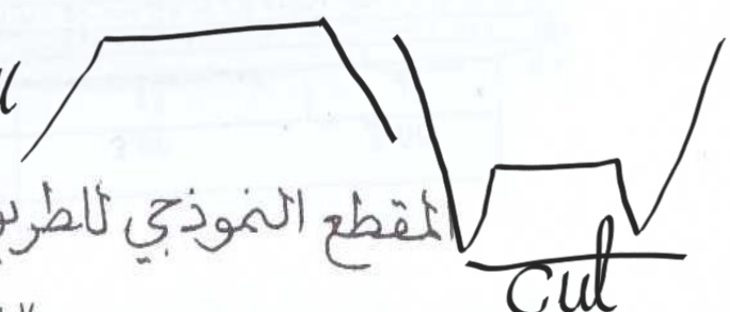
المقطع النموذجي للطريق الثانوي، في حالة الطمم

- 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. / H. 1:50

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

نهاية تلخيص شرح

الدكتور طالب شابتر

Pavement Types

رند الشويكي

Pavement Materials & Design (110401466/2104011466)
Bituminous Materials

2017

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

مواد بتيومية ← إذا كانت حرارة باردة

- 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.

* الطبقة السطحية هي عبارة عن اسفلت والاسفلت هو عبارة عن

خليط من agg واسفلت او Bitumens

* Bitumen :- ذات لون اسود مادة لزجة او صلبة [حسب درجة حرارة]

وفيها قوة ربط ومكوناتها هايدروجين وكاربون فهي Hydrocarbons

← وانت بتدرس مادة بدك تشوف شو مادة الي ممكن تذوبها فعنا

CS2 هو مذيب لمادة الاسفلت [إذا ما توفر ممكن مشتقات البترولية]

* اسباب او فوائد لاستخدام Bitumens materials :-

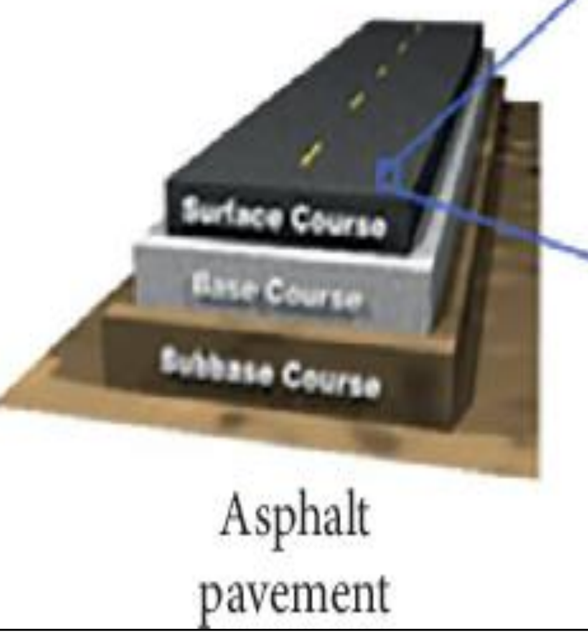
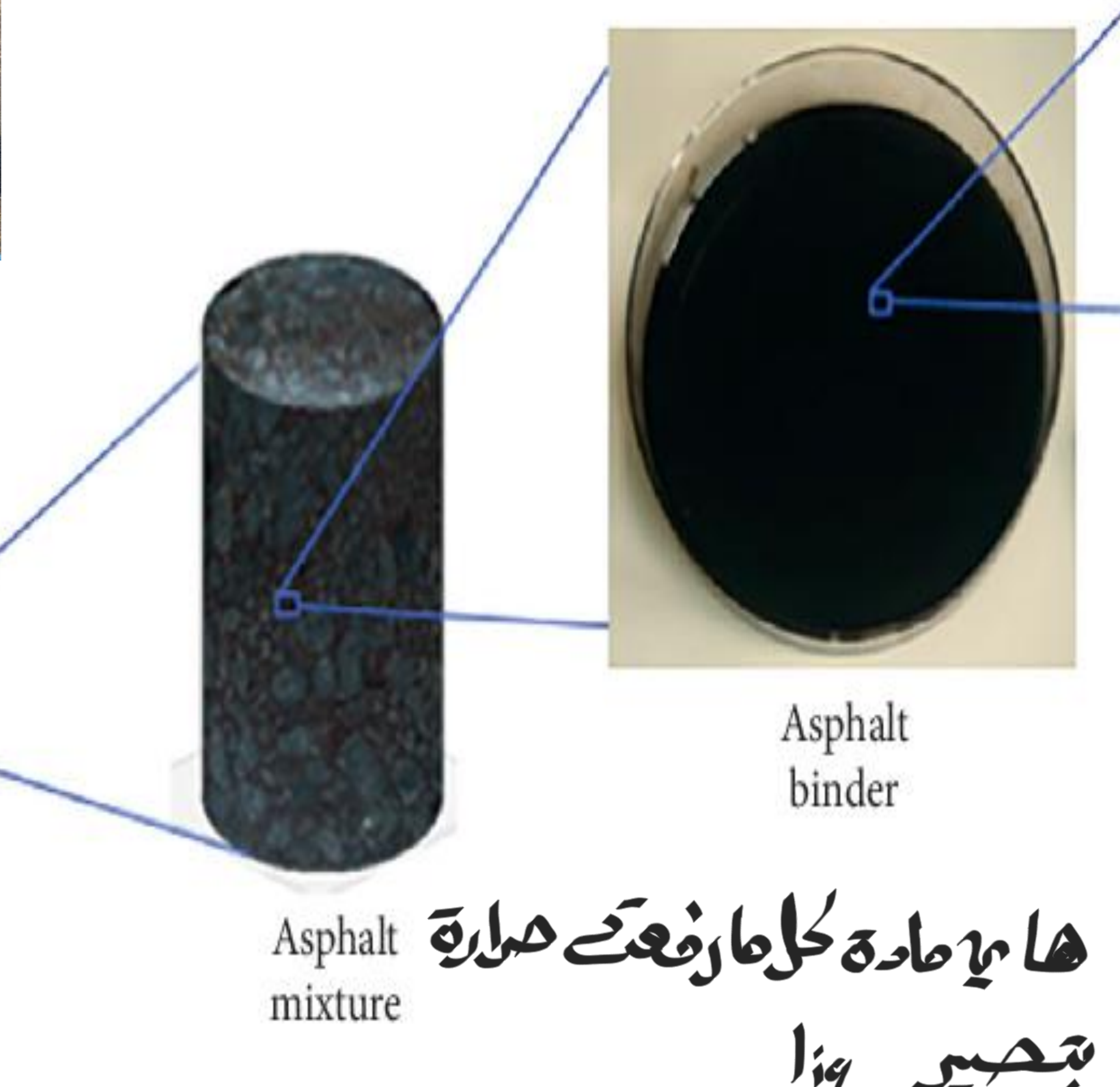
1- قوة الربط فيها ممتازة

2- انا بحاجة لمادة تكون عازلة للماء بحيث اضمن انه ماء

ما تدخل على الطبقات الموجودة تحت [agg or soil] بحيث

إذا زادت الرطوبة بتخلي طبقات ضعيفة ، فهو خارجي

3- أقل سعر مقارنة مع concrete

هاي مادة كل ما رفعت حرارة
بتصير liq

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

مصادر الاسفلت :-

A] Natural aspalt :-

1- Nativa :-

موجودة بالطبيعة ومتوفرة في دول المذكورة ، رح تستخدم على الغالب مشتقات النفطية [بكون كـ بحيرة]

2- Rock :-

بكون في صخر فرغانة مشبعة بالزيت مثل صخر sand stone او صخر limestone ، عملية الاستخلاص بتكون صعبة ومكلفة

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.

B- Petroleum Asphaltic materails النفط الخام

بعدة اعمال على نفط (التكرير) بنتج اسفلت صممنهم

-> بنتج عدة انواع من عملية تكرير منها :-

- Asphalt cement بعد ما نعمل عليه عدة عمليات بحيث يعطيني اشياء مختلفة (AC)

- Slow-curing
- Medium curing
- Rapid curing

] <= من انواع cutback

- Asphalt emulsions

عندي نوعين من الاسفلت السائل :-

-> مخلوط مع ماء <- Emulsions

-> مخلوط مع مادة بترولية <- cutback

Asphalt Paving types

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

بدرجة حرارة عادية

Asphalt cement (binder) منتج العادي

Emulsified asphalt مخلوط بماء

Cutback asphalt

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

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

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

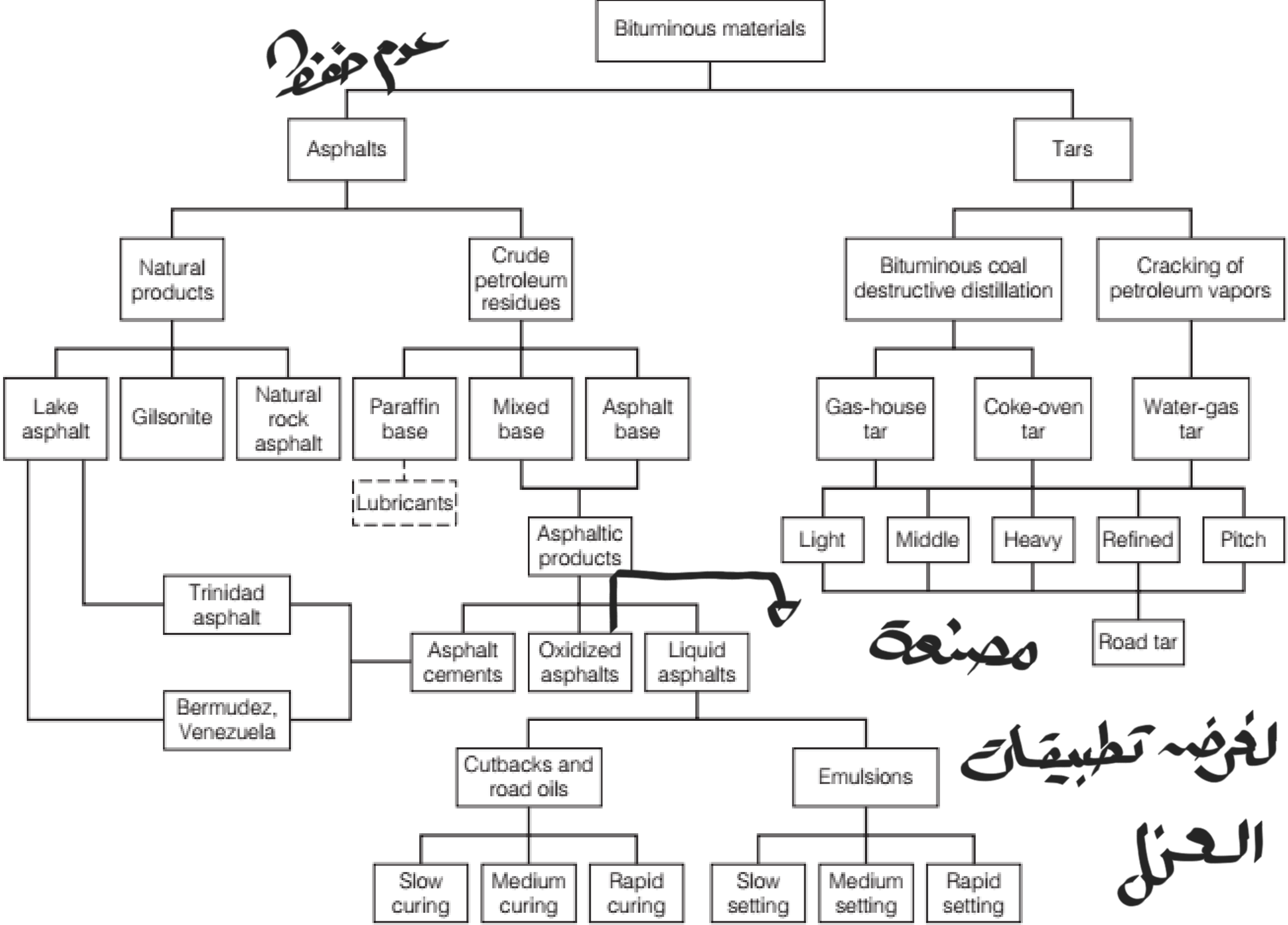


FIGURE 9.1 Classification of bituminous materials (Goetz and Wood, 1960).

Bituminous Materials Categories

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

شرح بعض نقاط ⇓

ASPHALT	TARS
يتم فصله عن عمليات تكرير او ممكن يكون موجود بالطبيعة	يتم من خلال عملية التحطيم وتعتبر chemical
مستخدم بالطرق كـ binder للطرق سريعة	بتعود تستخدمه بالطرق في حال عملت الكثير من Process
بذوب بالمواد البترولية	لا يذوب فيها يعتبر كإيجابية
مهم بتقاوم الاحوال الجوية اكثر وهذه ميزة	—
اقل تأثر بالحرارة مهم	
لا توجد رائحة للاسفلت	له رائحة نفاثة
اقل سعرًا	اغلى سعرًا
	يستخدم بالمطارات لانه ثباته احسن

Chemical Composition of Asphalt

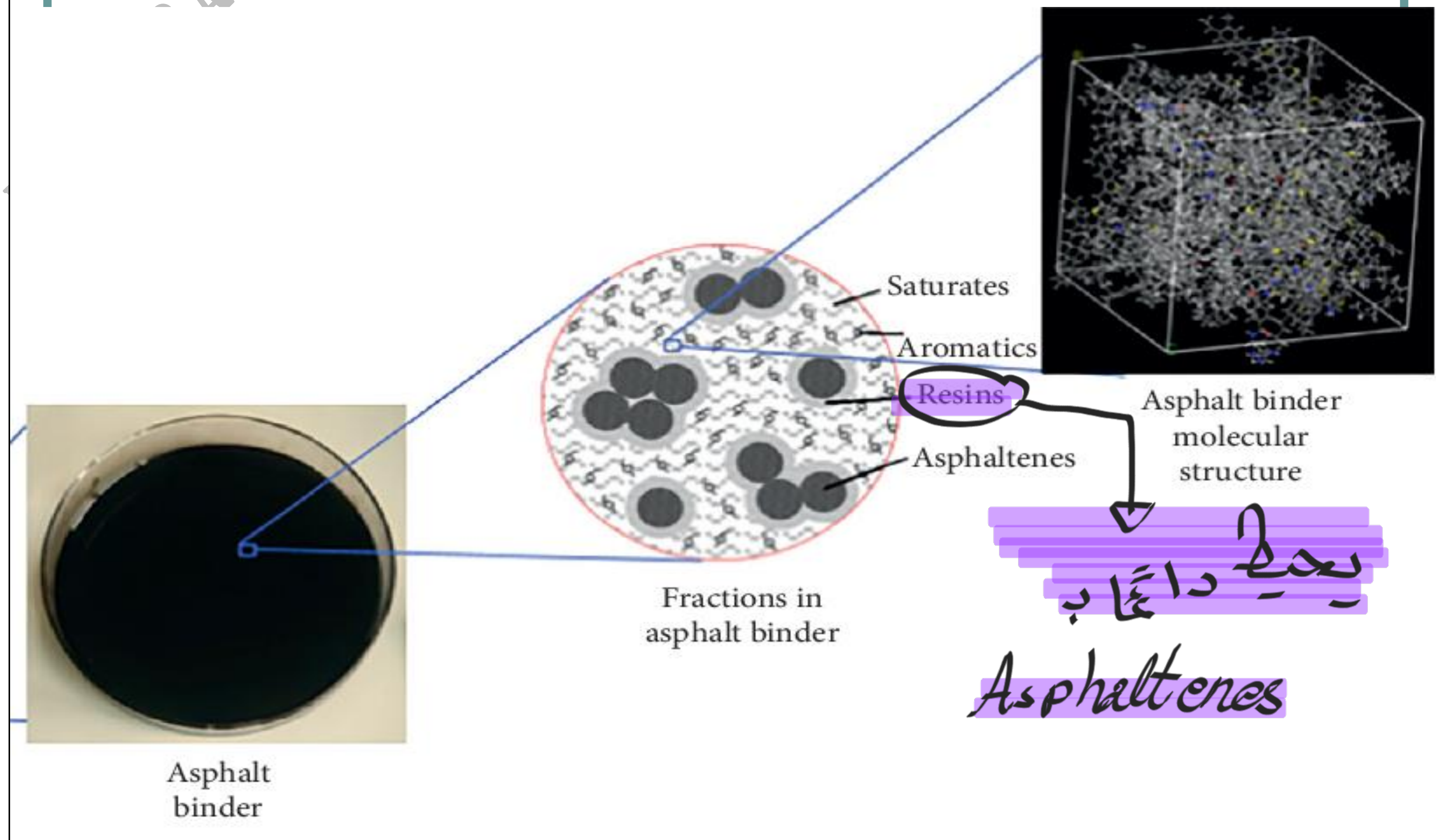
- Asphalt is a complex chemical compound composed predominately of carbon and hydrogen (hydrocarbon), with a small amount of heterocyclic compounds containing sulfur, nitrogen and oxygen
- Despite the complexity of asphalt's chemical composition, it is possible to be separated into two broad chemical groups:

مكونات رئيسية

  - **The asphaltenes**
  - **The maltenes:**
    - Saturated hydrocarbons ← هايدروكربون مشبع
    - 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

* اي تغير في نسب مكونات رح تتغير خصائصه (اللزوجة + درجة تأثره بالحرارة)

Chemical Composition of Asphalt



Chemical Composition of Asphalt

في الخواص الانسيابية

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.

← لما تزيد نسبة Asphaltenes يحدث الاتي :-

* بصير hard اكثر توضيح لباقي نقطة

penetration :- رح نخلي الابرة تنزل داخل الاسفلت بعد مدة معينة بنوخذ قراءة فلو فرضنا عينة 1 نزلت 3mm وعينة 2 نزلت بمقدار 6mm مين لينة (اطري اكثر؟) العينة 2 :. كل ما كان value لل penetration عالية معناها قوام اقل اولزوجة اقل :. لما نكرا نها low معناها صار قوامه اقوى

softening :- بنحط كرة على عينة من اسفلت ونبلش نسخن فلما يسخن بصير اطري فا الكرة بتنزل للداخل في مسافة فلما توصل الكرة على سطح base رح نسجل حرارة هادهو softening)

إذا كان عندي عينة 1 الها softening 60 وعينة 2 الها 90 مين softer ؟ 60 لانه عند درجة حرارة 60 صارت طرية كثير اما عينة 2 فخليت ارفع حرارة حتى تذوب لحتا وصل base

* بحيرا اللزوجة عالية

* نسبة الاسفلت 5%-28% ، بحيث نسبة % 10 من

الاسفلت غير من نسبة 20%

Resins :-

مادة صلبة او قريبة للصلابة ذات لون غامق

[اسفلتين موجود ضمن resins] ف resins هي حاملة

الاسفلتين

← نسبته مع الاسفلتين هي بتعطي خواص الخامة بالسيل

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

عملية تصنيع الاسفلت

- 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.)

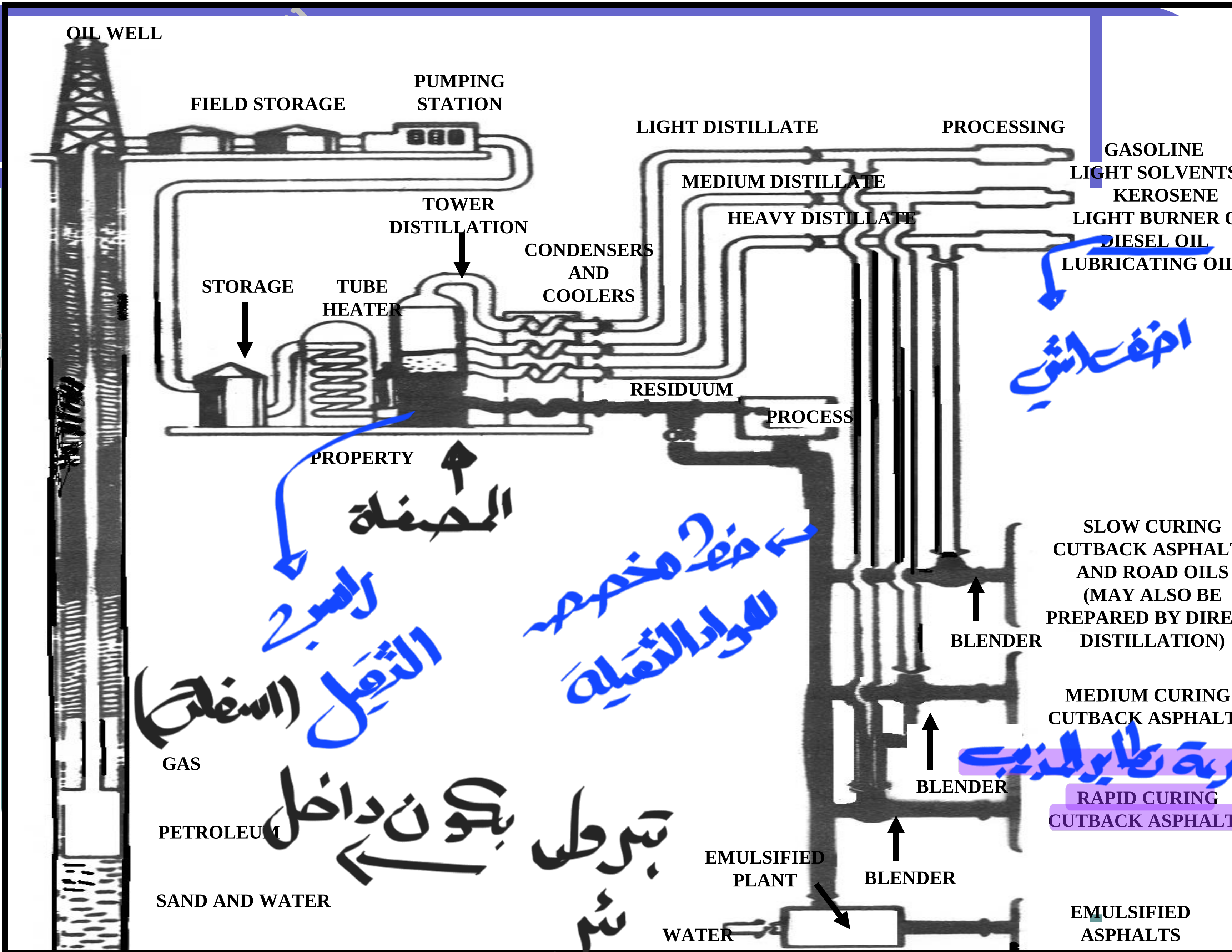
تعرض الاسفلت لهواء + وحرارة عالية

* الاسفلت هو بترسب افراشي بعد نتائج تكرار البترولية

* اعتماداً على مصدر وطبيعة الزيوت الخام ، انت شو بدك مواصفة بالاسفلت رح يصنعولك اياها فبالغالب مصدر الخام نفسه الو دخل ب نوعية الاسفلت الناتجة

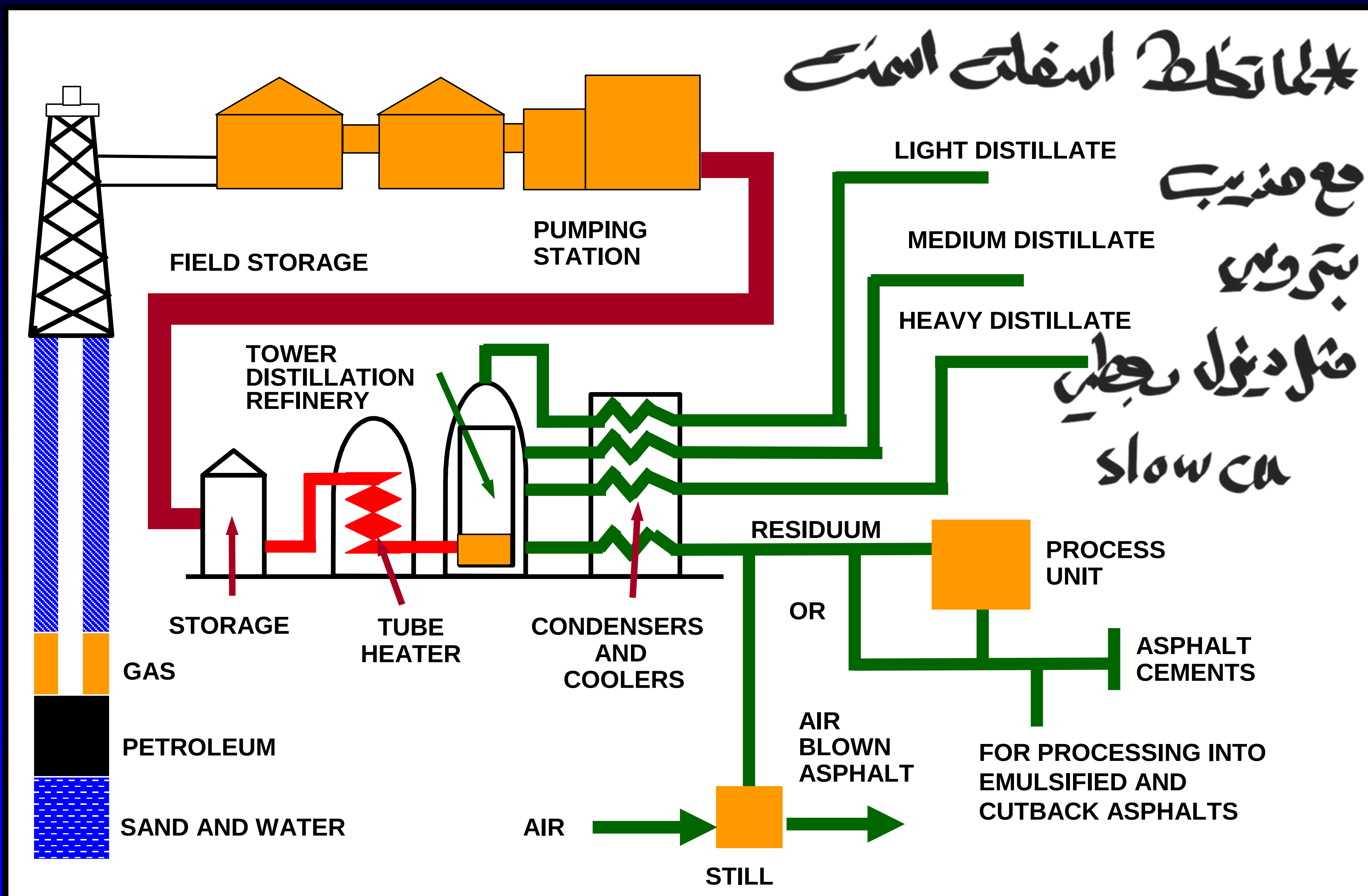
* تقدر تتحكم بقوام الاسفلت حسب كمية الزيوت الموجودة مع الاسفلت ، بحيث إذا سخنته وتبخرت الزيوت بصير ناشف [زيوت موجودة مع الاسفلت تعطي طراوة]

* Air blowing :- اثناء تعرض الاسفلت لهوا ساخن بتبخر منه الغازات الخفيفة

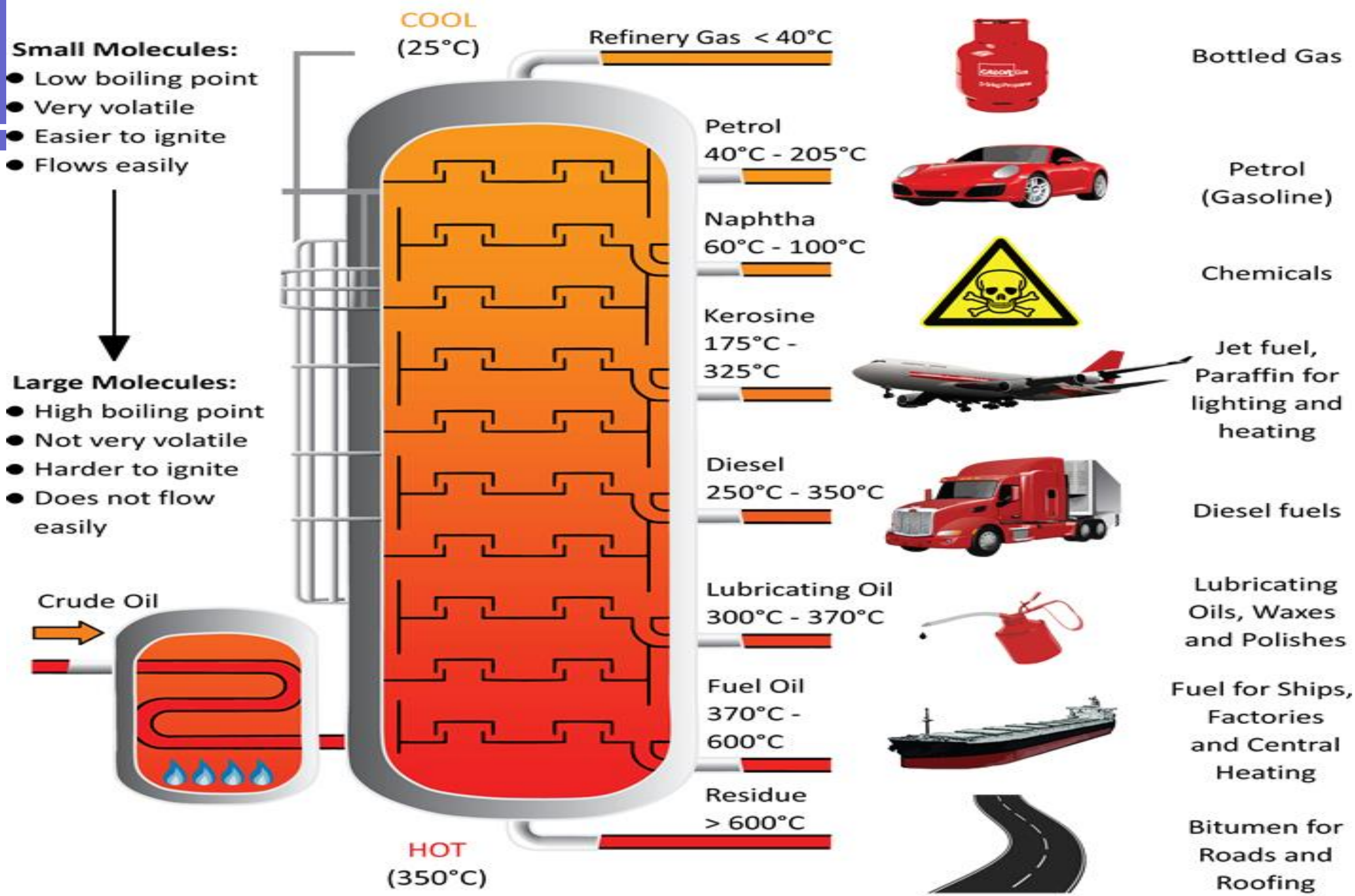


OIL WELL
FIELD STORAGE
PUMPING STATION
LIGHT DISTILLATE
PROCESSING
GASOLINE
LIGHT SOLVENTS
KEROSENE
LIGHT BURNER OIL
DIESEL OIL
LUBRICATING OILS
MEDIUM DISTILLATE
HEAVY DISTILLATE
TOWER DISTILLATION
CONDENSERS AND COOLERS
STORAGE
TUBE HEATER
RESIDUUM
PROCESS
PROPERTY
SLOW CURING CUTBACK ASPHALTS AND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

Refinery Operation



Fractional Distillation of Crude Oil



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. نرفع حرارة
- 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.

بتعطيني تصور عنه

سرعة تطاير

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 seal coat	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

Hot : خلطة بتكون مصممة بنسبة اسفلت معينة ممكن استخدمها بالترقيع

cold :- بتجهز خلطة على البارد ، عشان اخلط اسفلت مع agg فلازم يكون اسفلت سائل ممكن نستخدمها لتعبيد طريق

Fog :- رشة اسفلت ف العرف تعزل سطحه

Tack + Prime حكينا عنهم قبل

slurry :- خلطة agg + اسفلت + ماء، بتعمل خلطة جديدة للطرق الي عليها حركة خفيفة

AC Liquid Asphalt

- Asphalt cement is semisolid at room or normal temperature (stiff). بكون ناشف
- To make asphalt workable (soften) it should be heated. نسخنه
- Softening by heating is not feasible in all cases. مش سهل يتسخن
- In order to attain workable asphalt cement at ambient temp, they must be liquefied. انك تذوبه بمادة بترولية
- Asphalt is liquefied by two methods:

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

Cutback Asphalt

21/7

مذيبات متطايرة

- 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.

حسب سرعة تطاير المذيب تتعدد انواعه

- 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

انواع cutback

cutback : عبارة عن اسفلت + volatile solvents

حسب سرعة تطاير المذيب رح يكون عندي انواع :-

1- RC ← المذيب رح يكون سريع التطاير

2- MC   3- SC

* تذكر الاختصار

* تحت اي نوع عندي انواع اخرى والفرق بكون

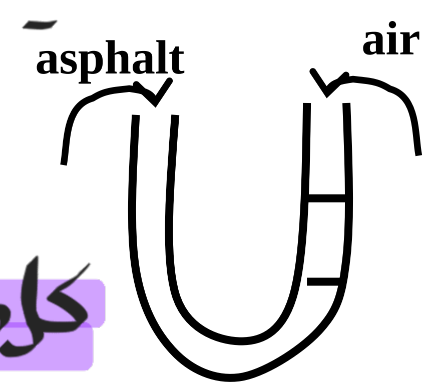
من كمية المذيب : بتحكم بالقوام من خلال كمية Solvent

Cutback Asphalts

الارقام مش حفظ

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)



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

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

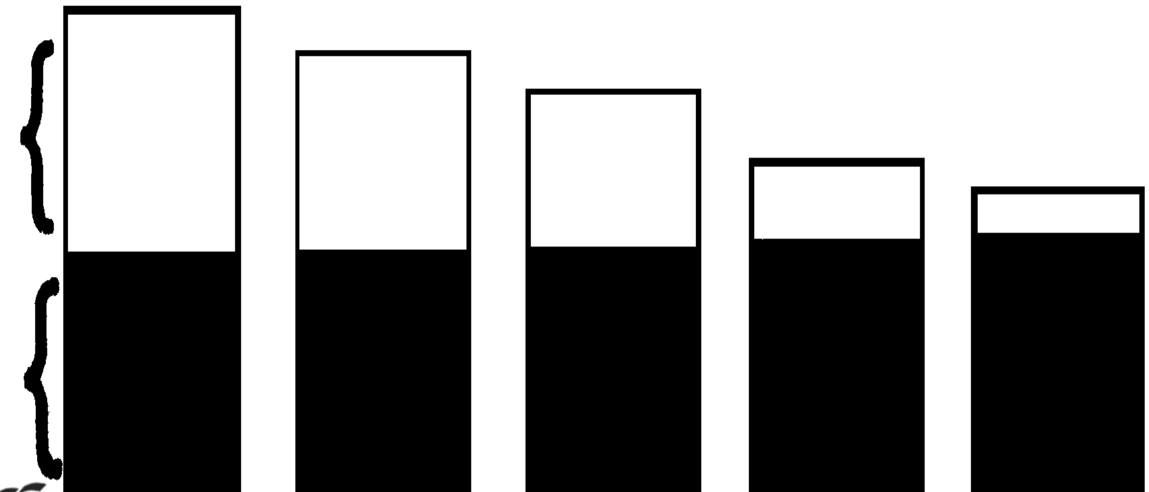
كلما كبر الرقم بكون اللزوجة عالية

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

التوجه العالمي كان بعدم استخدام بكثرة cut back

لاسباب التالية :-

١- عشان مذيب بترولي تبخر بالهواء على الغالب بأثر

على صحة البيئة

2- سعر cut back غالي لذلك إذا ما استخدمته بكون

اوفر

3- Flash pts :- هو كم درجة حرارة التي سوف يشتعل

عليها الاسفلت ، ولأنه بكون فيها مادة قابلة للاشتعال

بكون خطير التعامل معها

٤- عشان استخدمه فبحاجة ارفع الحرارة (تسخين

Emulsified Asphalts

- It's a mixture of asphalt cement, water, and emulsifying agent (1-2% by volume).

الاسفلت ذايب وب بالماء

- Emulsifying agents place electrical charge around each droplet of asphalt.

كل دقائق الاسفلت لها نفس الشحنة

- Negative (Anionic).
- Positive (Cationic).

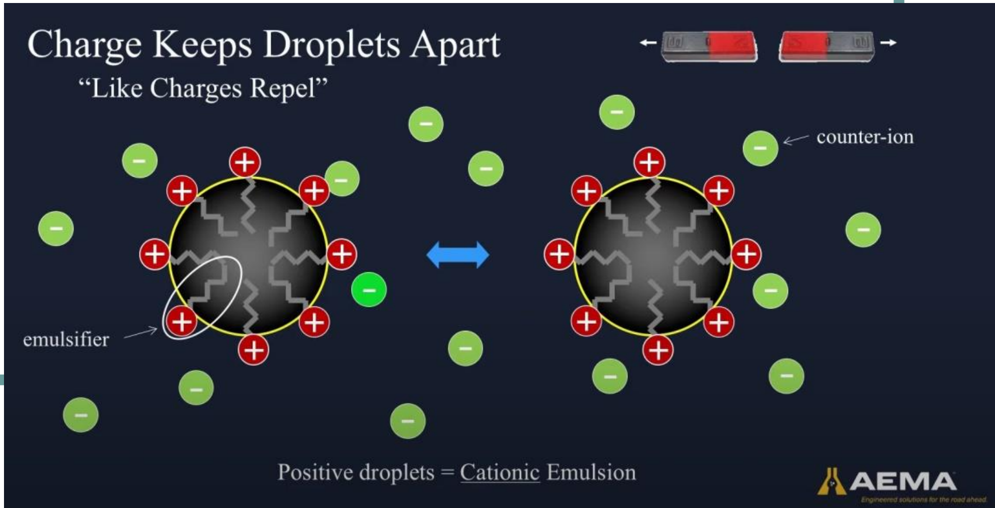
تنافر بظاهر يخلط مع الماء

- Since like electrical charges repel, asphalt droplets stay suspended in water.

ها يضله بتخلط لحد تبخر

- The emulsion stay in this stable situation until disturbed by:

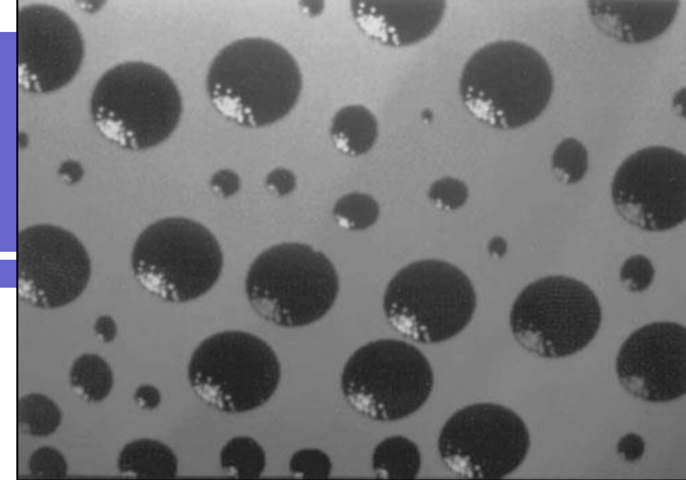
1. Mixing with aggregates.
2. Evaporation of water.



* الاسفلت مابذوب بالمه

* مادة كيميائية تضاف على خليط بحيث تخلي حبيبات الاسفلت معلقة بالمه ، الي بخليهم متعلقين بسبب الشحنات ، كل حبيبات الاسفلت بكون الهم نفس الشحنة بكون شحنات تنافر لذلك ببضل معلقة بالمه بروح ترابط هاد في حال نشفته او خلطته مع agg

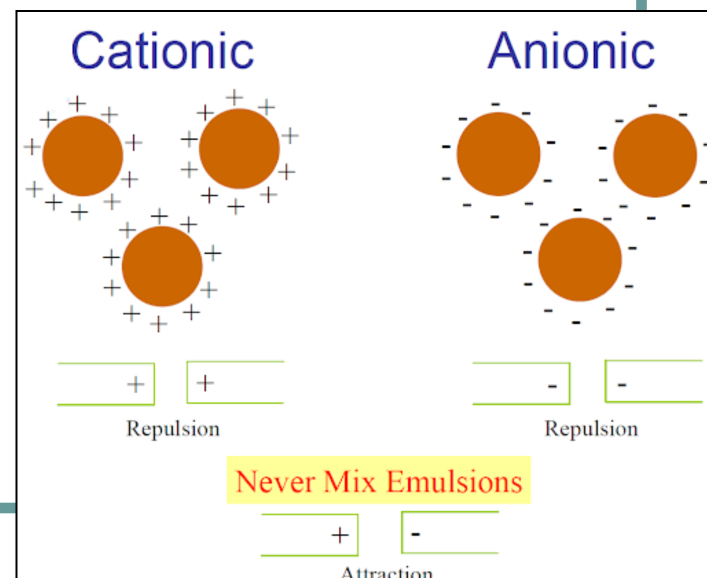
Emulsions



- 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



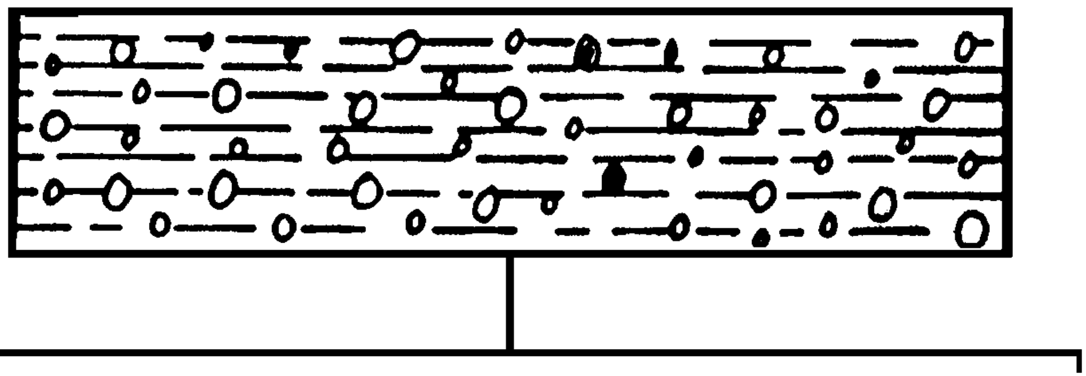
لما تعرض الهواء بتنشف فالرابطة هاي بتنكسر حسب نوع الاسفلت.

*معدل نشفانه الماء المحتوى تحت عشان 3 انواع :-
[SS , MS , RS] بمثلوا سرعة تبخر الماء

--> حطينا C قبل مشان نغير النقاط +ve او -ve

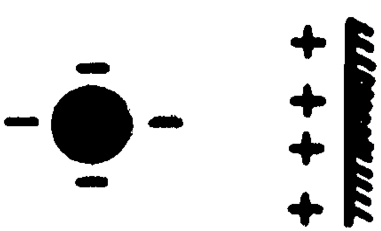
*إذا أجا رمز مثلاً CRS وطلب شو معنى لازم نكتب
Cationic Riped Setting emulsfyed asphalt

EMULSIONS

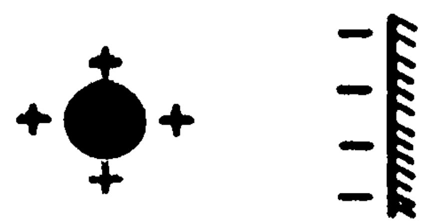


ASPHALT
+
WATER
+
EMULSIFIER

ANIONIC	CATIONIC
(-)	(+)
ALKALINE	ACID



LIMESTONE



SILICA
(Sil. Gravel)

Emulsions

RAPID SETTING (RS)
Tack Coat
Surface Treatment معالجة
(spray applications)
و
خلطات موقع

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	CRS - 1	more asph than anionic
	RS-2 (more viscous, more asph.)	CRS - 2	
MS	MS-1	CMS-2	
	MS-2	CMS-2h	
	MS-2h		
	HFMS-1, 2, 2h *		
SS	SS-1	CSS-1	
	SS-1h	CSS-1h	

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

كلما زاد الرقم معناها Harder أكثر

*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.

١- الذي سوف يتبخر هو ماء، فما بأثر على البيئة

2- مش بحاجة لتسخين

3- سعرها أرخص من cutback

4- بكون ال spreading إلها أفضل

Properties of Asphaltic Materials

خصائص الاسفلت

- Consistency → القوام
- Durability → الديمومة
- Rate of curing → معدل التبخر
- Resistance to water action → مقاومتها للماء

Consistency

- Considered under two conditions: قوام تتغير بناء على حرارة
  - 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.

* القوام تتغير حسب درجة الحرارة (مادة تتأثر بالحرارة)

بحيث كل ما رفعت الحرارة تتحول من صلب إلى سائل

* كل نوع اسفلت بتأثر بالحرارة بشكل مختلف ، في

اسفلت لما ترفع درجة حرارته 10° قوامه ممكن ما يتغير

بينما نوع ثاني ممكن قوامه يتغير

* لازم تذكر الحرارة لما تحكي عن القوام

Durability

ديمومة

مقاومة العوامل الجوية

- 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.

لازم تنتبه للتفاصيل

- **Durability** :The ability of asphalt to resist weathering.
- Factors influencing weathering: عوامل مؤثرة
  - Oxidation.
  - Volatilization. → تطاير
  - Temperature. → حرارة
  - Exposed surface area. → مساحة معرضة
  - Age hardening. → عمر الاسفلت

Durability: مقاومة العوامل الجوية

* لما البلاستيك الأسفلت يتعرض للأجواء الطبيعية بالأمش بصير في تآكل وبلش يتأثر بالعوامل الجوية بتأثير سلبي
بلش الاسفلت ينشف وتفقد البلاستيكية التي تملكها
وبتصير هشة فبلش يصير cracks

عشان في عوامل مؤثرة هي :-

Factors influencing weathering:
1) Oxidation
2) Volatilization
3) Temperatur
4) Exposed surface area
5) Age hardening

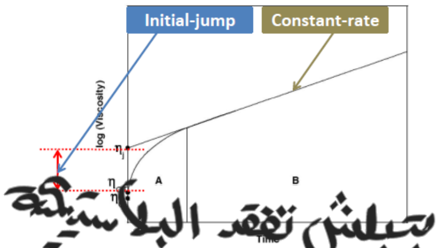
Durability/ Factors Influencing Weathering

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

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.



Aging Behavior

- Oxidation affects the mechanical behavior of the asphalt and usually reduces the pavement's service life
  - Reduction of penetration → لما تنشف بتصير اكثر لزوجة واقل
  - Increase of softening point
  - Reduction of elasticity and adhesion ability → مرونة بتقل
  - Increase of friability → بصير تفتته اكثر

- **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

تراكم التغيرات داخل object مع الوقت

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

لما يتعرض الأسفلت للحرارة والهواء بيصير عنده تغيرات

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

harder asphalt

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

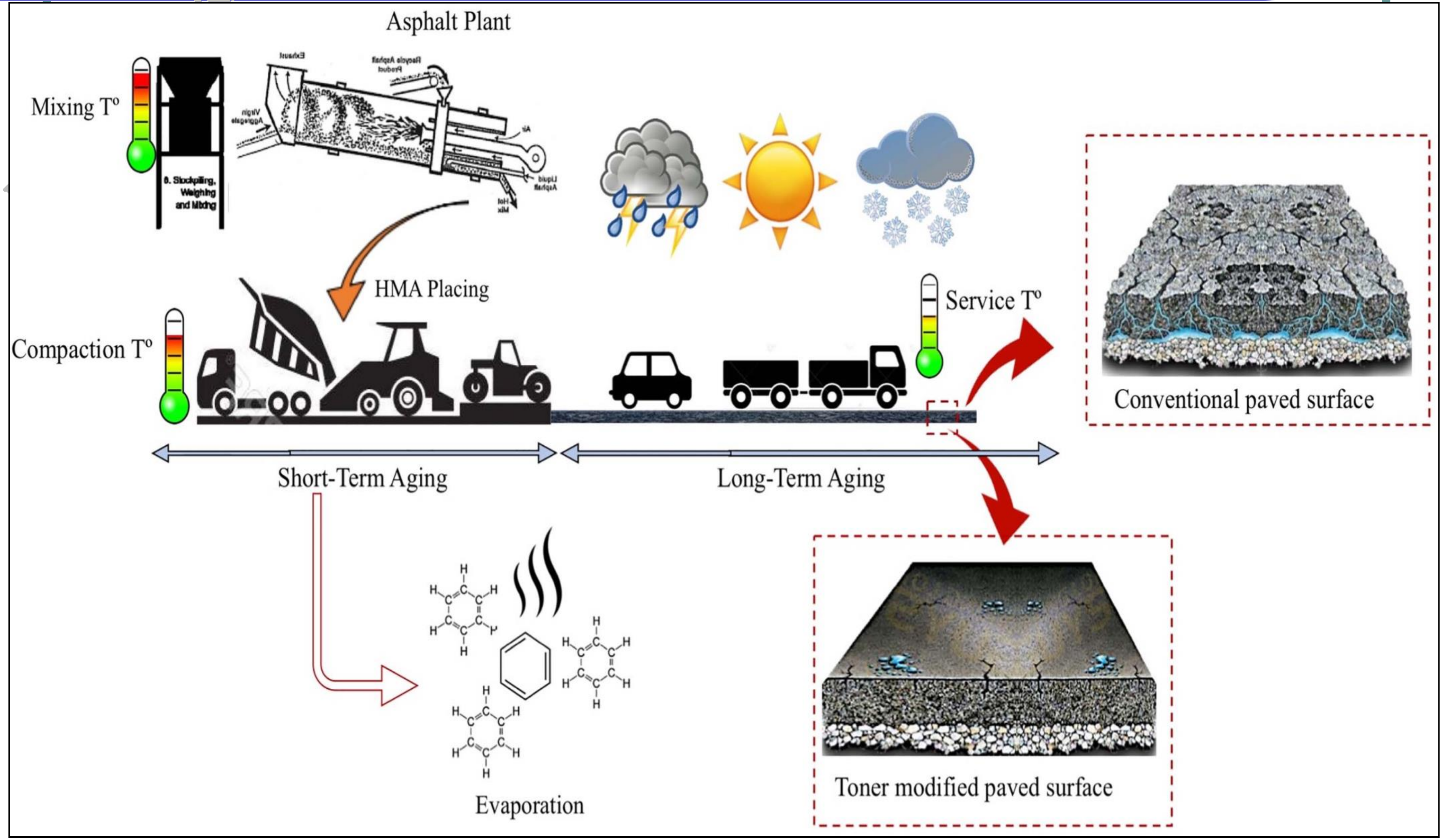
Typical ageing simulation tests are:

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

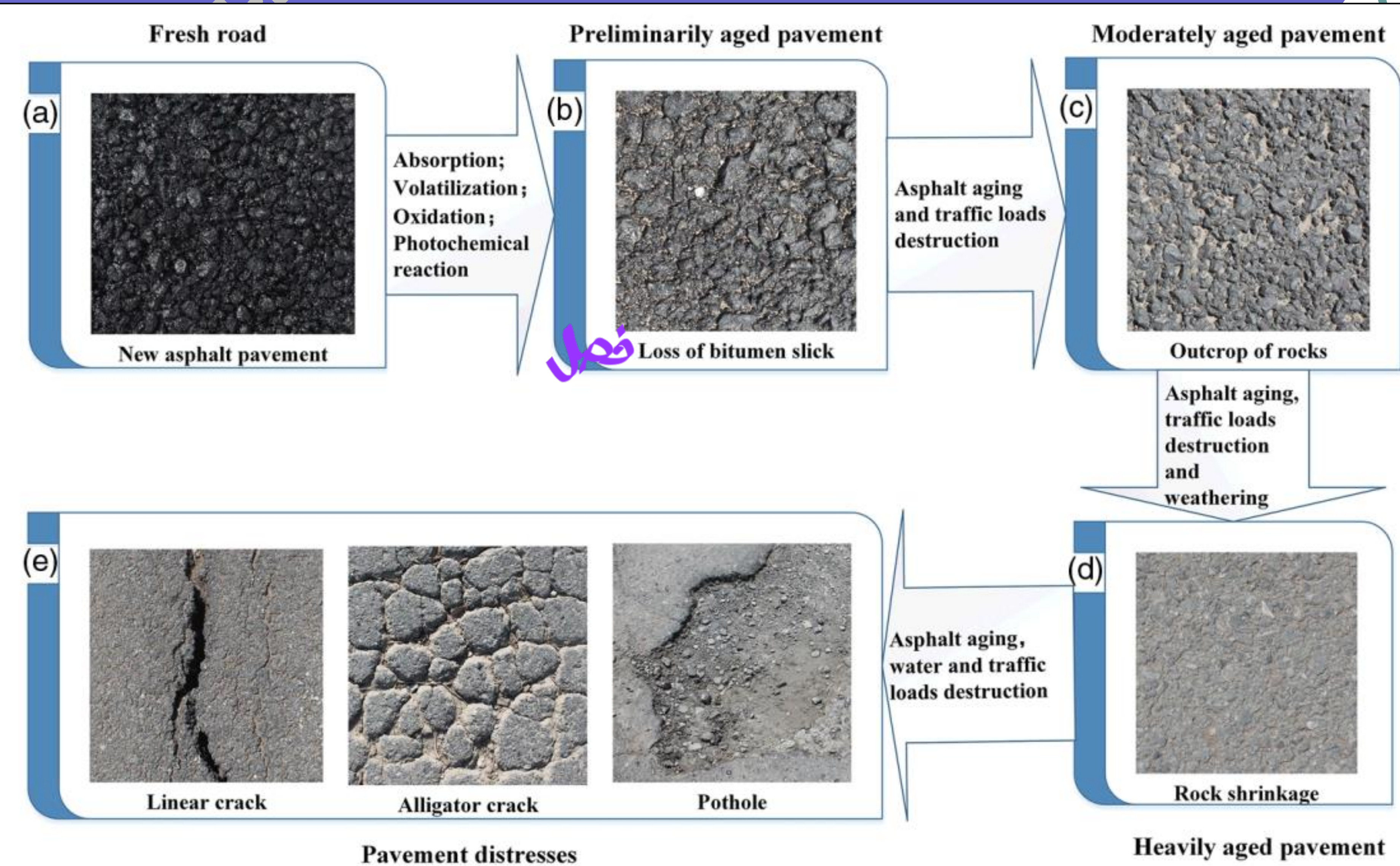
→ Short-term ageing

- 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

من المعروض والمهم يضل الاسفلت ملتصق ب agg طول الوقت ولو في ماء منشان تضل الرابطة

- Its important that asphalt continue to adhere to the aggregate even with the presence of water.

الاسفلت راح ينسلخ لمن يفقد الرابطة

- Asphalt will strip from the aggregate if the bond is lost which will result in deterioration of the pavement.

في تبجيج بينهم

فيؤدي إلى تآكل بالرصفات

معروض بالوضع طبيعي ما عندي مشكلة

- In HMA stripping does not normally occur.
- Commercial anti stripping additives are usually added to improve asphalt ability to adhere to asphalt.

مشكلة هون إذا ماء طولت

* ليش بنفحص الخاصية؟ عشان اتأكد انه بحقق شروط معينة

Bitumen Laboratory Tests

Purity Tests: نقاوة

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

Consistency Tests: للقوام

- 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)

فحوصات النقاوة

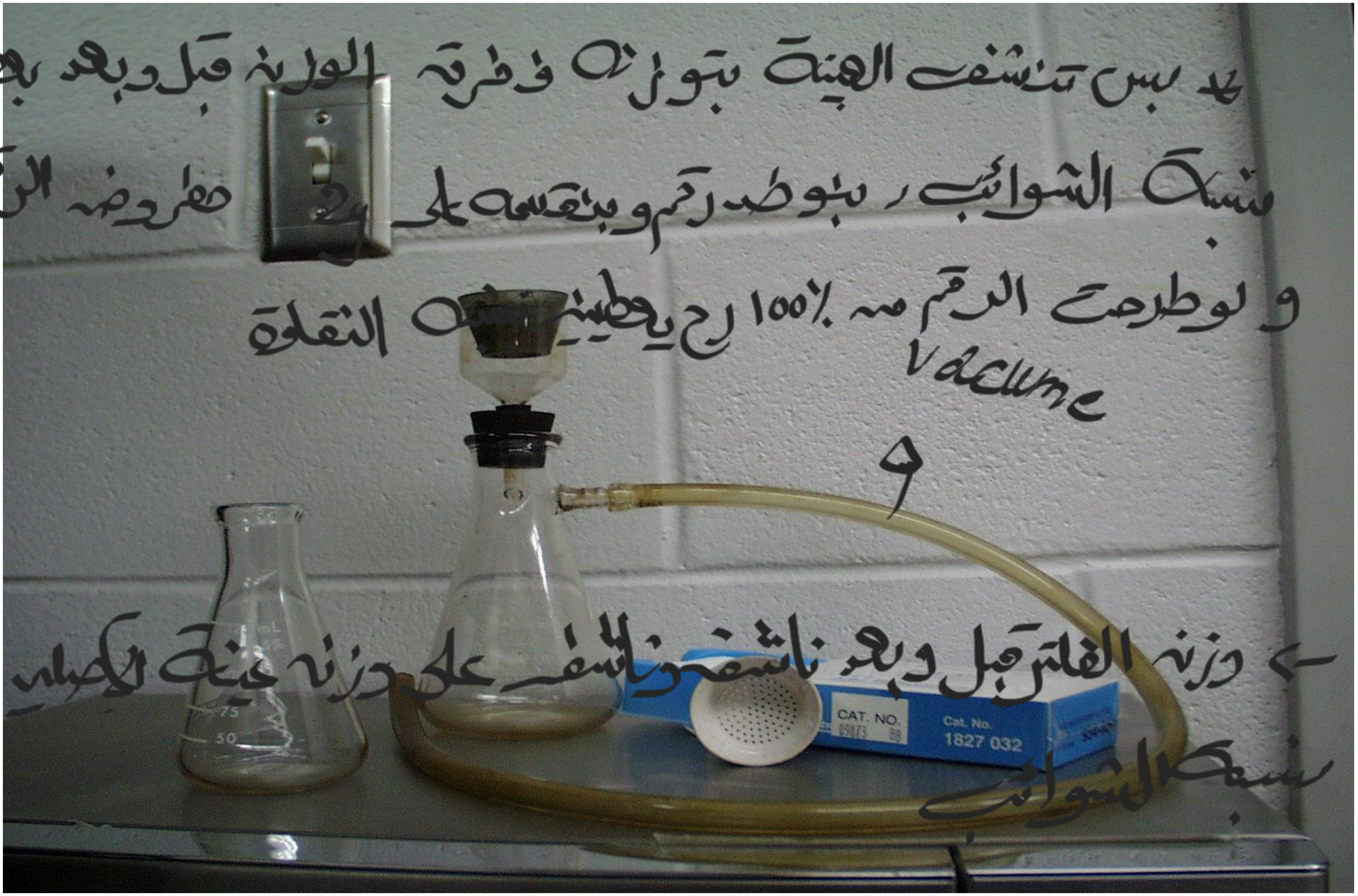
- Measures the purity of asphalt
- 2 g of AC dissolved in 100 ml of trichloroethylene and filtered through a fiberglass filter pad.
- Amount of material retained on the filter is weighed and expressed as % of original sample.

فرق بين الرقمين رح يعطيني نسبة الشوائب ولازم يكون < 1%

نقسمها على 2g

- Spec. + 99% pure.

Solubility in Trichloroethylene (ASTM D2042)



Purity Tests/ Presence of Water ASTM D95

تفاصيل عن خطوة يعني كيف عملنا التجربة

- 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:**

اسباب الفحص :-

عشان نعرفوا إذا كان فيه ماء وكم كميتها و

  - knowledge of the water content of petroleum products is important in the refining, purchase, sale, and transfer of products.

هاي مهمة

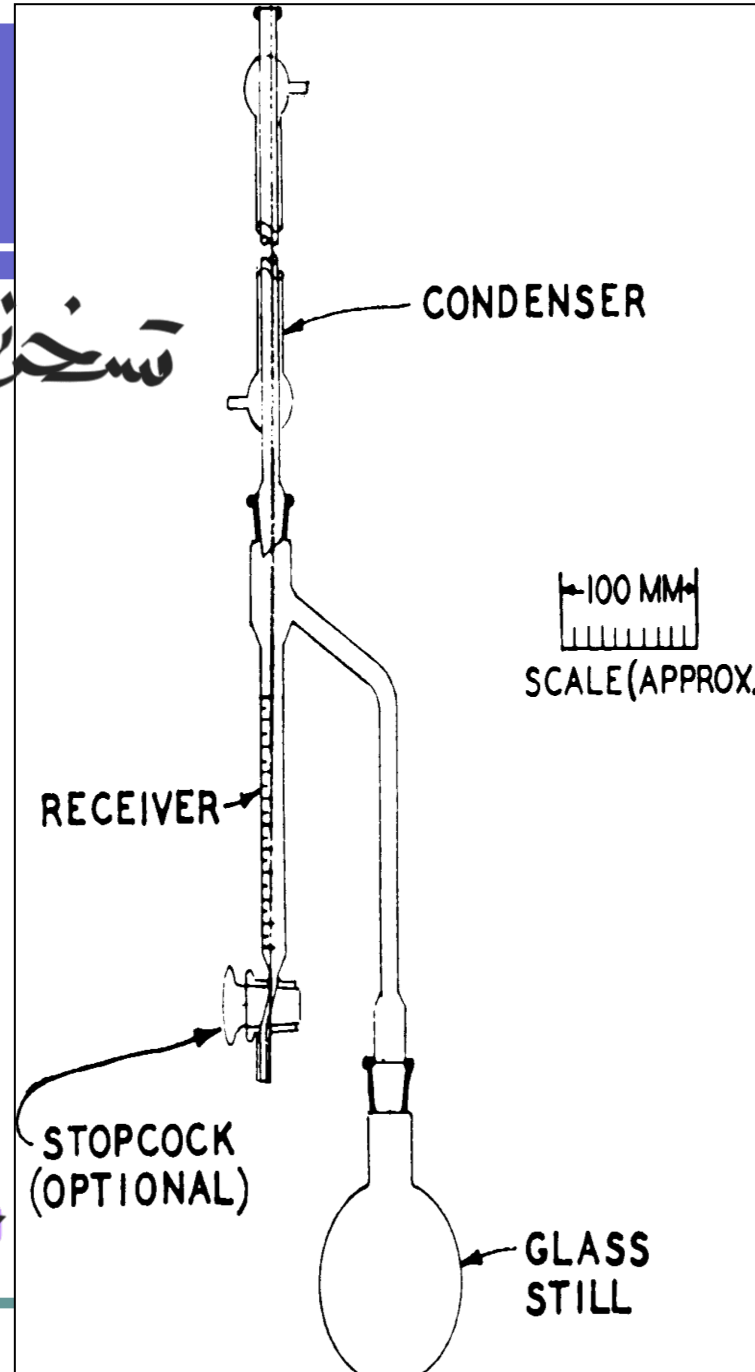
  - Water present in asphalt cause asphalt to foam when heated above 100 C.
  - The amount of water as determined by this test method (to the nearest 0.05 volume %) may be used to correct the volume involved in the custody transfer of petroleum products and bituminous materials.
  - The allowable amount of water may be specified in contracts.

Presence of Water

تسخين عينة اسفلت لحد ما اوصل درجة غليان

- 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.

* إذا الاسفلت في ماء بلجأ لهاد



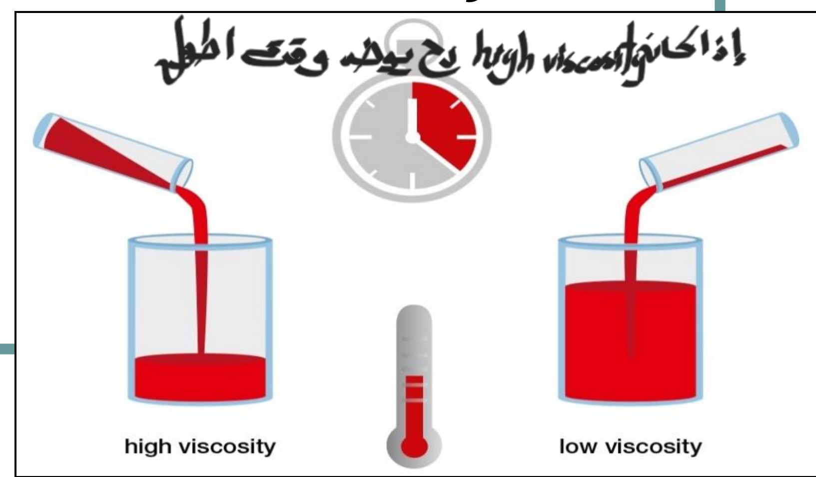
Consistency Tests/ Viscosity

فحوصات القوام 22/7

تعريف علمياً

- ***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. لما تتعرض Flow للشد
- The shear resistance in a fluid is caused by inter-molecular friction exerted when layers of fluid attempt to slide by one another. إذا في احتكاك عالي رح يكون high vic
- ***Viscosity is the measure of a fluid's resistance to flow***

أمثلة
  - golden syrup is highly viscous
  - water is medium viscous
  - gas is low viscous



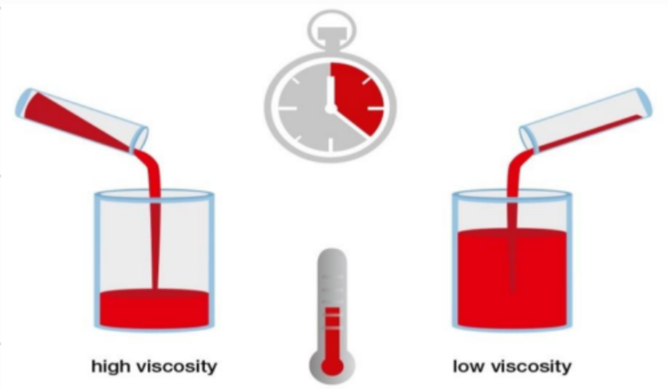
اللزوجة :- مقاومة flow للجريان

* لما تعرض العينة لشد ف deform بخليها تتحرك، بتعرض ل shear او شد بحيث تبعد الجزيئات عن بعض

* رح تتخيل انه الطبقات بتسحل على بعض (بتمشي مع بعض)

فاذا اي احتكاك بين جزيئات عالية فراح تكون حركة بطيئة

:. عندي مادة احتكاك داخلي بين الجزيئات بأثر على حركة طبقات



اعتمدنا على الوقت لتفسير انه لزج اولا

Consistency Tests/ Viscosity

إذ ابدي اخزنه او اتعامل مع الاسفلت

- 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

* وقت ↑ viscosity ↑

* density للاسفلت = 1.05

Consistency Tests/ Viscosity

Absolute (Dynamic) ASTM D2171/ ASTM D4402

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

- U-shaped tube with timing marks & filled with asphalt
- Placed in 60°C bath
- Vacuum used to pull asphalt through tube
- Time to pass marks

Visc. in Pa s (Poise =Ps) =

1 Pa s = 1 N s/m² = 1 kg/(m s)

- 1 Pa.s = 10 Ps = 1000 cPs

Kinematic ASTM D2170/ ASTM D445

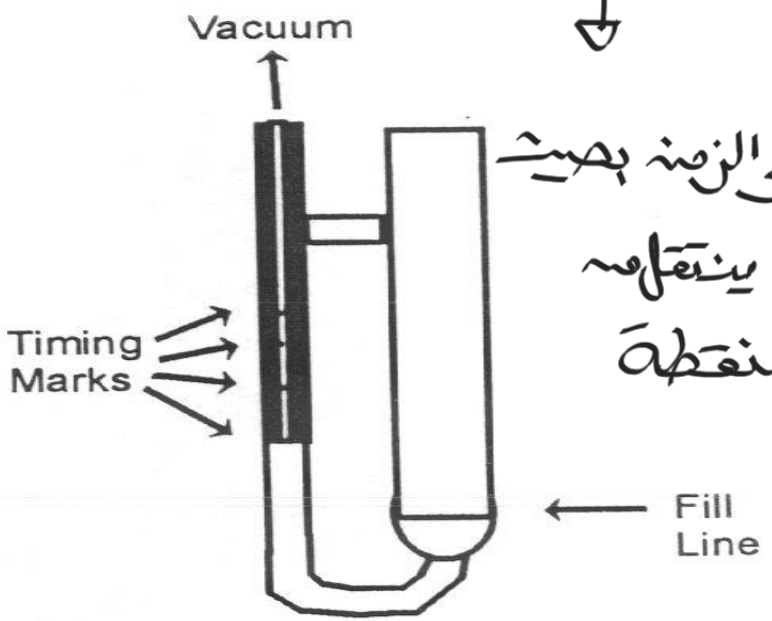
is the ratio of - *absolute (or dynamic) viscosity to density* - a quantity in which no force is involved

It tells how fast the fluid is moving when a certain force is applied

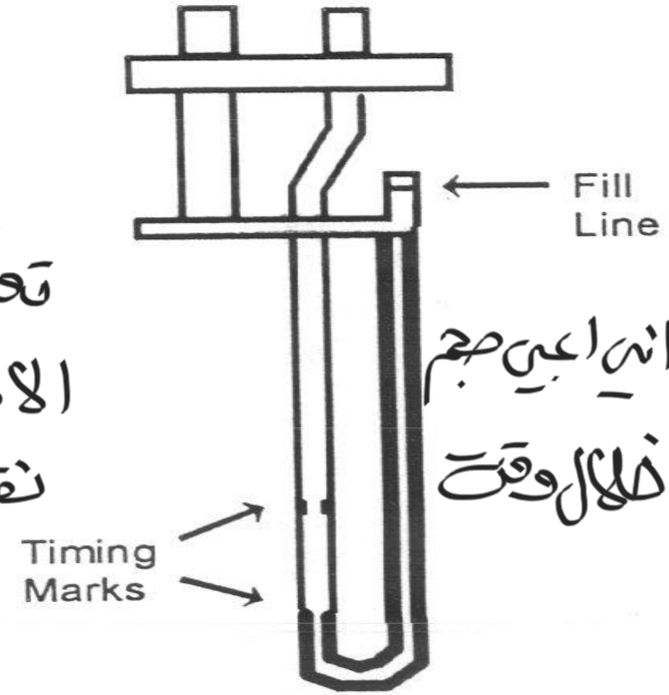
- Cross arm tube with timing marks & filled with asphalt
- Placed in 135 °C bath
- Once started gravity moves asphalt through tube
- Time to pass marks

- *1 St (Stokes) = 1 cm²/s*
- mm² / s = centistoke
- = Absolute/ density
- Pa.S = 1000 cst

Viscosity Tubes



Asphalt Institute Tube



Zietfuchs Cross-Arm Tube

لحساب اللزوجة معتمد على الوقت

Absolute (dynamic) viscosity test/ ASTM D2171

Calculation:

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

وقت

معيار

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

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

إذا كنت بمناطق حارة عالية فبكون بما high viscosity وإذا traffic عالي

- Viscosity of normal AC based on 60 °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

viscosity

عند ال Grade مختلفة بالزوجة

كل ما زاد رقم بكون more viscosity

إذا مستعمل 10 بكون Pas

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

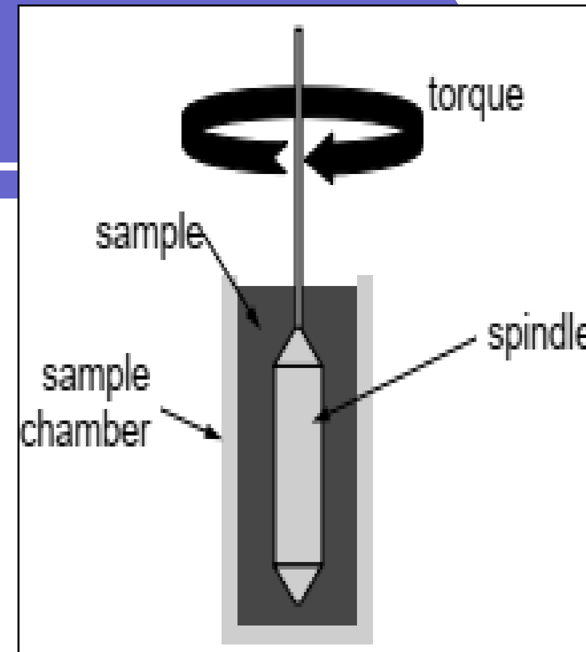
قياس viscosity بطريقة مختلفة عن إلي قبل

- ASTM D4402: Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer
- Scope: * مناطق الحارة بنستخدم لزوجة عالية
  - 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

ميزة ①: بقدر اعمل تجربة على أي حرارة

② ممكن يكون عنده قطع كبيرة مع الاسفلت فبهذا الاختبار مابفرق

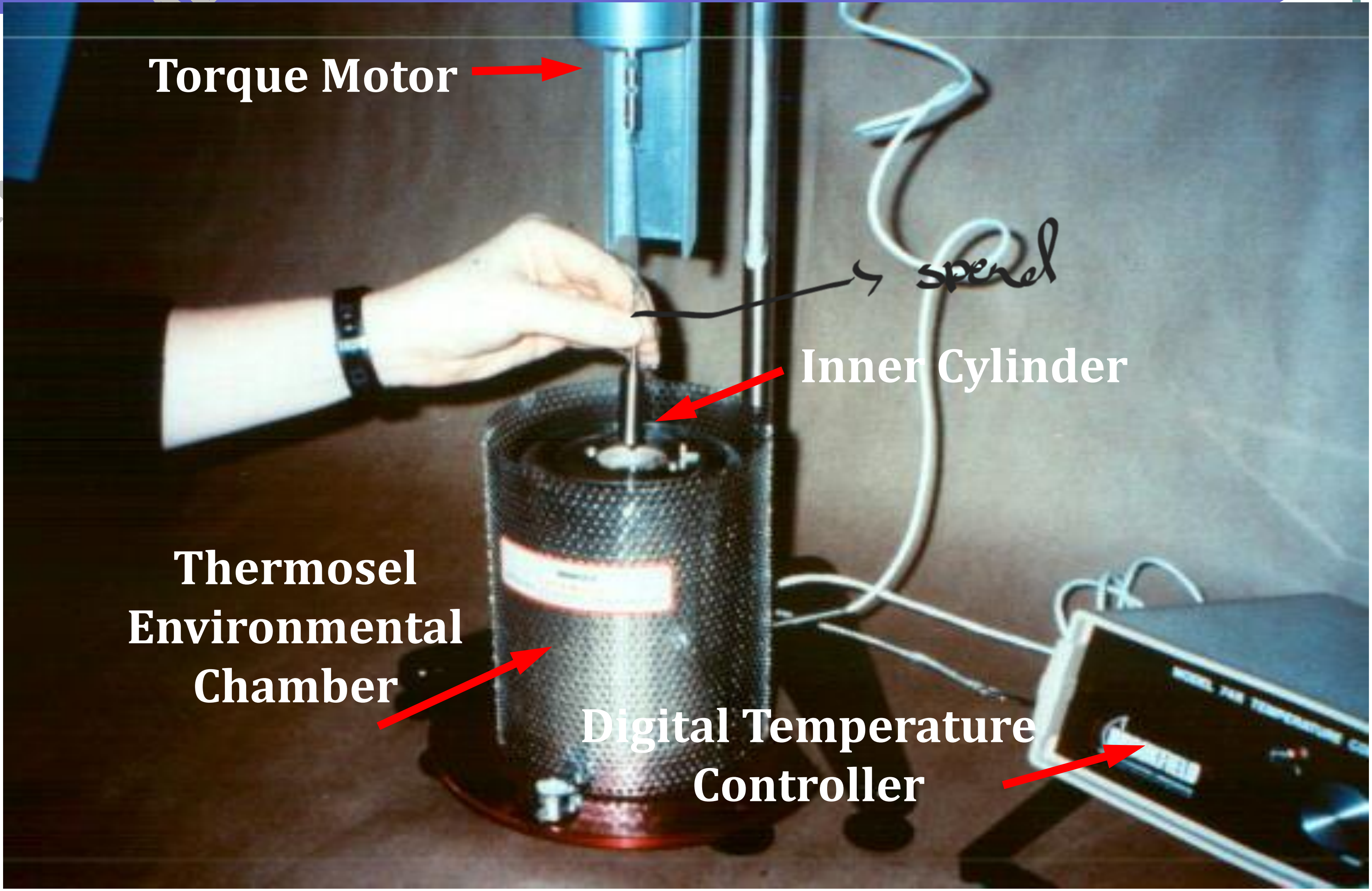
Absolute (dynamic) viscosity test/ ASTM D4402



- **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

فكرة :- عينة اسفلت رح يلف فيها
يلف بسرعة ثابتة ، إذا اسفلت
viscosity بكون عزم دوران عالي
عشان تحافظ على نفس سرعة
و جهاز بحول Torque للزوجة
وبكون سرعة اقل
بنعمل عينتين

Rotational Viscometer (Brookfield)



Absolute (dynamic) viscosity test/ ASTM D4402/ Procedure

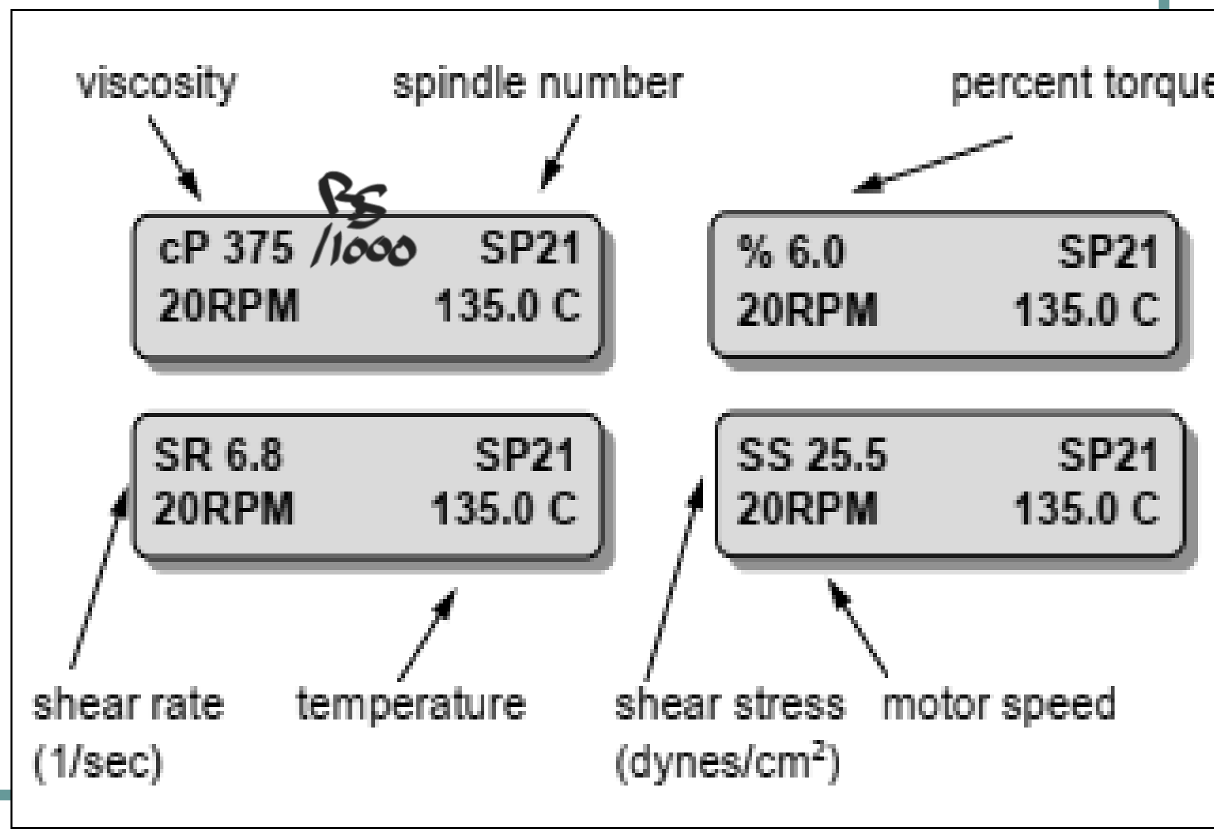
طريقة تحضير والعمل على الجهاز

- 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 ← رينج اللزوجة معطى
- **The laboratory Compaction temperatures**

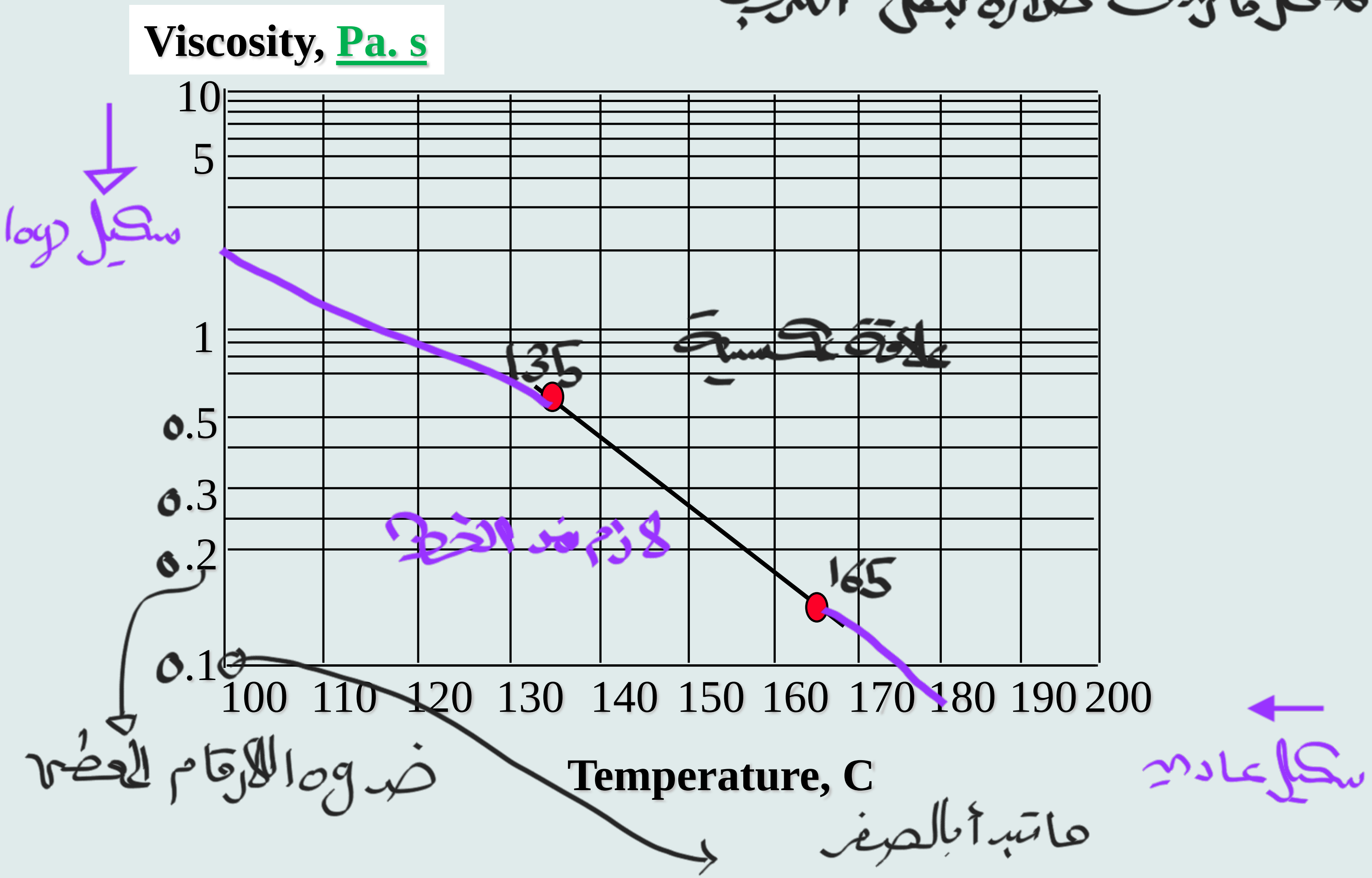
  Is the temperature where the viscosity-temperature line crosses the viscosity ranges of 0.28 ± 0.03 Pa-s رينج اللزوجة
- The corresponding temperatures may be reported as

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

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

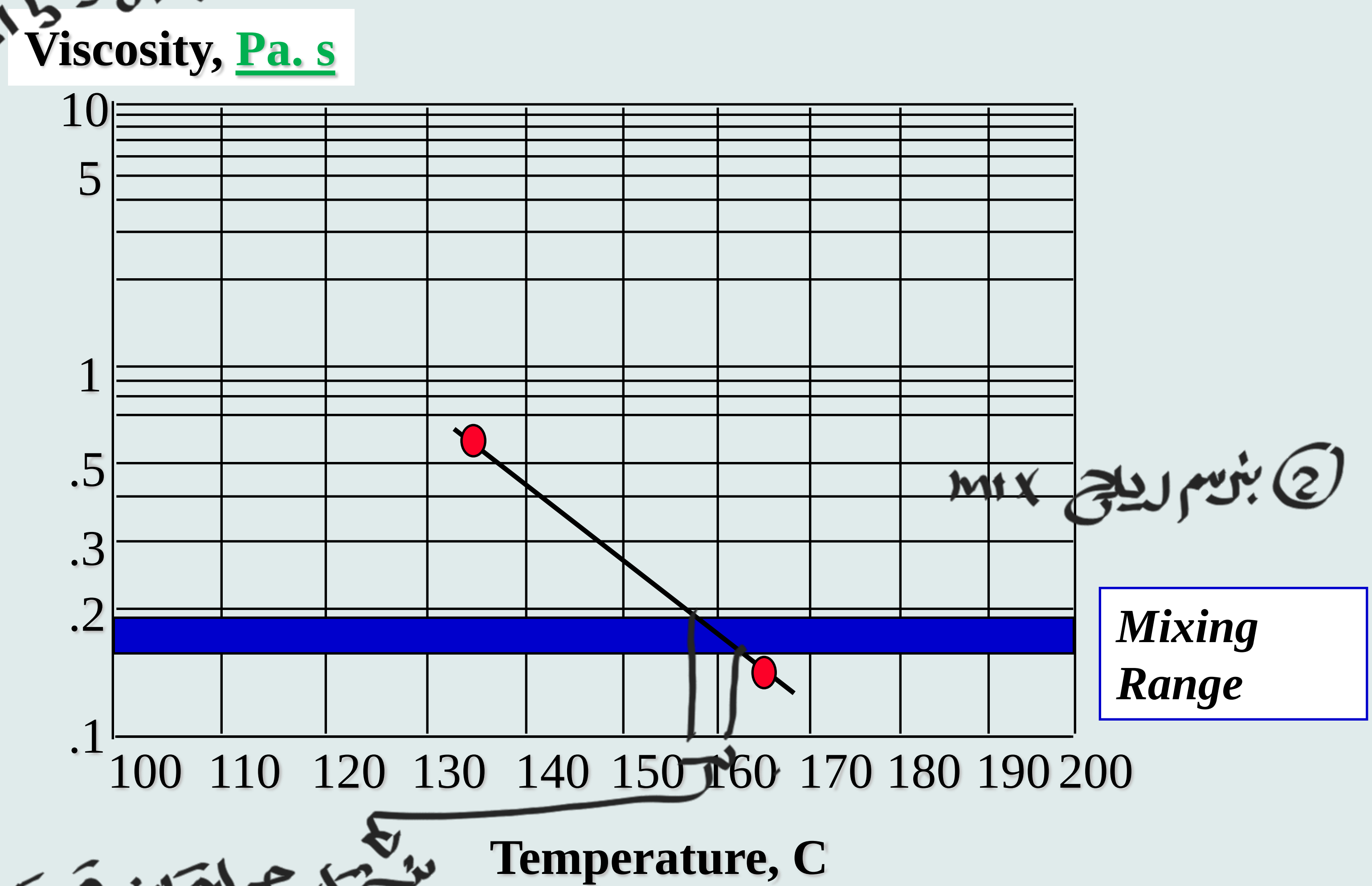
ها charts بنوجد بجم mix و com والطوبق دسج للّلزوجة

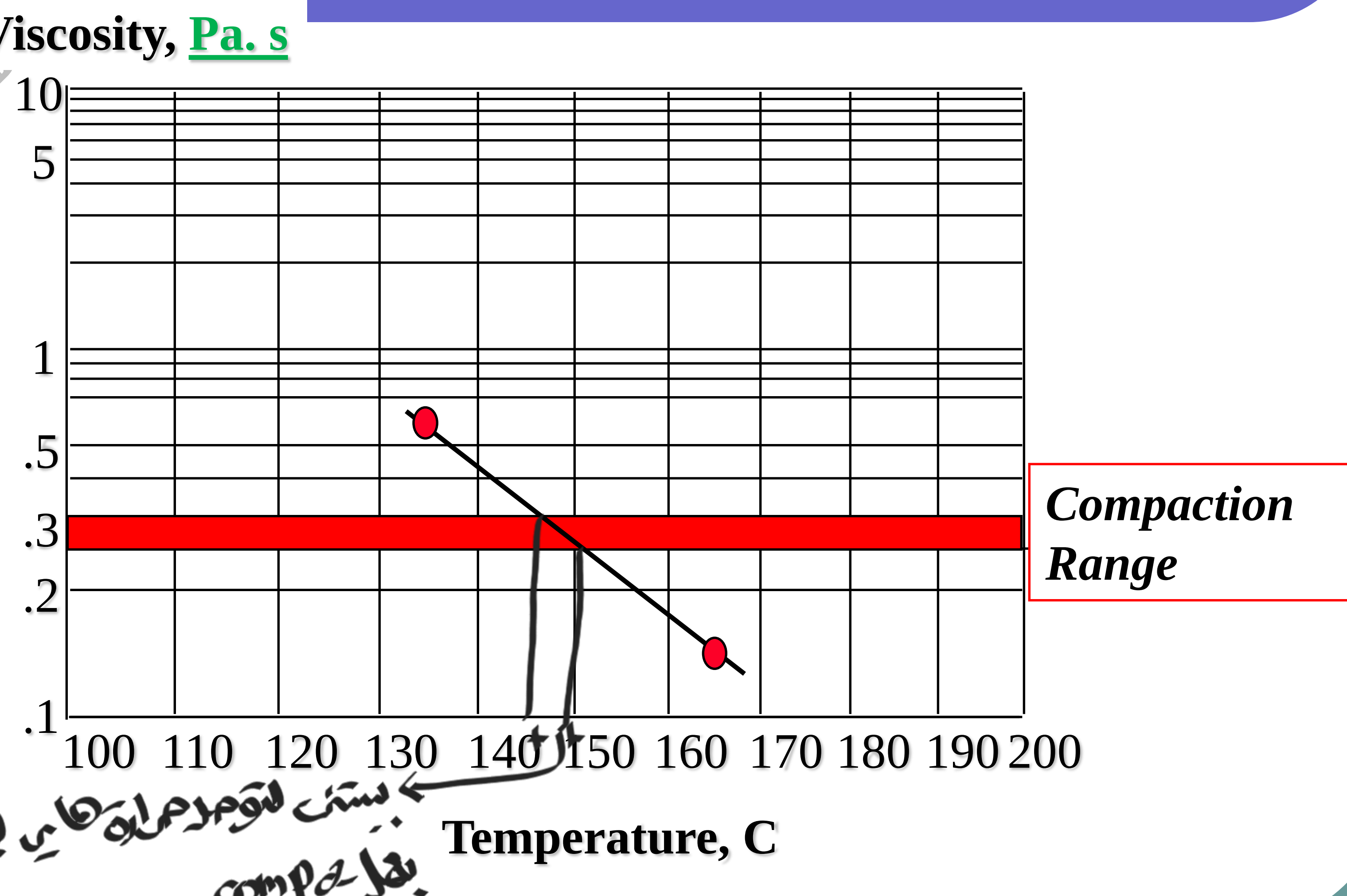
* كل ما زادت حرارة تقل اللزوجة



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)

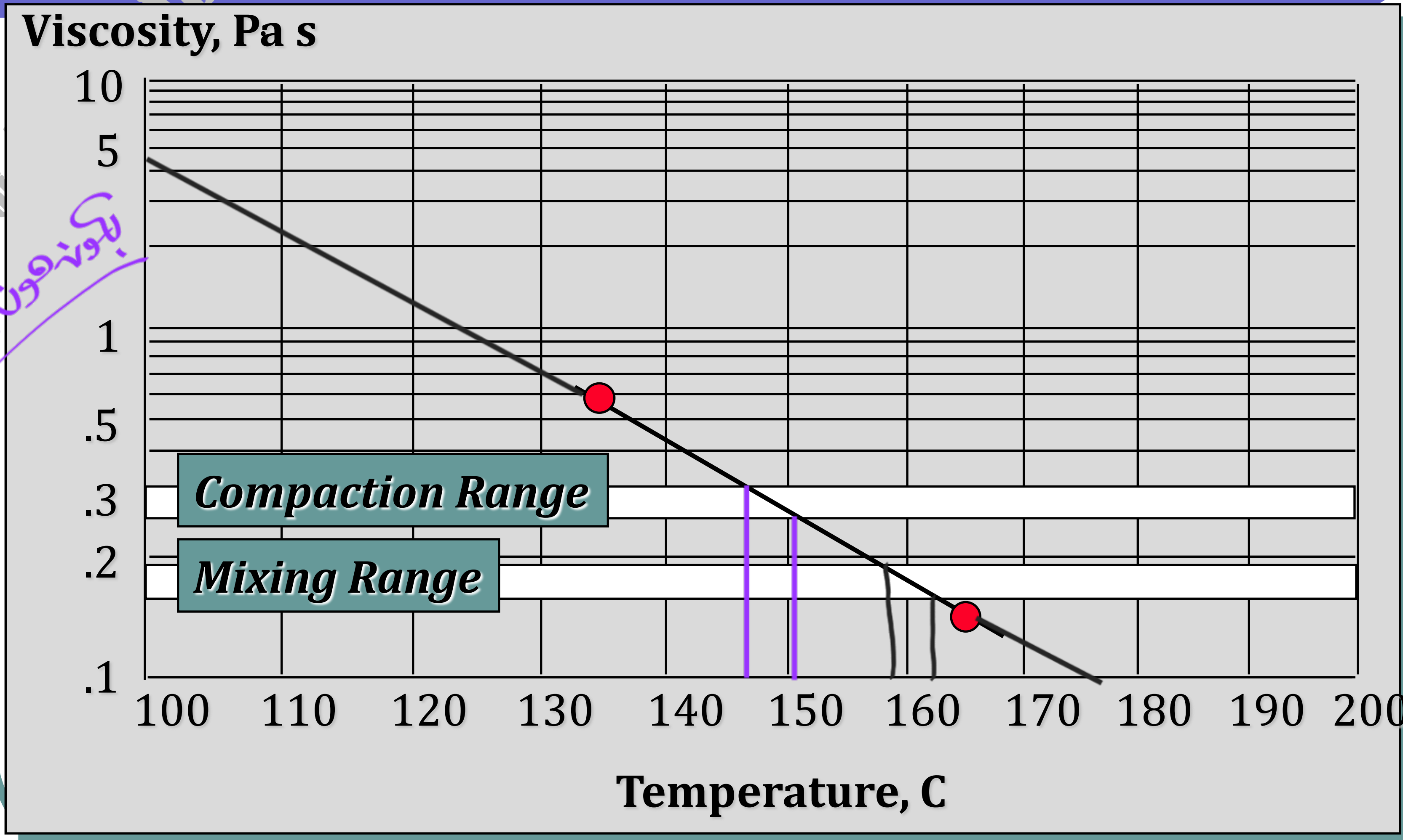




Mixing viscosity range (0.17 ± 0.02 Pa-s) or (170 +- 20 CSt)

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

23/7

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

  اعلى درجة حرارة لل HMA في 60

  - 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

  على الغالب 135 ممكن تسخين بيتيومين

- 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:

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

where:

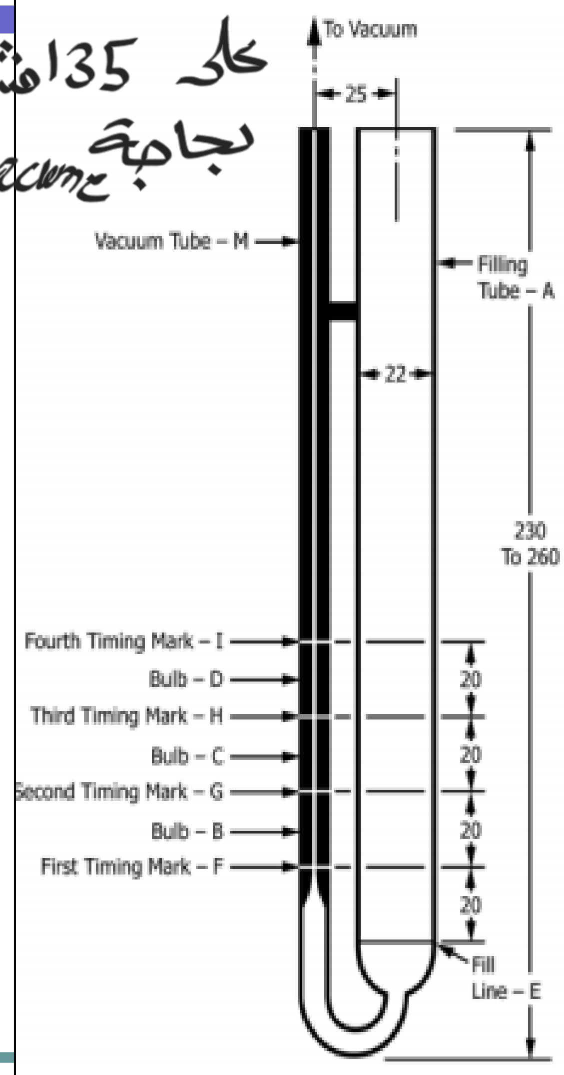
$\nu_{1,2}$ = determined kinematic viscosity values for ν_1 and ν_2, respectively, mm^2/s,
C = calibration constant of the viscometer, mm^2/s^2, and
$t_{1,2}$ = measured flow times for t_1 and t_2, respectively, s.

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

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

where:

η = dynamic viscosity, mPa·s,
ρ = density, kg/m^3, at the same temperature used for the determination of the kinematic viscosity, and
ν = kinematic viscosity, mm^2/s.



All dimensions are in millimetres.

Consistency Tests/ Penetration Test /ASTM D5

فحوصات القوام

- ASTM D5: Standard Test Method for Penetration of Bituminous Materials

  كل 10 قراءات بتمثل 1mm

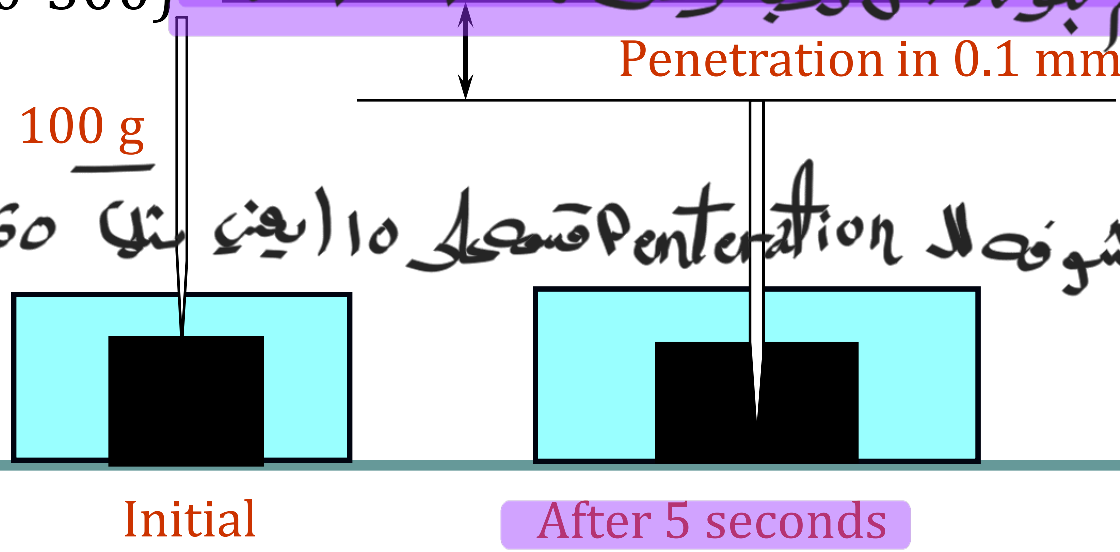
- The distance in tenths of millimeters to which a standard needle penetrates the material under known conditions of time, loading, and temp. (25)

  ظروف الاختبار

- Penetration grades: (40-50) (60-70) (85-100) (120-150) and (200-300)

  كل ما زاد رقم Penetration بكون اقل لزوجة واعلى

* اي رقم بشوفه لل Penetration قسمه على 10) يعني مثلا 60: الاختراق بمقدار 6mm)



Penetration Test /ASTM D5

stander

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 (وزنة الابرة)	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.

∴ إذا حرارة اقل من 25
بنزيد load وبنزيد الوقت
واذا حرارة اكثر من 25
بقلل load وبثبت الوقت

Consistency/ Softening Point

- ASTM D36: Standard Test Method for Softening Point of asphalt (Ring-and-Ball Apparatus) حلقة جهاز المستعمل
- 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.

*الوسط الذي ستكون فيه العينة تعتمد على الحرارة softening

فممكن استخدام مواد مختلفة

* بكون حلقتين بنحسب داخلها اسفلت (لي هو اسفلت قاعد

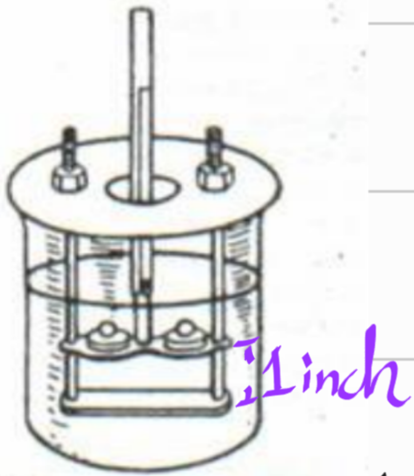
عليها) بنجيب كرات بوزن وحجم معين نضعهم على سطح العينة

ببلش المحلول يسخن والاسفلت تتغير قوامه بصير soft

فـ الكرة تدخل الاسفلت ، اللحظة التي تصل فيها الكرة

سطح ال base ناخذ قراءة الحرارة

وهاي هي softening : هي



(d) Two-Ring Assembly

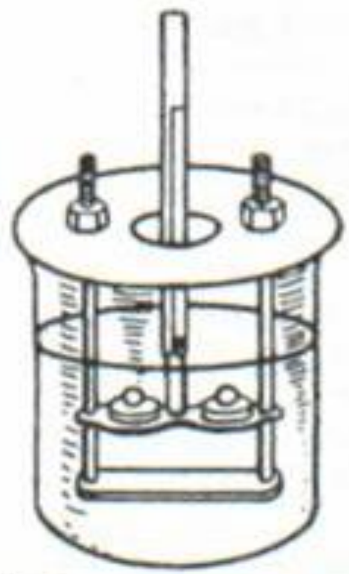
بتعطيني تصور عن مقاومة الخاصة

بالاسفلت فـ الفكرة انه كلما كان اسفلت

لزوجته عالية فبدي حرارة عالية لتقل لزوجته بس ماعندي

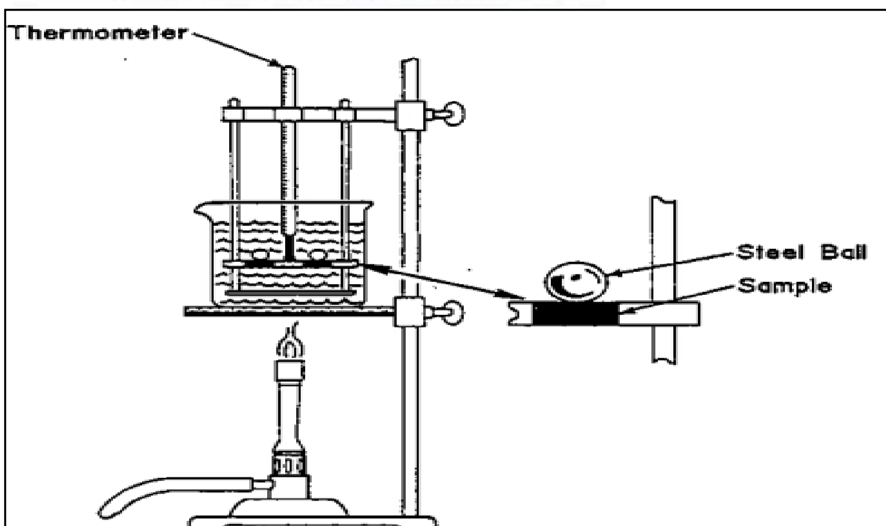
تدرج ولكنه زي ما ذكرنا قبل

Softening Point



(d) Two-Ring Assembly

بعطيني تصور
عن القوام



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

العادلة بتعطيني قيم قريبة للواقع

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

- $t_{R\&B} = 87.3 - 22.5 \times \text{Log}(P)$ ← مانتسى انها بـ mm
- Where

إذا كانه مش ضمن الرينج بنكتب cannot be solved.

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

Consistency Tests/ Ductility

نوضع عينة اسفلت ونسحبها

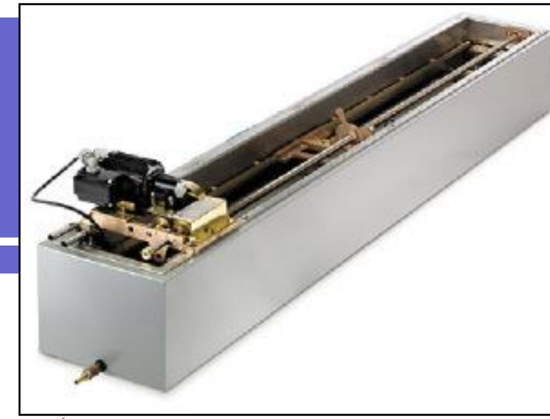
- ASTM D113: Standard Test Method for Ductility of Bituminous Materials
- Property of material that permits it to elongate (undergo great deformation) without breaking.
- Ductility: Distance in centimeters to which a standard sample may elongate without breaking.

كم مسافة التي تستطيع سحب الاسفلت

شروط تجربة

- 25 °C, 5 cm/min,
- Spec. +100 cm ← عشان تقبل العينة

Ductelometer



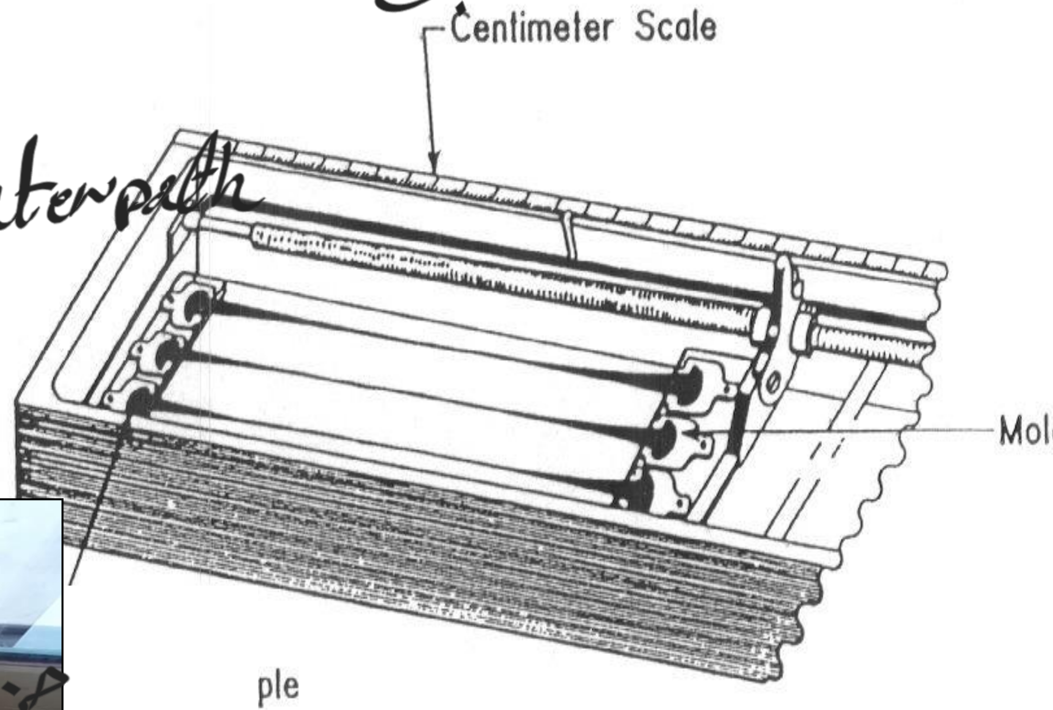
إذا الاسفلت ناشف كثير

بقطع

water path

جزء ثابت

جزء متحرك



-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

التجربة هي انه نحضر كمية من الاسفلت ونعرضها لتيار هواء ساخن لمدة من الزمن.

* بتعطيني تصور عن ديمومة الاسفلت وبعد الاختبار بعطيني فكرة عن شو ممكن يصير بالاسفلت خلال مرحلة short

* الاسفلت (الذي عملت له ageing) بترجع تذوبه ونعمل عليه تجربة Penteration او viscosity بحيث من المتوقع انه اللزوجة تزيد، لانه نشف اكثر و من متوقع انه ال Penetoration يقل

* عشان نعرف كم صار عندي penetration رح نوخذ القيمة الجديدة على القيمة الاصلية * 100% = rated pentration

* Penetration بعد تجربة TFO تقسيم Penetration

الأصلي ضريب ١٠٠٪ لازم تطلع 55٪ عشان اعتبر

إنه الاسفلت مقبول]⇐ المواصفة

إذا عندي مشكلة إنه أقل من 55٪ ف الاسفلت

بيشف كثير فبعمل مشاكل

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,

    وزن عينة راح ينزل
  - **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)**

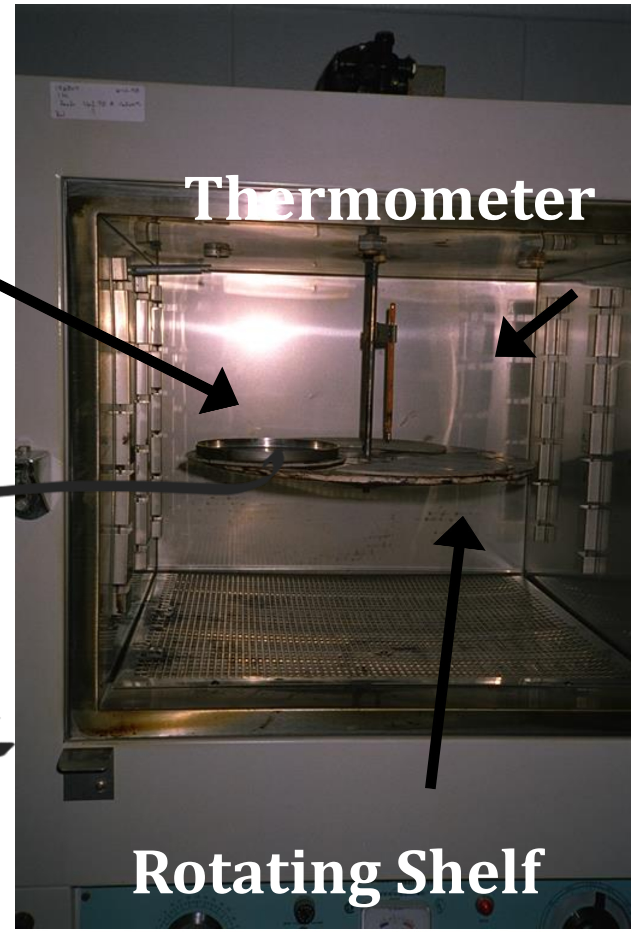
Test

شكل العينة تغير

Thin Film Oven

soft ↑ , visc ↑ , Pen ↓

Outside of Oven



أخذ 3 عينات

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)

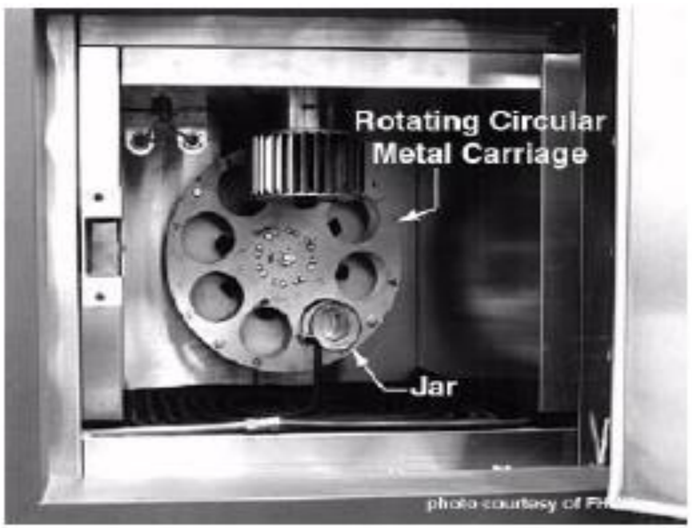


Figure : Rolling Thin-Film Oven Test

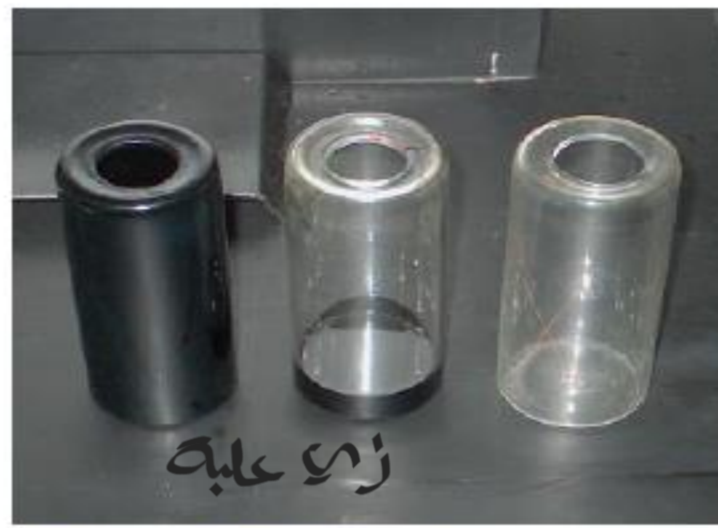


Figure : RTFO Samples
(left - after aging in the RTFO,
center - before aging in the RTFO,
right - empty sample jar)

*نضع بالعلبة شوي اسفلت وبعد عمل تجربة فبذوب

الهدف من الفكرة انه مساحة اكبر من الاسفلت يتعرض

للـ ageing فـ تتوزع على Area

* كمية الاسفلت المستعملة قلت

*مدة العمل اقل => 85 minuts وهي بامكانك بعد

75 تعوض العينة

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

نعرضها لمدة 20 hours

لازم يكون معموله short term ageing

Figure : Pressure Ageing Vessel

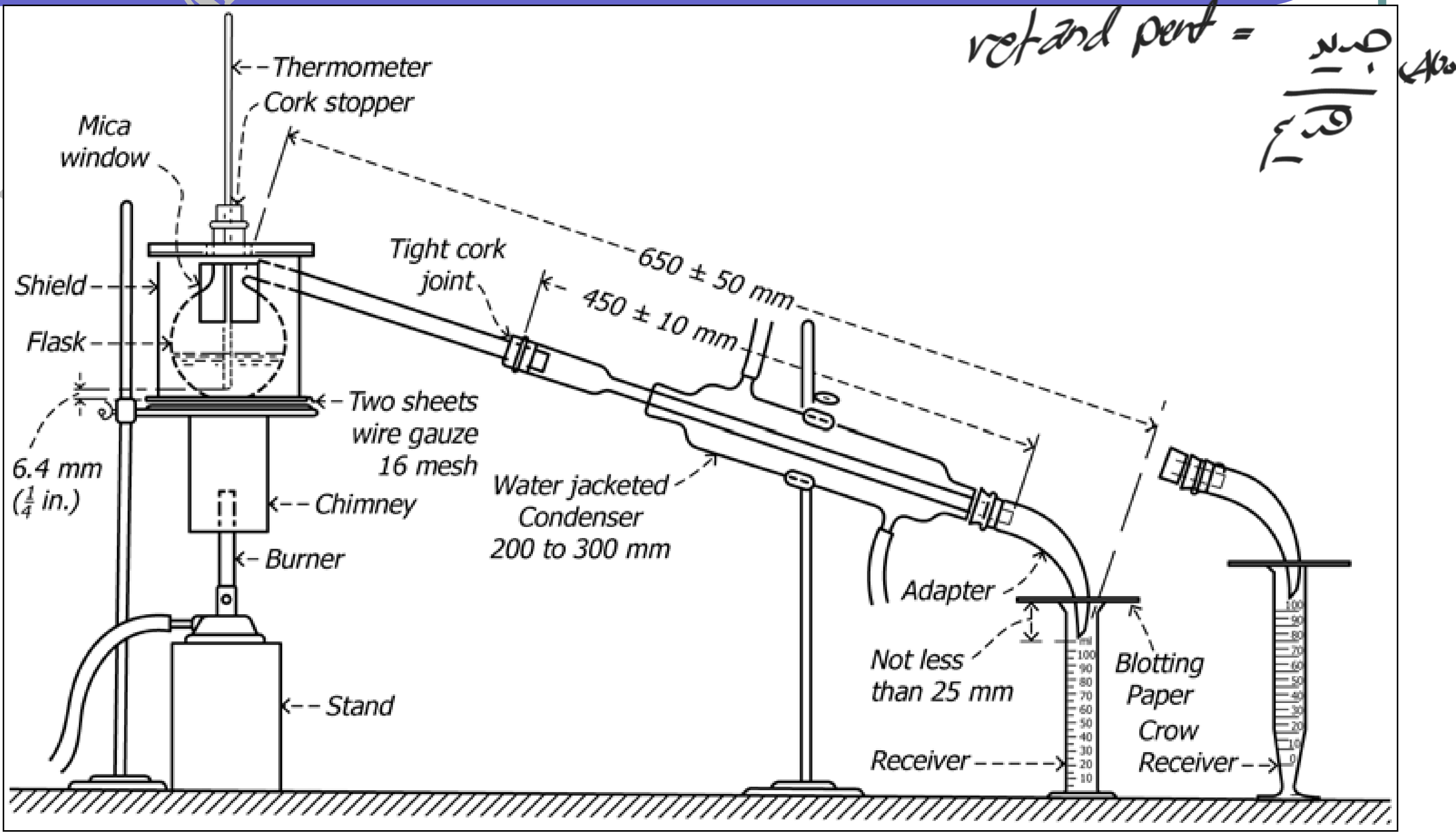
Figure: PAV Sample

Durability Tests / Distillation of CutBack Asphalt ASTM D402

بعض فحوصات

- ASTM D402 بالعادة بكونه مفحوص وجاهز
  - Standard Test Method for Distillation of Cutback Asphalt
- Scope
  - This test method covers a distillation test for cutback asphalts
- Significance and Use إذا طلب تعرف كم كمية المواد المتطايرة بنلجأ لهاد الاختبار
  - **This procedure measures the amount of the more volatile constituents in cutback asphalt.**
    - **Used to separate volatile from nonvolatile substances.**
- Summary of Method بنسخن بعدها بنعمله تكاثف وبنشوف كم حجم تقطير
  - 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

نفس الفكرة

- 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.

بتعرض عينة التسخين على زي RTFO
بس بتعرض كل العينة

- 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

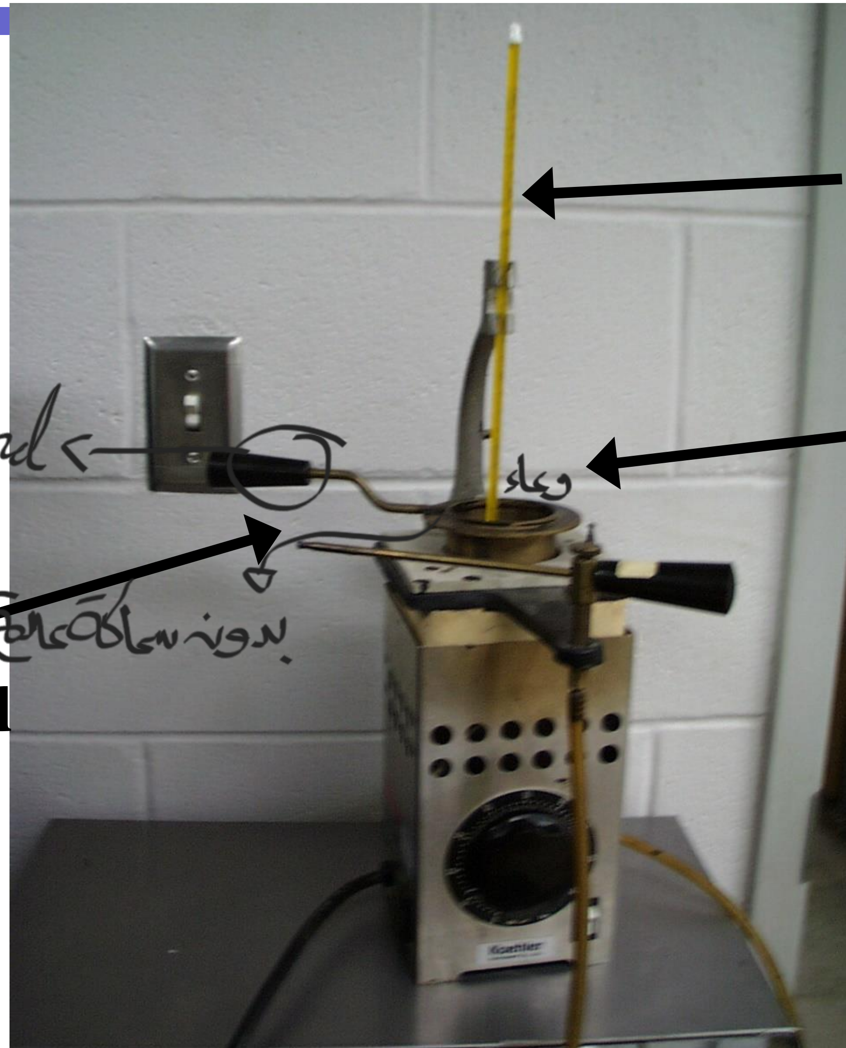
- Known as safety test.
- Cleveland Open cup. → (اسم اخر للاختبار)
- AC heated at specified rate.
- Flames pass across the surface.
- Min temp. at which sparks appear on the AC surface is reported as flash point.
- For any type of asphalt grade
  - Minimum Flash point value should be = 175 ºC
  - Minimum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

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

اهمية الفحص

1

- The flash and fire points are **useful for safety and security reasons for the avoidance of accidents in case of overheating the asphalt.**

2

- **The flash point is one measure of the tendency of the test specimen to form a flammable mixture** with air under controlled laboratory conditions.

نعطي فكرة متى رح يولع

- 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**

* بتبلش بتسخين فبطلع ابخرة في لحظة من اللحظات

لما يمر اللهب فوقهن رح نشوف شرارة بنسجل الحرارة

وبنسميها Flash point (درجة الوميض) بعدها بفترة قليلة

رح تولع النار تقريبًا لمدة 5sec بنسجل الحرارة وبكون

اسمها Fire point

هدول الحرارتين رح يعطوني فكرة الاسفلت على أي درجة

حرارة رح يشتعل

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.

*الوزن النوعي هو عبارة عن كثافة المادة على كثافة الماء

* علاقة الحرارة مع الكثافة عكسية شرح :-

لما تسخن المادة تتوسع وتنتشر جزيئات المادة بعطيني وزن أكثر : وزن أكبر وحجم أكبر >> كثافة أكثر ، مجرد ما تسخن بصير عندي طاقة بالجزيئات

1- الحرارة إذا اختلفت فالوضع رح يختلف ورقم رح يتغير فـ تعديلات يجب عملها

2- لازم تكون عارف Specific gravity لكل مواد التي تستعملها تكون عارفها

S.G. of Asphalt Cont.

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

في فتحة عشان ماء زيادة
تطلع برا

Calculating S.G. of Asphalt

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

وزن الاسفلت

وزن الماء التي ازيحت مكان الاسفلت

$$S.G = (C-A) / [(B-A) - (D-C)]$$

where: وزن الماء التي عبت Pycn

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:

Density = specific gravity * γ_w

عند درجة حرارة معينة

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

اول اشي رح نوزن pycometer فاضي بعدين نعبي فل ماء

واضح الوزن بعدها بنفرغ الماء ونحسب داخله اسفلت تقريبًا نصه او ⅔ منه ونوزنه بعدين بنحط فوقه

الاسفلت ماء لنعبي فل ونوزنه

← وللتذكير فـ SG هو وزن حجم معين من المادة على وزن حجم الماء

← ممكن يعطي وزن الماء الي عبت pycon تساوي كذا

فممكن يكون معطينا فروقات جاهزة :

قانونه هو $\frac{\text{وزن الاسفلت}}{\text{وزن الماء الي تمثل حجم الاسفلت}}$

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.

Viscosity Graded Original

ذكرناه قبل وحكينا إله كلما زاد الرقم بكون more viscosity

Viscosity Graded Residual

بنوخذ الاسفلت إلي عملناله Ageing (اختبارات) وكل

فا كبر الرقم بكون more viscosity

Penetration Grades

كلما زاد الرقم بكون low viscosity hige penetration

Asphalt binder grading systems

Available systems : اختبار قديم

- Grading By Chewing مضغ
- 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) احدث الاشي
- Superpave Performance Grade (PG) system

Penetration Grading system

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

Grade	Penetration min.	Penetration 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.

Specifications of Asphalt 60-70

مش للحفظ

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. → %100 × جديد / قديم	%	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

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

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

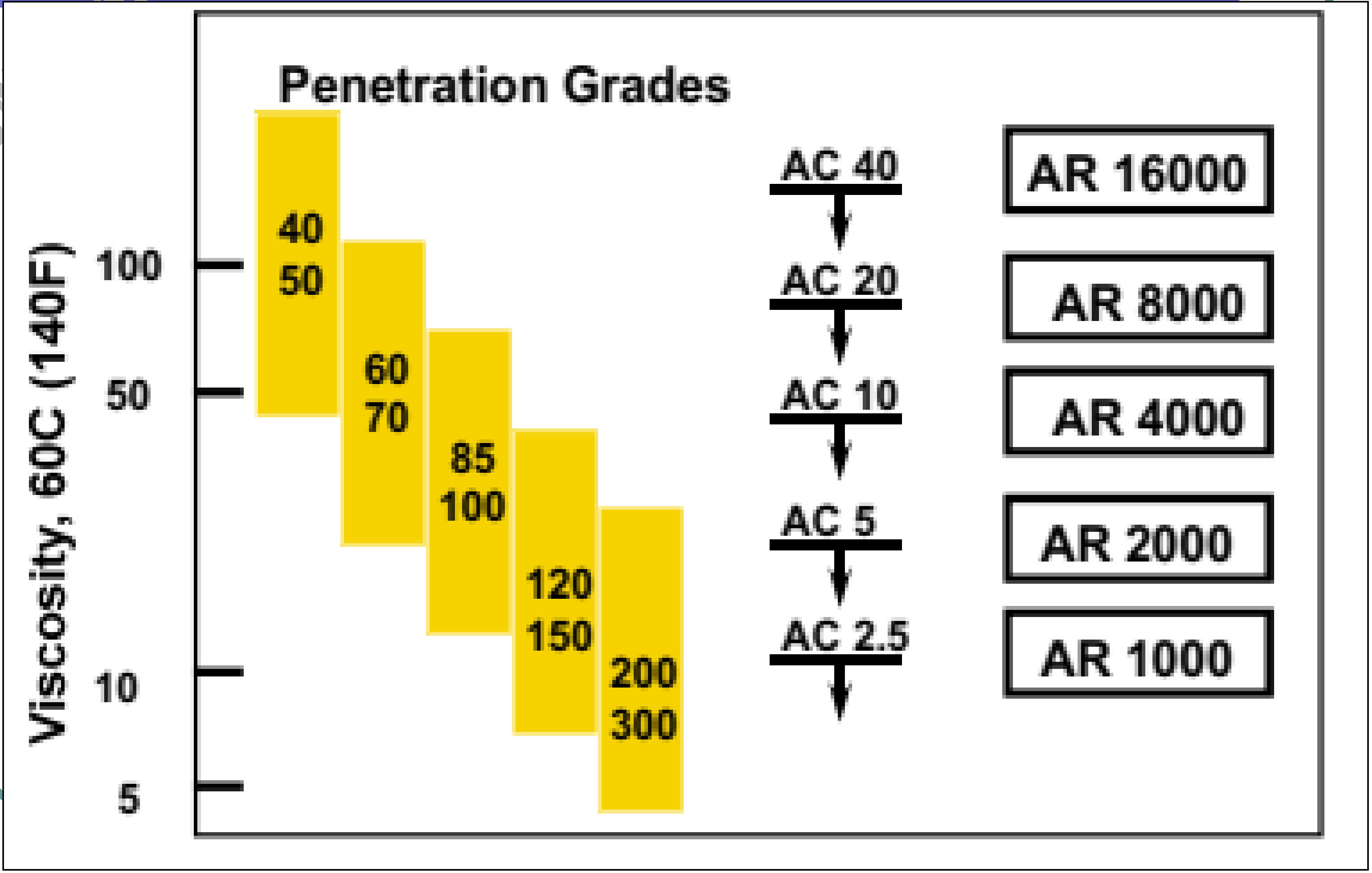


Table 5.5
Summary of the Superpave Test and Requirements

	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	≤ 3 Pa s	(≥ 1.0 kPa)	(≥ 2.2 kPa)	(≤ 5000 kPa)	≤ 300 MPa	≥ 0.3	$\geq 1.0\%$

$$\frac{64+(-22)}{2}+4$$

Superpave Performance Grading

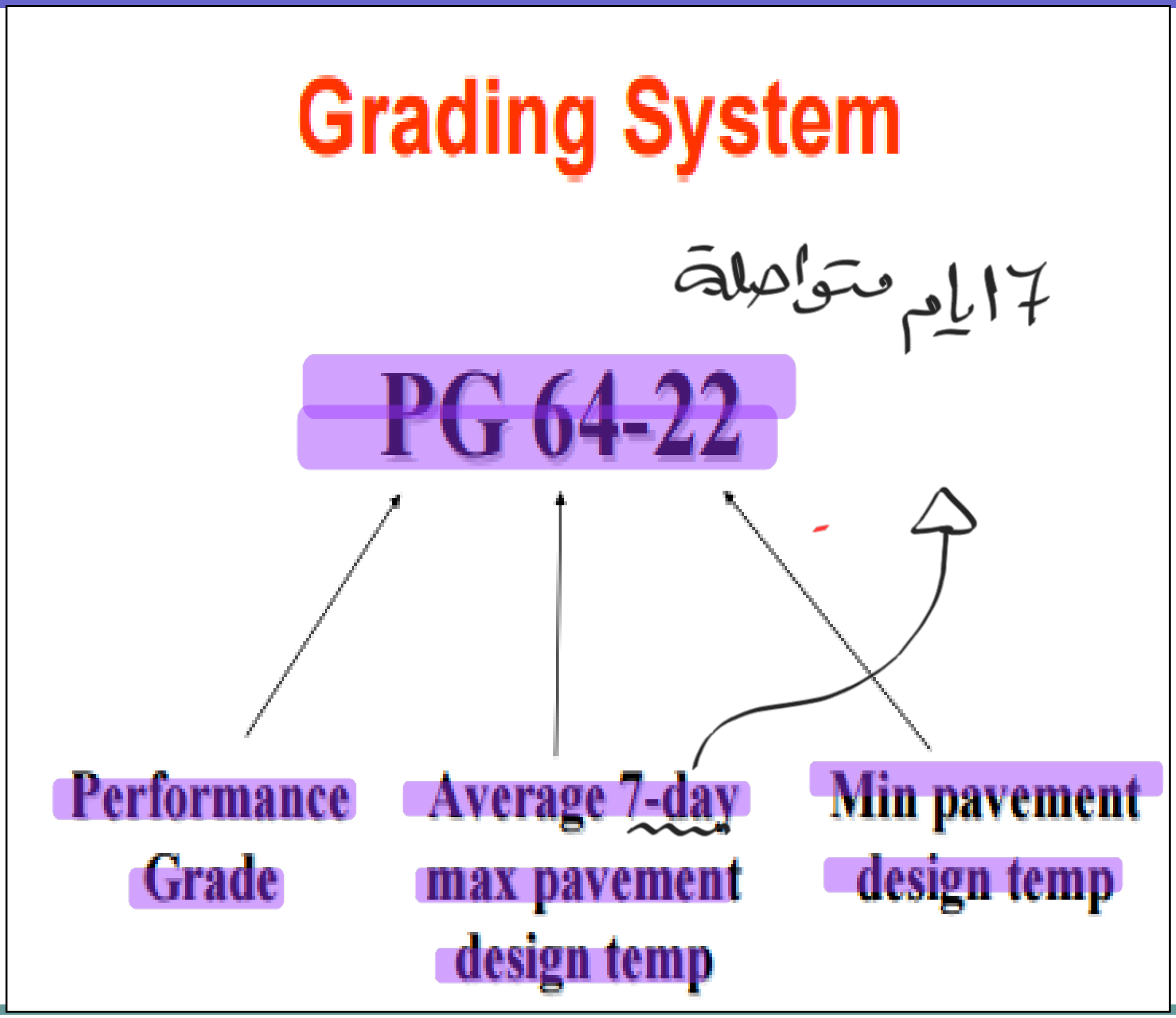


Image source: http://rahabitumen.com/performance-grade-pg-bitumen/

Superpave Performance Grading

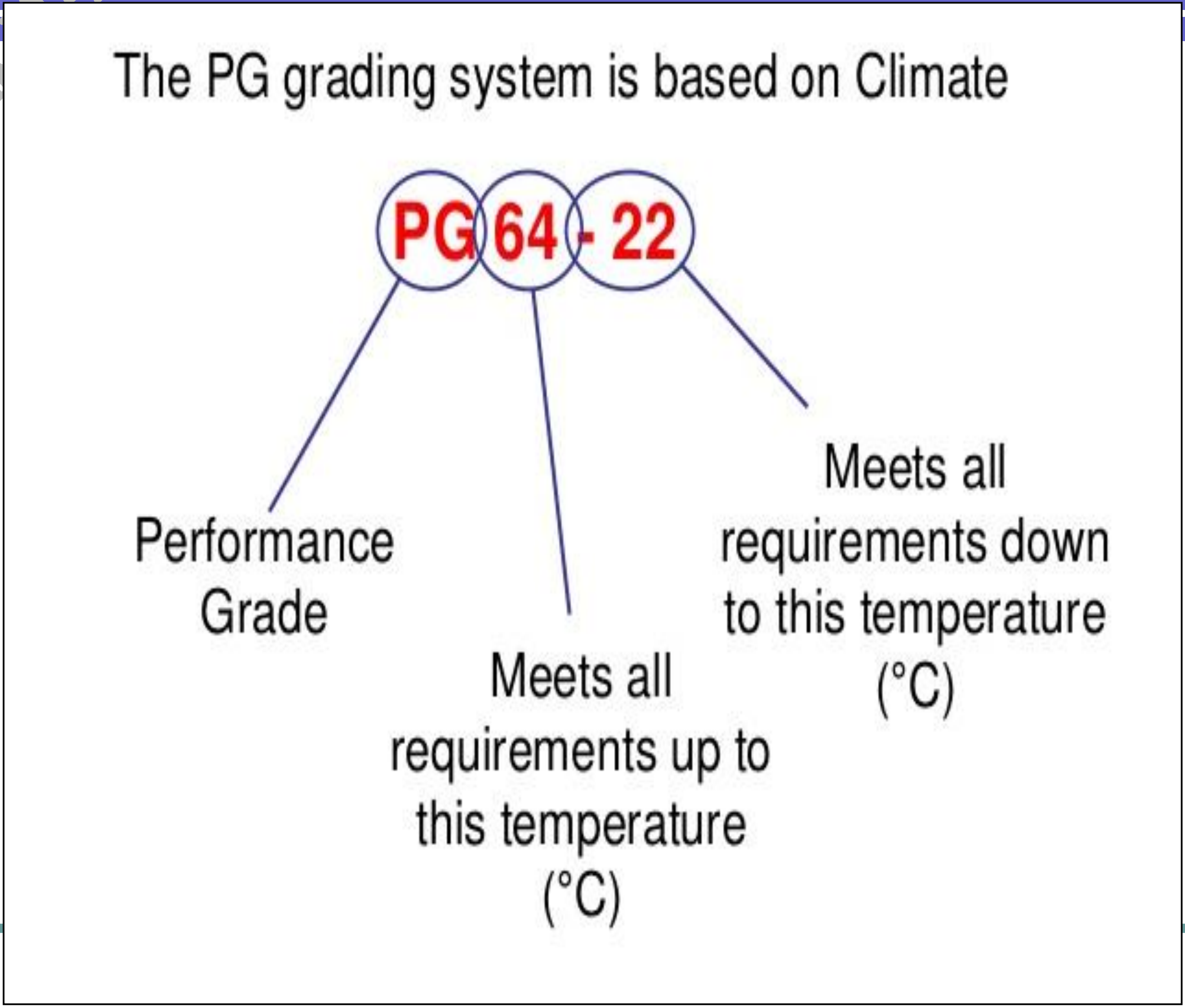


Image source: https://www.slideshare.net/CaliforniaAsphalt/asphalt-binders-101

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 → لما يصير الفرق أكبر من 90

76+40 = 116 > 90

∴ بحاجة modification

Superpave Performance Grading

TABLE 9.2 Binder Grades in the Performance Grade Specifications

فهم مش حفظ

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

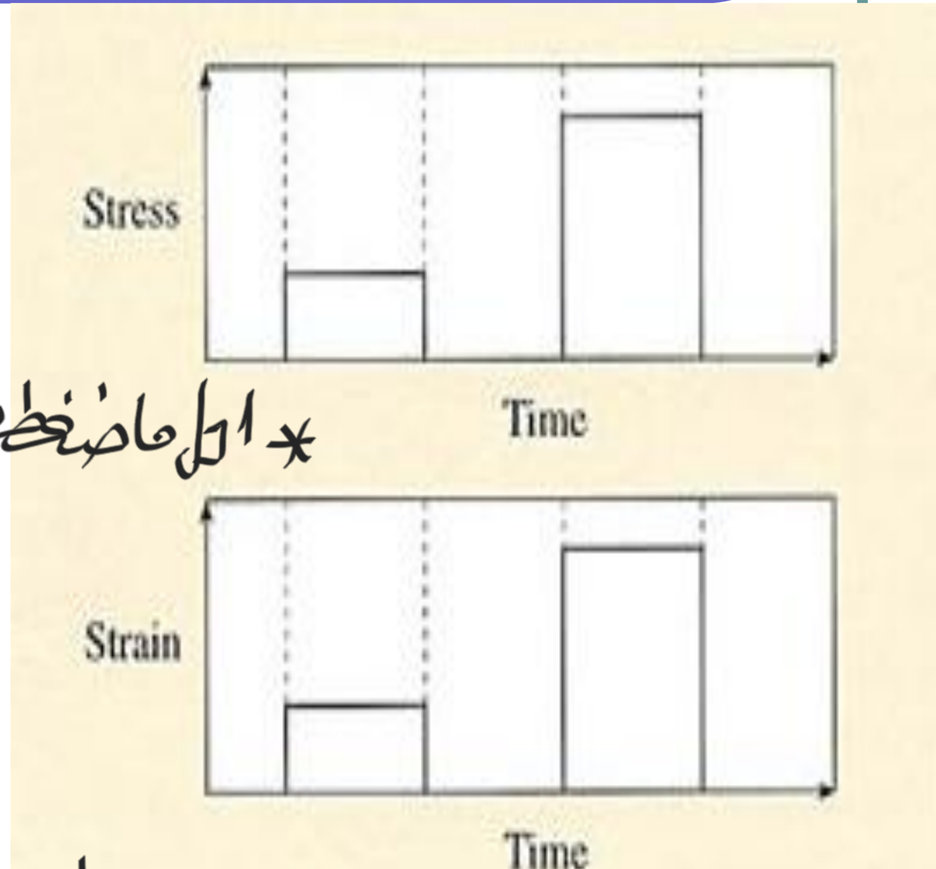
Asphalt Binder Selection

يوضح مزايا

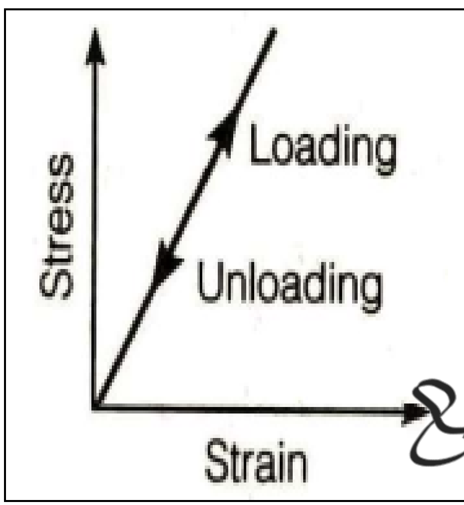
Grading System	Climate	Traffic	Structural Design	Layer Location	Fundamental Properties Measured
Penetration	✓				
Viscosity	✓				✓
PG	✓	✓	✓	✓	✓

How Asphalt Behaves

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



* اول ما ضغطت بلش strain مباشرة

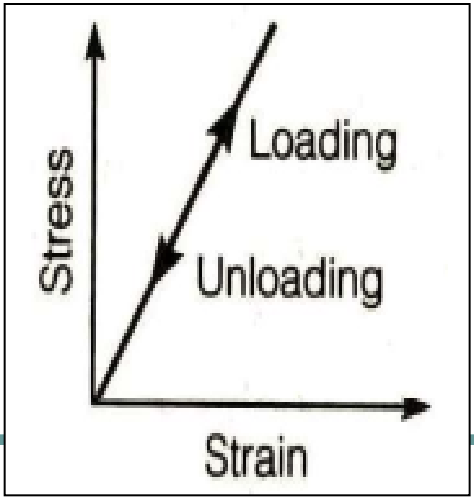


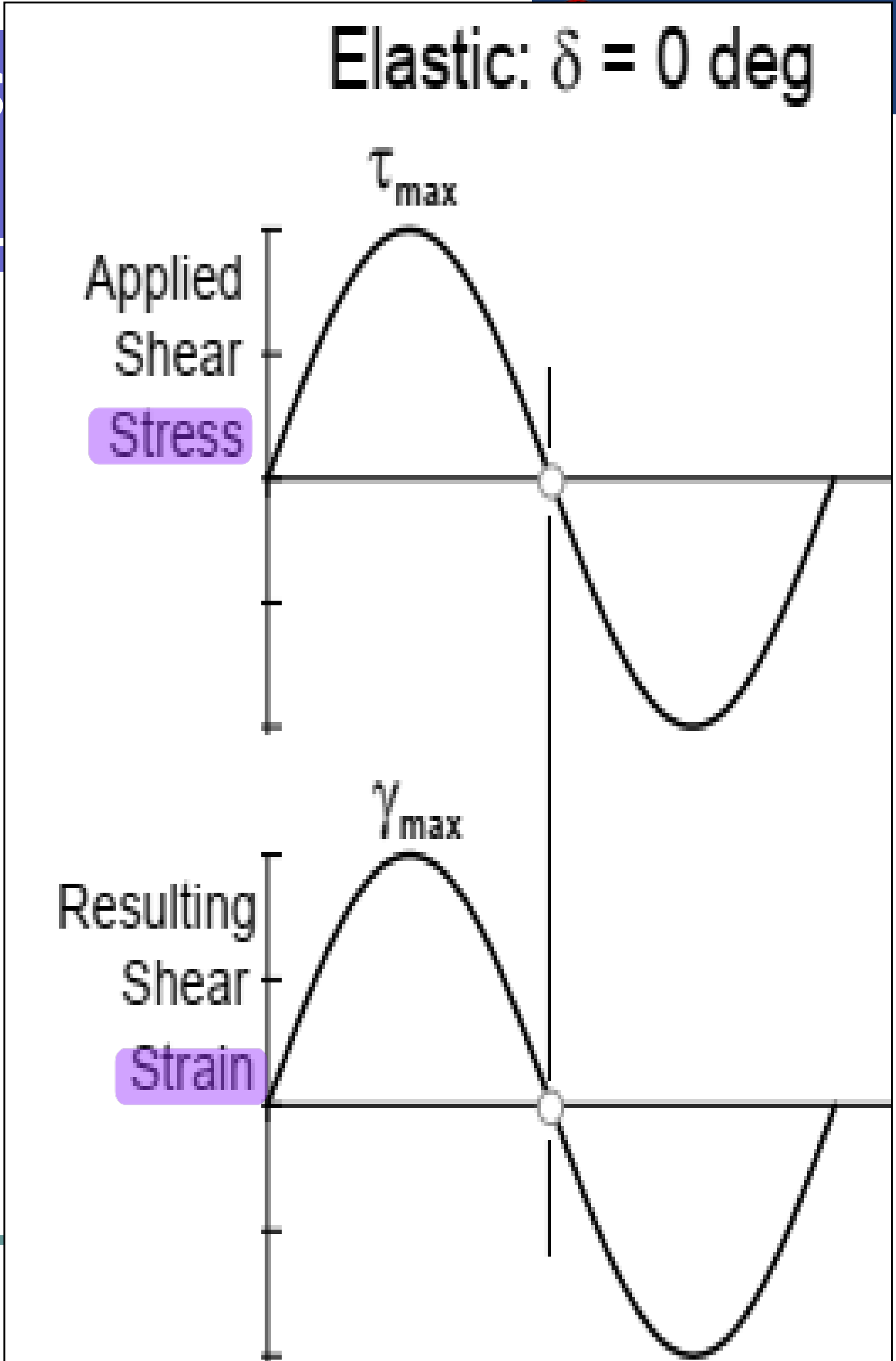
* مباشرة بس نوقف stress برجع للوضع الطبيعي

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

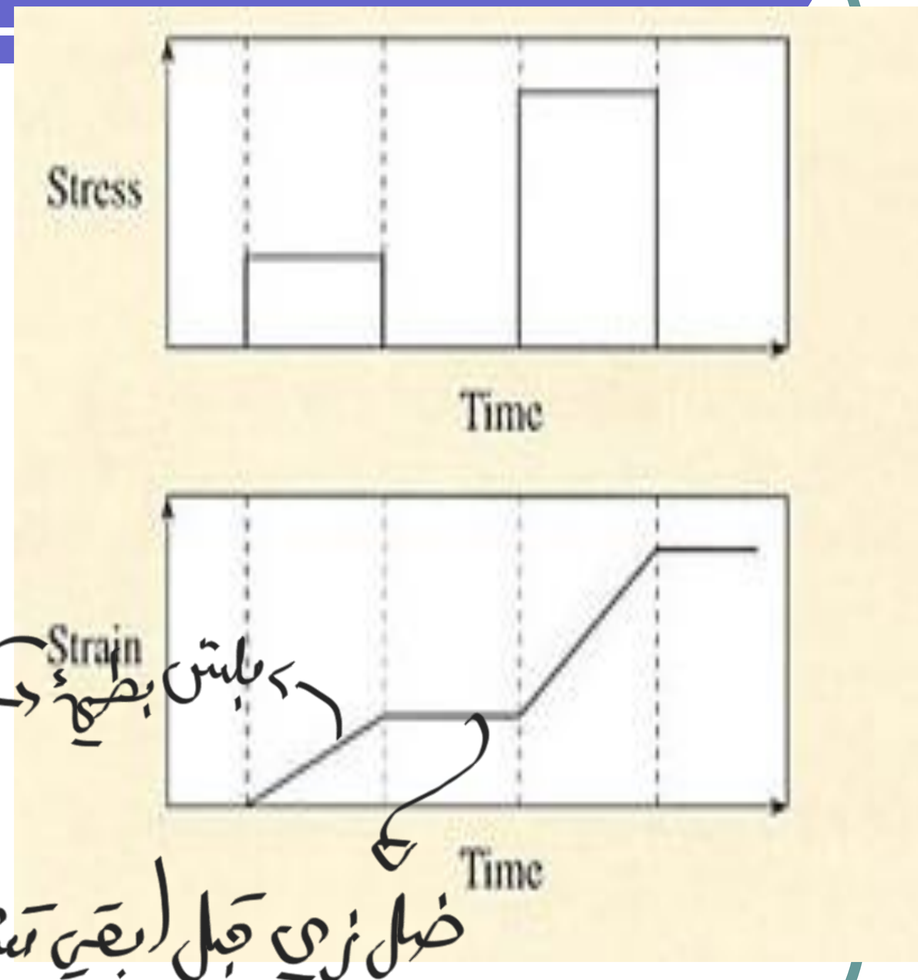
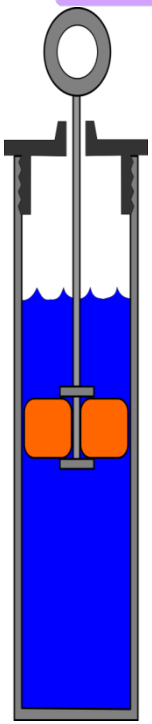


Image source: https://www.open.edu/openlearn/science-maths-technology/science/chemistry/introduction-polymers/content-section-5.2.2

How Asphalt Behaves

- Viscous Behavior
  - Have delayed response



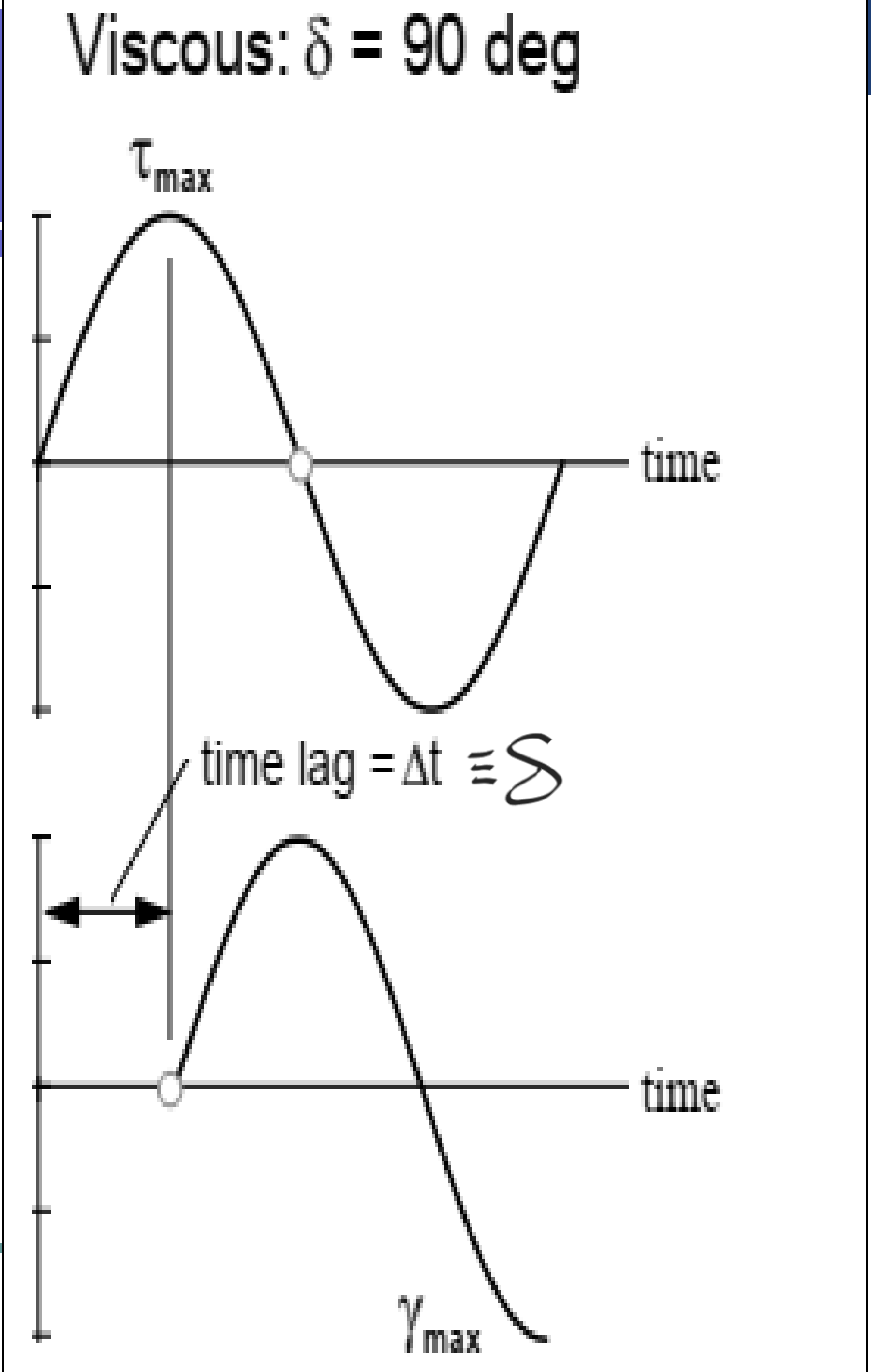
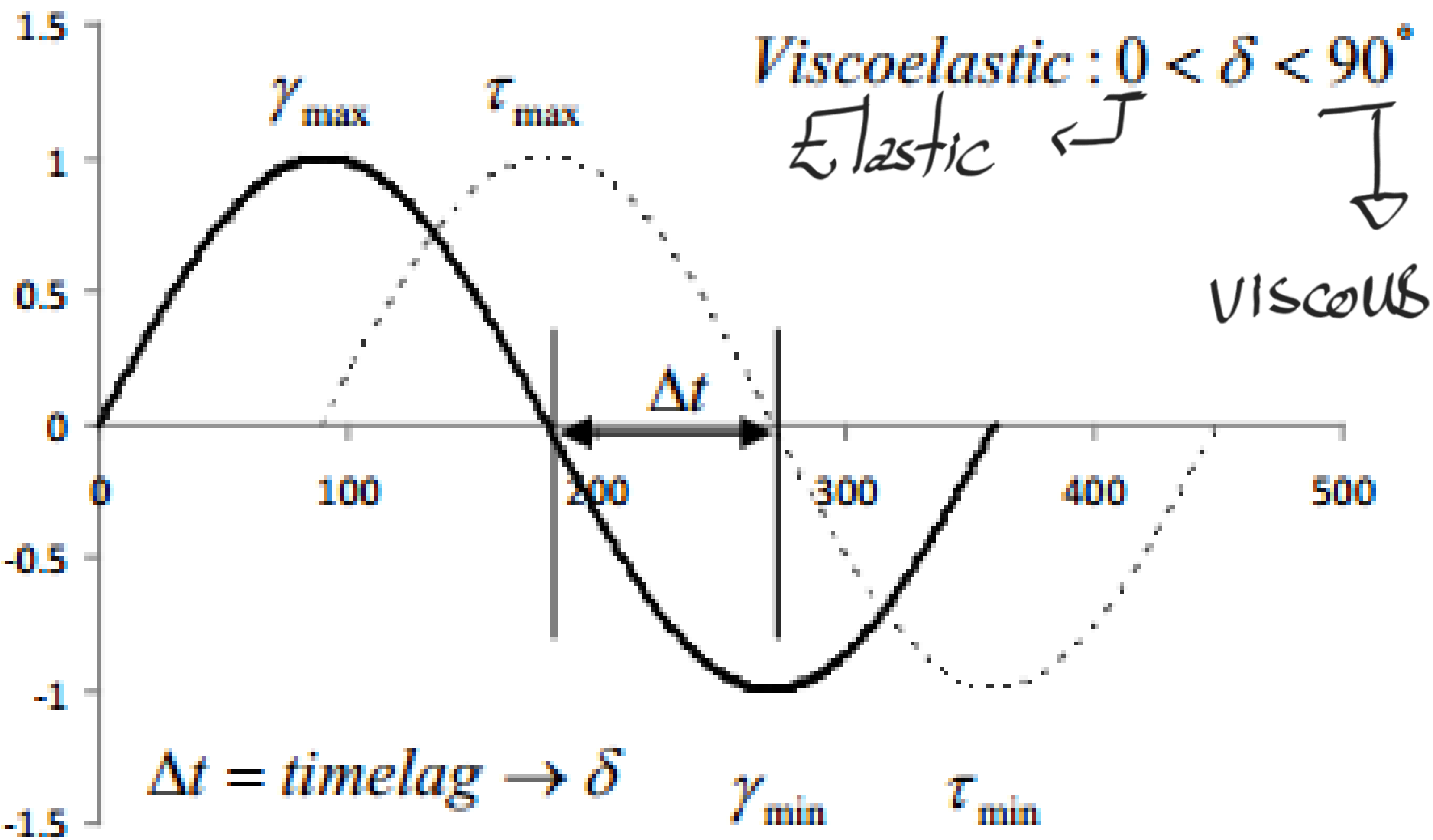
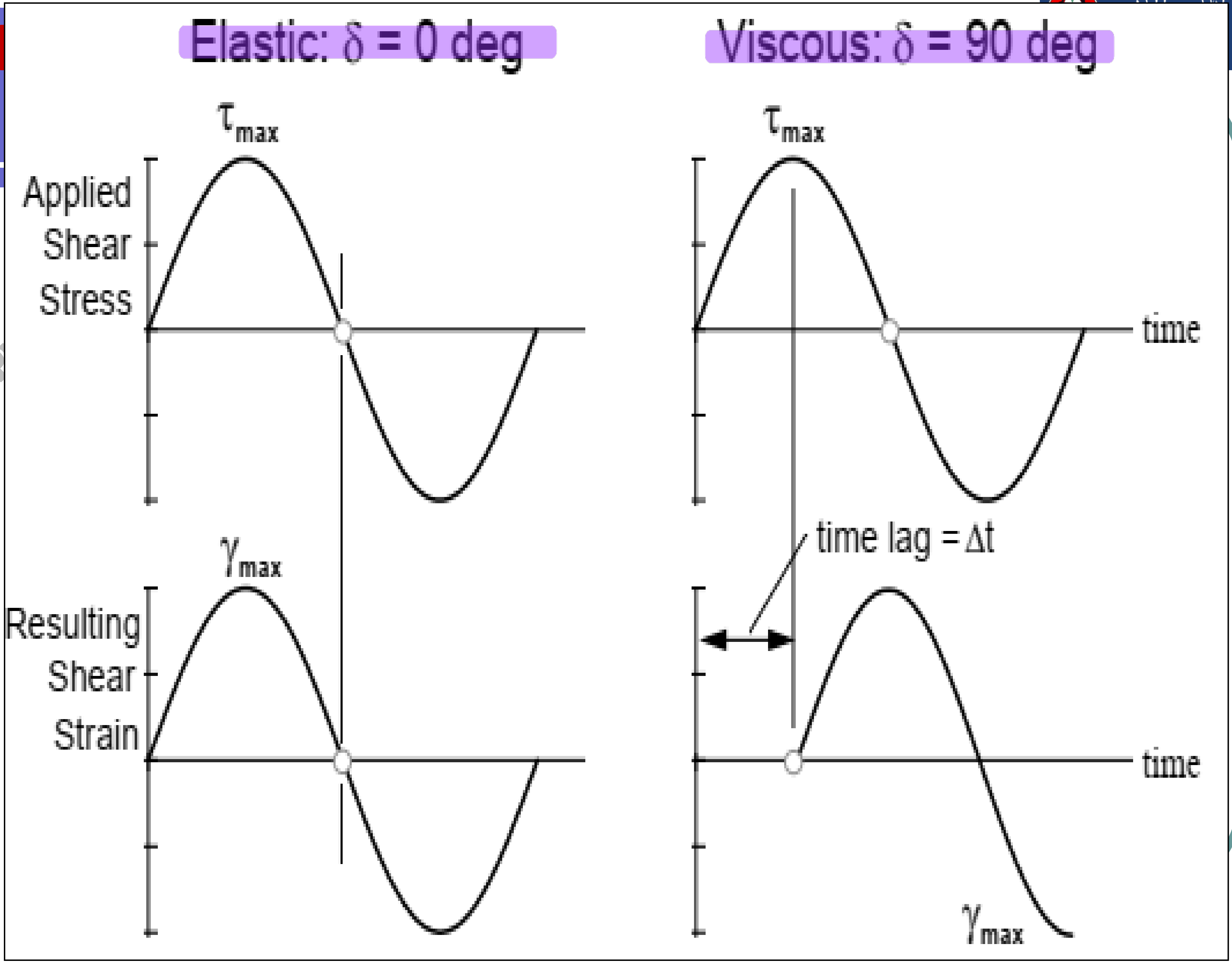


Image source: https://www.wikiwand.com/en/Dashpot

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
τ_{max}
τ_{max}
Applied Shear Stress
time
time lag = Δt
γ_{max}
Resulting Shear Strain
time
γ_{max}

How Asphalt Behaves/ Viscoelastic Behavior

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

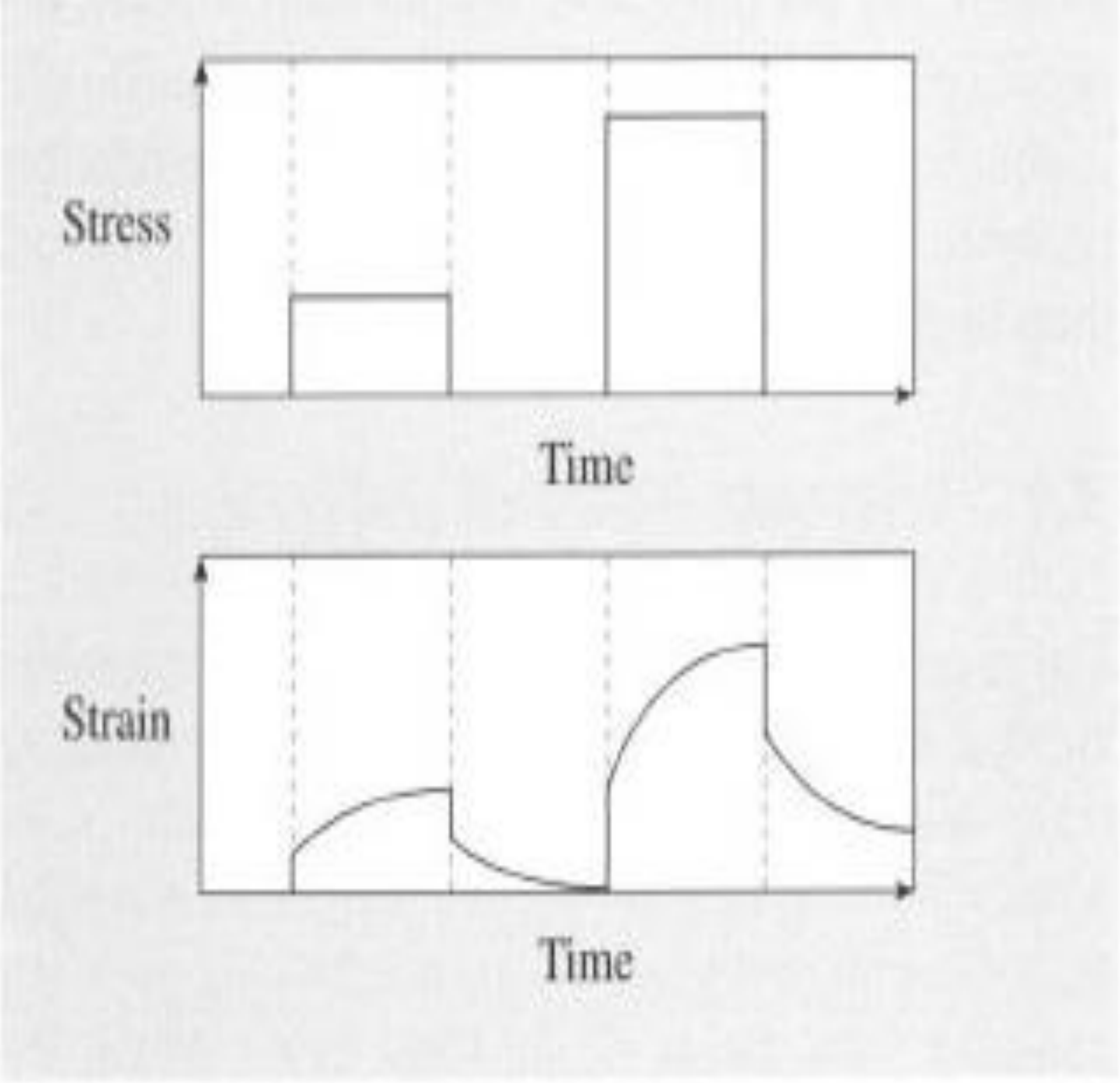
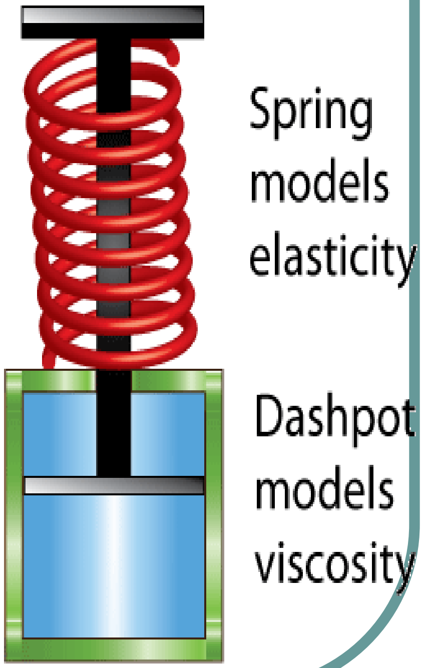


Image source: https://www.open.edu/openlearn/science-maths-technology/science/chemistry/introduction-polymers/content-section-5.3

How Asphalt Behaves/ Viscoelastic Behavior

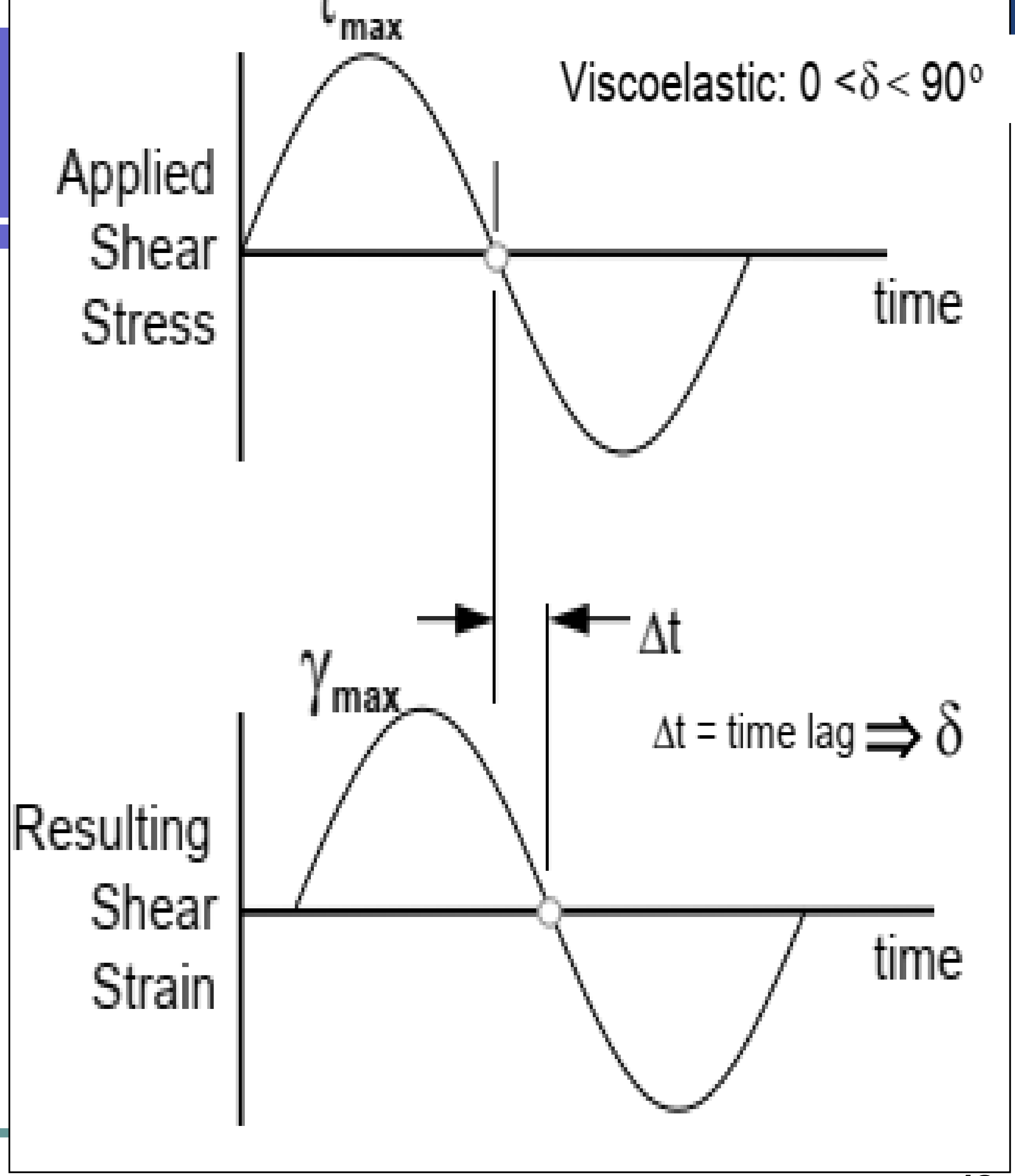
- Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation
- Viscoelastic Materials
  - Have both elastic and viscous response
  - Have delayed response
  - Deformation depends on
    - Duration of Load
    - Rate of Loading
    -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

Viscoelastic Model

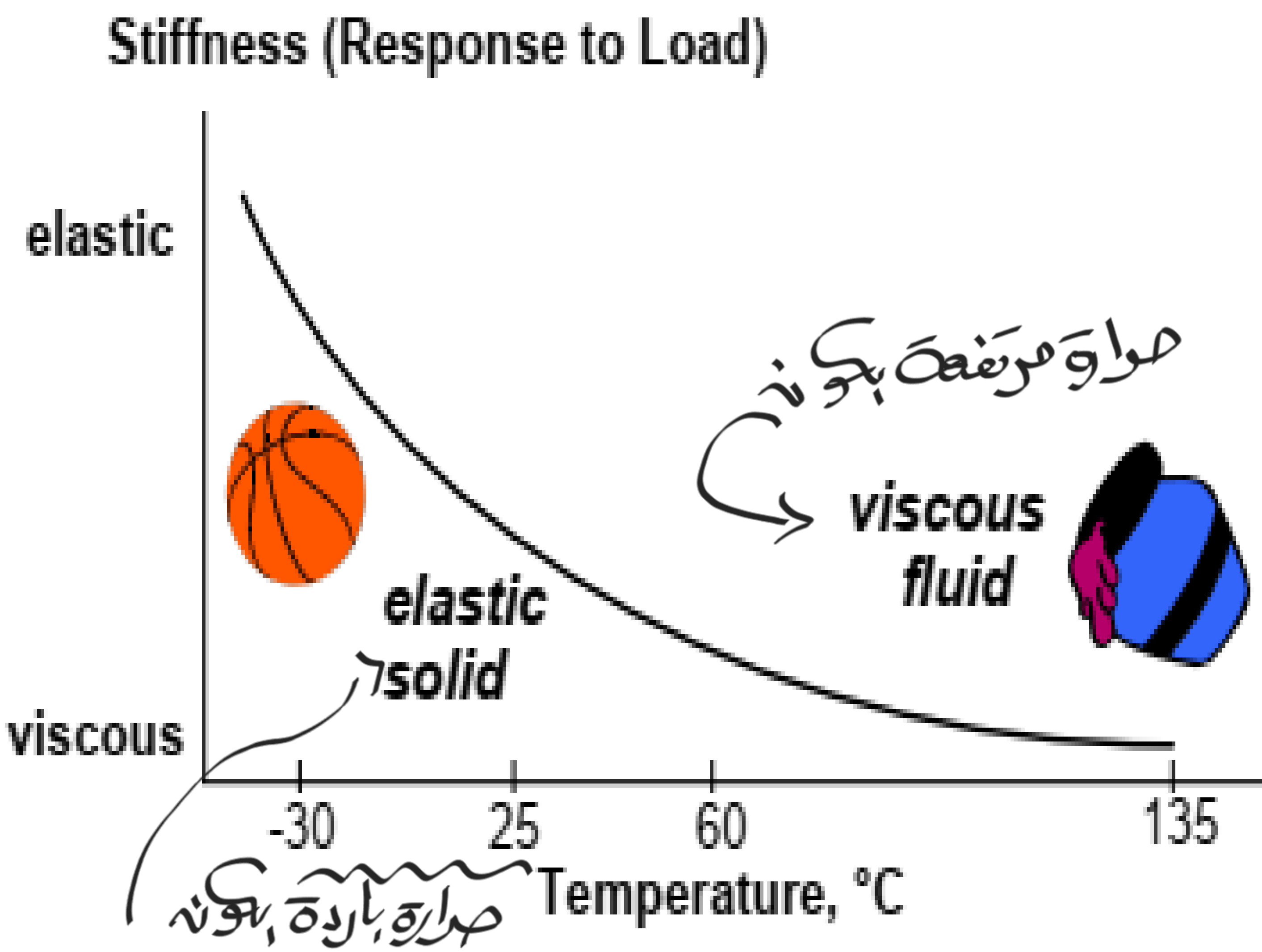


How Asphalt Behaves

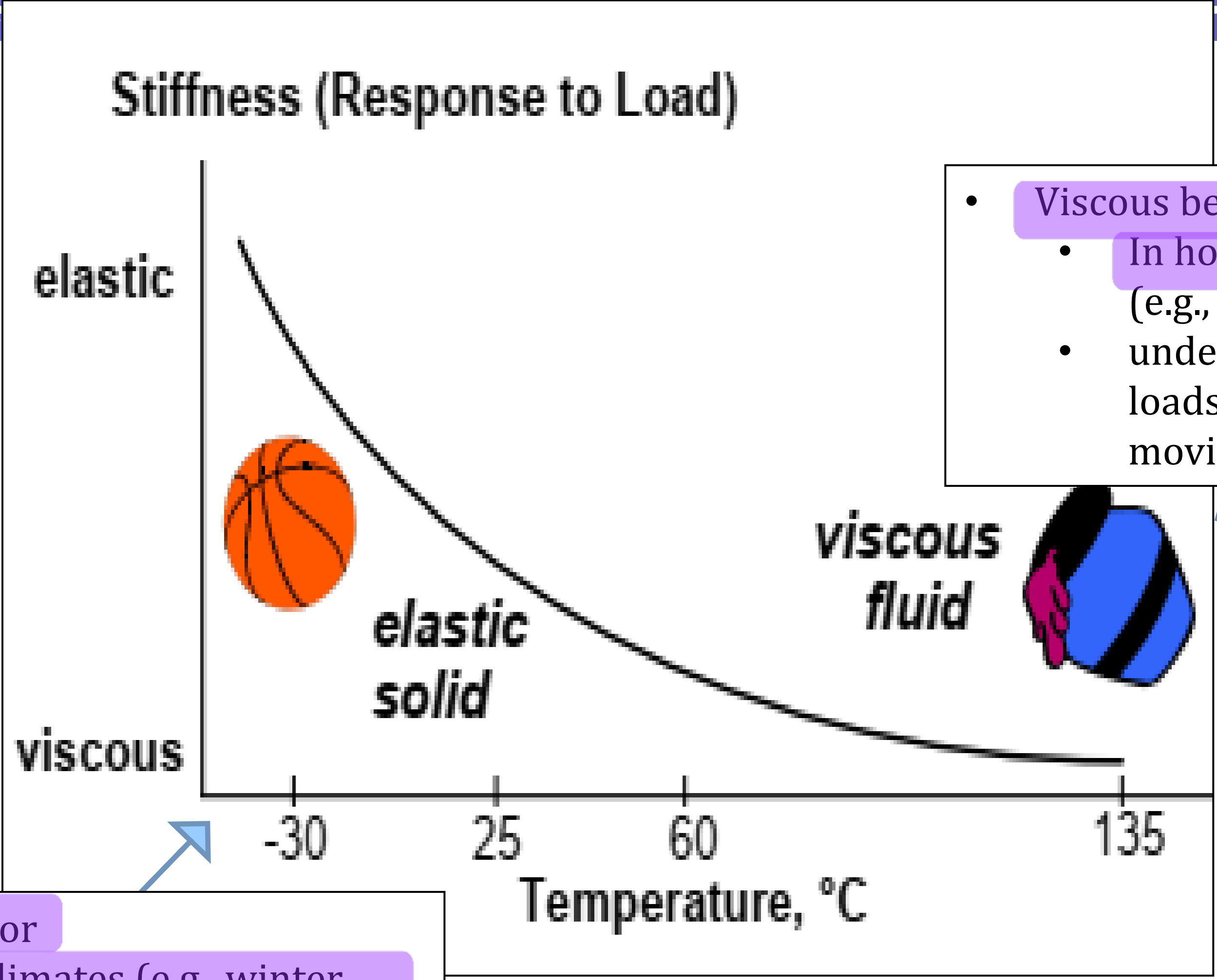
Have delayed response



How Asphalt Behaves/ Temperature Dependency



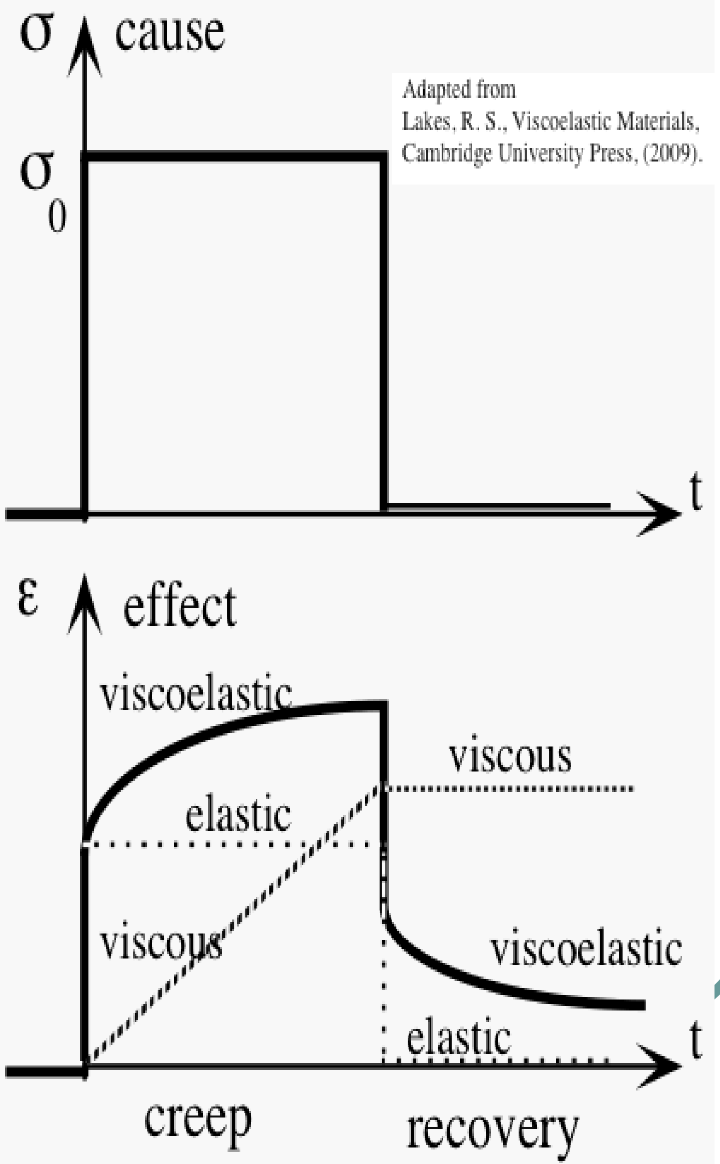
How Asphalt Behaves/ Temperature Dependency



- 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



Group	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 ?

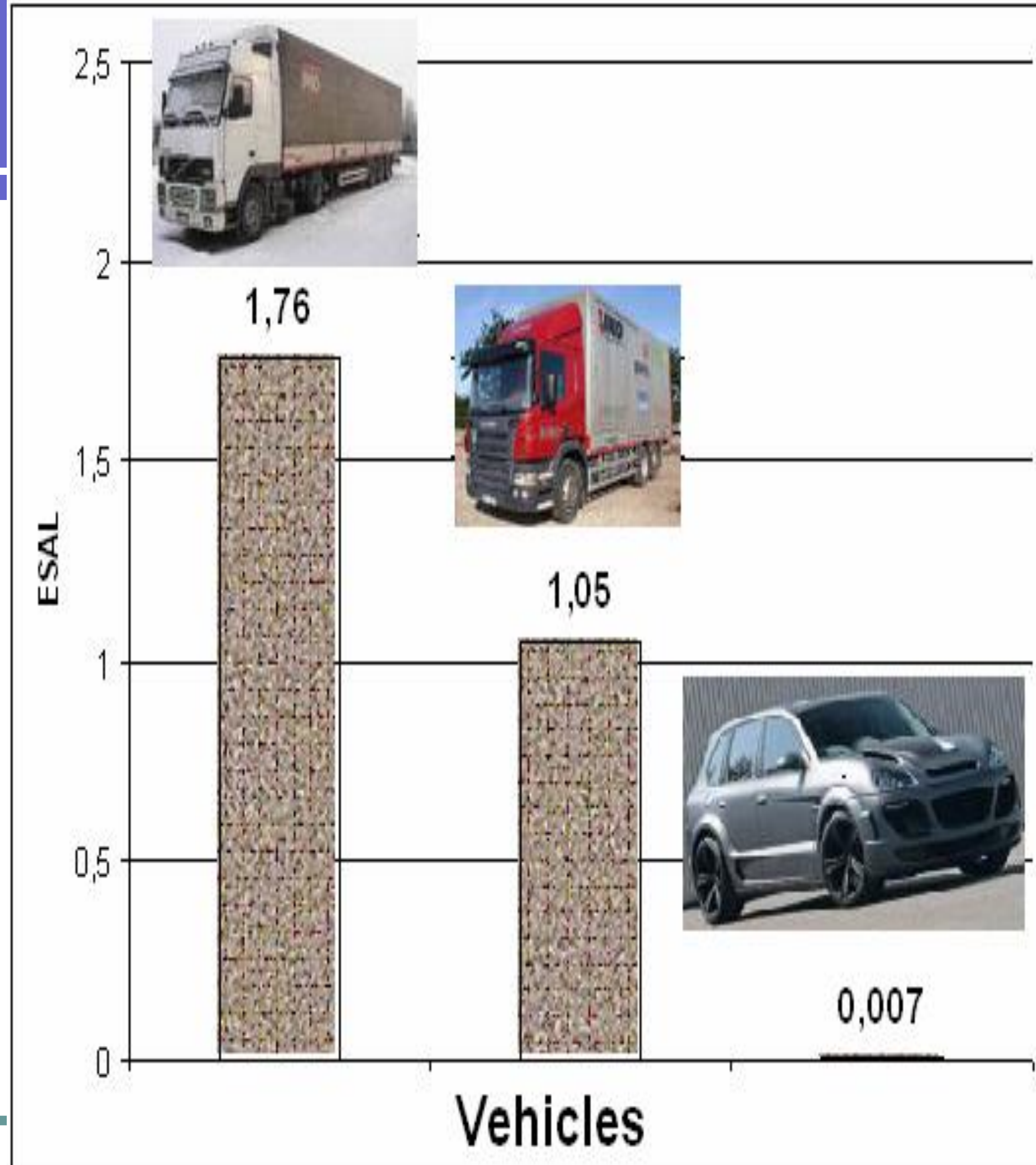
https://in.pinterest.com/pin/433541901607683832/

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

What do You think ?

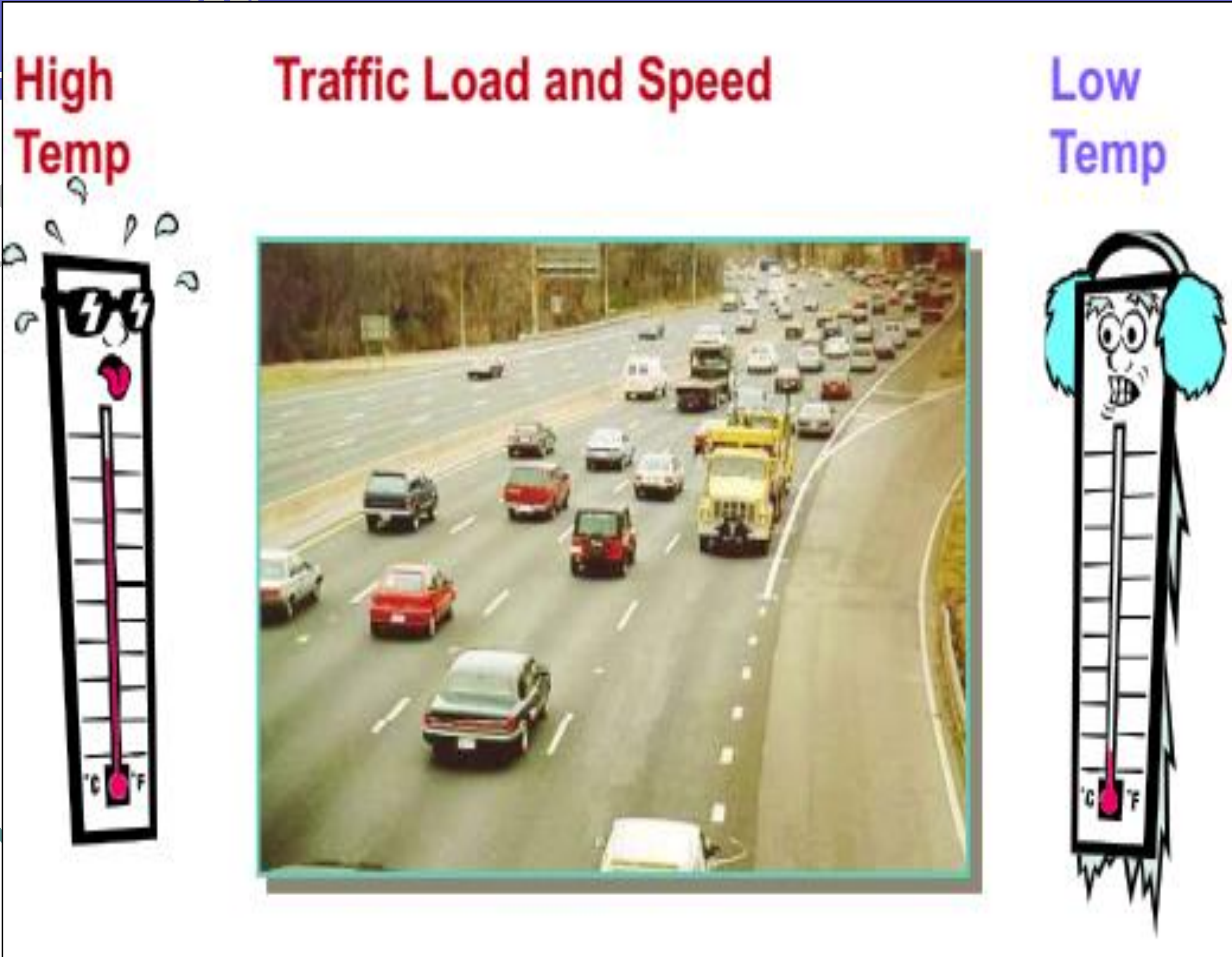
Image source https://www.behance.net/gallery/67086875/Iconic-Cars-Animated-GIF

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



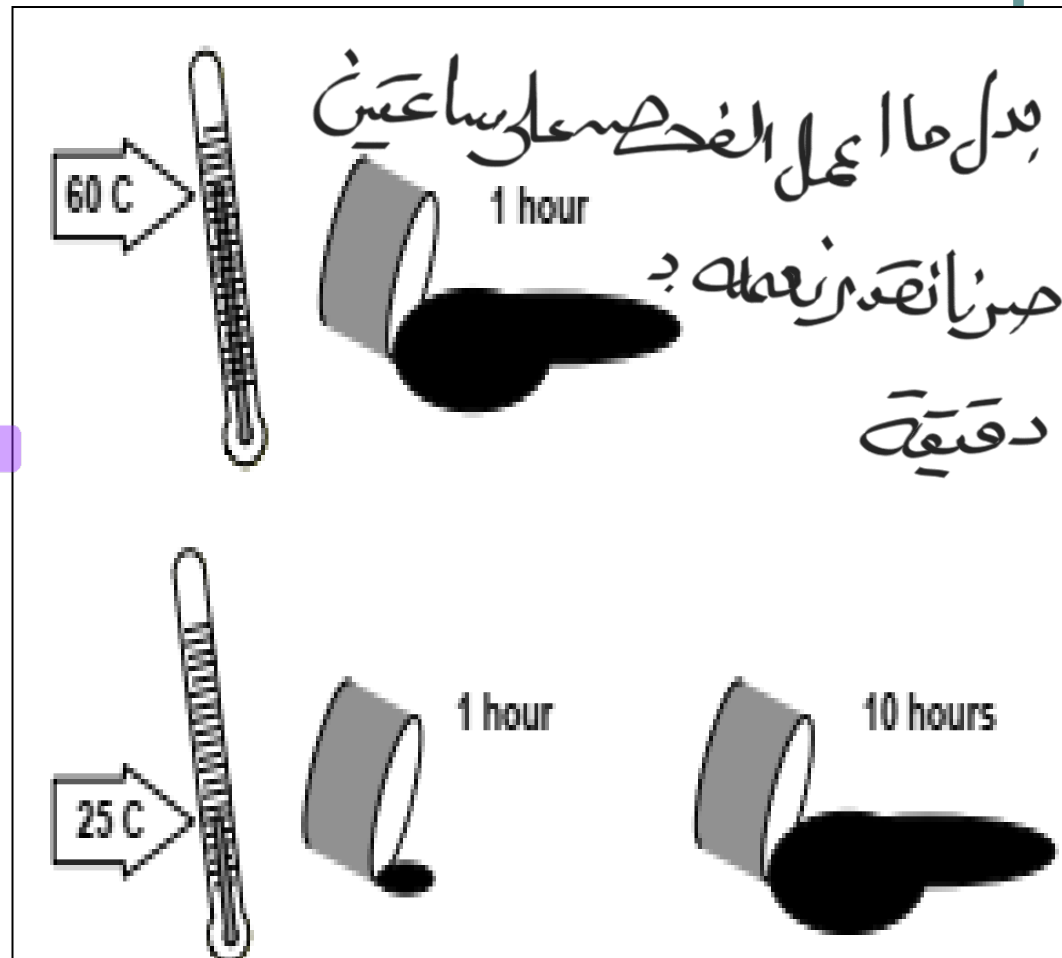
Haritonovs, Viktors & Smirnovs, Juris & Naudžuns, Juris. (2010). Prediction of Rutting Formation in Asphalt Concrete Pavement. Baltic Journal of Road and Bridge Engineering - BALT J ROAD BRIDGE ENG. 5. 38-42. 10.3846/bjrbe.2010.05.

What do You think ?

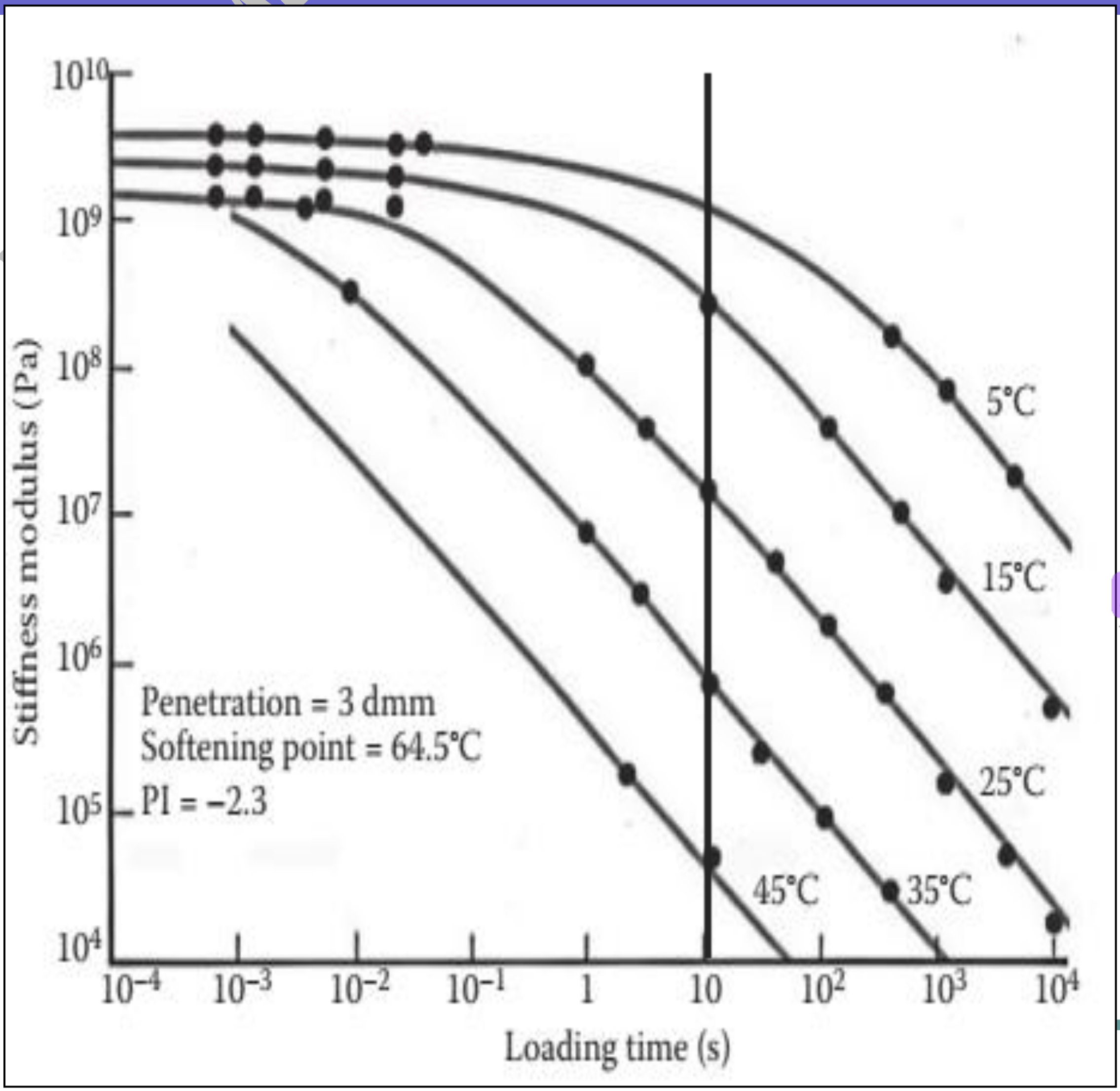


How Asphalt Behaves/ Time-Temperature shift (or superposition)

- 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



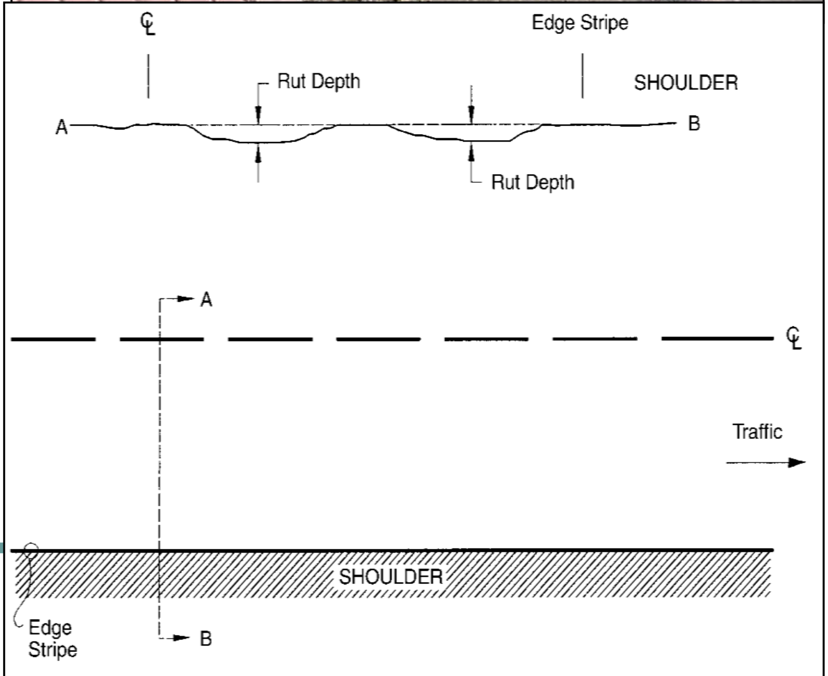
PI: penetration Index. The value of PI ranges from **around -3 for high temperature susceptible** bitumen to around +7 for highly blown low temperature susceptible (high PI) bitumen.

* العلاقة بين load و stif
عكسية

* علاقة بين حرارة و stif
عكسية

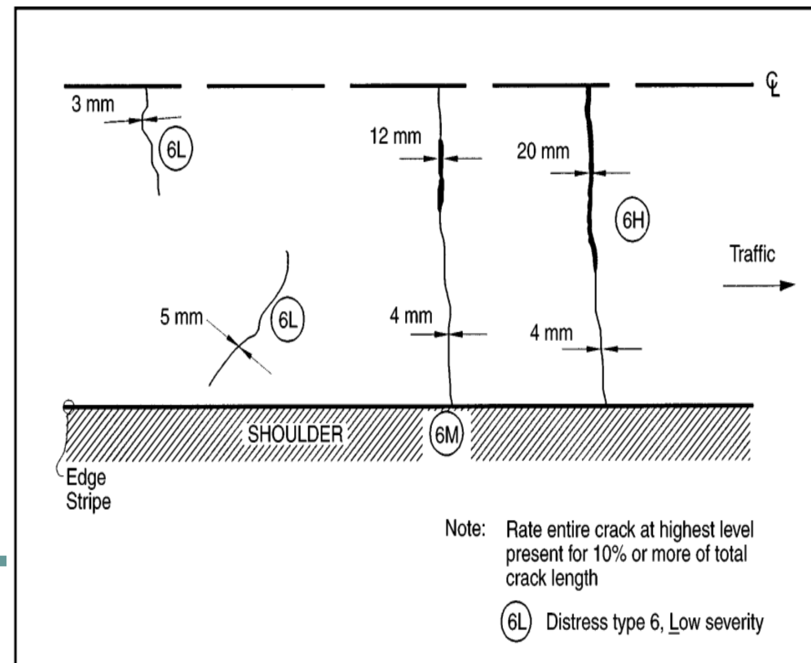
High Temperature Behavior

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



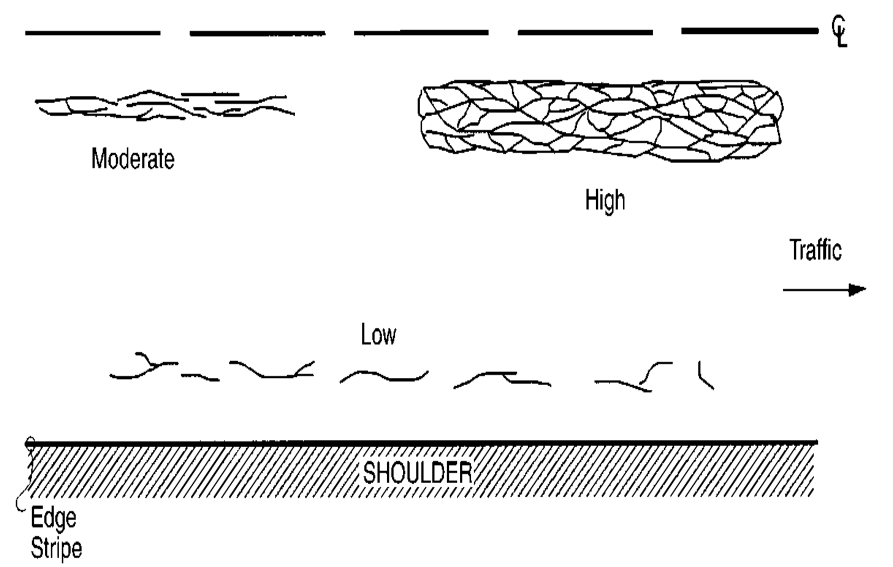
Low Temperature Behavior

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



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



Pavement Materials & Design (110401466/2104011466) Aggregates

2817

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.

Aggregates :- شكلها صخري ، محتواها معدني

* مكينا من تطبيقات agg انها موجودة بالطبقة السطحية الاسفلتية كونكريتية وبرضه يتواجد aggregate لحالة ب base و subbase وممكن تكون بال wearing وعمليات الردم

Aggregate Sources

مصادر الـ aggregate

موجودة بالطبيعة

- Natural deposits of sand and gravel.
- Pulverized concrete and asphalt (إعادة تدوير) pavements.

  ممكن نحصل تكسير الـ concrete القديم

- Crushed stone ناتج الكسارة
- Blast furnace slag

  → نوع من انواع المتبقي (خبث الحديد)

Aggregate processing

crushed stone حصى

- Excavations حفر
- Transportation نقل
- Crushing تكسير
- Sizing → نتيجة تكسير بصير عندي احجام (بطلع احجام مختلفة)
- Stockpiling → تشوين (الكومة)

Excavation

Excavation


CAT
320


CAT
320 L
CAT
12 3 '00


Transportation


1 5 '88


'99 2 1

Crushing

ملساء (أقرب للشكل بيضوي)

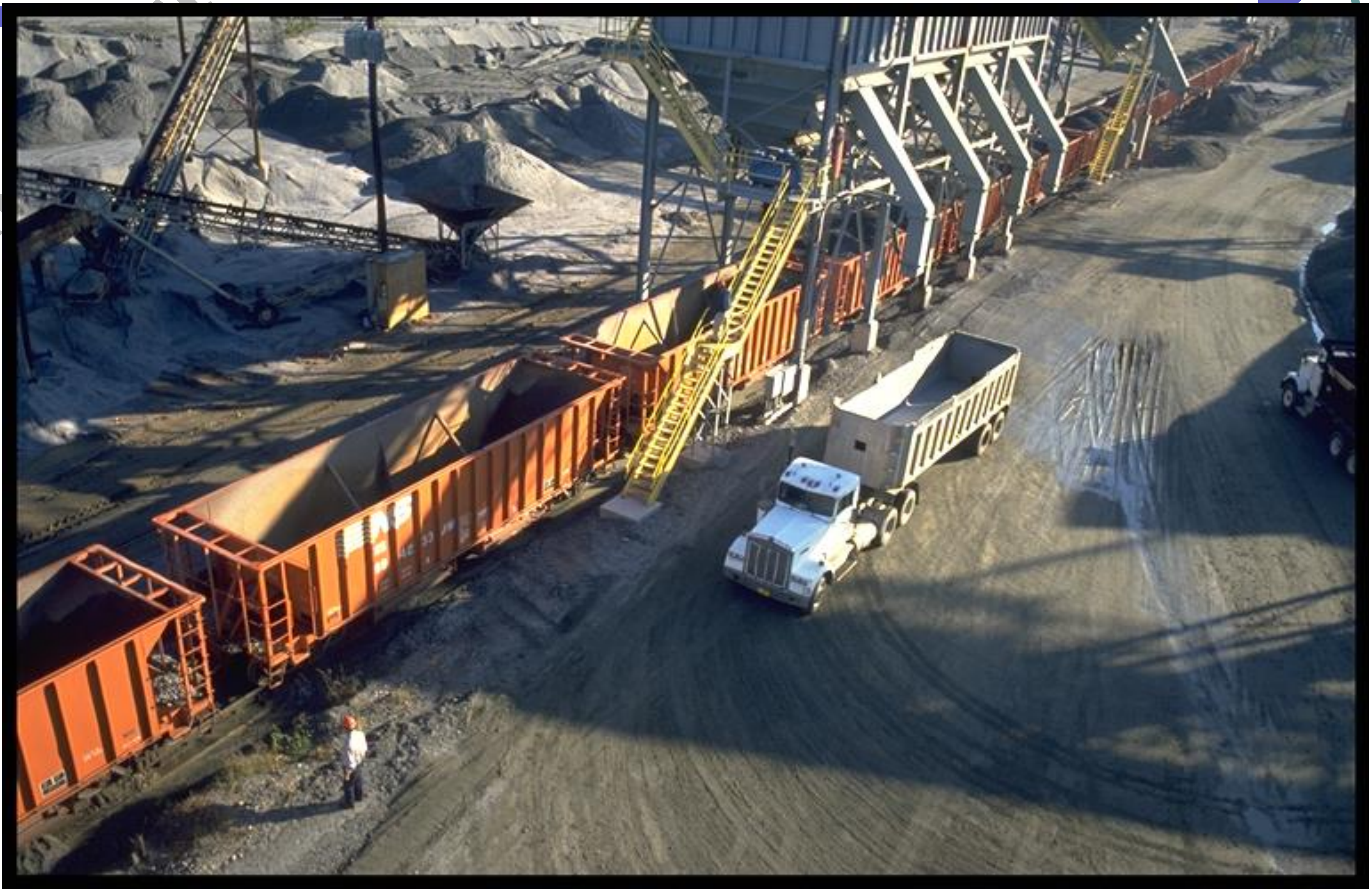
فيهم زوايا

Sizing


(ستوبل) stokebiling

Stockpiling

Moving for Usage




CAT
980G
'99 2 1

Properties of Aggregates

خصائص

1. Particle size and gradation.
2. Hardness or resistance to wear. فحص قساوة
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. خلوها من المواد الضارة

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..

* Gradation :- هو عبارة عن وجود أحجام مختلفة من agg بالخلطة الموجودة عندي

ال Gradation بأثر على الغالب بأغلب خصائص ال concrete

وعندي chart رح نستفيد منه بالعديد من معلومات

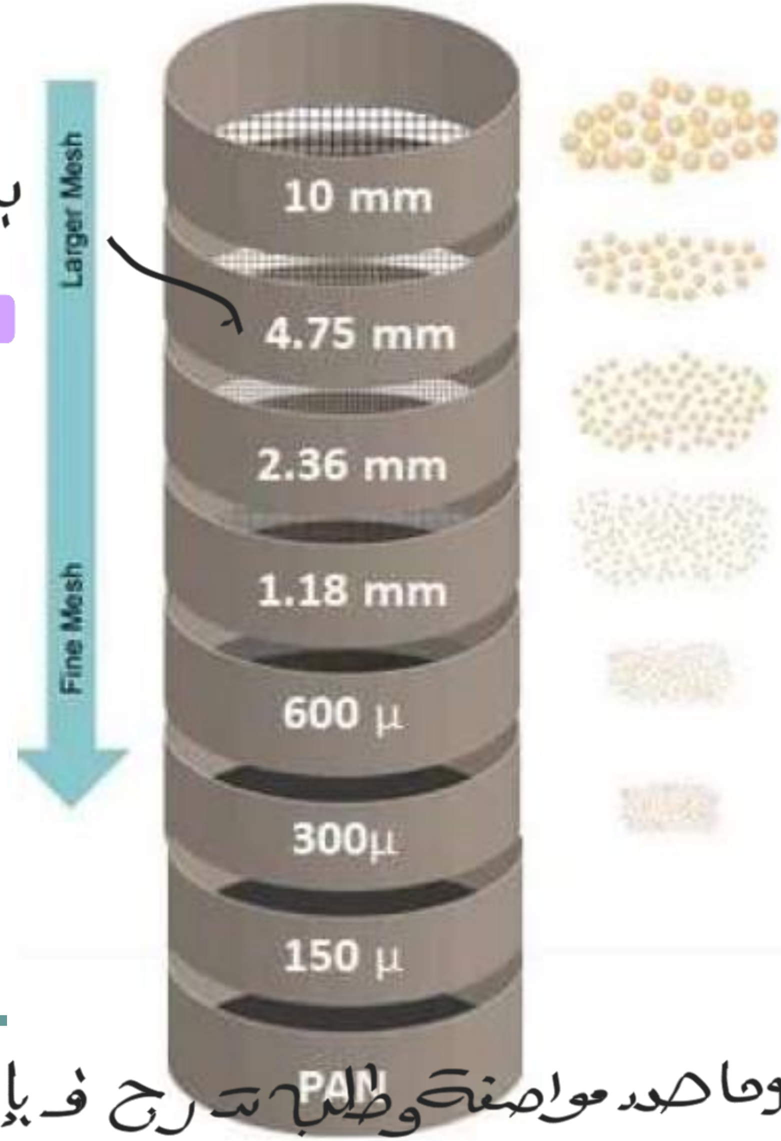
*مثلاً #4 يعني بالانش الطول الواحد عندي اربع فتحات

لتحويل mm إلى inch ← اقسم mm على 25

Mechanical Sieve

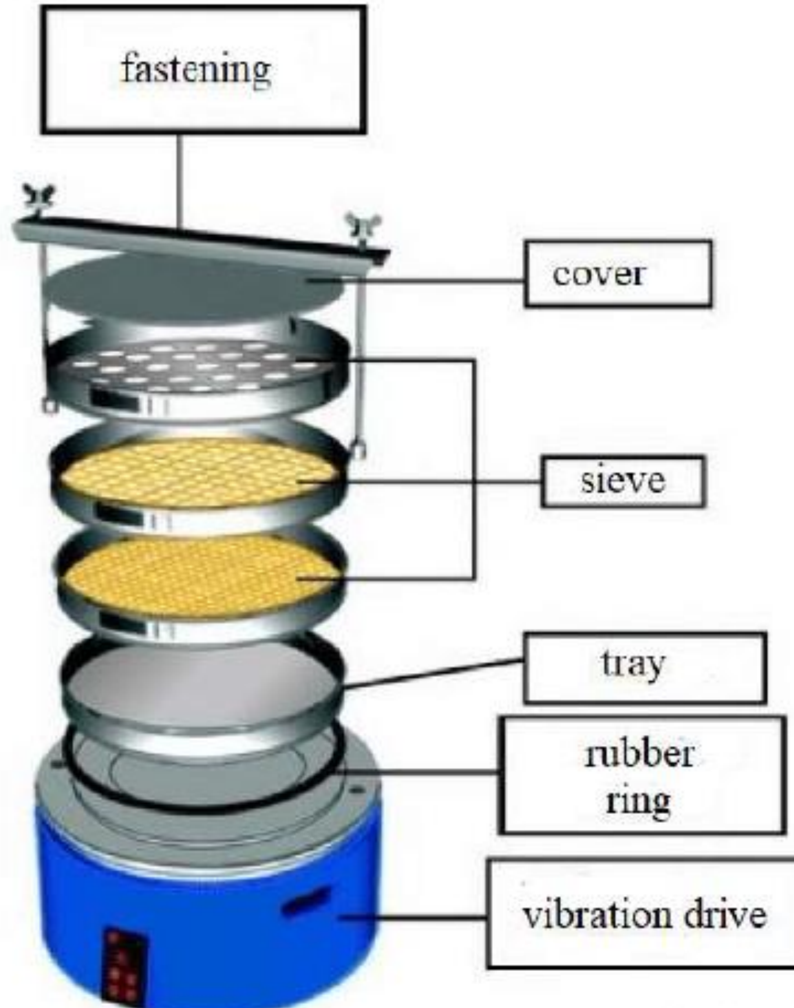
بنسمي #4

من الأكبر للأصغر



*لو واحد مواصفة وطلب تدرج ف بإمكانك توحد كل ما فاصل

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 تصنيف محلياً

العدسية

الفولية

الجوزية

رمل

الناعمة (السمسية)

الحمصية

لهم نفس حجم تقريباً

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

uniform (single)

60%

40%

two size

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.

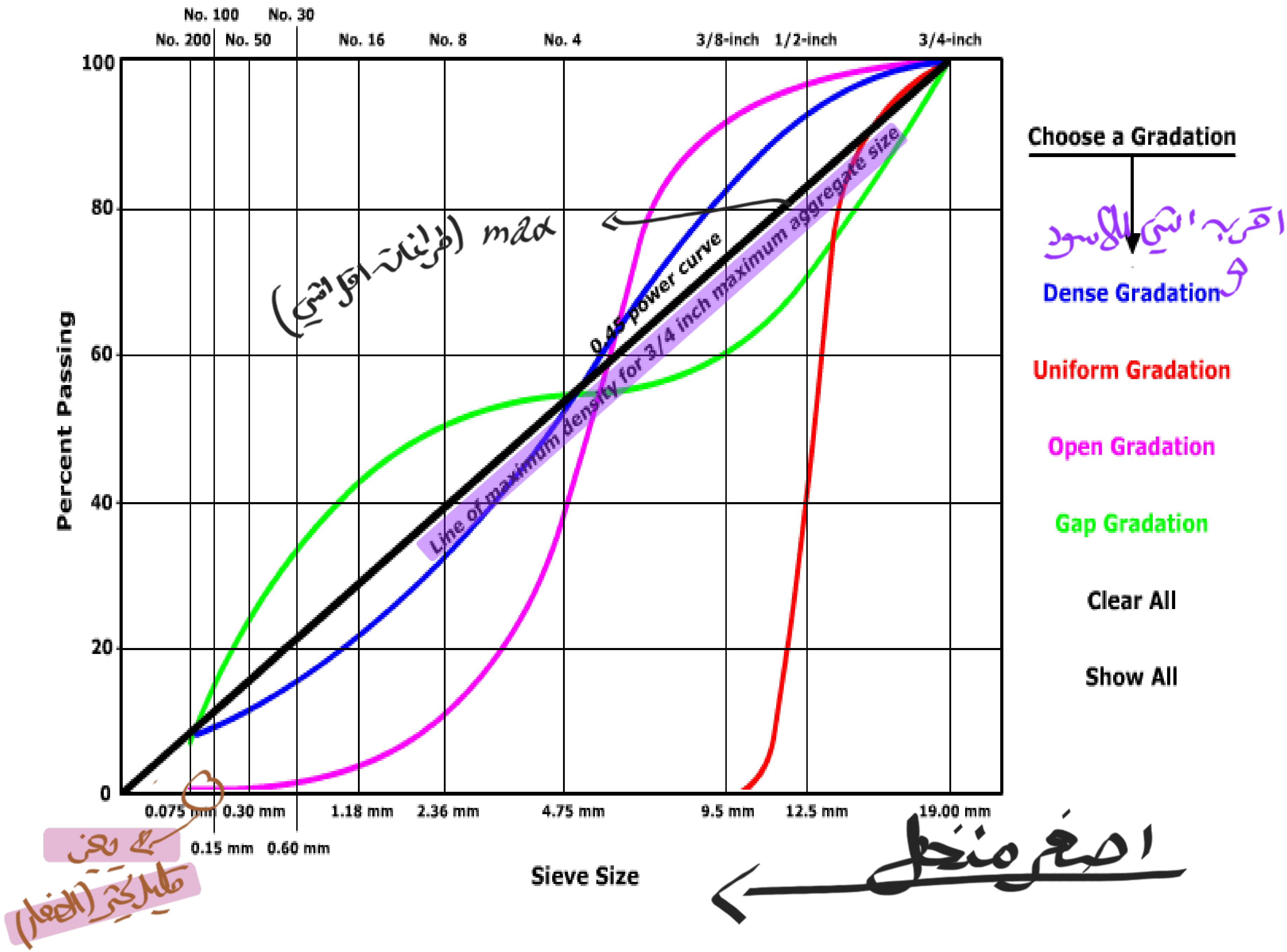
Dense : الأكثر استخداما بالخلطات الاسفلتية الساخنة لانه بحطينه density عالية

Gap : بالرسم بكون بالنص في مستقيم (احجام الوسطى غير موجودة)

Open : كمية المواد الناعمة قليلة فبكون flat بالرسم عند الاحجام الصغيرة [فراغاتا مفتوحة]

Uniformly : مثلاً زي الفولية فهي لحالها بتكون مع نوع uniformly

* تدرج بكون مناسب إذا كان موازي الخط الاسود
لانه بحاجة يكون عندي شوية فراغات



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

Dense هو اقرب اشي للخط Bad الأسود وبكون بينه
two sizes

Uniform معناه يكون بالـ Fine بالرسمة عنا موجود
ال uniform Coarse وهو محصور بين two sizes
:: على الغالب المحصور بين 2-3 sizes بكون uniform

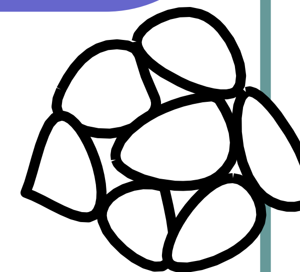
Open (مشروح على جدول ب اللون البني) توضيح موضوعه

Flat :- هو يعني الماتيريال بعاد السايز المعين صغار ومتكتلة
يكونوا عددهم قليل (بكون بعاد يحلة ميلان خفيف)

:: بالرسمة بوضح انه size الصغيرة ماعنا منها وهاد مهم
(الـ Very الصغيرة بتجي فرتمات فراح تكون فراغات مفتوحة)

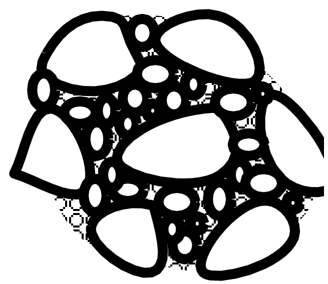
Gap الوسط عنده ميلان خفيف مشكلته هي
segregation انه هو اصلاً مفصول

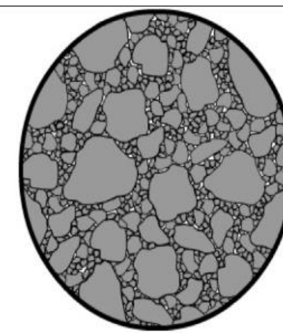
Types of Gradations



* Uniformly graded

- Few points of contact → ارتباطهم قليل و
- Poor interlock (shape dependent) ← يعتمد على شكل — تشابك قليل
- High permeability ← نفاذية عالية



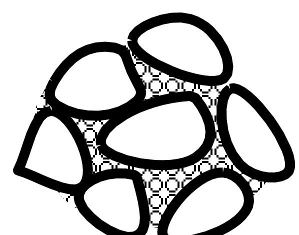


* Dense or Well graded

- Good interlock
- Low permeability

* Gap graded → ناعم والحجم الكبير

- Only limited sizes
- Good interlock
- Low permeability



Sieve Analysis Example

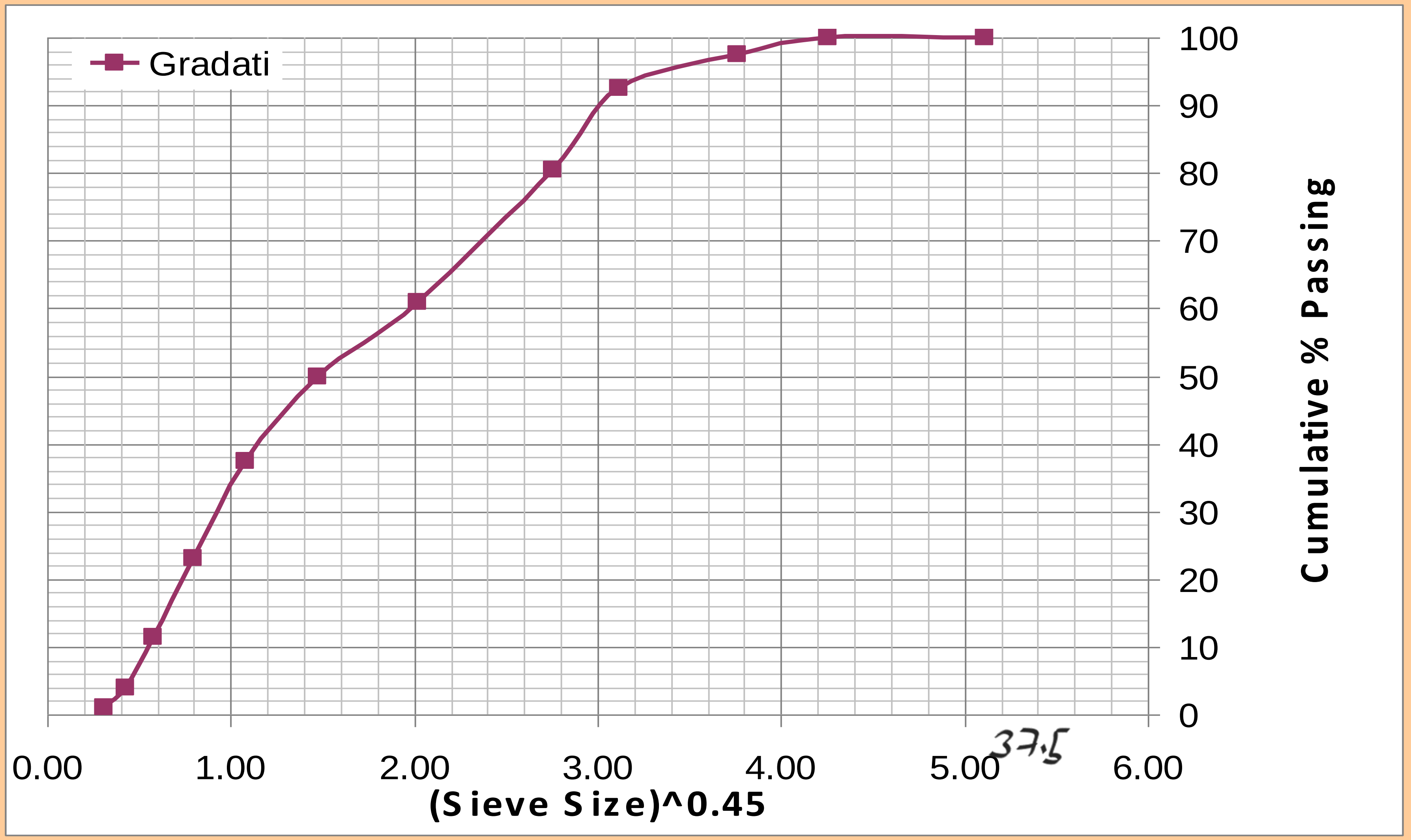
Sieve No.	Sieve Size	Wt. Retained (g)	% Retained	Cumulative % Retained	Cum. % Passing
inch	mm		(wt. ret./ Total) 100%	Sum % Retained	100 - Cum. Ret.
1.5"	37.5	0	0	0	100
1"	25	0	0	0	100
3/4"	19	25	2.5	2.5	97.5
1/2"	12.5	50	5	7.5	92.5
3/8"	9.5	120	12	19.5	80.5
# 4	4.75	195	19.5	39	61
# 8	2.36	110	11	50	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

* إذا بتوضح بالانشات فلازم #4 يتوصل لانش

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

هون طلع جمع بعدها عمل النسبة

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			

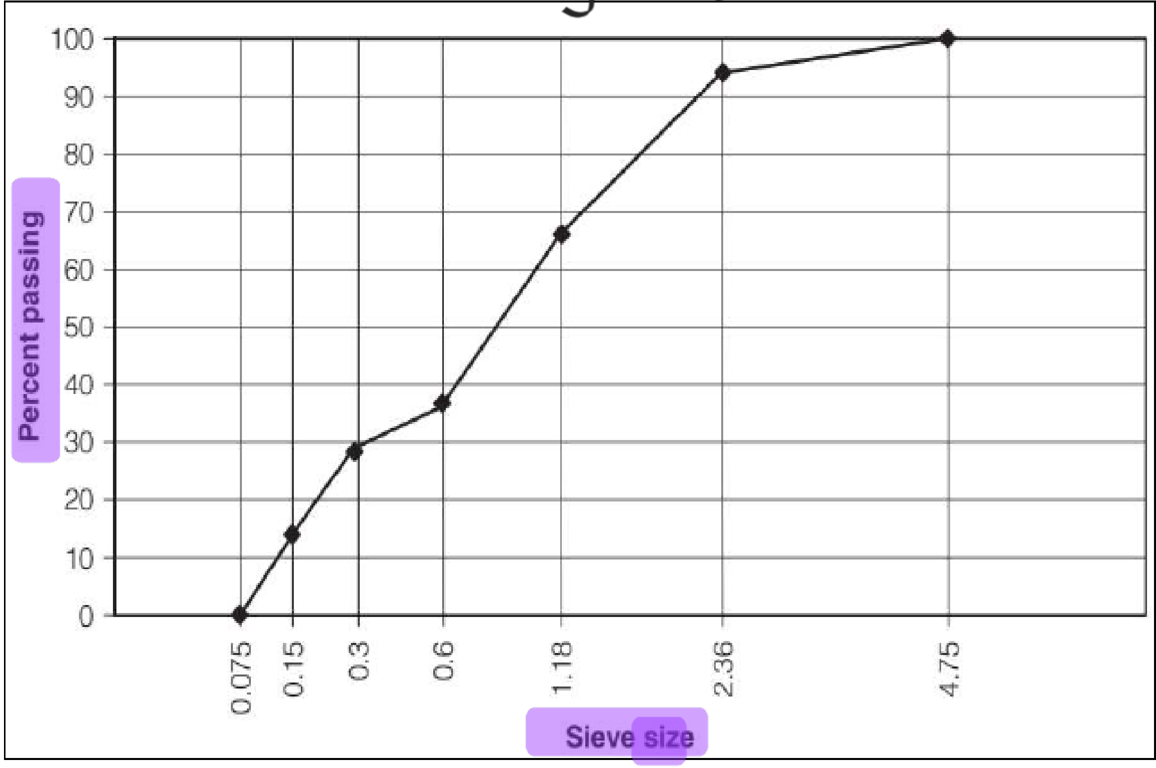
$\frac{33.2}{510.9} * 100$

Sieve Analysis Example 2

Draw a 0.45 power gradation chart

* المواصفات ذكرت انه محور x بكون إما log(size) أو $size^{0.45}$

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



لما نحطها على محور بدنا نكون
عارفين انها هي نفسها 4.75

Maximum & Nominal Max. Agg. Size

Maximum Aggregate Size

- Two parameters are used to represent the maximum aggregate size

1. *Nominal Maximum Aggregate Size (NMAS)* → اصغر منخل باك 90
   - 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* → اصغر منخل بمرر 100%
   - 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

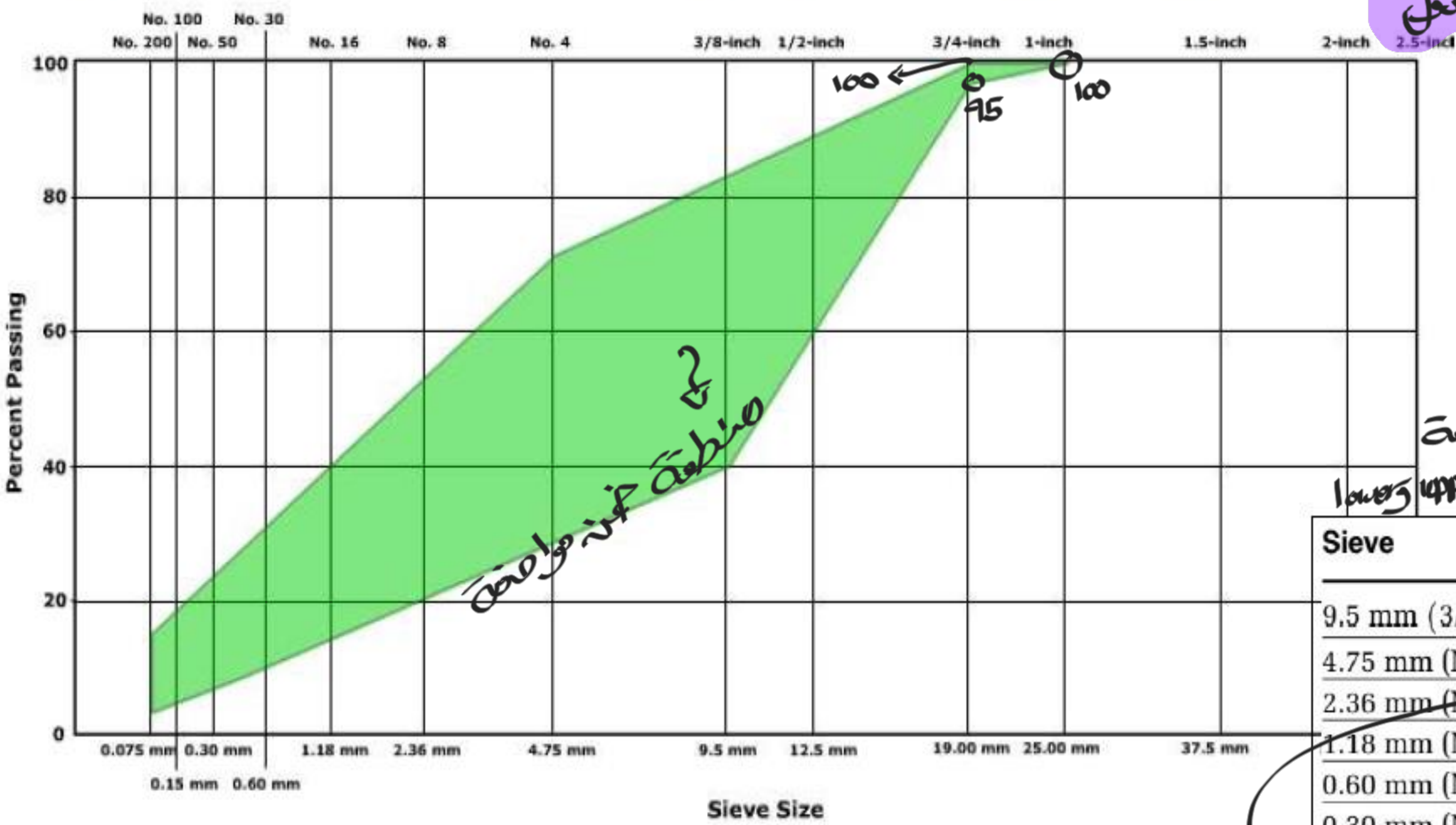
Gradation specifications (limits)

- 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

* المواصفات بتعطي رينج Lower و upper

* بس يكون معك الشرح ورسمته ورسمة

معه المواصفة بنقدر نحكم إذا ضمن المواصفة

* المنطقة المحصورة بين خطي المواصفات

هي Area المقبولة

شرح رسمة الأولى :- لا يقعوا ضمن المواصفة

(خطين خارج مساحة المواصفة) مجرد ما طلع خط

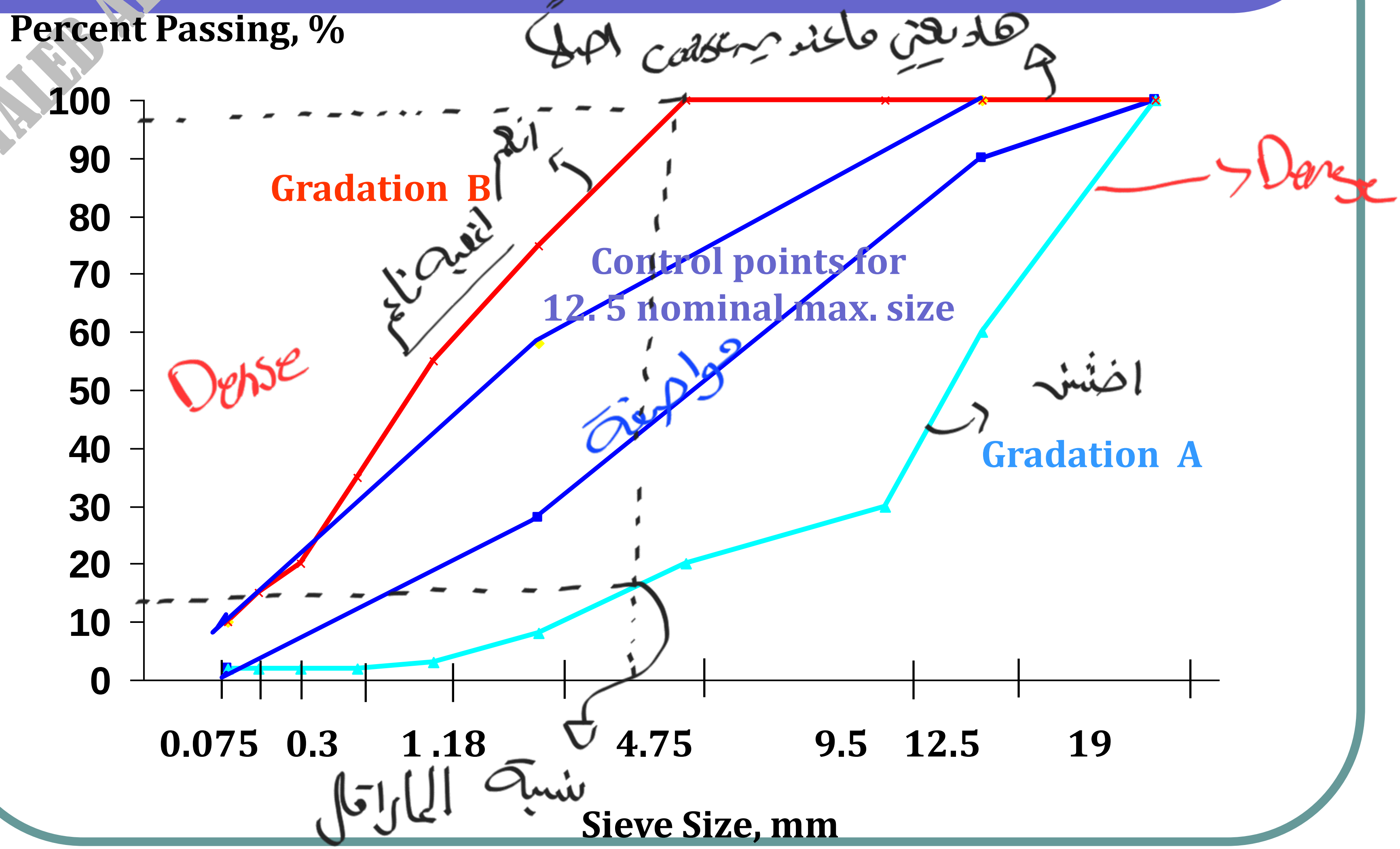
خارج منطقة :: يكون مش ضمن المواصفة ، لازم

الاثنين يكونوا ضمن المواصفة

A أخشن من B بحيث كلما تحركنا هيك ⟵

يكون أخشن

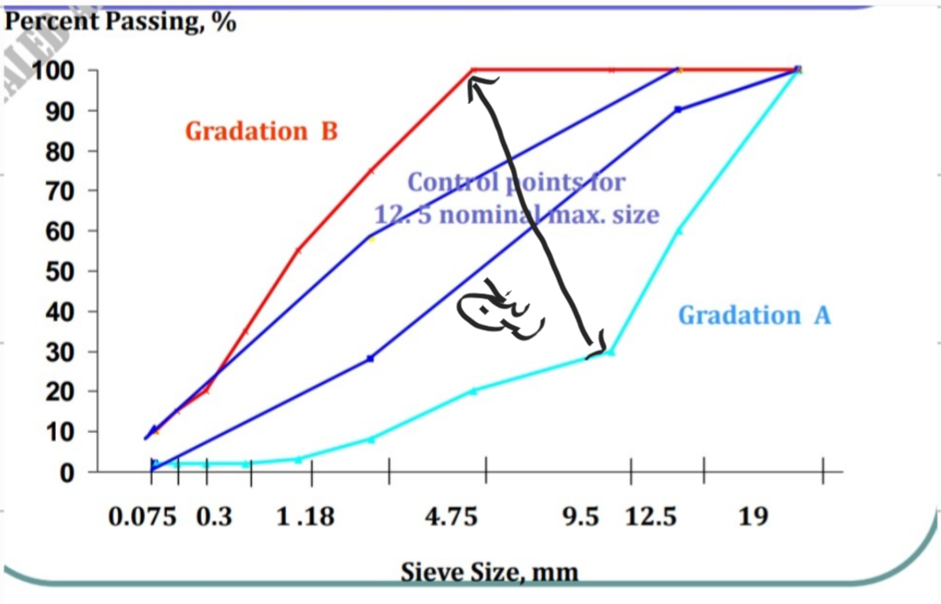
All possible combinations fall between A and B



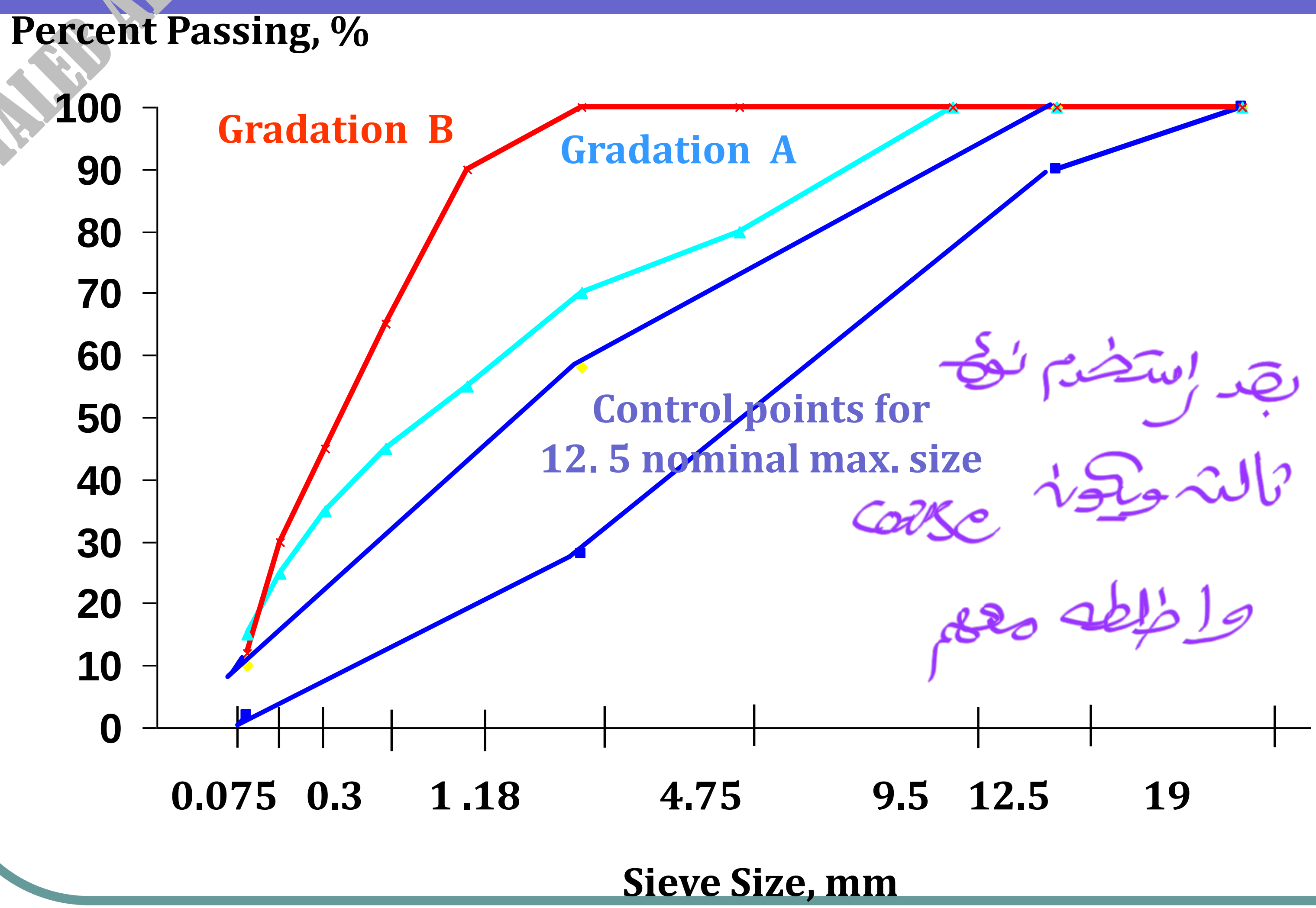
مجرد ما رسمت chart بطلع منه معلومات :

1) بحدد اذا ضمن مواصفة
2) احدد إذا coarse او Fine
3) بقدر اعرف نوع التدرج

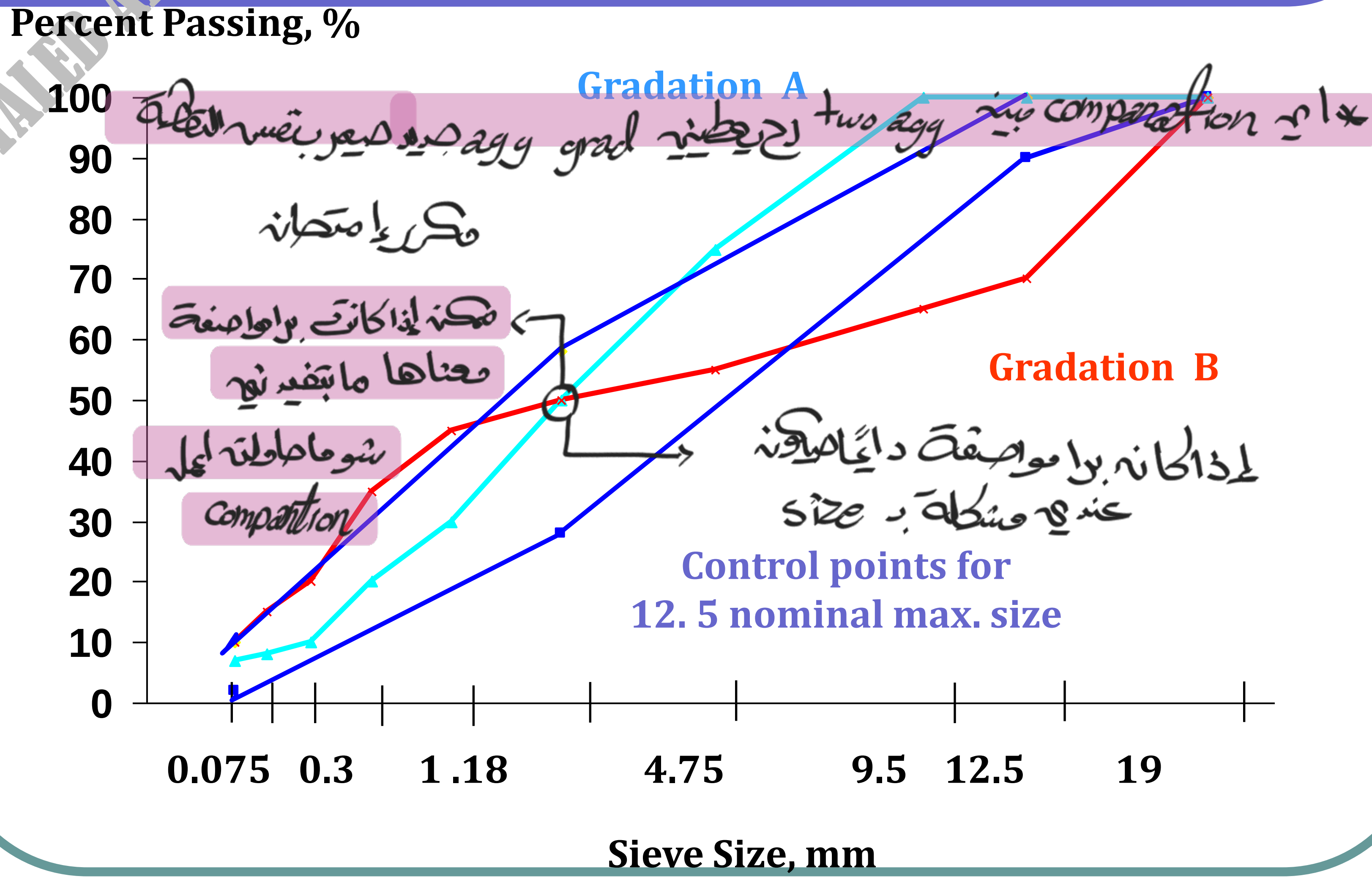
* ممكن من الرسمة الاولى نخلي ضمن المواصفة من خلال خلطهم بحال كان تدرج واحد يمين وواحد شمال فممكن يزبط يجي بالنص



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



* متوقع سؤال على الجدول السابق

* ١ حضار مسطرة

* الامتحان خيارات متعدد + سؤال رسم وسؤال حل

نهاية مادة الفيرست //

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

1- لما نفرد اسفلت على السطح بندمجها وضعها base course

2- سيارات لما تمشي عليه بصير فيه تآكل ب agg

3- وكمان اجزاء داخل المادة نفسها بكون بينها احتكاك

ولذلك لازم نضمن تآكل بصير اقل ما يمكن ويكون hard ذريح

نستخدم فحص LA

بتجربة LA رح نلاحظ تكسر العينات نتيجة impact and wear

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

impact and wear

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

Durability & Resistance to Weathering (Soundness Test)

فحص الأصالة

Coarse عينة

- Soundness Test AASHTO T104, (ASTM C88 / C88M - 18 Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate) مدة الاختبار 5 ايام
- Measures the resistance of aggregate to disintegration in a saturated solution of sodium or magnesium sulfate (Na_2SO_4, $MgSO_4$). نحطها بمحلول
- 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

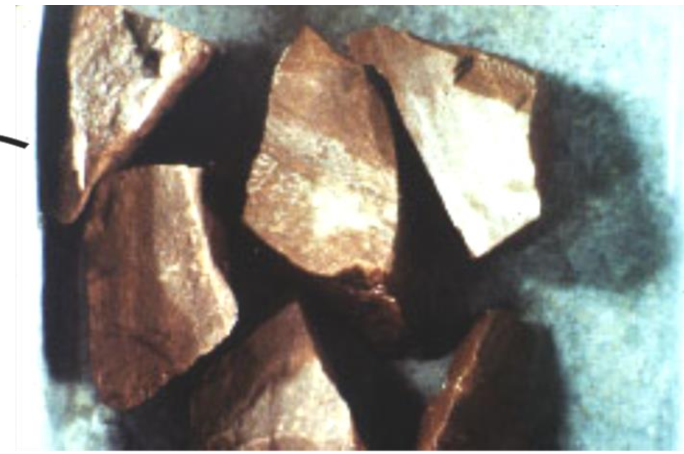
كل ما زادت القيمة كانت اسوء

Soundness Test

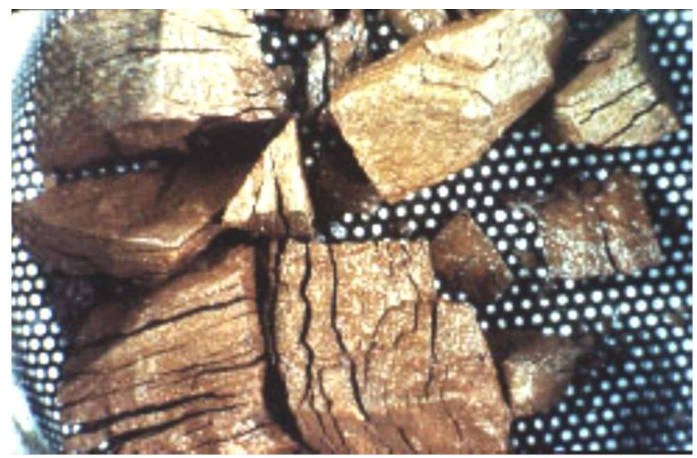
بنحطه 24 ساعة

بتغسله وبتنشفه
وترجعه للمحلول

Before



After



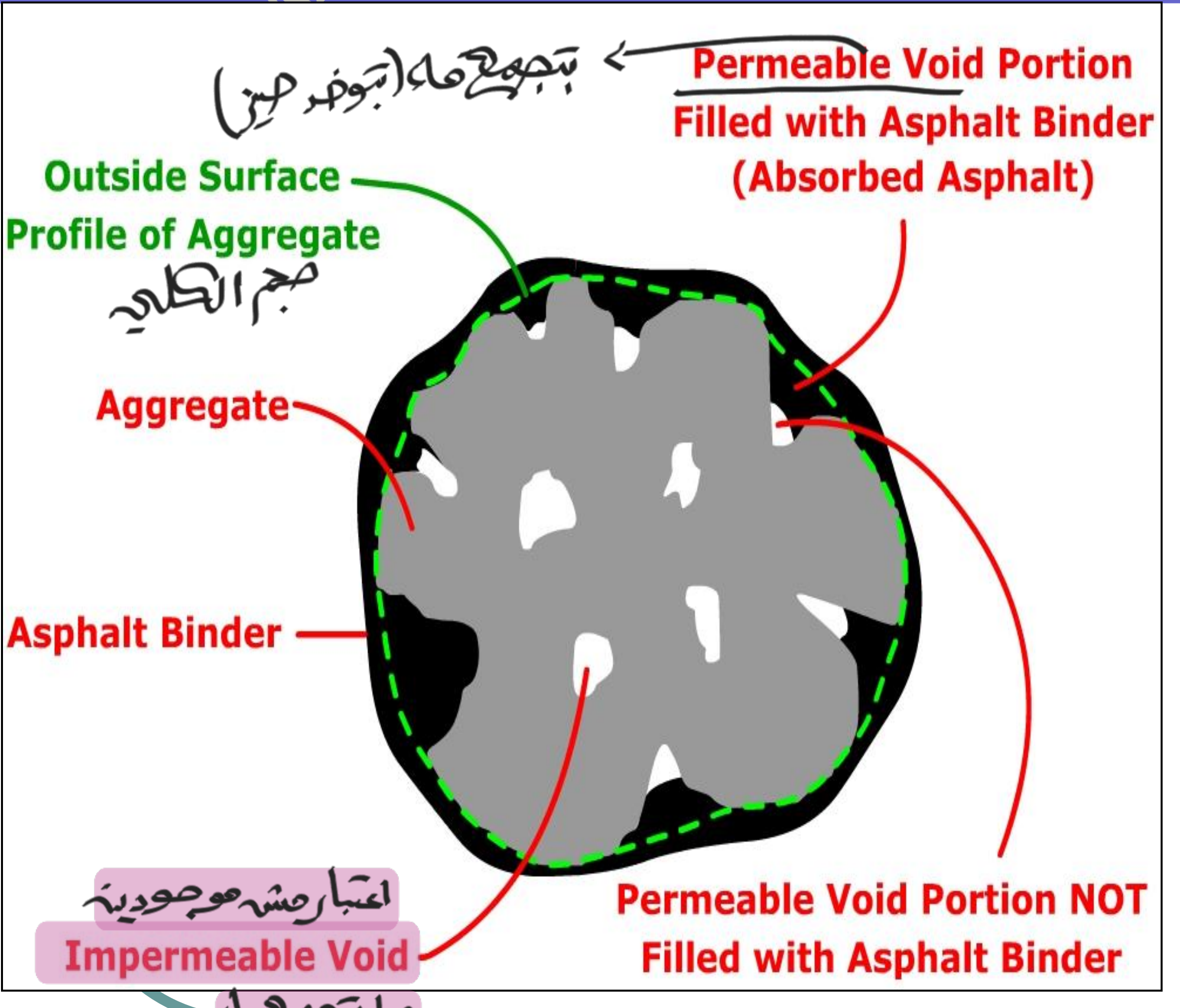
Specific Gravity & Absorption

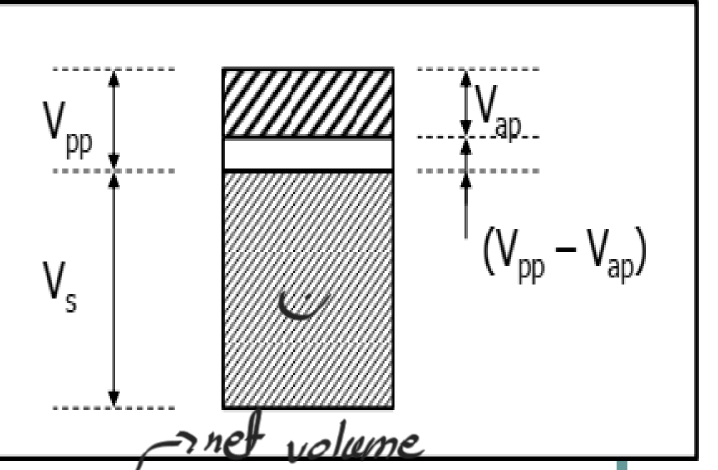
الأهم

وزن حجم معين مادة / وزن نفس حجم ماء

- 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}) net volume (مش حاسبين حساب فراغات فيها)
  - 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*

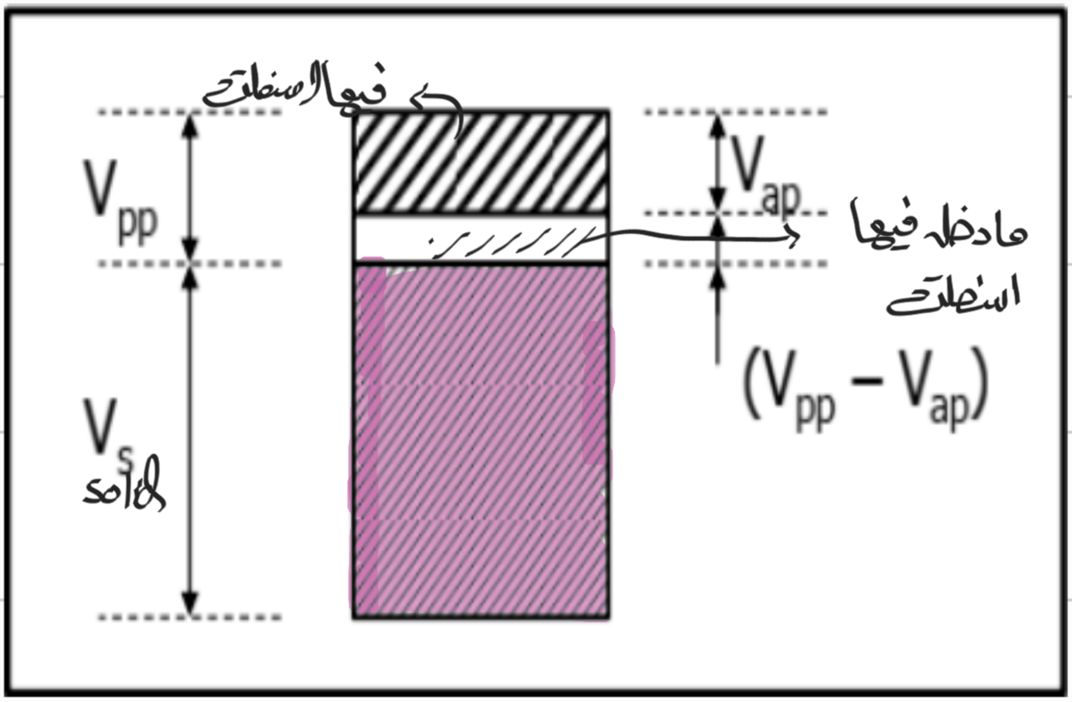
مبدأياً رح نحكي انه عندي مجسم :- 1 حجم كامل مع فراغات

2 رح نشيل فراغات فيها بصير عندي volume of soild

رح يدخل فيها اسفلت

3 وفي عندي مناطق صغيرة ما وصلها اسفلت داخل فراغات هاي

بتعطيني حجم 3



صار عندي ::

1 $V_{pp} + V_s$ → bulk volume (الأكبر)

2 V_s → net volume (الأصغر حجم)

حجم صلب منه غير فراغات

3 $V_s + (V_{pp} - V_{ap})$ → effective volume

* إذا تعريفي في bulk معناها رح نسميه S.G
→ Bulk specific gravity

* وإذا رح توضح net رح يكون Apparent specific gravity

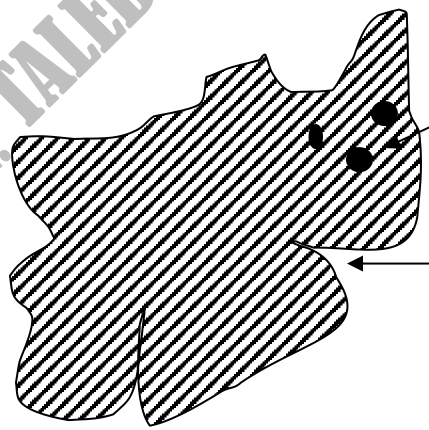
* وإذا effective بدو يكون Effective specific gravity

∴ عشان هيك صار عندي احجام مختلفة فصار عندي S.G مختلفين وسببه الاختلاف الفراغات

← بالامتحان ممكن يجيب داتا جاهزة ويطلب S.G او ممكن يعطي معلومات عن volume Bulk وهكذا

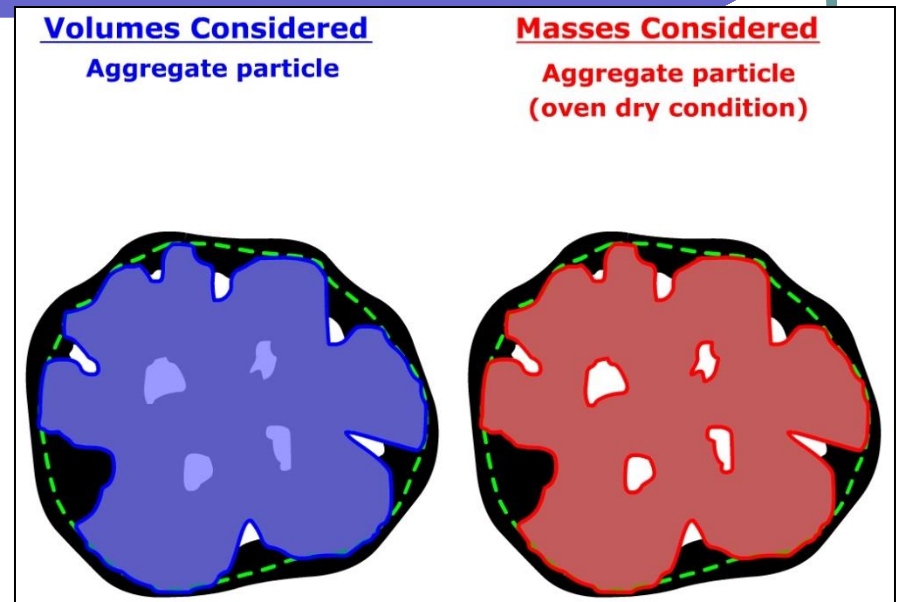
Apparent Specific Gravity (G_{sa})

Computed based on net volume of the aggregates



impermeable voids (ip)

permeable voids (pp)



net volume

$$G_{sa} = \frac{W_s}{(V_s + \text{[redacted]})\gamma_w}$$

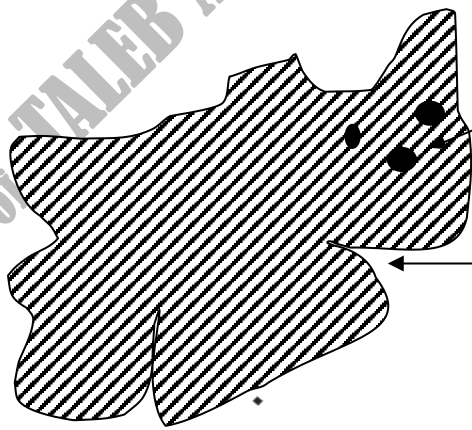
Corse — Fine

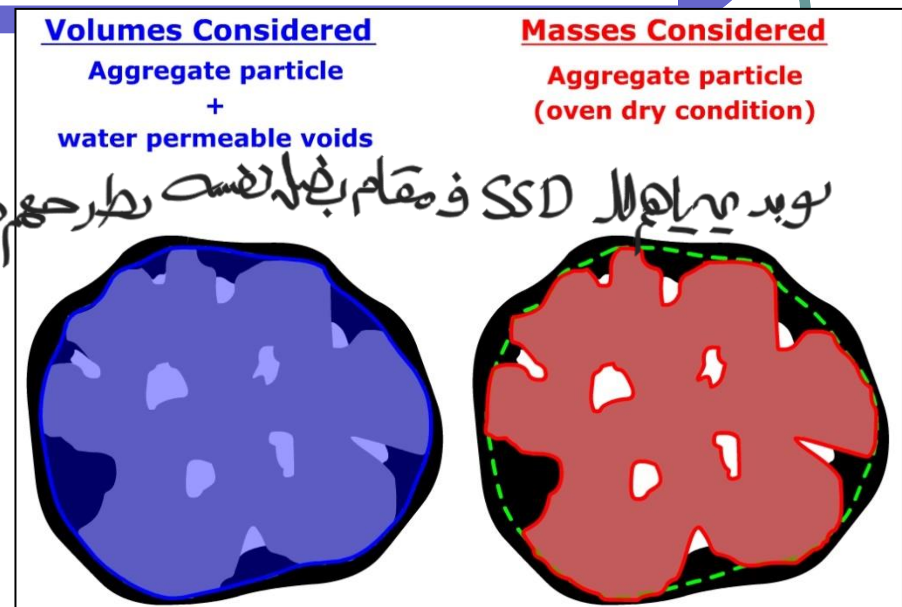
$$G_{sa} = \frac{W_s}{W_s - W_{sub}} = \frac{W_s}{W_{pyc+w1} + W_s - W_{pyc+agg+w2}}$$

A / (A" − C") ; A / (B" + A" − C")

Bulk Specific Gravity (G_{sb})

Computed based on total volume of the aggregates





$$G_{sb} = \frac{W_s}{(V_s + \text{[redacted]} + V_{pp})\gamma_w}$$

Corse / Fine

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

B − C

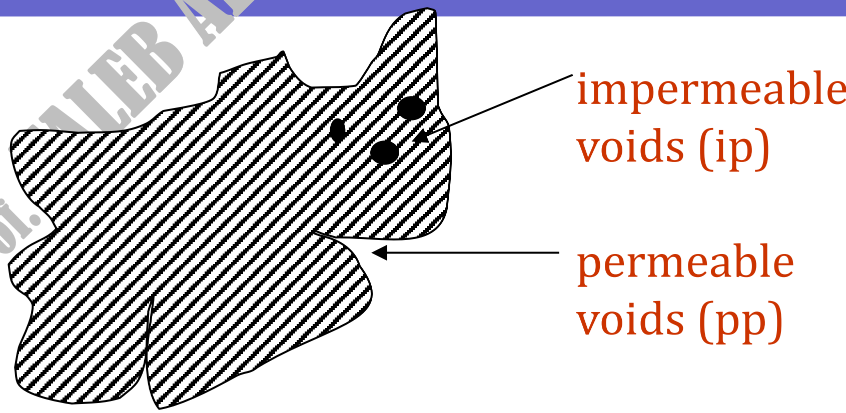
B + D − C

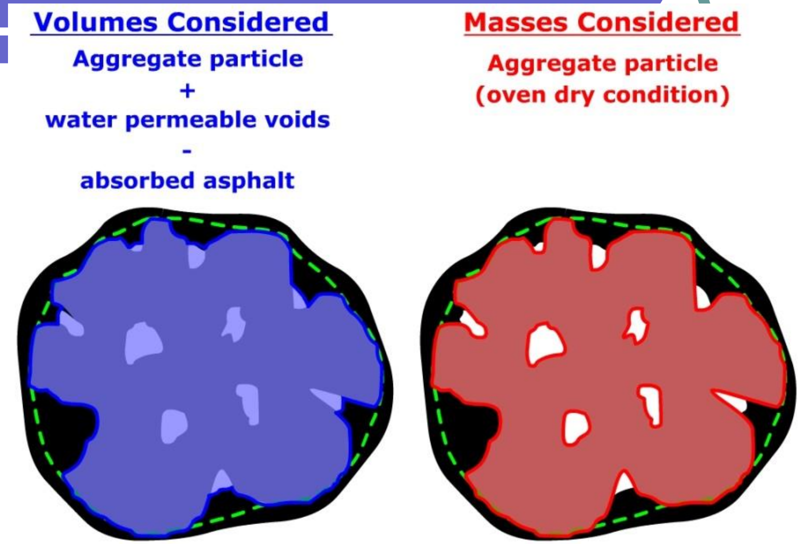
Effective Specific Gravity (G_{se})

- 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.





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

غير مطلوب

Calculated from mixture information

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

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. → حتى اضمن انه الماء دخل
- 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) ← وزنه اخف → مغمور بالماء
- 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

$$G_{sa} = \frac{A}{A-C}$$ → Apparent

$$G_{sb} = \frac{A}{B-C}$$ → bulk S.G ovendry

$$G_{s,SSD} = \frac{B}{B-C}$$ → Bulk S.G SSD

الامتصاص

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

(SSD − oven)/oven

← مابنفع نقارن oven مع SSD من ناحية مين

أكبر ولكن لو مثلاً قارنت بين Apparent و

bulk Gsb فالأكبر هي Gsa لأنه مقام أقل العا

[Net Volume أقل]

الامتصاص هو الزيادة في وزن المادة بسبب انه فراغات امتلأت

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

امتصاصه عالي غير مرغوب

- 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.

رينج

- The water absorption rate is calculated by the following equation as outlined in AASHTO T 85

(SSD-oven) /oven

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

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

نسبة امتصاص ماء فرضًا 2٪ في الاسفلت كم؟ الا معقولة

Absorption for Aggregate Blend

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

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

نسبة agg * Absorption الخاصة به

- 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

4/8

تأثير على الرابطة معالجة بعض مواد

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

Love — انسلاخ بتعمله — تضعف الرابطة

- Hydrauphilic Agg.: Water-loving such as gravels and silicates (acidic) have a negative surface charge (show reduce strength).
- Gravels may tend to create a weaker interfacial zone in concrete than lime-stone aggregates.
- Surface coating (dust of clay, silt, gypsum) tend to reduce bond strength.
- Immersion stripping test

نجيب خلطة اسفلتية ونسخنه إذا شفنا في انسلاخ معناها في stripping

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:

  زيادة الحجم نتيجة زيادة الرطوبة

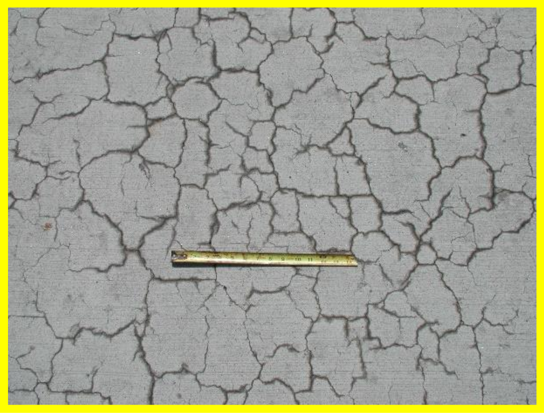
  - Source of alkali - Internal and external
  - Reactive silica (aggregate)
  - Water (humidity) > 80 %
- ASR results in formation of expansive gels which produce internal stresses which may cause cracking of concrete.

  تطور عملية التشقق (سريع)
- Environmental factors such as freeze-thaw cycles, wetting/drying cycles, and traffic loading propagate cracking.

  املاح اجواء بحرية
- Deicing salts, marine environments, can accelerate ASR expansion and deterioration processes. ASR can accelerate corrosion deterioration

ASR Cont.

[Rigid]



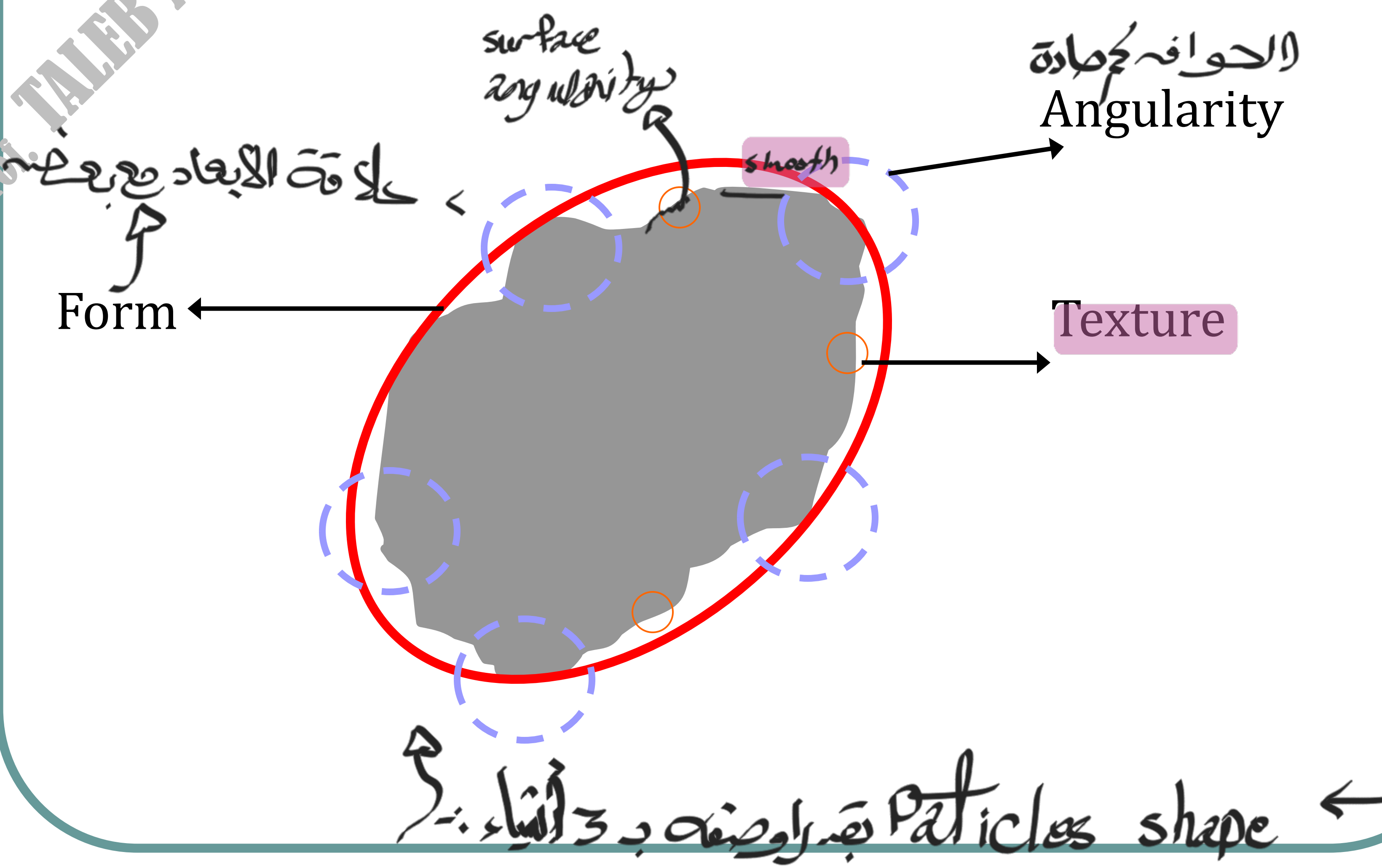
Aggregate Shape & Surface Texture

- 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

شرح التجربة ☆

بتكون عينة صغيرة من Fine ولازم تكون عاملة S.G Bulk

قبل التجربة وبتكون هي حجم + وزن فبحسب

الكثافة وتسمى Bulk density (كثافة ما بين مع فراغات)

لما نحسب Bulk density الهدف لوصل void ratio

UNCOPMACTED VOID CONTENT OF COARSE AGGREGATES AASHTO TP 56

Void Content

Voids ratio = agg $\rightarrow$ * γ_{water}

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

من تجربة

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

indirect

- 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 (texture) coarse aggregate, or a combination of these factors.

void content	decrease	increase
Angularity	more rounded	Angular
Form	spherical	less spherical
Texture	Smooth	rough

بالامتحان ممكن يجيب نوعين agg وتحسب voidratio

او ممكن يعطيني لكل واحد void ratio الخاص فيه ويسأل

مين فيهم more rounded فالّي يعني

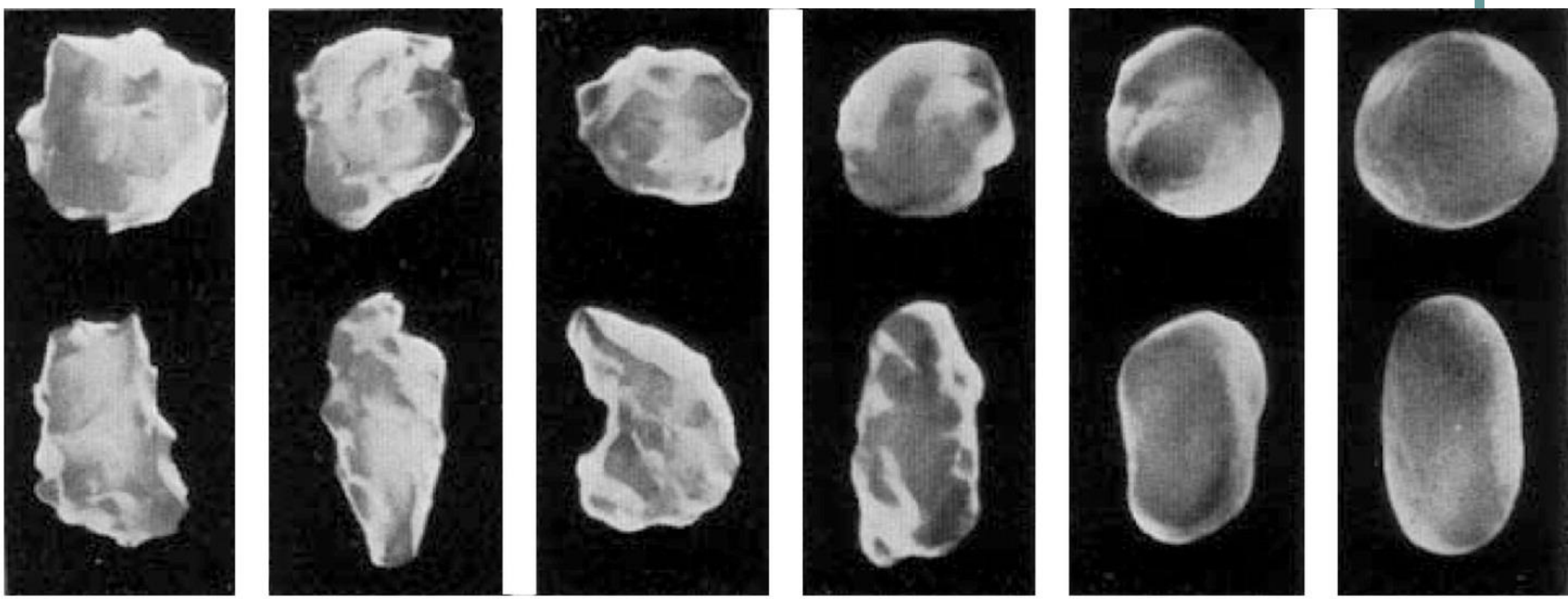
Examples on Sphericity and Angularity

Form and angularity

Form

High sphericity
ابعادها متساوية

Low sphericity
ابعادها غير متساوية



Very angular	Angular	Subangular	Subrounded	Rounded	Well rounded
R = 0.12 – 0.17	0.17 – 0.25	0.25 – 0.35	0.35 – 0.49	0.49 – 0.70	0.70 – 1.00

فعليًا ما عندي علاقة بين Angularity و Form و texture

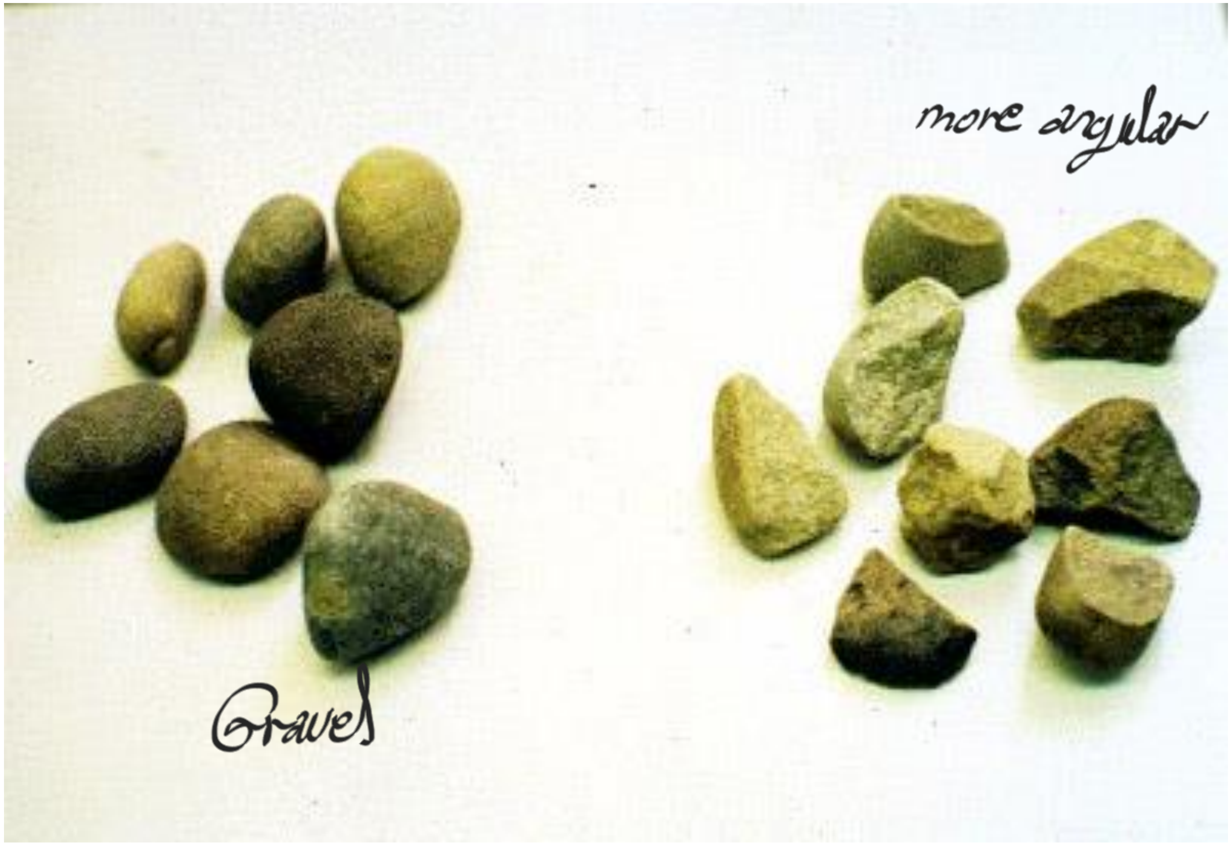
% OF FRACTURED PARTICLES IN COARSE AGGREGATES ASTM D5821

- *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

coarse agg.

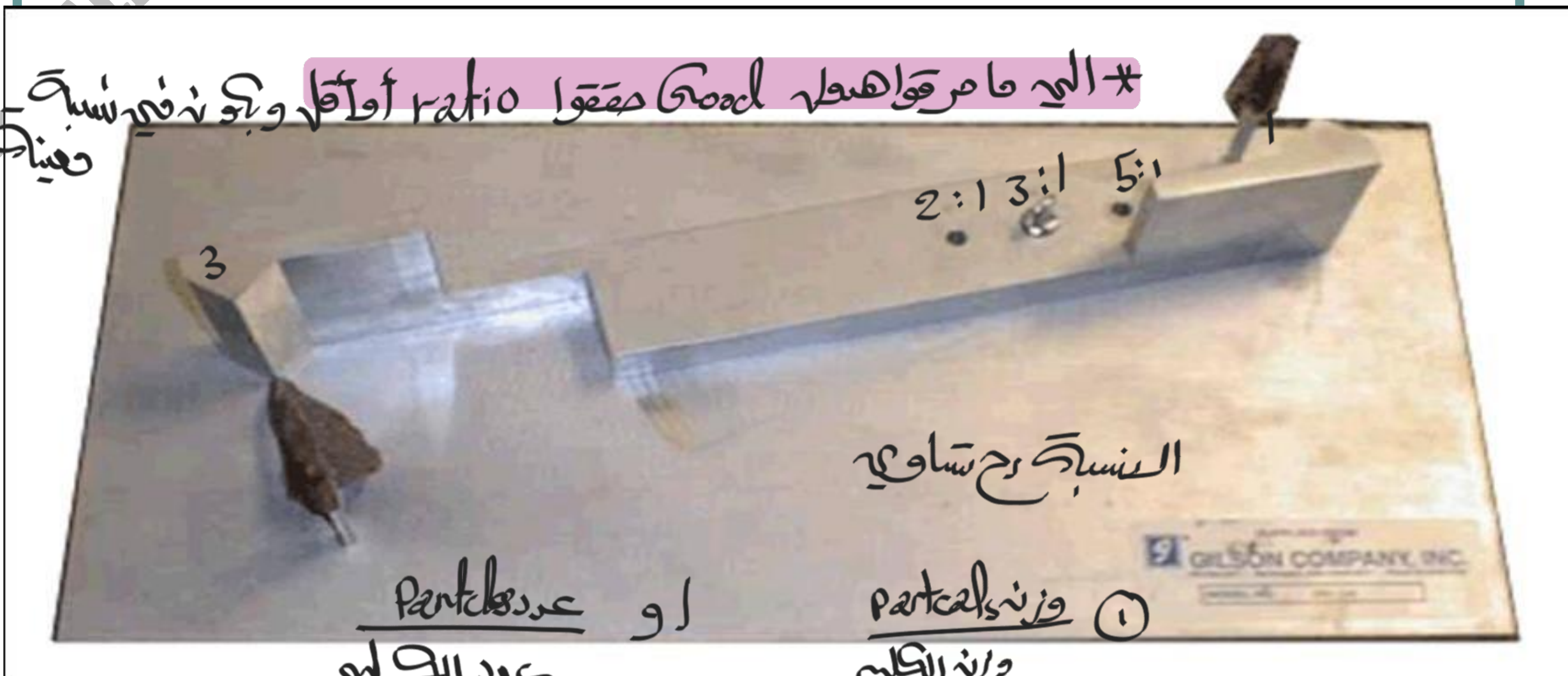
- ASTM D4791 - 19 Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
- This method provides the percentage by number or weight of flat, elongated, or both flat and elongated particles in a given sample of coarse aggregate.
- The procedure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

3:1

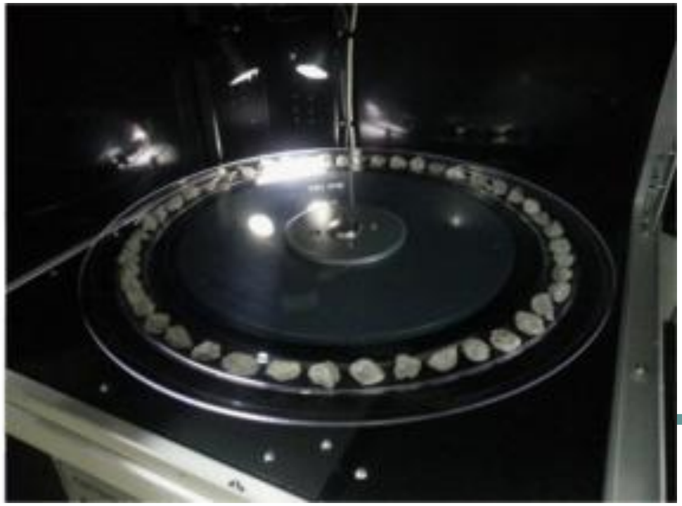
5:1 أو

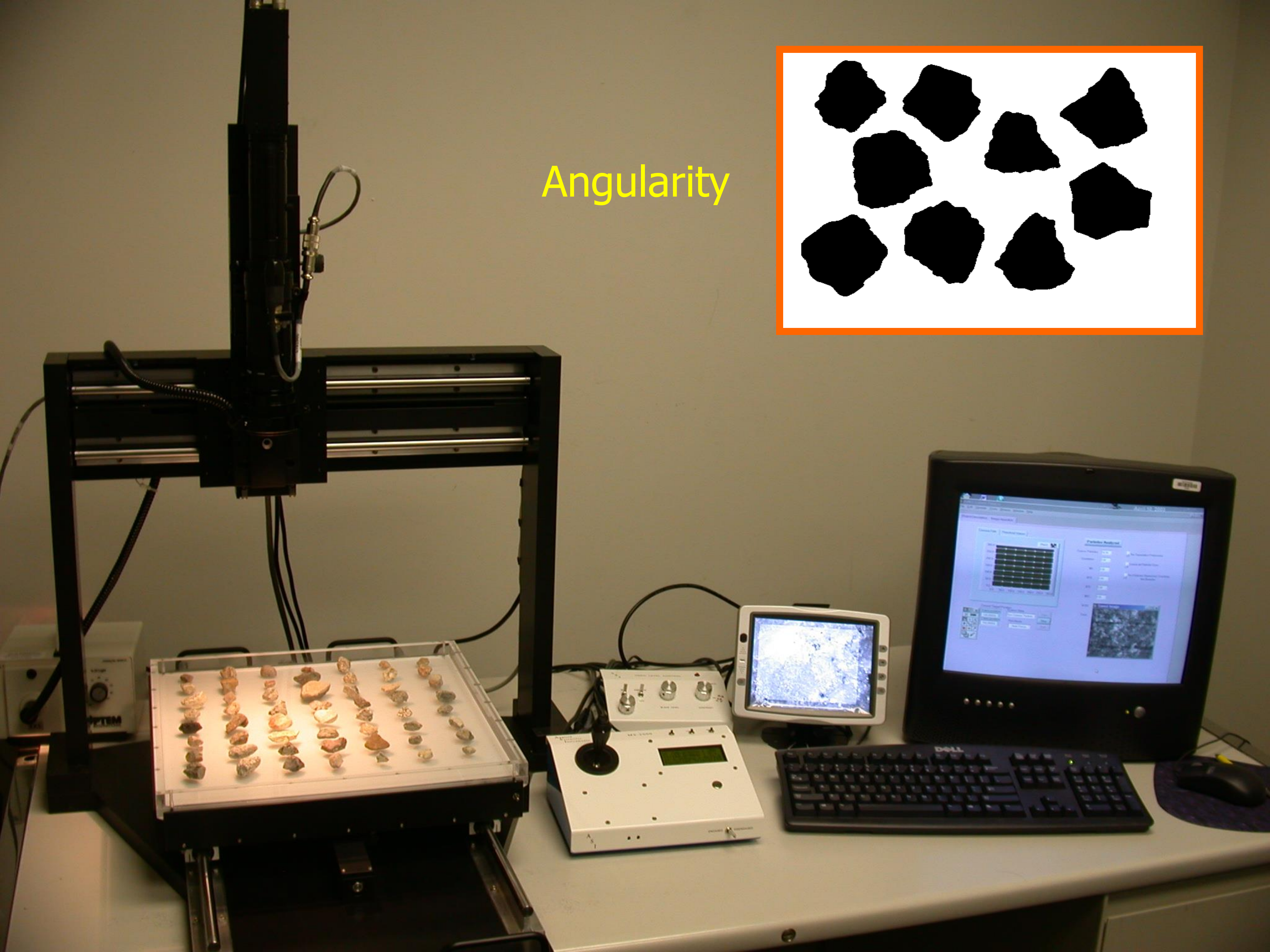
2:1

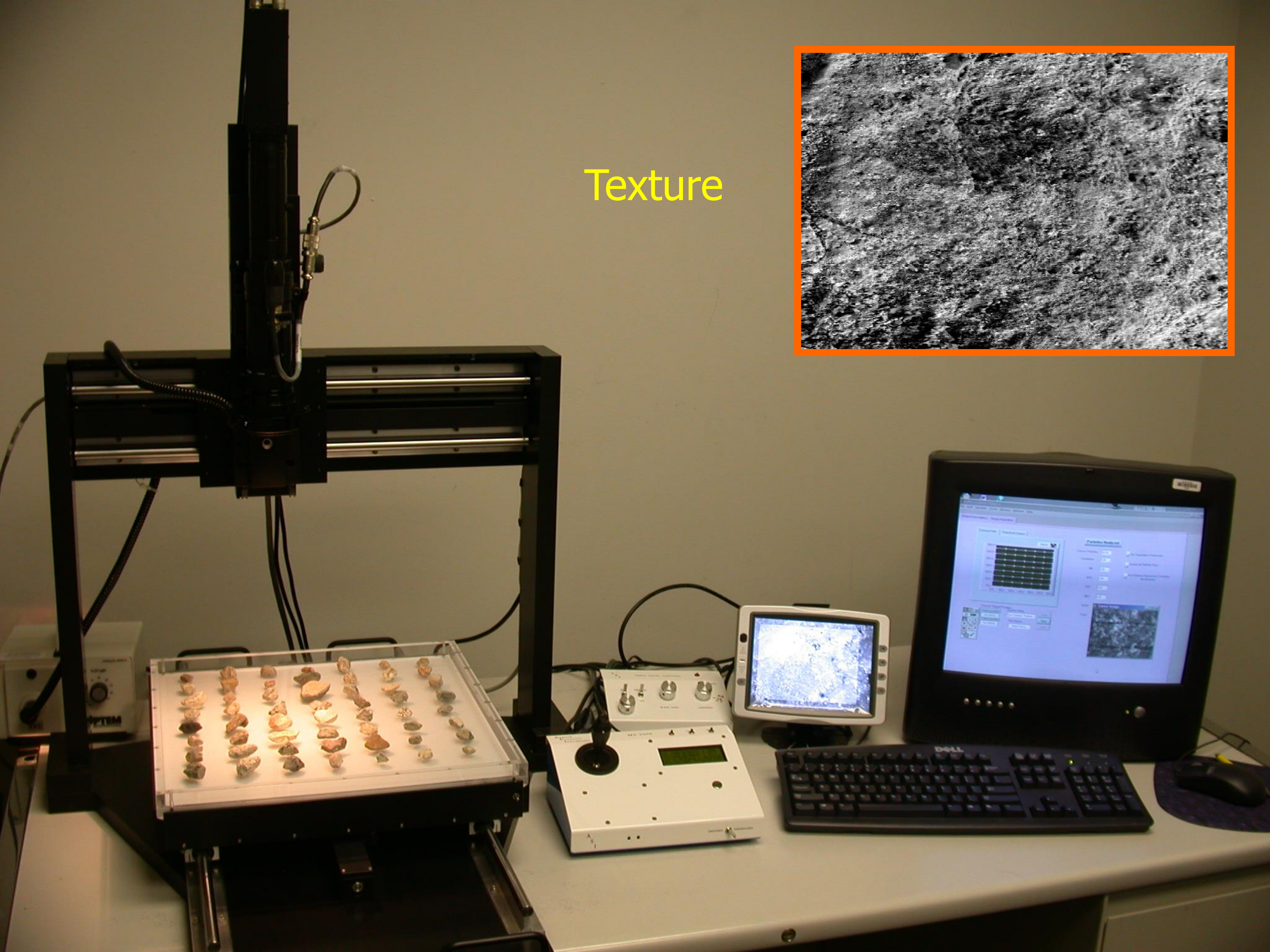
Flat and Elongated Coarse Aggregate Caliper



Aggregate Imaging System AIMS




Angularity


Texture

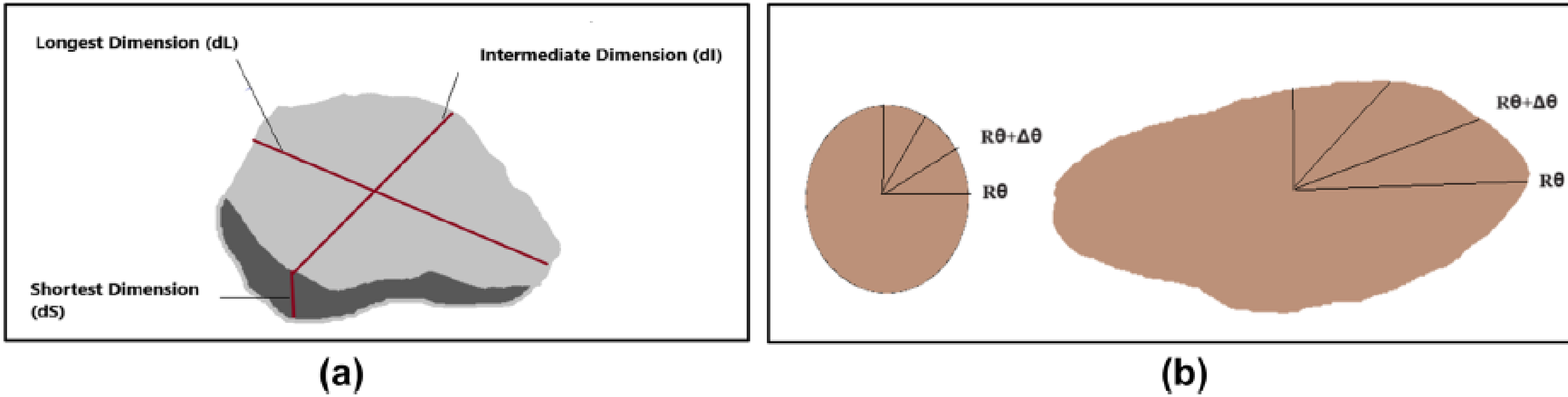


Fig. 5 Illustrations for measure principles of: **a** Sphericity; **b** 2-D form

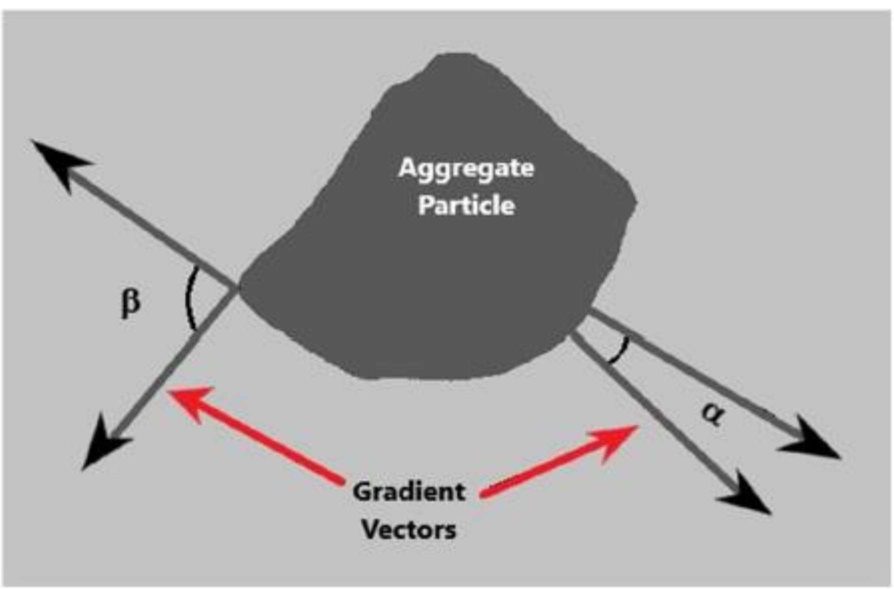


Fig. 6 Comparing angularity of rounded corners and sharp corners on the outline of an aggregate image

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 5/8

coarse agg لا

كتل طينية وحبيبات المتفتتة

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

بنعمل تجربة عشان نكشف حبيبات

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

وزن قبل - وزن بعد = وزن حبيبات

Cleanliness : تعبر عن نظافة الـ agg

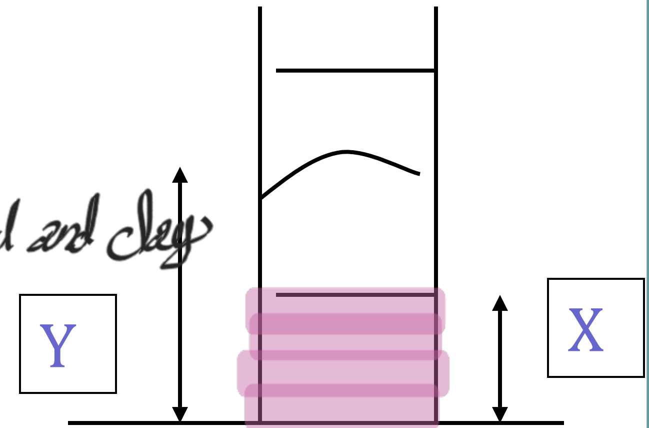
*حبيبات بسبب الرطوبة هاي حبيبات ناعمة تلتصق بـ agg فبعمله اختبار Clay Lumps and Friable Particales

*وزنه قبل تجربة ووزنه بعد تجربة بعطيني وزن الكتل التي كانت موجودة

← هاي تجربة للـ coarse agg

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

harde

Aggregates should be clean, tough, durable,

shaped خدمات المعمل

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 .

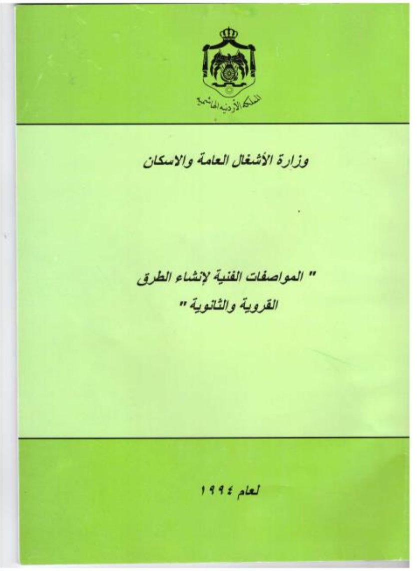


TABLE (6) :

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 (100 REV / 500 REV)	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

المواصفات غير مطلوبة

- 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**. نسبة رطوبة
- 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 لازم يكون واصل منهدول تدرج					
	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 Classification for Highway Purposes 5/8

تحاول توقع اداء الماتيرال

- 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.

رح نعمل اختبارات على تربة وبناءعليه نتائج والخبرة رح يصنفوا تربة

- 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.

← بس نعرف تصنيف بكون سهل اعرف الاداء

- 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

نسبة رطوبة الي مارح تتغير نهائي

- **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).

يساعدوا بحساب PI

- **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. ← مش جيد

Sand…….. Cohesion less……….Non Plastic (NP).

المدى الذي تكون به التربة بـ بلاستيك رينج

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

PI زادت

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

* PI لما نزيد يعني اشي سيء

- 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.

← LI : بستخدم كمؤشر بوصف حالة التربة في موقعها

يعني تربة بتكون undisturbed (تعكس القيمة حقيقية التربة)

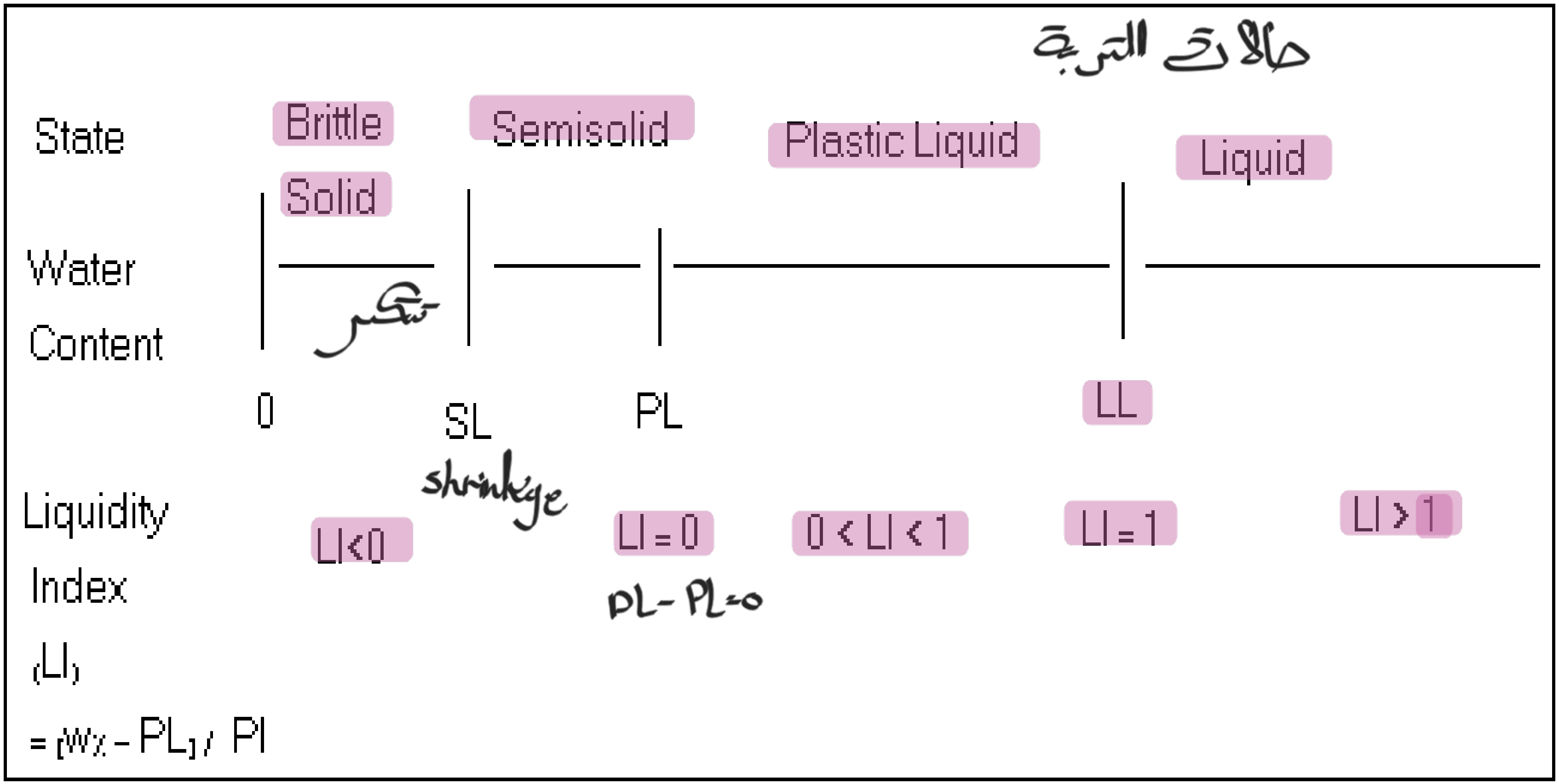
← disturbed و undisturbed ممكن يعطوني اشياء مختلفة

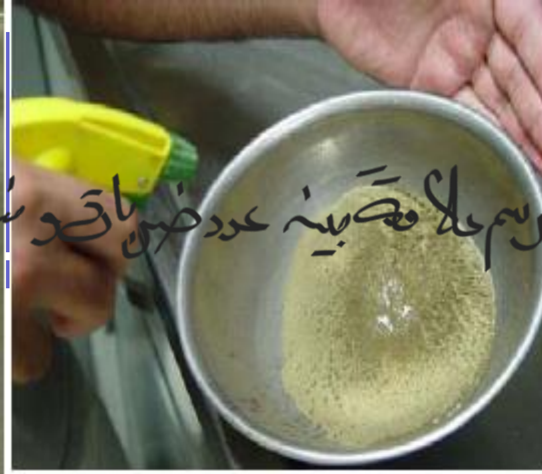
عن بعض [state مختلفة]

← لما تكون KLI رح يعطيني quick clay وهاي بتعمل

انهيارات

Consistency Limits





* رح نرسم علاقة بين عدد ضربات و نسبة رطوبة

بنعمل خندق

لما تكون ناشفة بكون بدي ضربات اكثر

Casagrande Liquid Limit Apparatus

* علاقة عكسية بين رطوبة وعدد ضربات

لما يسكر بمقدار 0.5" بنوقف

← بعيد تجربة وكله مرة نزيد ماء

بعد دحل الحرما يلبطش
crack يبينه بنكون نهاية
نهاية

AASHTO Classification System

عشان اصنفه لازم يكون معي -

- Classifies soils into 7-groups based on laboratory determination of particle size distribution, liquid limit (LL), and Plasticity Index (PI).

LL و PI
PI وتدرج

- Evaluation of soils within each group is made by means of group index.
- *AASHTO classification in shown in Table 18.1(Text Book).*

ممكن يصير عندي نوعين نفس تصنيفه (نفس الأداء)
وعملوا قروبات

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

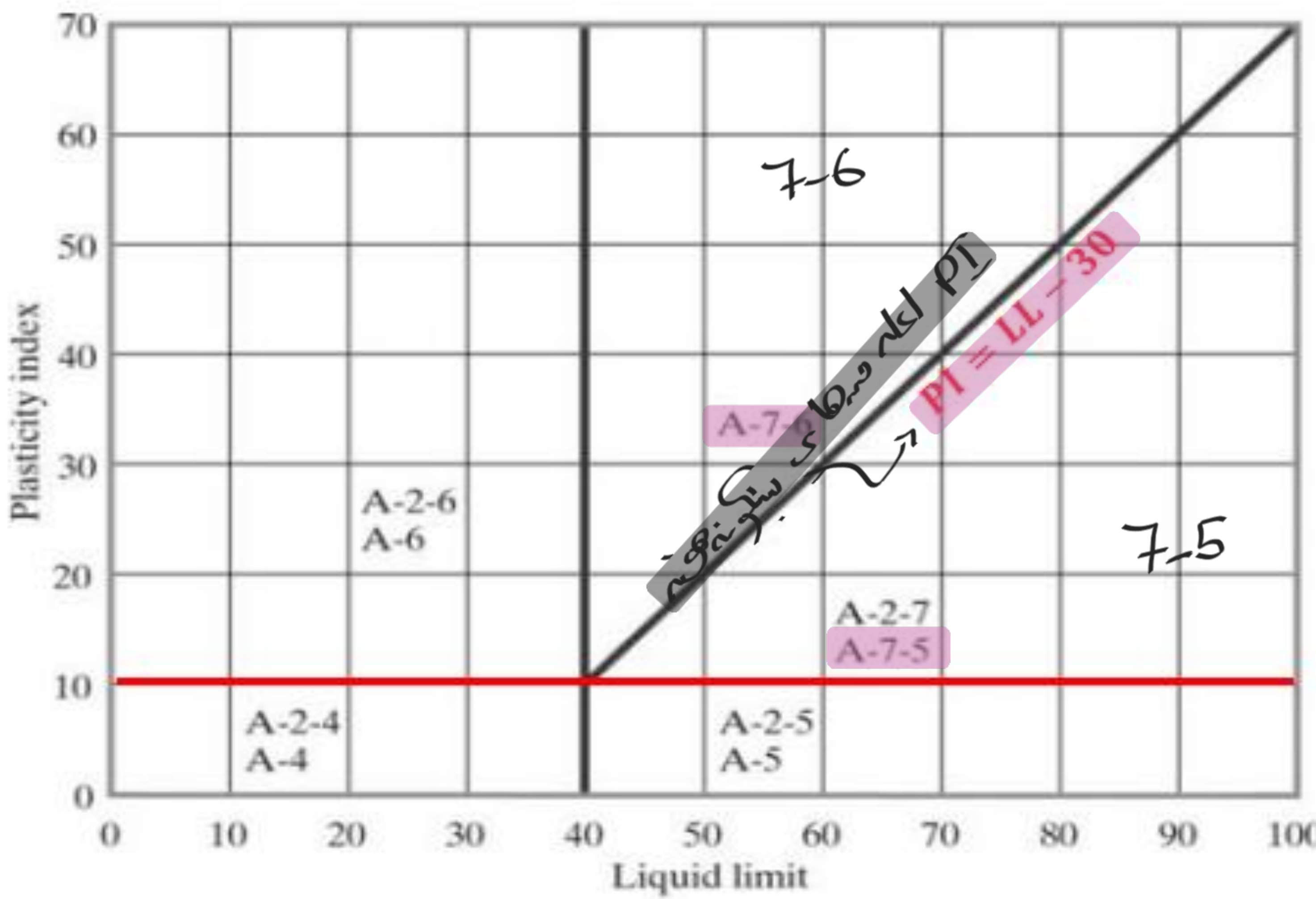
General Classification	Granular Materials (35% or less passing No. 200)							Silt-Clay Materials (more than 35% passing No. 200)			
	A-1			A-2							A-7
Group Classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5, A-7-6
Sieve analysis, percent passing											
No. 10 (2.0 mm)	50 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			

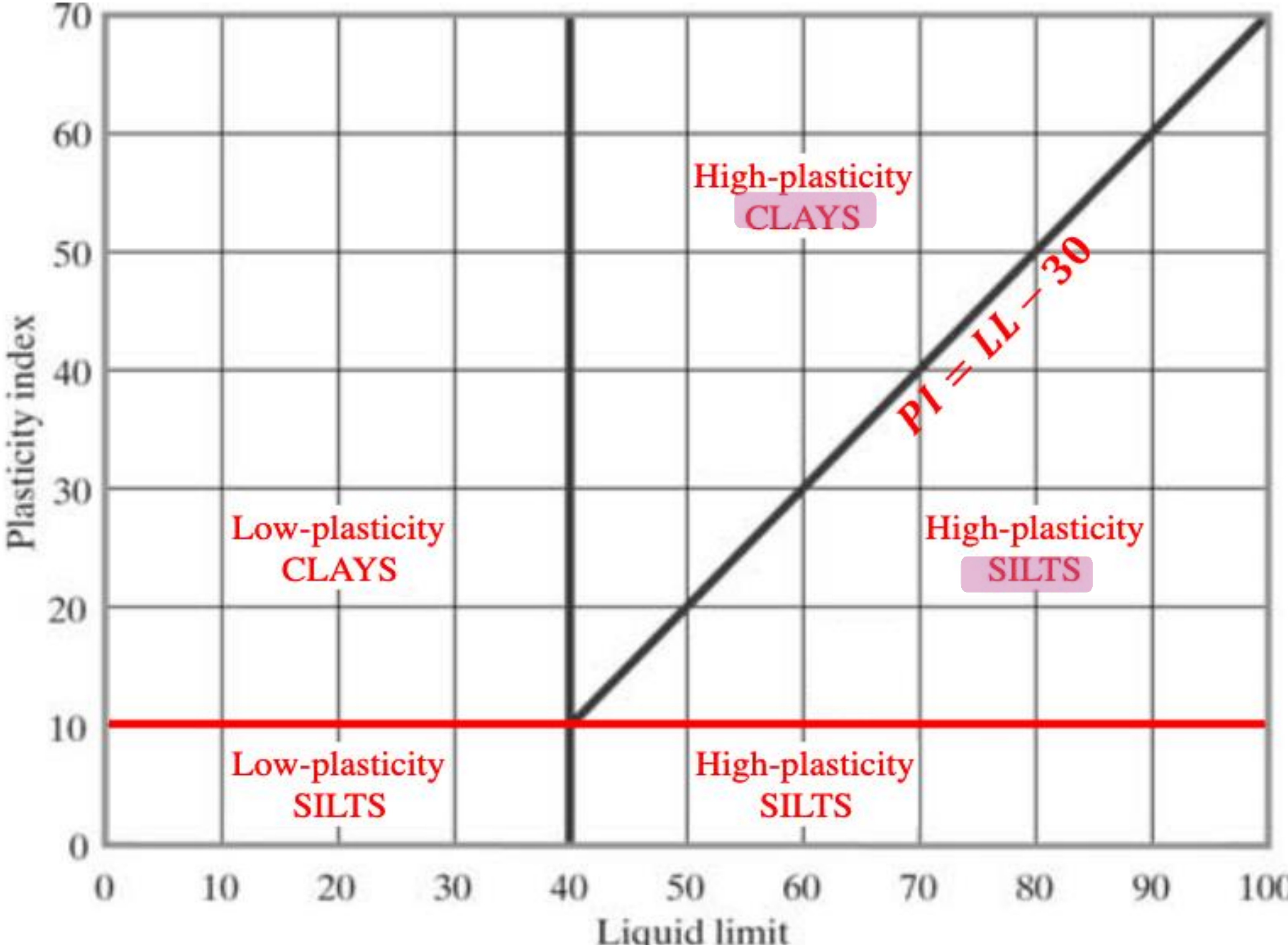
[a]Classification procedure: With required test data available, proceed from left to right on the chart, and correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

[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


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



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

Group Index

بميز حتى لو كان سويلين بنفس مواصفات فهو بميزلي الاحسن

مهم

بتكون مهم

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

% passing No. 200

Partial Index for A-2-6 and A-2-7

لو كان تصنيفها A-2-6 او A-2-7 فقط بنحط جزء ثاني

اذا طلع سالب بنحطها صفر

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

GI = zero

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)

strength

Group index : بميزلي حتى لوكان عندي two soiles

نفس تصنيف فهو بميزلي مين احسن

بيكون معطى

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

F: % passing No. 200

$0.01(F - 15)(PI - 10)$: Partial Index for A-2-6 and A-2-7

← A-1 , A-3 , A-2-4 , A-2-5 هدول دايمًا

GI = zero

← لما توجد (مهم) تصنيف ويطلع A-2-6 أو A-2-7 ف

معادلة GI بيكون : 0.01(F − 15)(PI − 10)

← Inverse ratio لما نحكي 1/1 و 1/10 فالاكبر هي 1/1

معناها كل ما قلت G كان افضل فمثلاً كان عندي

two aggregate نفس تصنيف واحد طلع GI=1 وثاني GI=5

ف الاحسن هو GI=1

Soil Classification Example1

% passing #10 = 100%

*لما يكون مثلاً G=0.9 بنحطه 1

% passing # 40 = 85.2%

G = 3.1 ⟵ G = 3 دائماً

% passing # 200 = 52.1

نقرب لأقرب عدد صحيح

LL = 29.2 & PI = 5.0

$* (52.1 - 35)[0.2 + 0.005(29.2 - 40)] + 0.01(52.1 - 15)(5 - 10)$

Solution: G = 1

G.I

A – 4 material

A-4 (")

Soil Classification Example 2

% passing # 200 = 55 %

LL = 40 & PI = 25

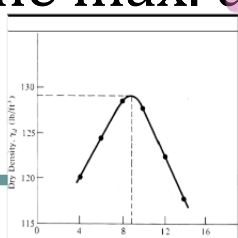
من قانون تعويض مباشر

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.

الكلي

$$\text{Dry unit wt.} = \text{Wet unit wt.} / (1+\omega\%)$$

- 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

الفحص هاد عشان نطلع نسبة optimum

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 وزنه وارتفاعه وعدد layers مختلفين
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

تقدر تستخدم "6 أو "4

	T 99	T 180
Mold Volume, ft^3	Methods A, C: 0.0333 ±0.0005	Methods A, C: 0.0333 ±0.0005
	Methods B, D: 0.07500 ±0.0009	Methods B, D: 0.07500 ±0.0009
Mold Diameter, in.	Methods A, C: 4.000 ±0.016	Methods A, C: 4.000 ±0.016
	Methods B, D: 6.000 ±0.026	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. ارتفاع	12 ±0.06	18 ±0.06
Layers	3	5
Blows per Layer عدد ضربات	Methods A, C: 25	Methods A, C: 25
	Methods B, D: 56	Methods B, D: 56
Material Size, in.	Methods A, B: No. 4 minus	Methods A, B: No.4 minus
	Methods C, D: 3/4 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.

الاختلاف بين الفحصين :- عدد Layers وارتفاع Rammer

ووزن Rammer

← ما بختلفوا بـ ماتيريال ولا agg size و mold diam

مختصر التجربة :- بنجيب تربة وماx size تقريبًا 4# وبنشغلها

وبنخلط معها نسبة ماء قليلة ونعبيها بـ cone رح نشتغل ا على طبقات

مثلا Modified بحيث كل طبقة نعمل compaction لـ 25 أو 56 بارتفاع

ثابت (اسقاط حر) بتوزيع ضربات على محيط طبقة ونفس الاشي لباقي

طبقات ، اما الـ mold الذي سوف نستخدمه بكون حجمه ووزنه معروفين

بس اخلص اخر طبقة باخد وزنه ومع معلوماتي بوجد wet density

بنرجع نستخدم تربة مرة ثانية وبنزيد ماء ولما نفك الـ mold ونوخذ ماتيريال رح نوخذ

عينة من النص ونحسب رطوبة عشان نحسب Dry unit wt

وبنضل نعيد وبنوقف لما وزن الـ mold تنزل عن الأول ، بعدها رح نرسم الرسمة

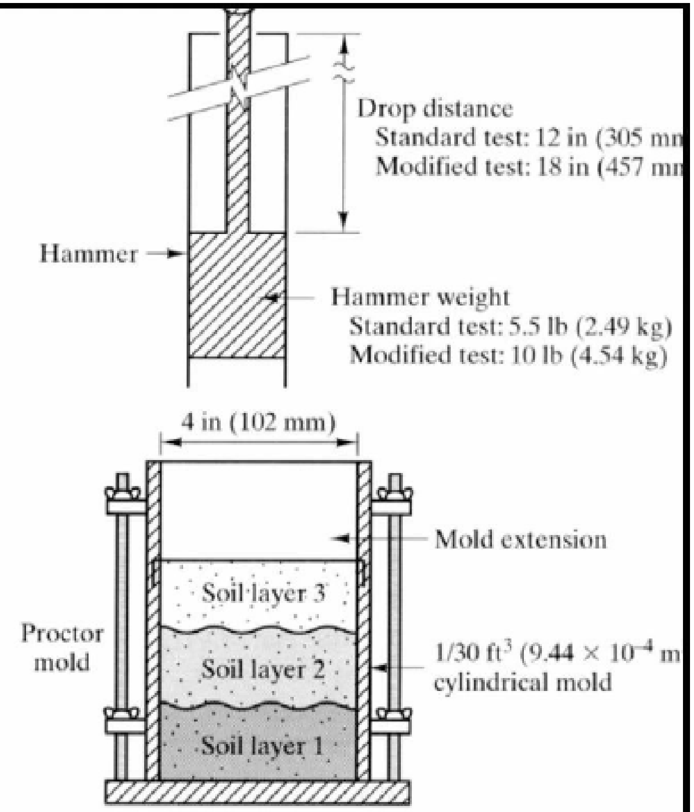
صار عندي معلومة عن Optimum مقدار و الرطوبة التي نتعامل معها

بـ sites بحيث لما ادخل تعطيني max density

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.



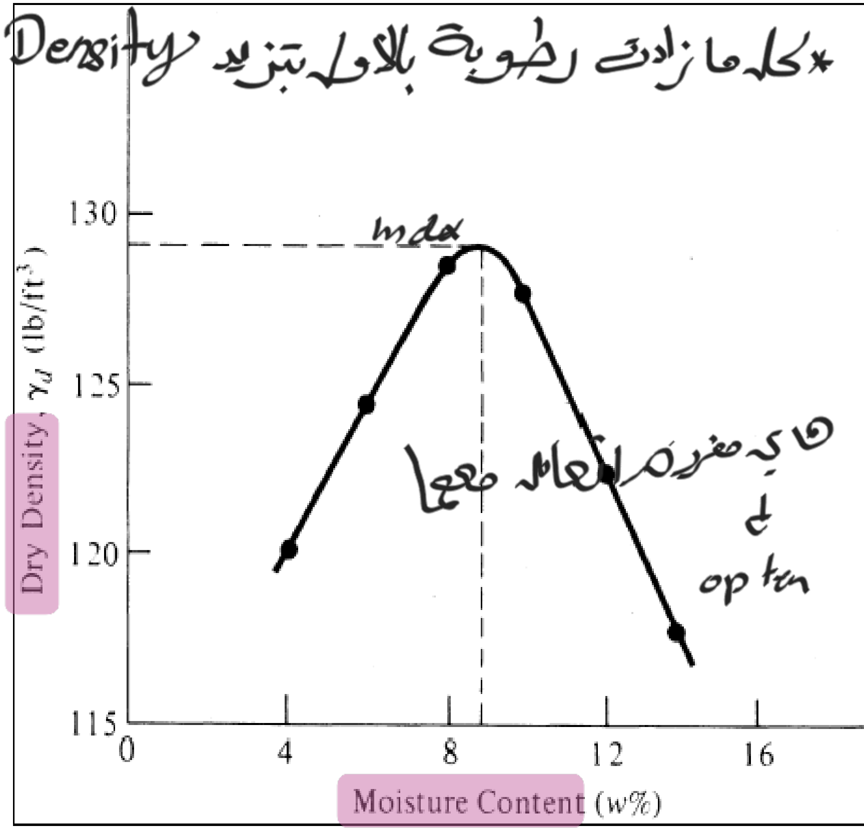
- *Method A*—A 101.60-mm (4-in.) mold: Soil material passing a 4.75-mm (No. 4) sieve Sections 4 and 5.
- *Method B*—A 152.40-mm (6-in.) mold: Soil material passing a 4.75-mm (No. 4) sieve Sections 6 and 7.
- *Method C*—A 101.60-mm (4-in.) mold: Soil material passing a 19.0-mm ($^3/_4$-in.) sieve Sections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

*كلما زادت رطوبة بالاول تتزيد Density بعدين بصير فيي هبوط

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

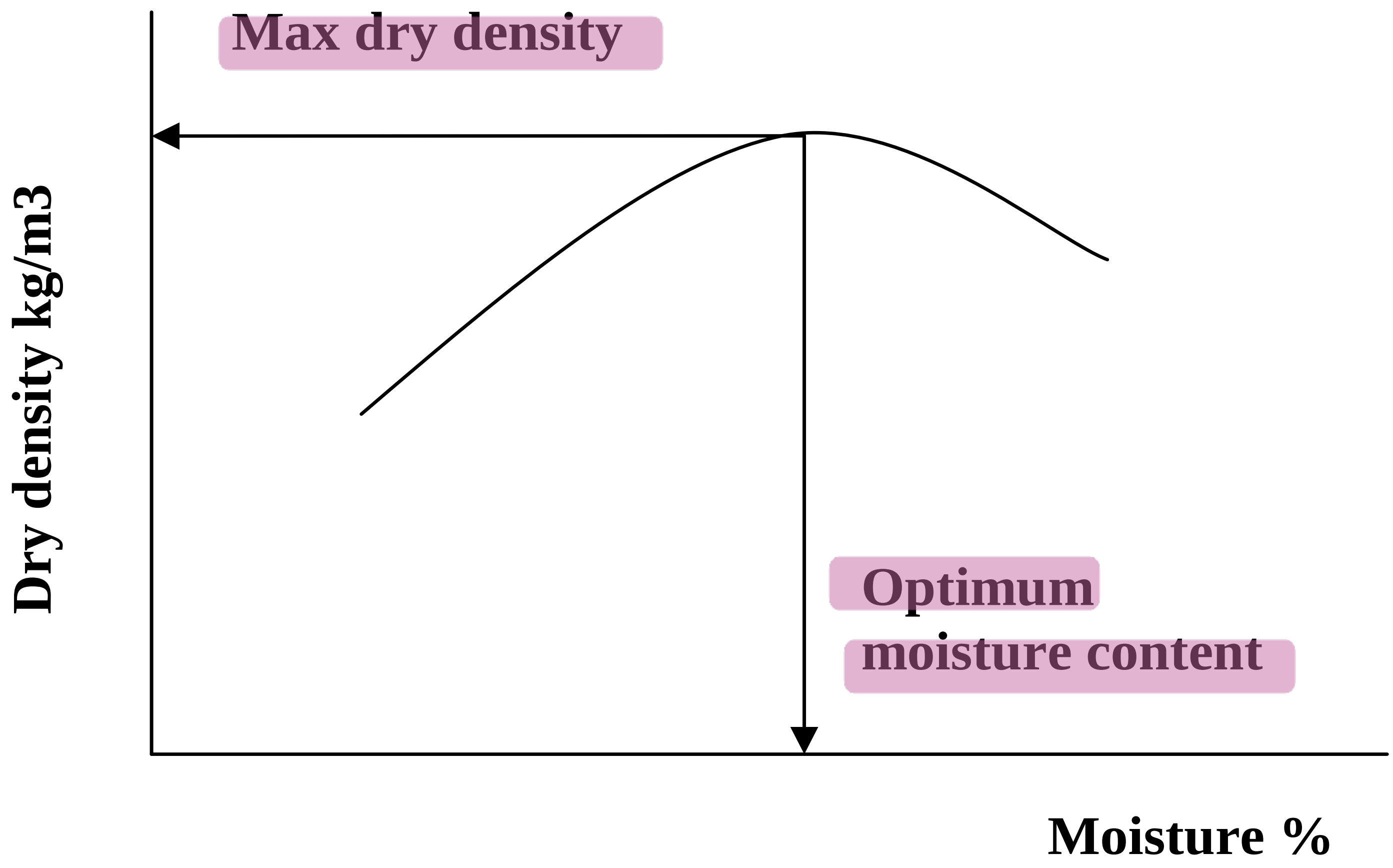


Dry unit wt. = Wet unit wt. / (1+ω%)

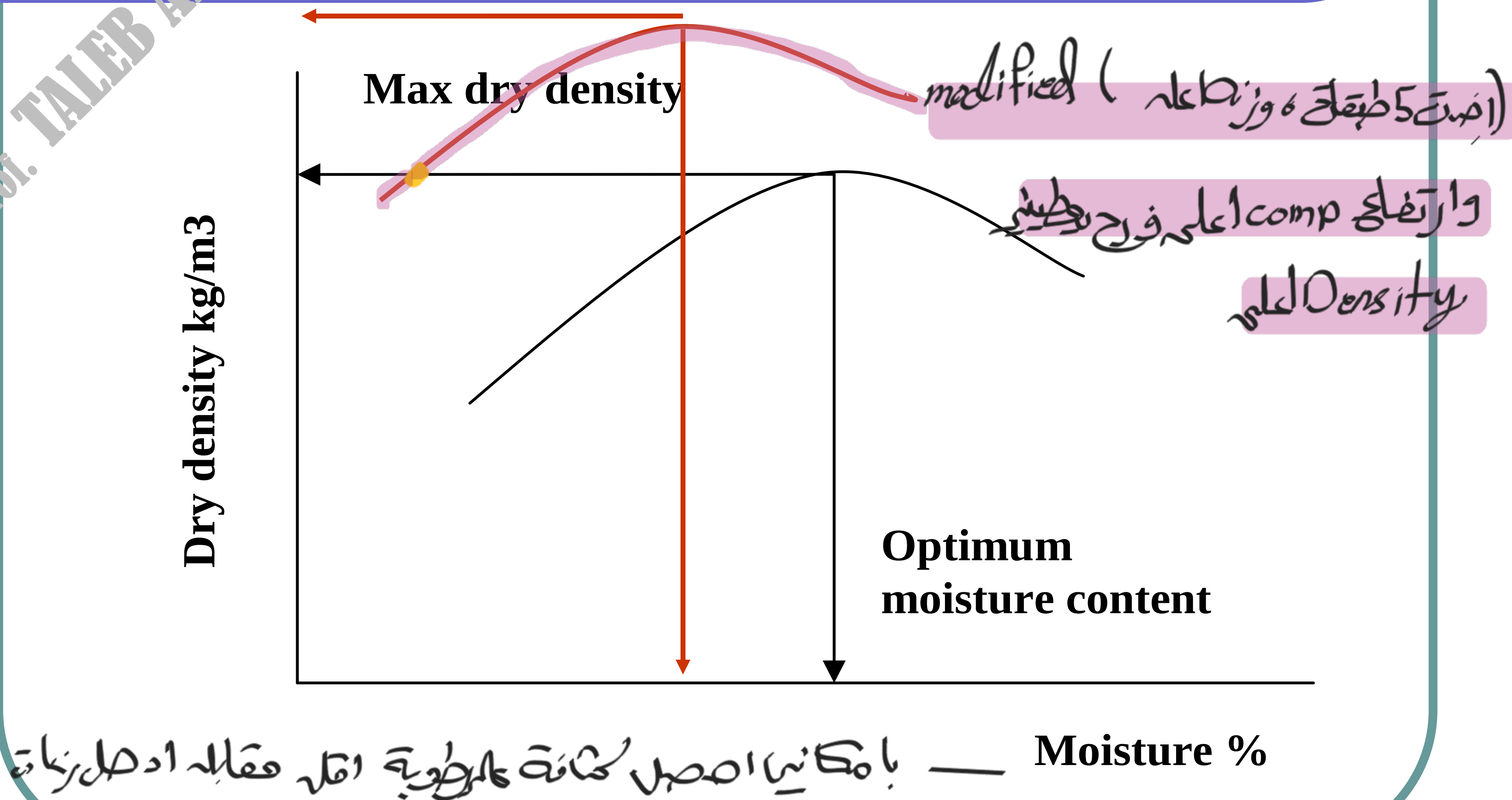
This curve is unique

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

Moisture Density Relationship



Effect of Compactive Effort



الامر هو compaction effort زيادة

نلاحظ الاتي :-

اولاً :- Modified ← اصبحت 5 طبقات ∴ وزنه ↑ وارتقاع compaction ↑

فرح يعطيني Density ↑

ثانياً :- نلاحظ انه max density الـ standard هي فعلياً حصلناها عند

رطوبة اقل ، هاي بتعطينا معلومة عن الواقع بإمكانية احصل

Density هاي عند رطوبة اقل ولكن لازم تحصل زيادة

∴ إذا الكانت عندي كمية الرطوبة قليلة (ناشفة) بدك تدخل زيادة

حتى توصل max Density

الرطوبة مهمة انها بتقلل عدد الدحل

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. نوعية ماتيرال المستخدمه تؤثر على comp
- Type of soil has great effect on density obtained under a given compactive efforts:
  - Moisture content is less critical for clay than plastic sand. نسبة رطوبة حرجة اكثر للتربة التي تحتوي على clay
  - Granular and well graded soils react sharply with small changes in moisture. هاد بتغيرها بحتاج جهد كثير
  - Clean, poorly graded, non plastic sands are relatively insensitive to changes in moisture.
  - Amount of coarse aggregates.

حباتها الحرفية مش بحاجة جهد اكثر فبتاثر على كمية جهد مستعملة

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.

بالاول بتكون التربة ناشفة فرها في الشي سيسهل حركتهم فبتكون

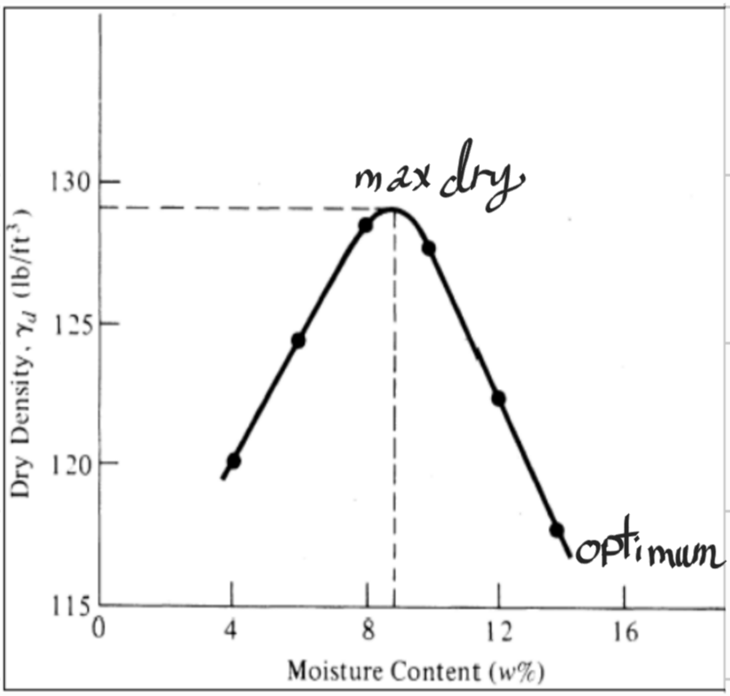
Density قليلة ، لما نزود الماء (تزيد رطوبة) بصير زي تشحيم

بتصير جزيئات تقرب لبعض أكثر لما نعمل compaction

فبصير أسهل يعني بالمختصر فيه سهولة لحد معين وبعده

إذا ضليت ازيد ماء رح تصير تعبي فراغات ماء هيك رح تقل

Density أقل

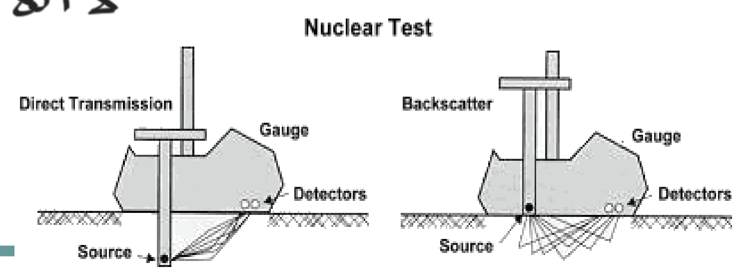


يفضل وأنت بالموقع تحاول ما تكون رطبة كثير ولا تكون ناشفة

← يفضل التربة بالموقع قبل دكها تكون تقريبًا تساوي نسبة Optimum هاي بنجيبها عن طريق المختبر

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



رح نعمل اختبار بالموقع نحسب منه Density لل base course مدحول مثلاً

ونقارنها مع max density الخاصة بـ Proctor إذا طلعوا نفس

قيمة معناته compaction ممتاز إذا طلعت أقل معناته مش واصل 100%

Proctor هو المقام (اللي رح نقسم عليه) وفي مصلحة للمقاول

انه يكون قليل عشان كله الشي ينجح ، احنا رح نقسم Density موقع

على Density الخاصة بـ Proctor

شرح تجربة :- دائرة بنحفرها مكانها ومواد اللي تطلع نضعها داخل

كيس بلاستيك (نعمل نحفر حفرة طبقة ثانية) ، في علبة بلاستيك بتكون معبية

sand بس اطلع ماتيريال بفتح العلبة فـ الرمل رح يعبي الحفرة و cone [حجم الي

عبا cone معروف] فرضاً جايب رمل 5kg و ال cone اخذ 1kg وضل كيلو بالعلبة :: 3kg

وهي كثافة sand بطلع الحجم ، التربة اللي اخذتها من حفرة معنا وزنها و حجمها فبحسب

كثافتها wet density ويروح للمختبر باخذ عينة من التربة وبحسب مقدار الرطوبة [حطينا بكيس

بلاستيك عشان ما يصير ماء الموجودة داخل تربة] ، وبحسب dry density بعدها

بقسم dry density على dry density Proctor بطلع نسبة إذا كانت 100% مقارنة لو 98, 99

ممكن نرش وندحل وهكذا

$$\text{Percent compaction} = \frac{\text{Field density}}{\text{Max density (Dry)}} \times 100$$

← مختبر

كيف ممكن يقل المقام؟ عدد طبقات (اقللها)، عدد ضربات (يقللها)،

عدم رفع جهاز Rammer (يرفعه بمقدار أقل من المطلوب)، وزنه يقلله

(ممكن مشكلة بالميزان)

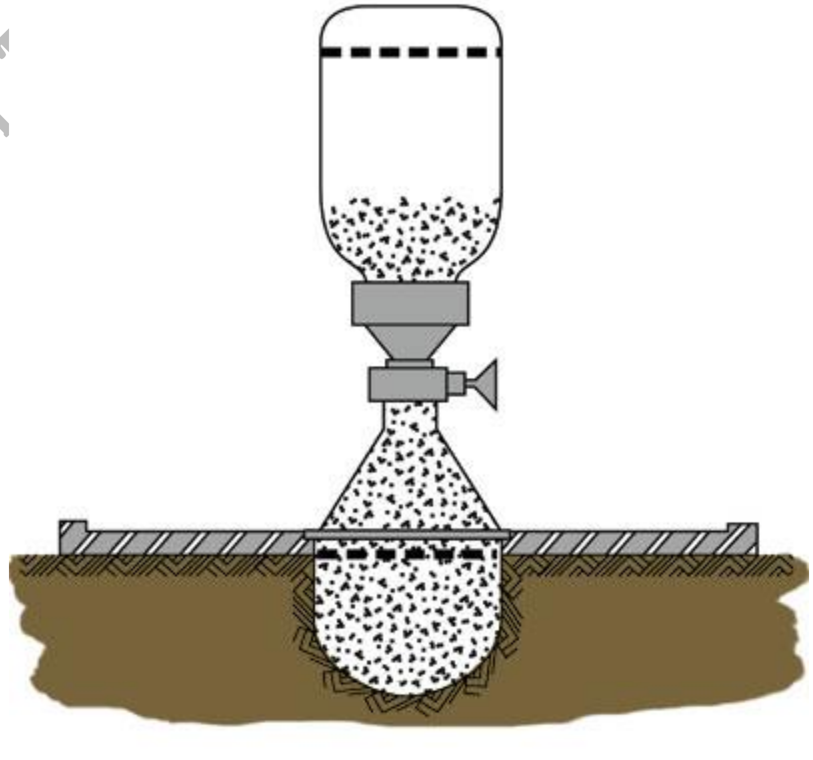
كيف ممكن ازيد البسط؟ وزنه تربة يكون عالي (وزنه تربة موقع)،

يقلل volume (ممكن يحط حجر)

← لما يكون عندي vibration زيادة بعمل compaction (مشمنه

مصلحة مقاطل) لا نصرح يحطه volume عالي

field density test using sand cone method



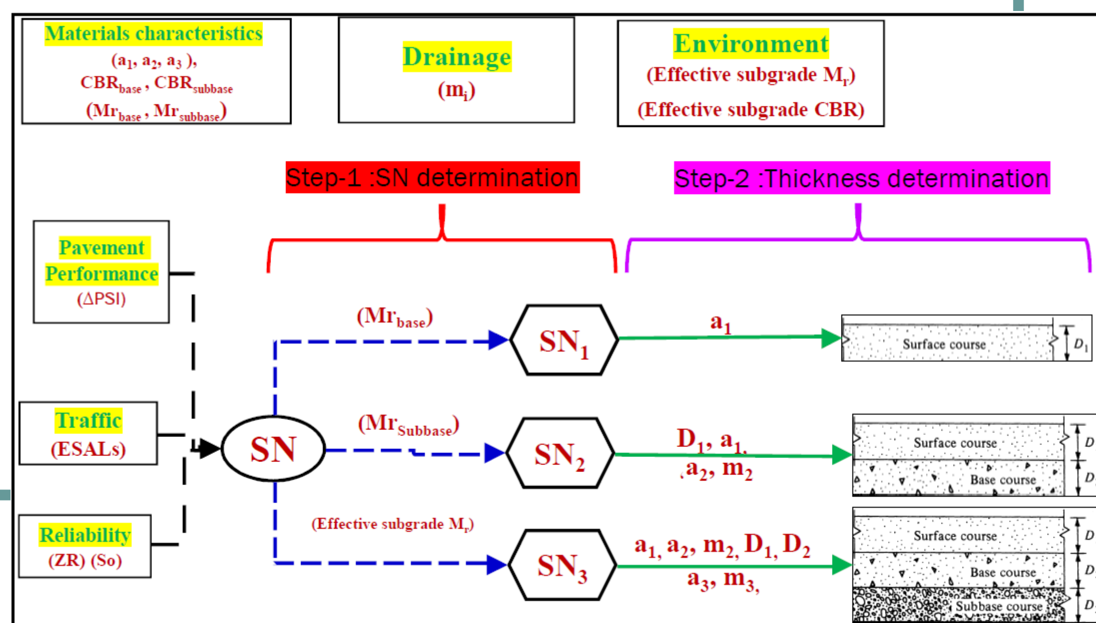
وزنه الي خلد - وزن الي عباء cone = الي عبا الحفرة ، كثافة معروفة ووزنه معروف ، بحسب حجم حفرة

Special Soil Tests for Pavement Design

10/8

- California Bearing Ratio test (CBR): بنفحص قوة تربة
  - 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) ← من فحوصات التي تقيس الشدة
    - 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

12

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 adopted 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:

  CBR فوائد

  - 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

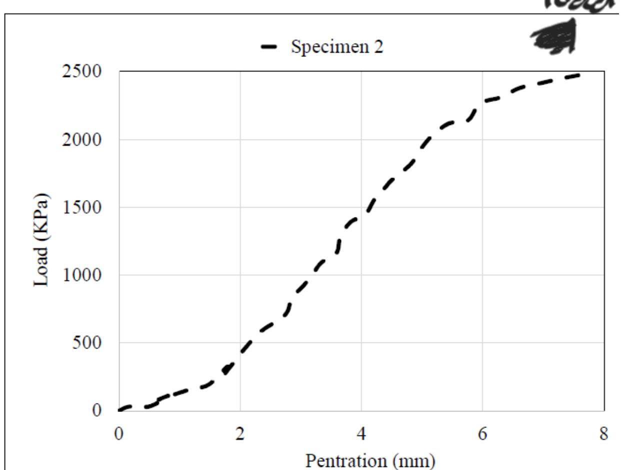
CBR

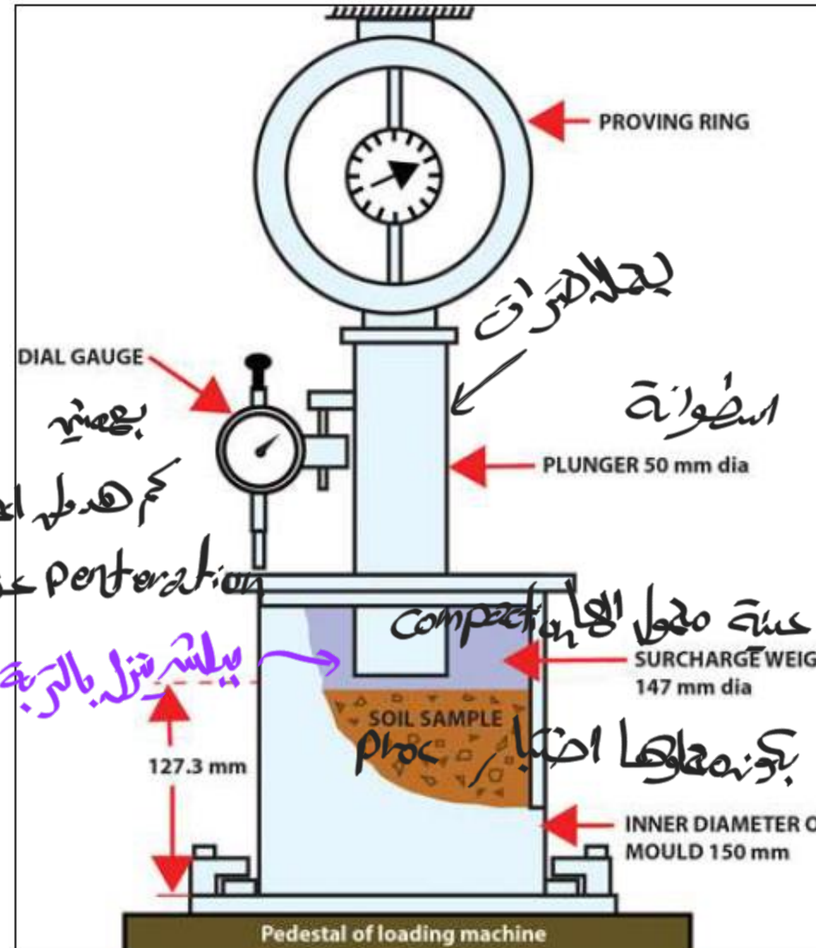
- It is a penetration test wherein a standardized piston, having an end diameter of 49.53mm (1.95in), is caused to penetrate the soil at a standard rate of 1.27mm/min (0.05in/min).
- The CBR value is calculated as the ratio of the load or stress at 2.54mm (0.1in) penetration to a standard load or stress.

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





بجيب عينة من التربة وبخلي الاسطوانة تنزل عليها ، هاي

عينة بكون معمول الها compaction وبكون عامل الها اختبار Pro

بكون مثلاً عينة هي subgrade بكون عليها يماثل وزن طبقات موجودة

فوقها ، وبضعه بالماء ٤ ايام ، باخد قراءات بعدها (قراءت

مقدار انتفاخ بعدها بنحسب amount of swal (مسافة

التي تحركها ب ملليميتر مقسومة على 25 (ارتفاع عينة الاصلية

بلاش بيسجل قراءة pentration load لحد نهاية التجربة

فيه ارقام رح تكون CBR بناء عليها ، بيعني كم load الي

وصلت الها عند 0.1 و 0.2 بحيث لما تتجاوز 0.2 بتقدر توقف

تجربة . بالتجربة عند pentration مقداره 0.1 عند load وعند

0.2 عند load هدول (load او stress الفرق هو Area)

و CBR هو عبارة عن ratio ستريس او load مقسوم على

standred stress / load) التي حصلنا من High quality agg

احنا اصلا معنا ارقام standred فكله الي علينا الرقم الي بطلع من تجربة نقسمه على standred رح يعطيني ratio

* CBR بتهمني بشغلتين نقدر نحسب منها اشياء ثانية

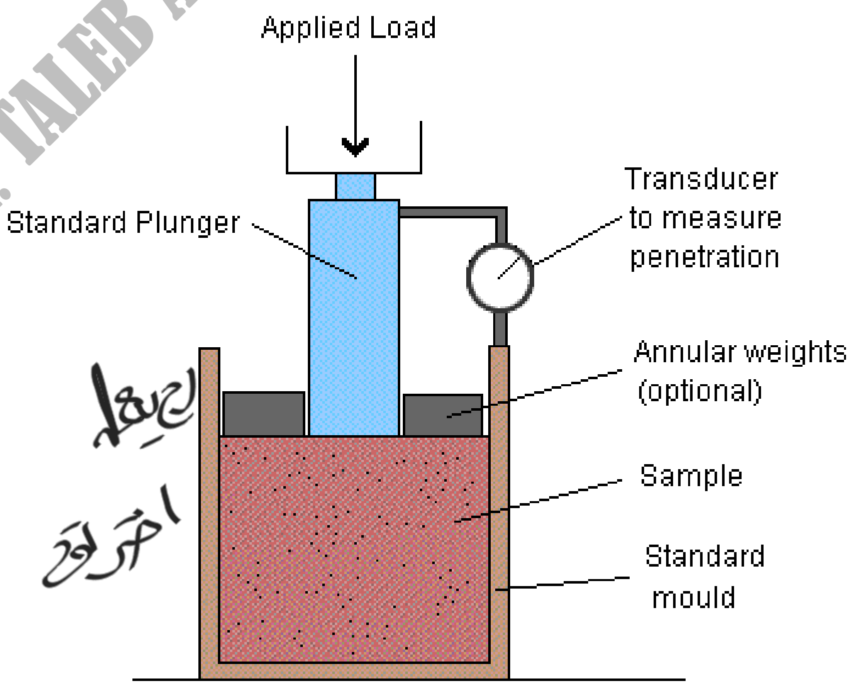
1500 * CBR = resilient modulus

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)
- $CBR(\%) = \dfrac{\text{Unit load of test materils}}{\text{Unit load of standard crushed stone}}$ 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



حجم الاسطوانة معروفة ← A*h

mass= volume*dens والوزنة معروف

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.

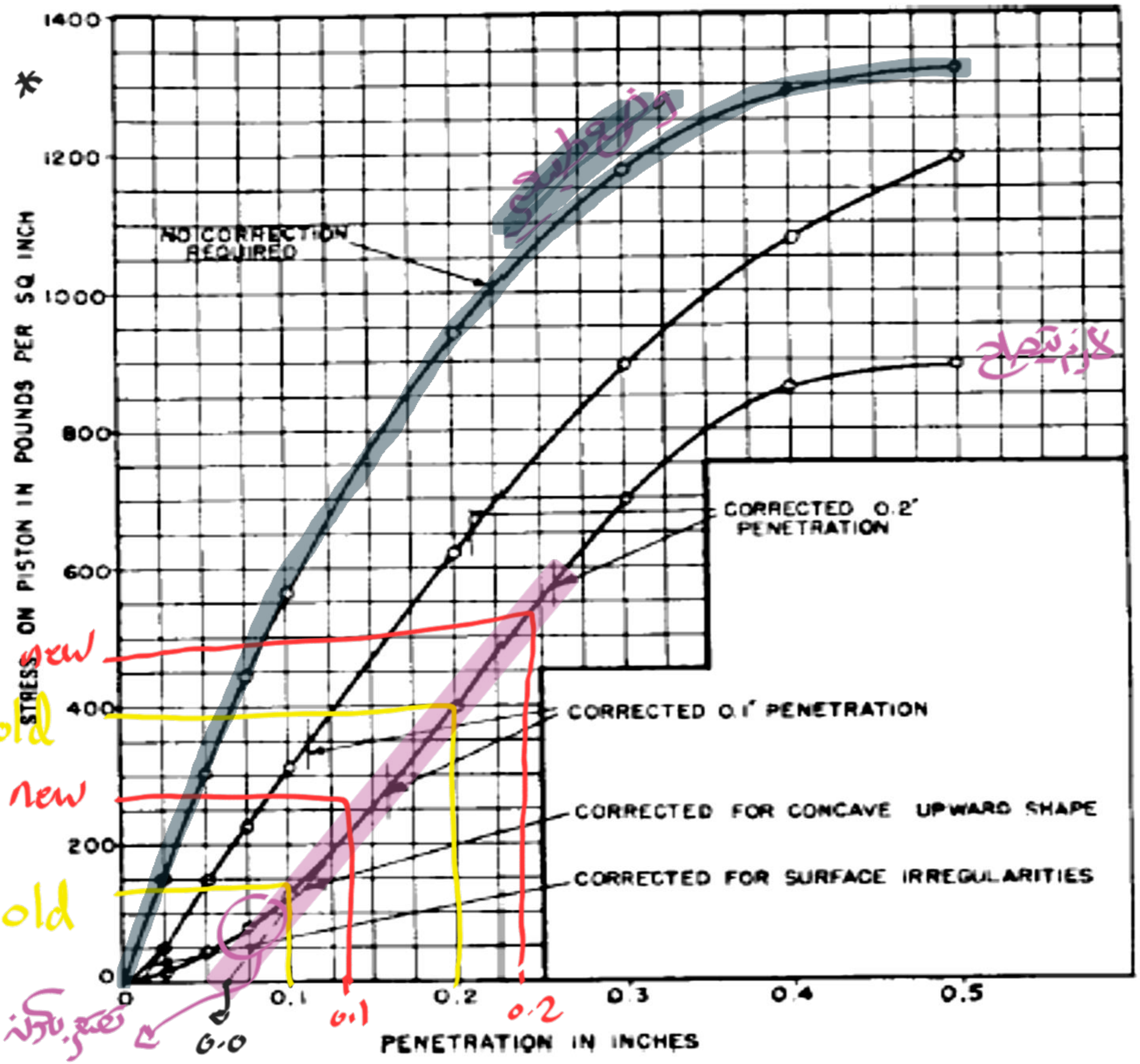
The CBR Plot

- 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.

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

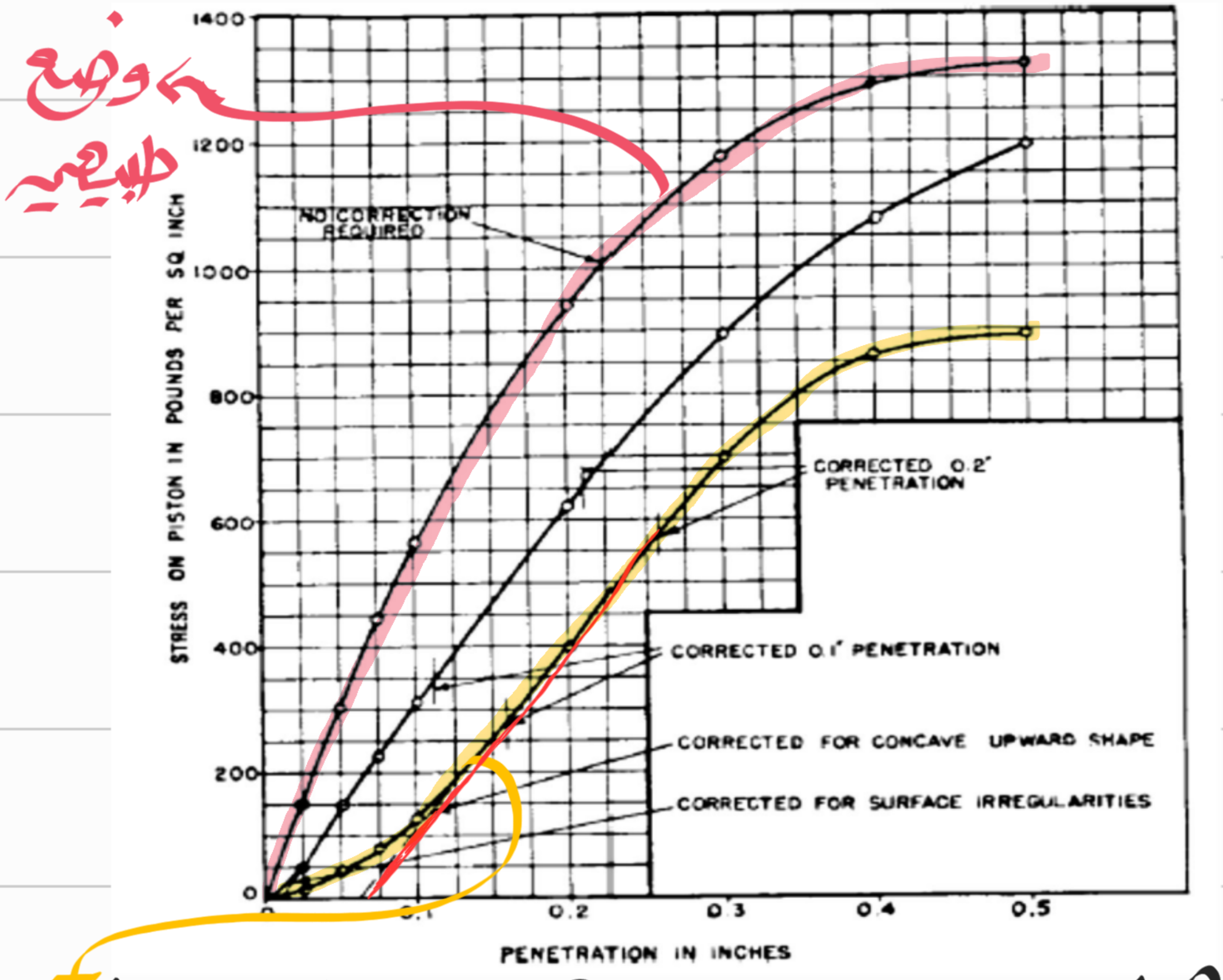
$$CBR\,(\%) = \frac{\text{Load at 5.0mm penetration (kg)}}{2045\,\text{kg}} \times 100$$

CBR Plot



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

كل ما زاد stress ف penetration بزيد



نلاحظ انه عند ي تقعر وسبب يكون انه Piston الـ لما حطيته بكون

ملامس التربة ولكن بالبداية ما يكون Fullcont مع تربة ف بكون

بالبداية قراءات غير صحيحة ، عشان نصلح الـ curve برسم مماس

(اللون الاحمر) بنلاحظ انه صار يشبه كيرف الطبيعي بس مو مبلشة

من الصفر، صارت بداية الخط جديد هي صفر وصار عندي shaft ف

رح نعمل إزاحة للارقام فلما بدنا ناخذ قيم بنوخذها بعد تعديل الكيرف


Plot correction
Resistance to Penetration (kPa)
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
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.

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

CBR (California Bearing Ratio)

تلخيص

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.

← بالعادة بتكون قراءة عند 0.1 اكبر من قراءة عند 0.2 وفي هاي

حالة بنوخذ قراءة 0.1 وهاد الطبيعي

← ممكن يصير انه قراءة 0.2 هي الاعلى بهاي الحالة

بنرجع نعيد التجربة هون عندي خيارين :-

الاول ← إذا بعد الاعادة طلعت كمان 0.2 اعلى فبعتمدها

الثاني ← إذا بعد الاعادة طلعت 0.1 هي الاعلى فبعتمد 0.1

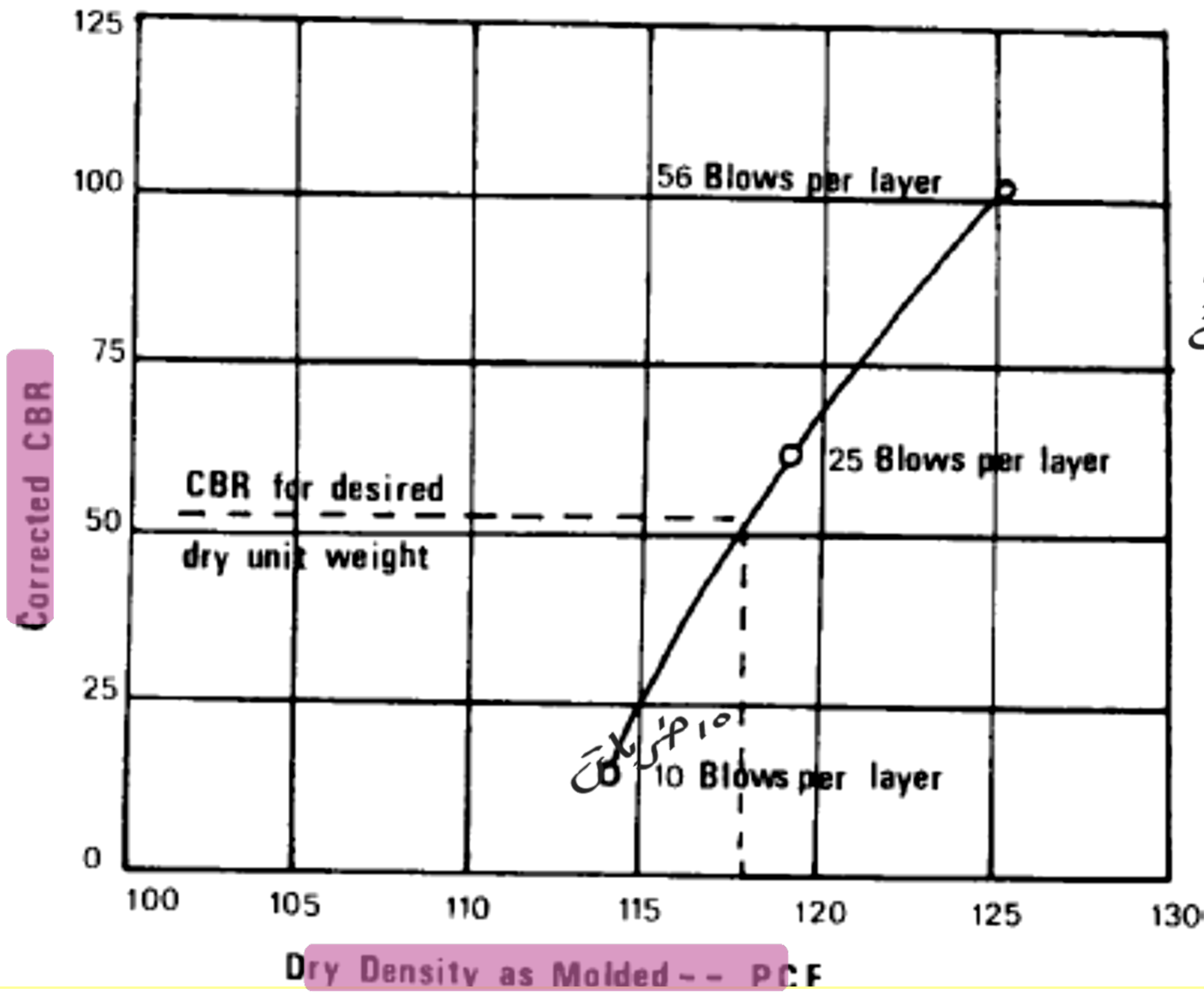
∴ بالحالة الثانية نعتمد نتيجة الاعلى شو ما كانت ★

← بسبب انه قراءة عند 0.1 اعلى مفروض يعني ليه stress عند 0.1 اعلى من عند 0.2

وذلك بسبب ممانعة التربة

Dry Density vs CBR

كلما زاد عدد ضربات يكبر CBR



moldes
مختلفين

الاختلاف بينهم
هو عدد الضربات

رح نشوف انه كلما زادت عدد ضربات بتكون تربة مرصوصة

الحشر فـ penetration بكون صعب فبعطيني ممانعة الحشر

لعالي CBR وكثافة أعلى

الفائدة من الرسمة : مثلاً بقدر اتوقع قيمة CBR عند عدد ضربات

معينة من خلال density

← لما نقلب القالب (بكون وزن القالب وحده معروف) بحسب

ال density وبكون اسمها dry density وبطلع مقدار رطوبة

Swell Determination

حكينا عنه بنحط قوالب بالمية لمدة اربع ايام ونحسب مقدار الانتفاخ نقسمه على ارتفاع التربة

- 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).

مسافة الي تحركها

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

ارتفاع عينة الاصلية

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

← كلما زادت نسبة بتعطيني كوالتي أقل

Frost Action in Soils

البرد القارص لفترات طويلة

- 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).

يكون عندي رطوبة التربة فلما تكون درجات حرارة كثير منخفضة

تتجمد فبزيد حجمها بصير انتفاخ فبحركي التربة ولما ترجع درجة

حرارة طبيعية بذوب الثلج فبعطيني نسبة رطوبة اعلى مما

يؤدي إلى اضعافها

: لما ترتفع نسبة رطوبة بسبب ذوبان الجليد بصير فيها ضعف

كبير

Frost Action in Soils

- Occurrence require: تربة قريبة من سطح الارض
  - Shallow water table that provides capillary water to the frost line; تربة قابلة يصير فيها هيك
  - Frost susceptible soil (*most sever in silty soils because upward movement of water in silt is faster than in clay*); عرضة الحر لهيك حالة
  - Ambient temperature must be lower than zero for several days.
- Treatment: معالجة
  - Remove soil subjected to frost action; تشيل التربة المعرضة يصير فيها
  - 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

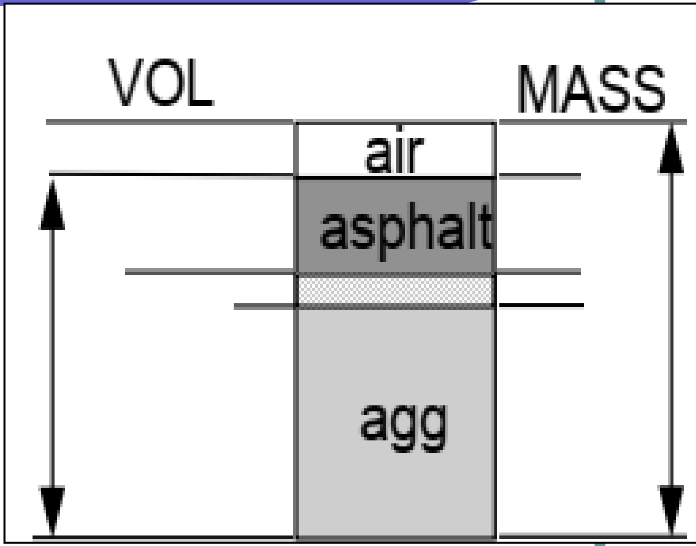
Asphaltic Concretes

10/8

- 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 → تحضر وتنفذ ساخنة
  - Hot-mix, cold laid
  - Cold-mix, cold laid

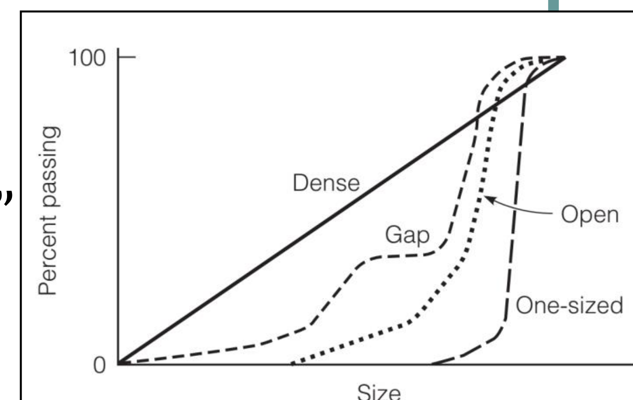
    Asphalt concrete مطلوب
  - Asphalt concrete should resist deformation from imposed traffic, skid resistance even when wet, and not be easily affected by weathering forces.

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 ºC) 170 -325 ºF.
- 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.

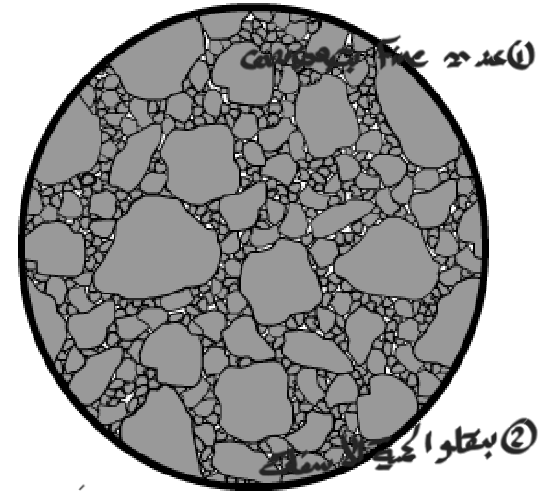


Dense Graded Asphalt Mixtures

- 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.

هوالأشهر

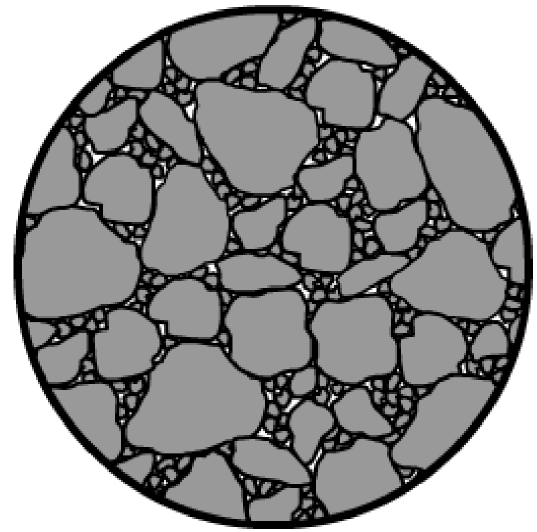
- Superpave, Marshall and Hveem are methods of designing dense-graded Mixtures



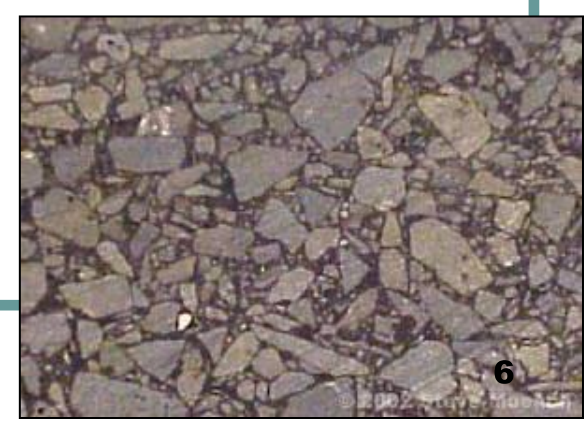
Dense graded HMA contains all sizes of aggregate particles. There are enough fine particles to effectivly separate many of the coarse particles. Therefore, stress transmission through the HMA structure relies on both the coarse and fine particles. VMA is generally between 11 and 17%, air voids are generally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

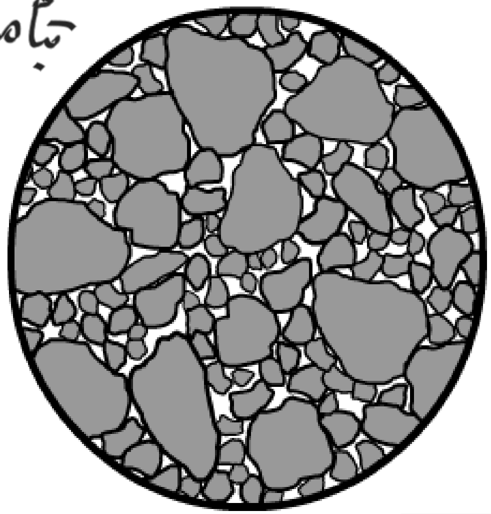


Gap graded HMA contains few mid-sized particles. Stress transmission goes through a coarse particle matrix, while the fine particles generally fill in spac between the coarse particles giving the HMA more resistance to deformation VMA (17%+) is higher than for dense graded HMA but asphalt binder conten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

uniform graded ← ممكن يعمل طبقات اسفلتية

تطبيقها :- تصريف ماء ، وعشان مرات بعملوا فيها

اشيا ديكورية (بكون singlesize)

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

- HMA Widely used in urban & rural areas.

يصمم و تنفذ بشكل جيد

- 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

قدرة تحمل بحيث يصير فيها deform بنسبة مقبولة

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.

لازم تكون

2. Durability: Property of compacted mixture to withstand the detrimental effects of air, water, & temperature changes. قدرة مقاومته للعوامل الجوية

Density of HMA

compaction ← density ← ارتفاع اقل

- Both stability & durability are related to the density of the mix.
- Density is expressed in terms of voids in the mixture.

  كلما قلت void بتزيد Density

  تعريف

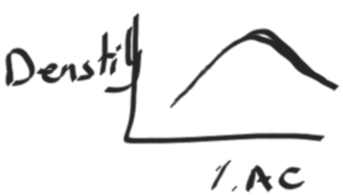
- Voids: Amount of space in the compacted mixture that is not filled with aggregates or bituminous materials (i.e. filled with air).
- Dense mixture…….low voids
- Loose mixture……high voids
- Extent of voids is determined by % of AC in the mix.

  ← كلما زادت كمية اسفلت فال air voids بتقل

Goal of Mix Design

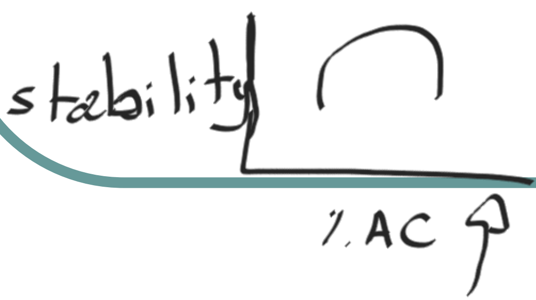
الهدف منه

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.



الهدف منه تحديد كمية اسفلت المناسبة

بحيث تعطيني خصائص معينة منه



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.

لما تتعبى كل void اسفلت

- It is not practical to say that the best AC would be the one that would just fill the voids in the compacted mixture.

الاسفلت بتمدد ← نزيف

- 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

كمية عالية

- 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.

تسريب هواء ورطوبة

فراغات العالية تسبب الاتي :- الهوا وماء رح يدخلوا
(ماء تسبب رطوبة)

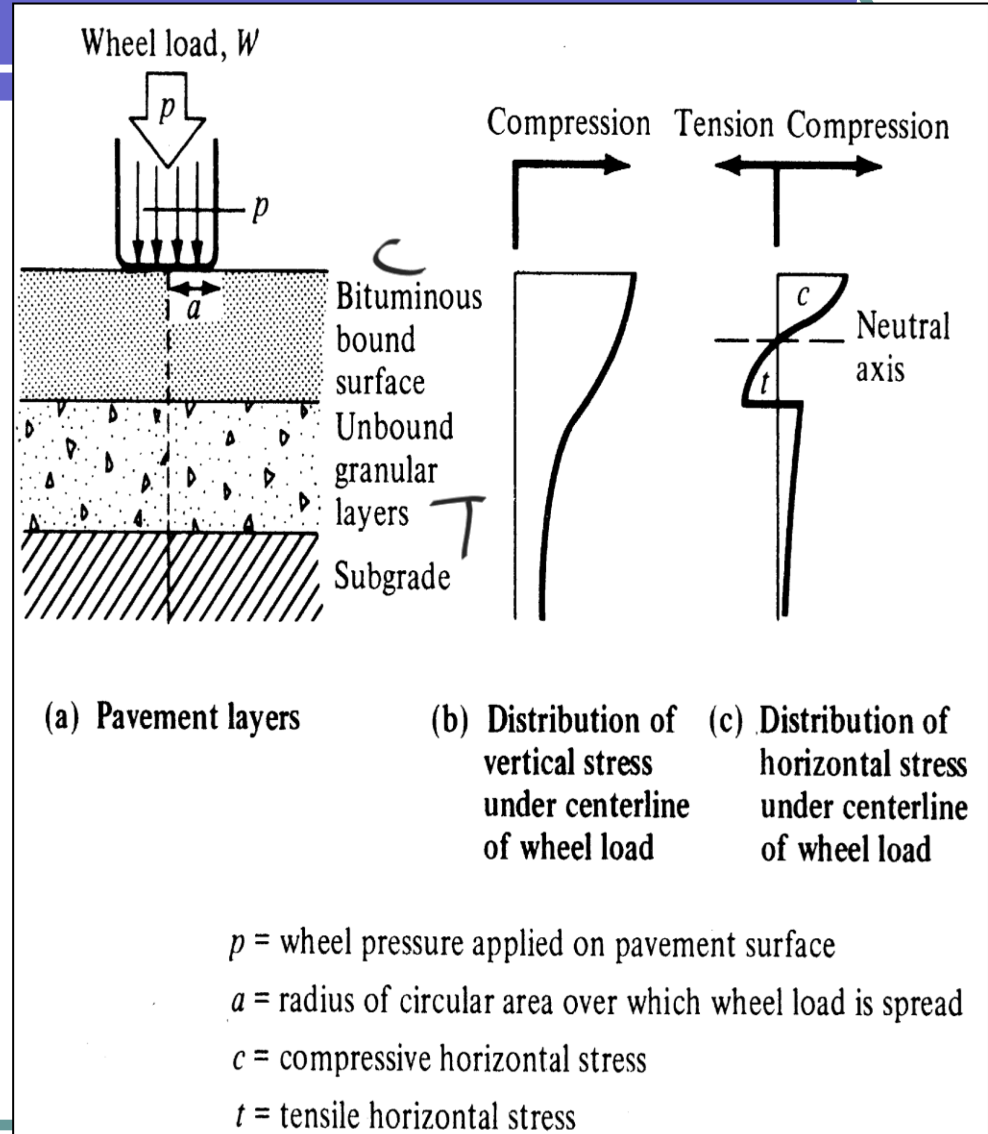
* الفراغات العالية لما يكون في ضغط علي ناتج من الاحمال

Sufficient workability ← السماح بسهولة الصب بغير
اي مشاكل

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.



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, <u>asphalt mixture behavior</u> 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.

Rutting (تخدد)

Desired properties considered for mix design
Resistance to Permanent Deformation

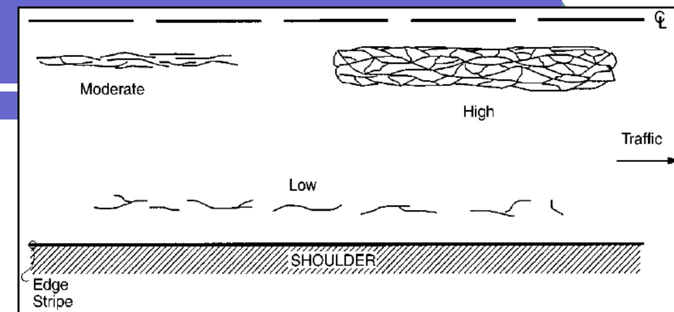
<u>Depends primarily</u> on:

- 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).

توصل لحد معين بعدها بلشت crack بمنطقة كبيرة

- 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

ما في سماكة عالية

  - Insufficient pavement thickness
  - Air voids فراغات كثيرة
  - Asphalt binder properties

طبيعة نوع الاسفلت

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

يحدث بسبب انخفاض درجات حرارة بشكل كاف لتولد اجهاد حراري تتجاوز قوة شد الخلطة الاسفلتية

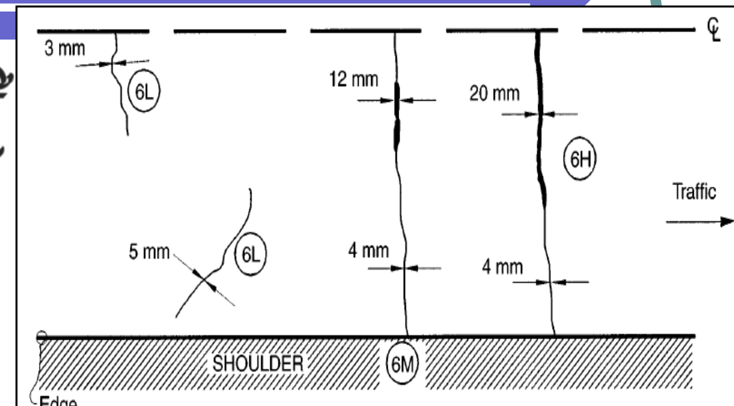
- Normally occurs when the temperature at the surface of the pavement drops sufficiently to produce thermally induced stress in the HMA layer that exceeds the tensile strength of the asphalt mixture.

viscous قليل

- In general, the solution to this problem is the proper choice of binder.

(طري) soft binder

اذا كان stiff بكون خطير



Desired properties considered for mix design
Moisture Resistance/ Impermeability

- A major durability problem is associated with moisture damage, commonly referred to as "stripping."
  انسلاخ
  - 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
    تطبيق
    عجلة سيارة لما يعمل ضغط ها ي ماء بتصير جوا فراغات بعدين برجعوا يطلعوا
- The best line of defense against stripping is:
  كمية اسفلت كفاية
  - Having sufficient binder in the mix
    تأكد انها انضغطت منيح
  - 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/

تلخيص :-

Rutting → strain → Friction↑, cohesion↑ → stifness↑ , temperature↓

[Stifness asphalt]

Fatigue → Bending → air void↑, thickness↓, AS prop

حلول :- ديزاين على load ، ازيد سماكة ، تحسين تصريف ، عدم تعرضها للرطوبة ، استخدم

خلطات اسفلتية كافية [Soft asphalt]

Low Temp → use binder with low viscous

Stripping → لما يكون في مي و load عالي بعمل مشاكل

Desired properties considered for mix design

Durability

- The durability of an asphalt pavement is the ability to resist factors such as

  Pavement عيوب بتصير بحياة

  - Aging of the asphalt
  - Disintegration of the aggregate تفتت
  - 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;

    بستخدم كمية اسفلت كافية
  - 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). دمك جيد

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 more workable are generally more prone to permanent deformation.
  - 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 <u>ensure</u> 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

تم تصميم خلطات اسفلتية باستخدام انواع واحجام مختلفة

- 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. دوره هو
  - Function in stability by interlocking & frictional resistance. اسئلة عليه
  - Crushed stone, crushed gravel, crushed slag.
  - Should be hard, durable, and clean.
- Fine Aggregates
  - Pass #8 retained # 200 دوره
  - Function in stability by interlocking & frictional resistance.
  - Crushed materials and sand. اسئلة
  - Void filling of coarse aggregates. دوره

void يملأ

Materials for Asphalt Concrete Paving Mixes

- Mineral Filler
  - Pass # 200.
  - Function in voids filling. امتلاء
  - Limestone dust, Portland cement, Slag, Dolomite dust.
  - Required to be dry & free from lumps.
  - Hydrophobic in nature. يكره ماء
- 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**

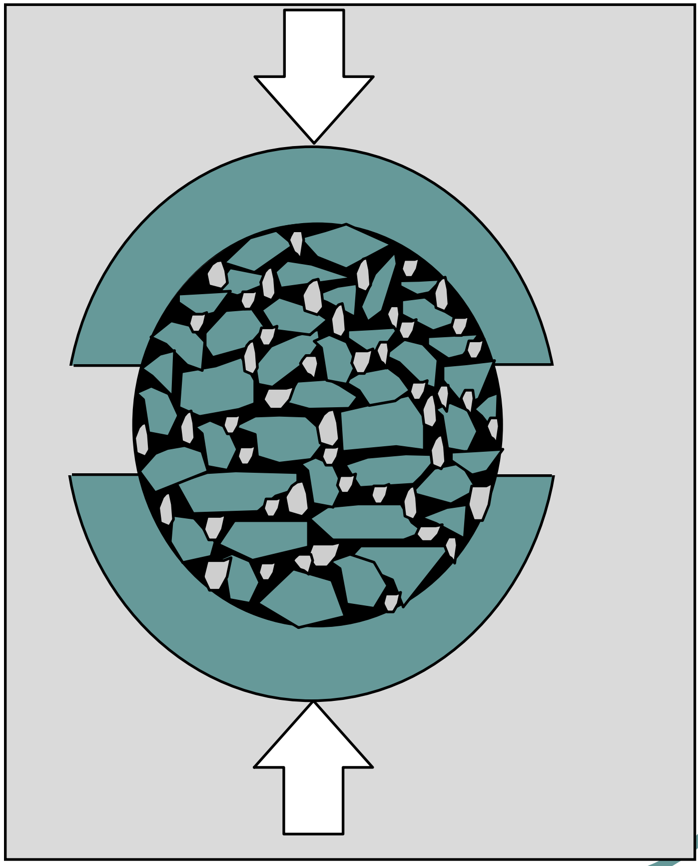
Currently used in Jordan

1993
- **Superpave**

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

MARSHALL MIX DESIGN

Part 1

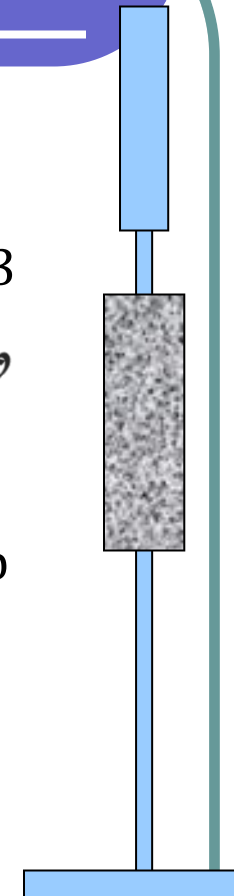


Marshall Mix Design

- 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)

  وزنه + ارتفاع + عدد ضربات كانه محدد
  - Evaluated compaction effort
    - No. of blows, foot design, etc.
    - Decided on 10 lb.. Hammer, 50 blows/side, 18" drop
    - 4% voids after traffic

  نفخ الطارق وتصميم أصناف للـ Pavement لكونه صار عنده سيارات اكثر
- 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 Mass (g)	Pass	Ret.
1"	100	100	100					
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			

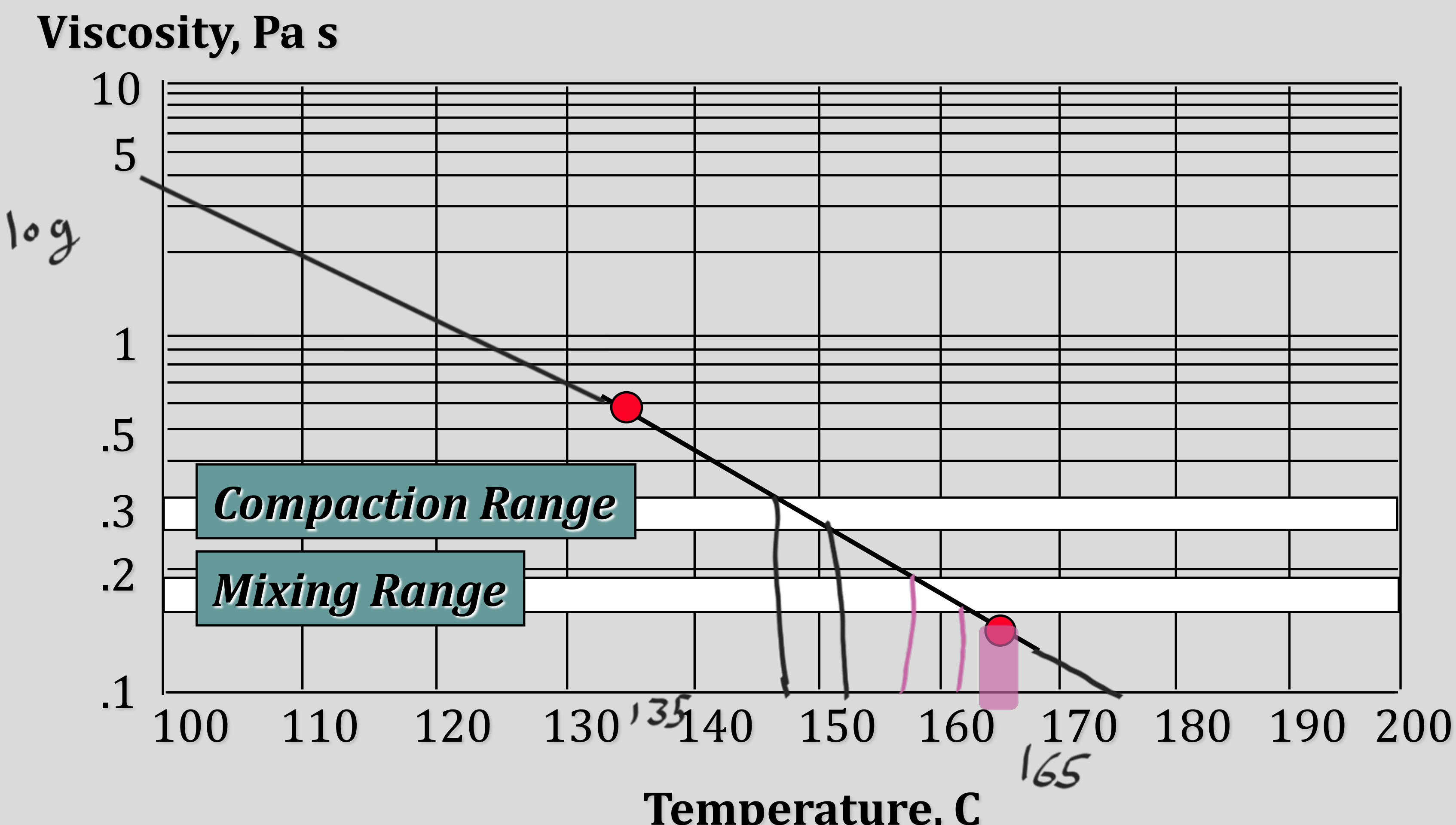
Marshall Mix Design Procedure Cont.

مفروض يكون مطابق للمواصفات

Step 2: Asphalt cement evaluation

- Determine appropriate asphalt cement grade for type & geographic location. ← * بختار الاسفلت حسب
- Verify that spec. properties are acceptable.
- Determine AC viscosity & S.G. ← نعمل عليه تجربه بس نختار
- 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



هيك بنحدد درجة حرارة mix و درجة حرارة com المناسبة لتجهيز خلطة

Marshall Mix Design Procedure Cont.

نجهز عينات مارشل

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. نضيف عليها الاسفلت بنسب مختلفة
- Weigh out 18 specimens in separate containers and heat to mixing temperature. بنسب جهزناها وصب اوزانه بنسخنه كمية اسفلت ونضيف على كل عينة نسبة مطلوبة
- 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). ارتفاع عينة الي عملتها compacted بعد ما ارتفاع الـ mold
- Adjust quantity of aggregate by Q = (2.5/h1)* 1150. نسبة وزنها
- Heat sufficient AC to prepare a total of 18 specimens

بامكانا نوضعها تجريبية عشان نتأكد من ارتفاعها

← بتقدر توخذ عينة تجريبية عشان تتأكد من ارتفاع بحيث

$Q = \frac{2.5}{h_1} \times 1150$ ، في حال كانت $h_1 < 2.5$ رح تكون الـ ratio أقل

من 1 معناها رح يعطيني رقم أقل من 1150 هون برجع لعمل

على أوزان الـ agg ، وفي حال كانت $h_1 > 2.5$ رح تكون الـ ratio أكبر

من 1 معناها رح يعطيني رقم أكبر من 1150 بحيث أنا بحاجة لزيد كمية

agg مشان تعبي الـ mold بطريقة صحيحة

⇑ وهاي طريقة تجريبية قبل ما نجهز 18 عينة

* كل عينات الـ 18 نفس وزنه رح نضيف الهم نفس كمية اسفلت ، حيث

كل 3 عينات بنضيف الهم 5 نسب مختلفة (حيث فرق بين نسب 0.5%)

مثلاً ← فلاكان الـ optimum 5% بوخذ نسبتين من اسفلت أقل منها بـ 0.5% ونسبتين أعلى من

0.5% يعني رح أجهز 3 عينات على 5% وبعدها بنزل 0.5% وبجهز 3 عينات على 4.5% وكمان

3 عينات على 4% وكمان 3 عينات على 5.5% و 3 عينات على 6% وح يكون عندي 6 عينات

مخلوطة على نسبة optimum هيك بصير عندي 18 عينة

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. ← نسبة اسفلت بحددها من خبرة
- Prepare three loose mixture specimens near optimum AC to measure Rice or Maximum theoretical S.G. (TMD = Theoretical Max density).

  رح تضاف كمية اسفلت للمكس من تحت نسبة مطلوبة (اسفلت يضاف كنسبة من mix مش من agg)
- *Note: Some agencies require that Rice S.G. conducted at all asphalt contents.*

  يعني 5% نسبة اسفلت في = 5% = وزن اسفلت / وزن مكس (من وزن اسفلت + وزن agg)
- *Precision is better when mixture is close to optimum.*
- Marshall mold is (4inch diameter X 2.5 inch height).

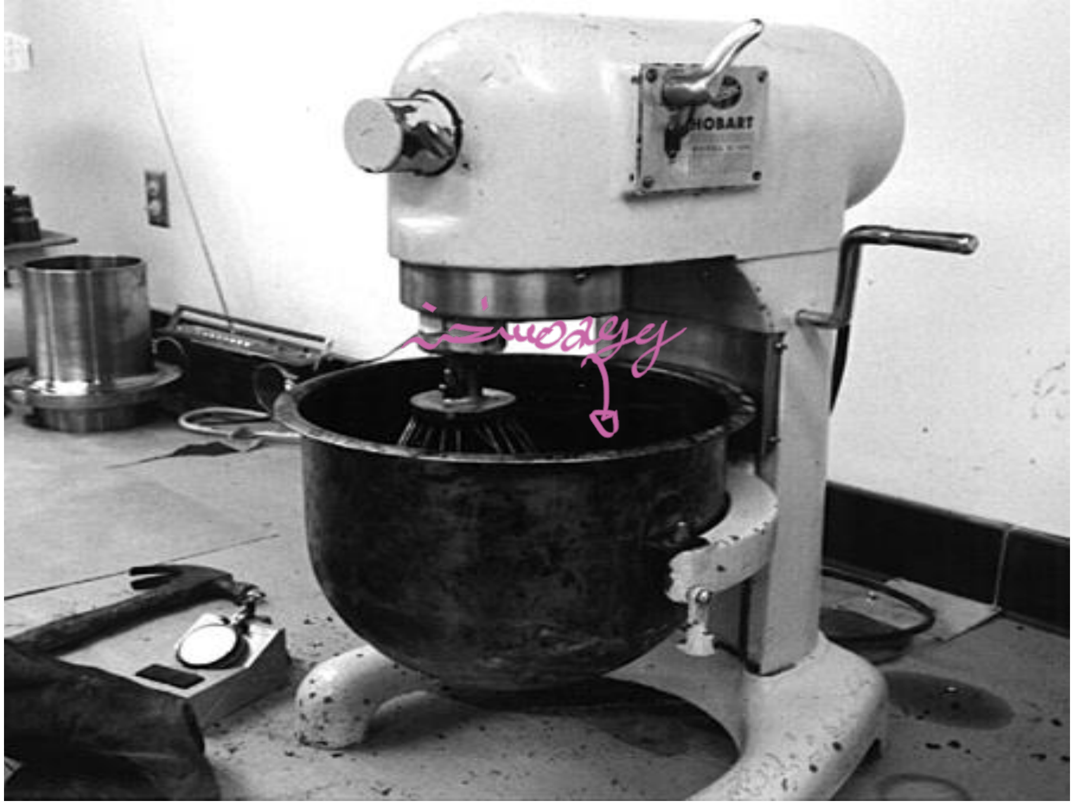
بعمل على 3 عينات لوحدها ناخذهم → optimum

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

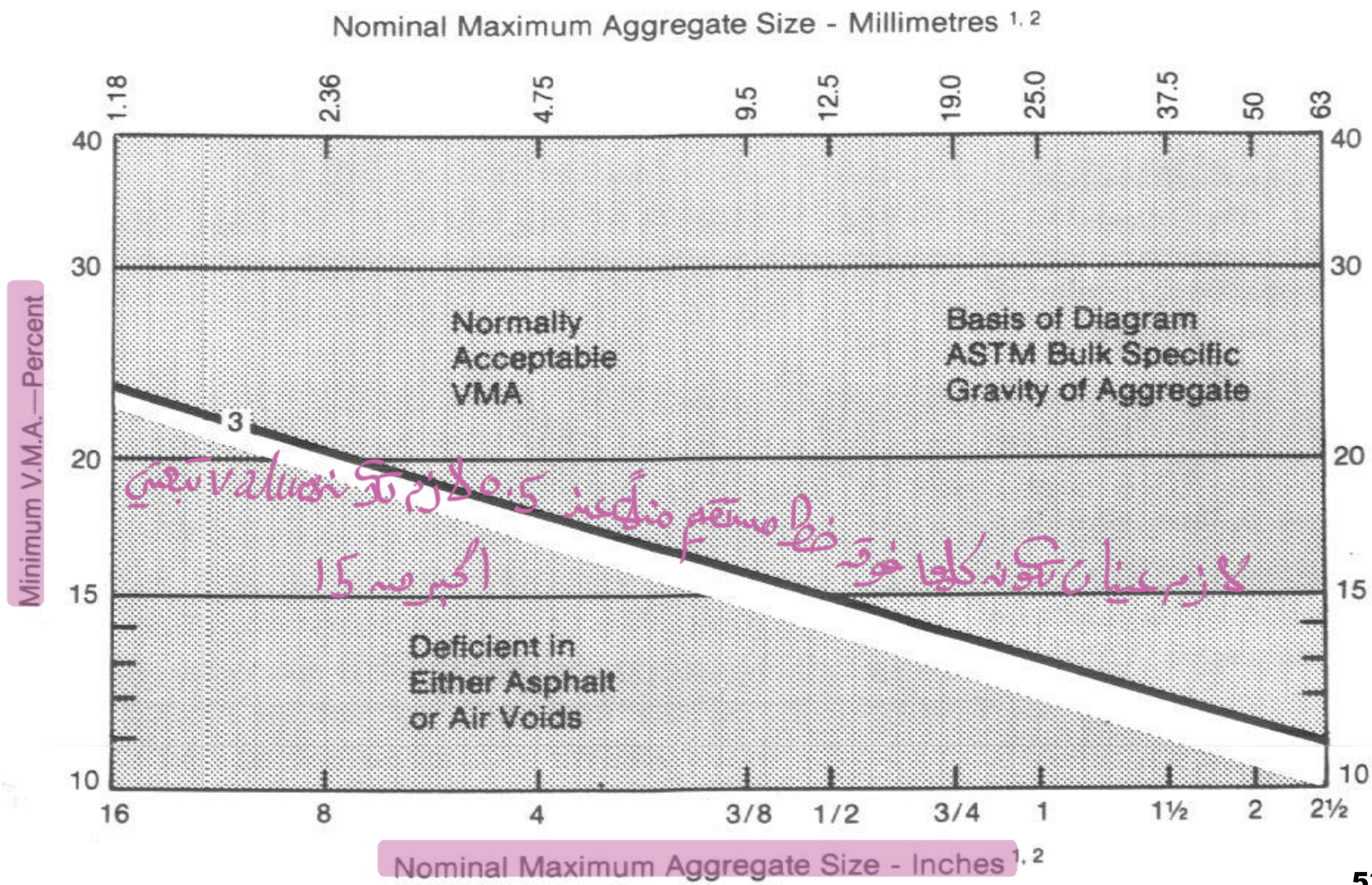
Place bowl on mixer and mix until aggregate is well-coated



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.

بعد ما تخلص compaction بنشيل فلتر ونتركها تبرد ونشيلها عن طريق jack

- Remove paper filter from top & bottom of specimen and allow to cool then extrude from mold using hydraulic jack.

نتركهم يبردوا

- Mark and allow to sit @ room temp. overnight before further testing.
- Determine Bulk S.G. of each compacted specimen.

15 العينة ، حيث كل 3 مخلوطين على نفس نسبة samples

- Measure Rice S.G. for the loose mix specimen.

← 3 عينات مخلوطين على نسبة optimum

الهدف رح نحسب volume للعينات ونقدر نطلع اشياء مطلوبة

Bulk S.G. of Compacted Mix

dry

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

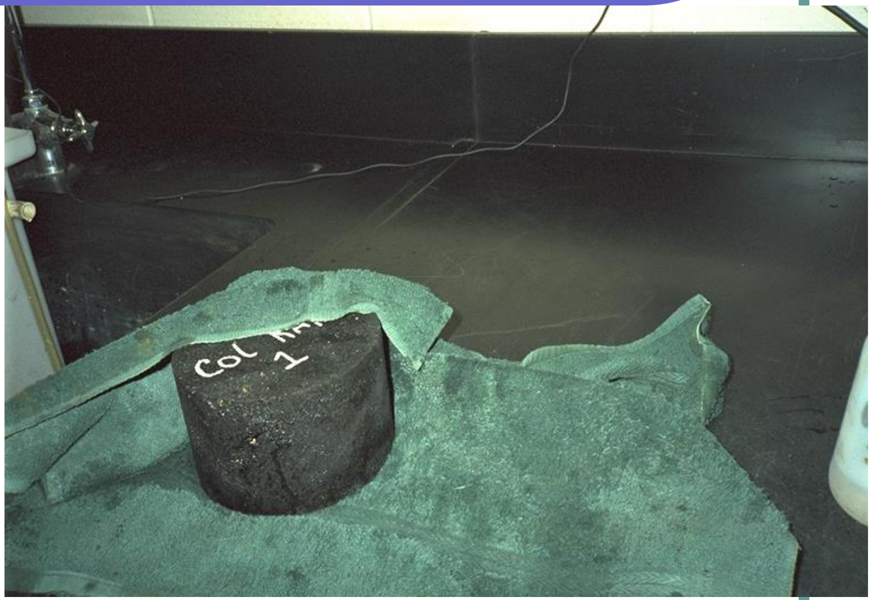
بنعملها على عينة compacted

رح نحسب لكل عينات وبالآخر رح نجيب

في افريج عند كل نسبة

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

Bulk S.G. of Compacted Mix Cont.



اخدوا شكل
mold

Rice S.G. of Loose Mix

هدفه احسب the max volume بعدها

- 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 (فصلهم).....Cool to room temp......place in container....determine dry weight (***A***).
- Fill pycnometer with water & take wt. (***D***). نسحب هوا فيها
- 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.

إذا شبه امتحلمه aqy عالية رح نعمل الآتي :- نجيب 3 عينات الي

عند شبه اسطهم بالفرن لمدة 6 ساعات على درجة حرارة mix فيتخلص

من ال visous اقل هدف هاد حتى ما اعيش حسابات عشان تكون صحيحة

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

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

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

← لأنو نص

نسبة mix مش عدد

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

S.G. of Aggregates

Bulk S.G. of combined aggregates

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

P_{Wt_i} = % by wt of material i

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

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

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

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

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

Effective S.G. of Aggregates

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

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

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

Pb = % of asphalt by total wt. of mixture

Gmm = Max. theoretical S.G

Gasp = Gb = S.G. of asphalt

Max. Theoretical S.G

نحسبها لكل نسبة اسفلت

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.

لح يكون عندي رقم عند كل نسبة فلأ ٤٪، ٥.٥٪ وهكذا

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

نسبة اسفلت — ثابت — ثابتة

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

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

Pb = % of asphalt by total wt. of mixture

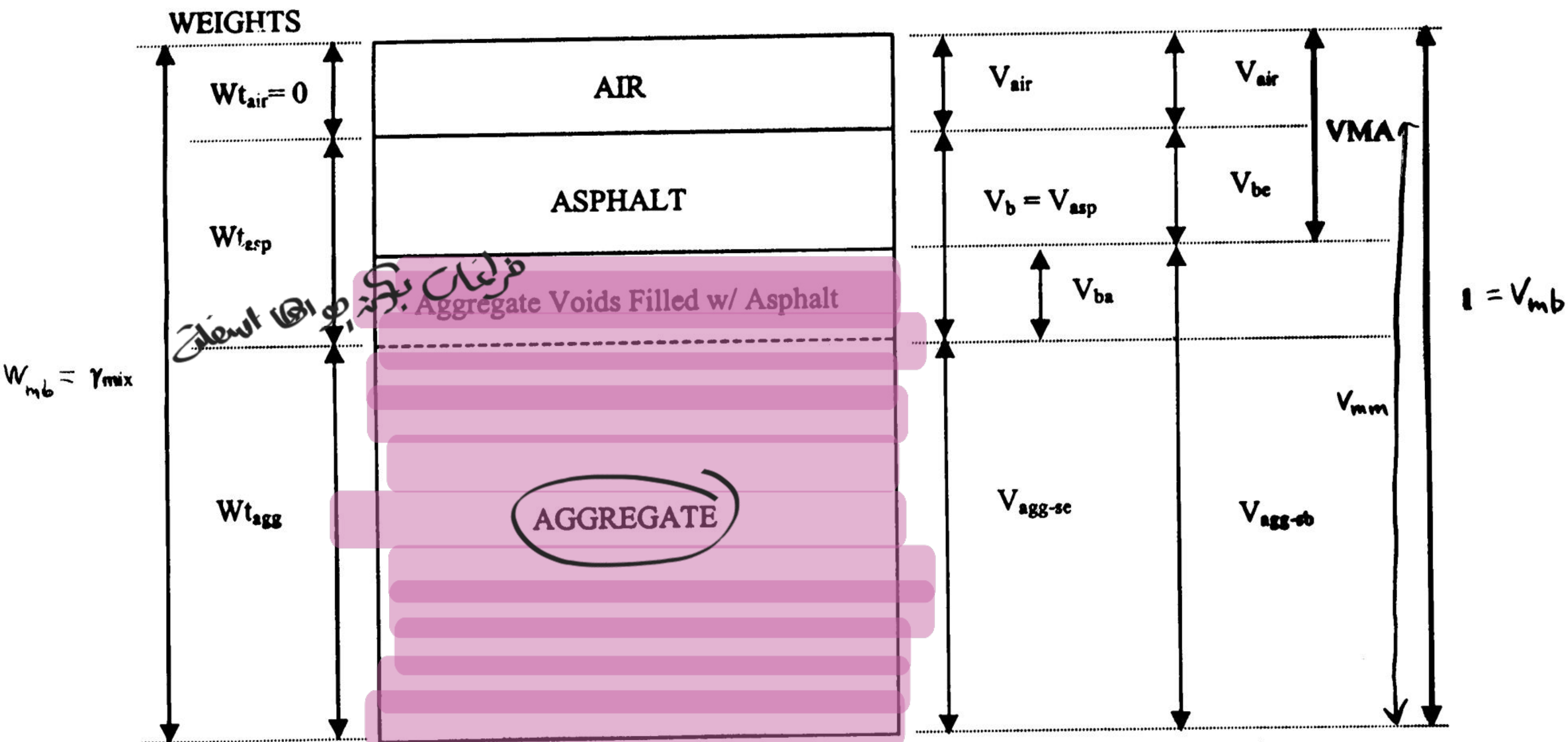
Gse = Effective S.G. of aggregates

فلأ بدي احسب Gmm عند ٤٪ بكون Ps = 96 و Pb = 4

Gb = S.G. of asphalt

Density Void Analysis

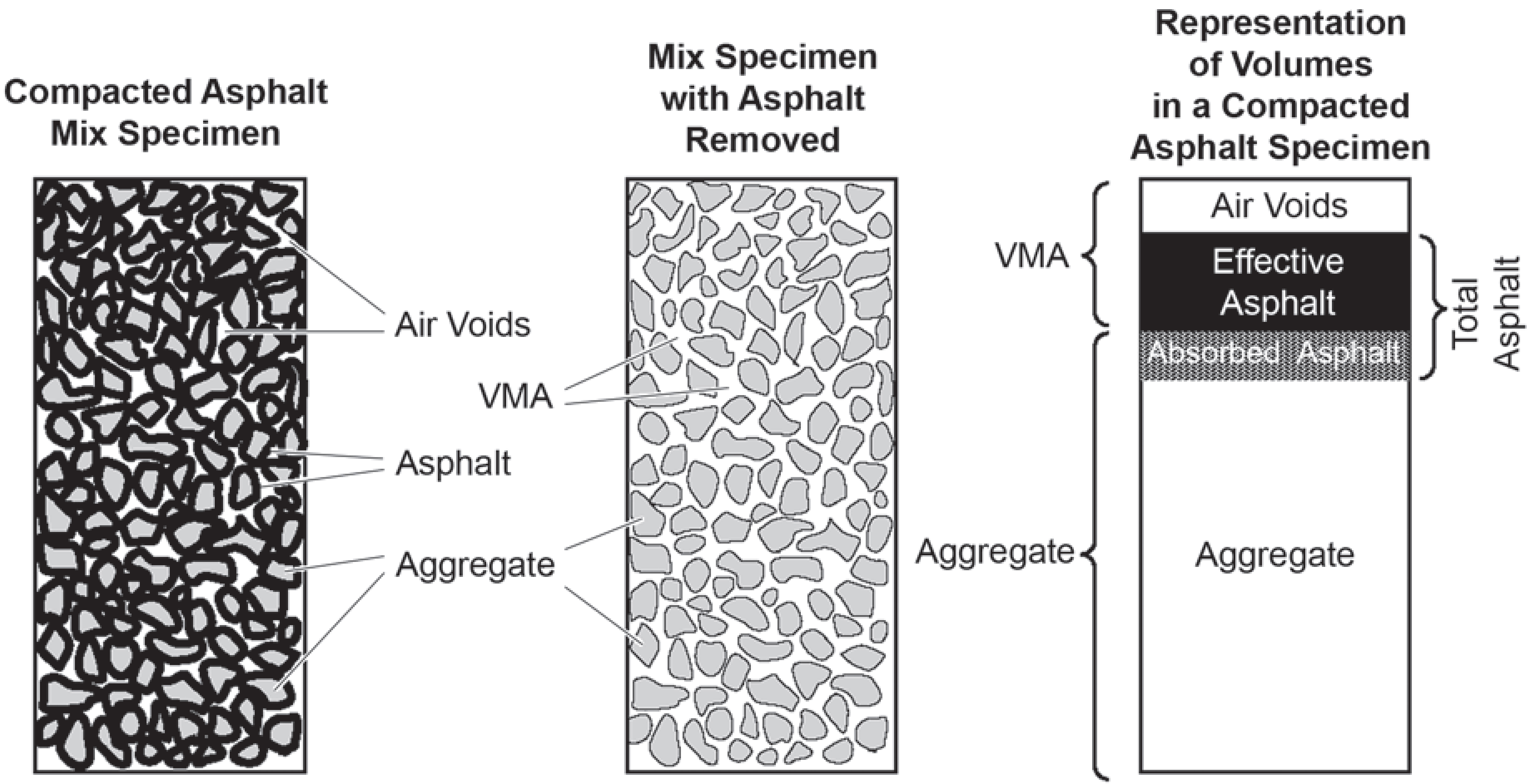
WEIGHT-VOLUME RELATIONSHIPS FOR ASPHALT CONCRETE



given γ_{mix}, % a.c. → weights

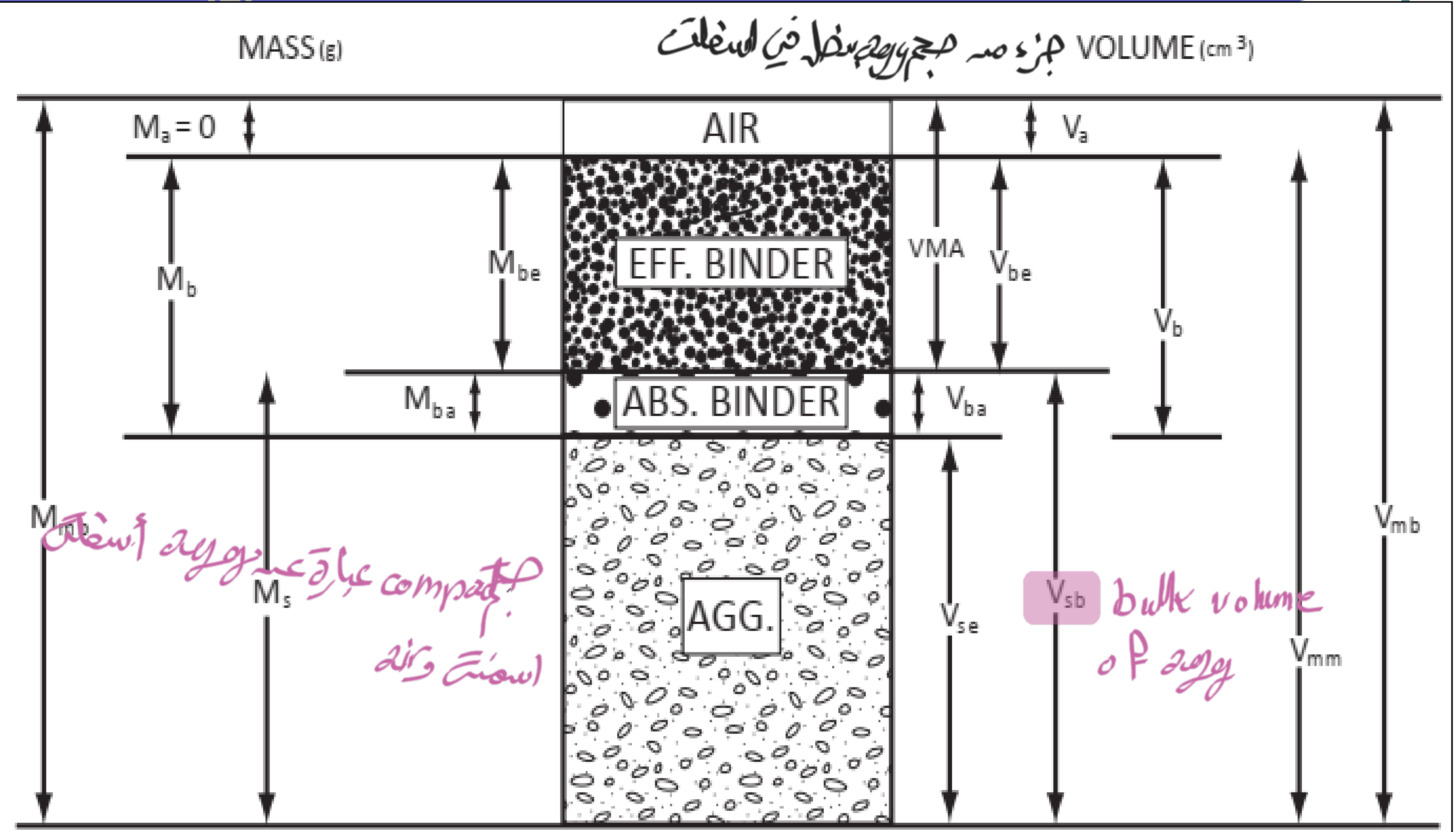
to convert to volumes → $G_{sb\text{-}od}$, G_{se}, G_{mm}, G_{asp}

Volumetric Analysis (Phase Diagram)



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

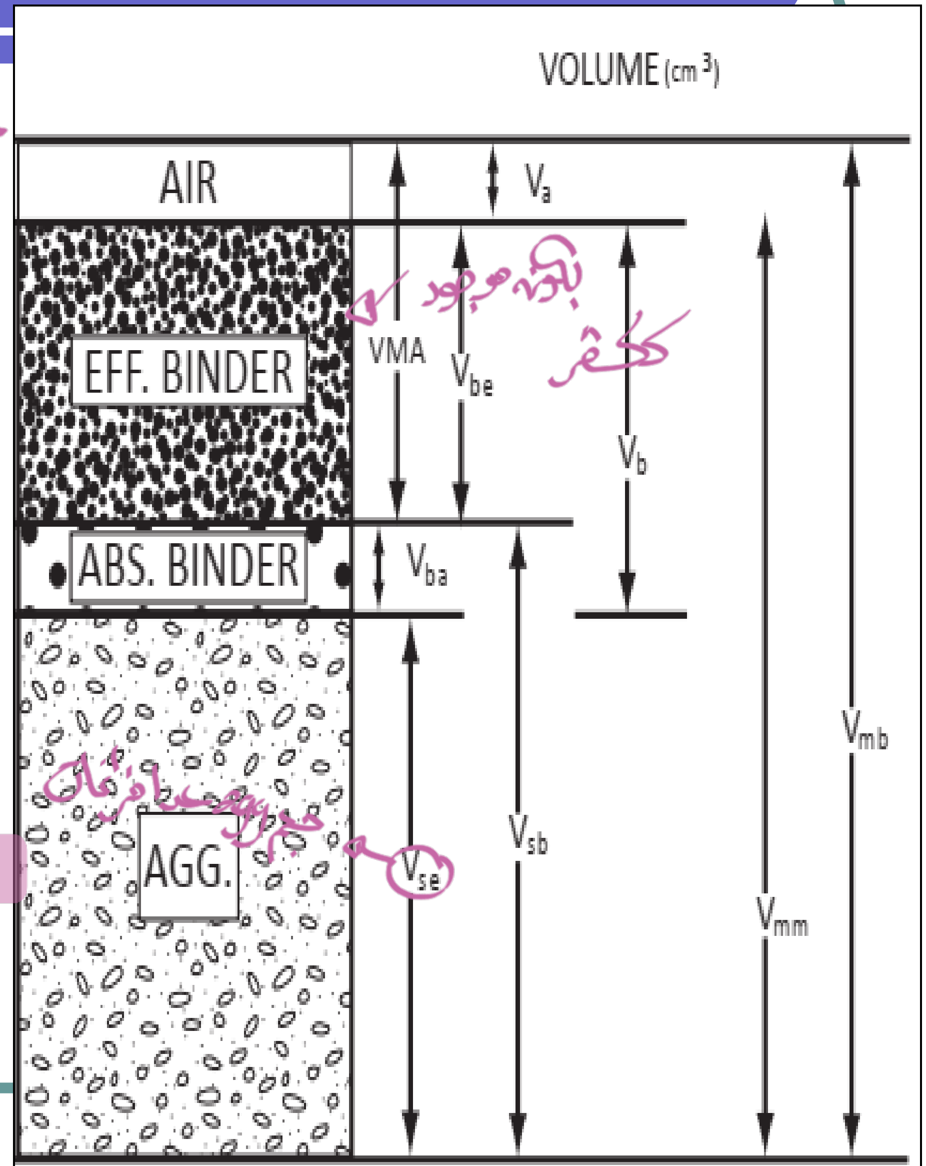
Volumetric Analysis (Phase Diagram)



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

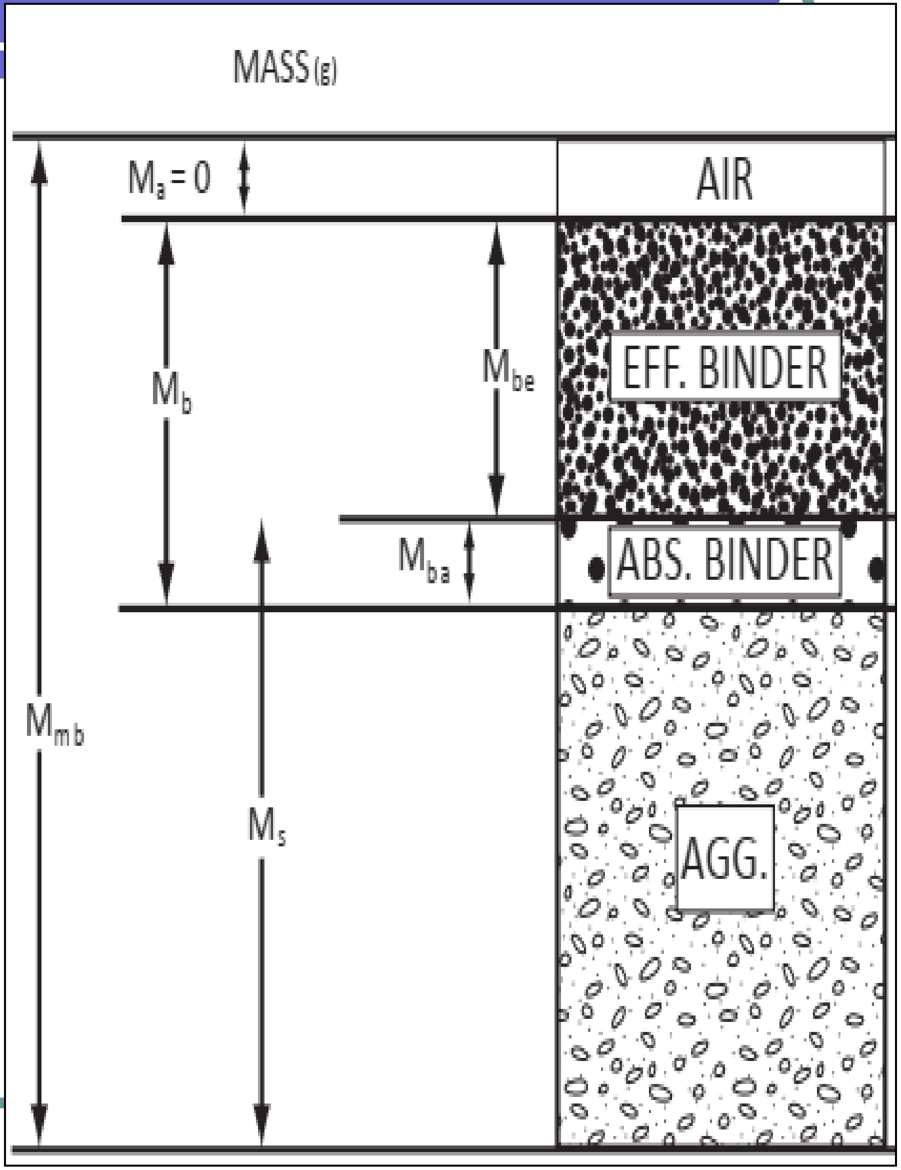


Phase Diagram

Terms

vsb = bulk volume * bulk density

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

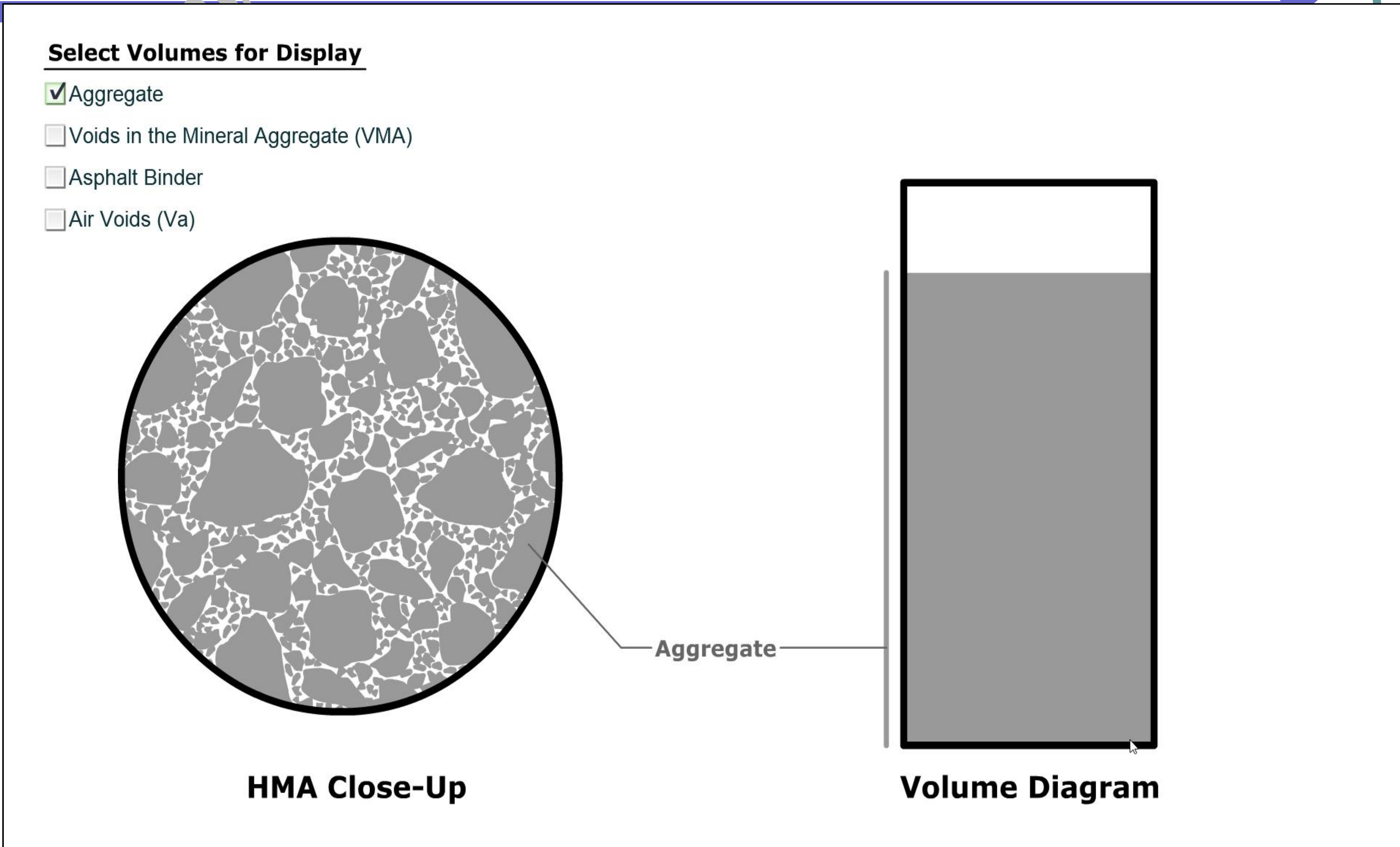


*Image source:*https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

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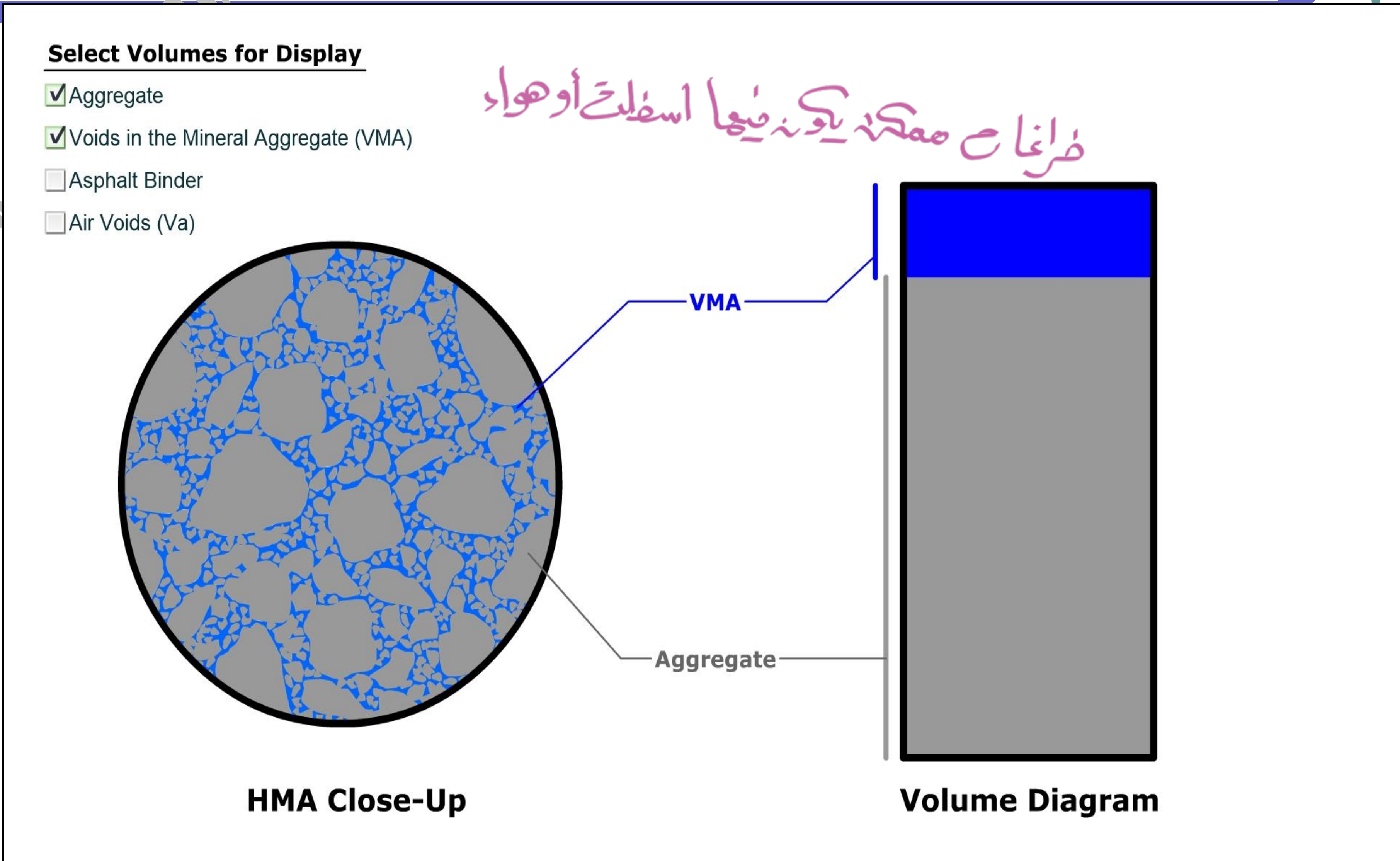

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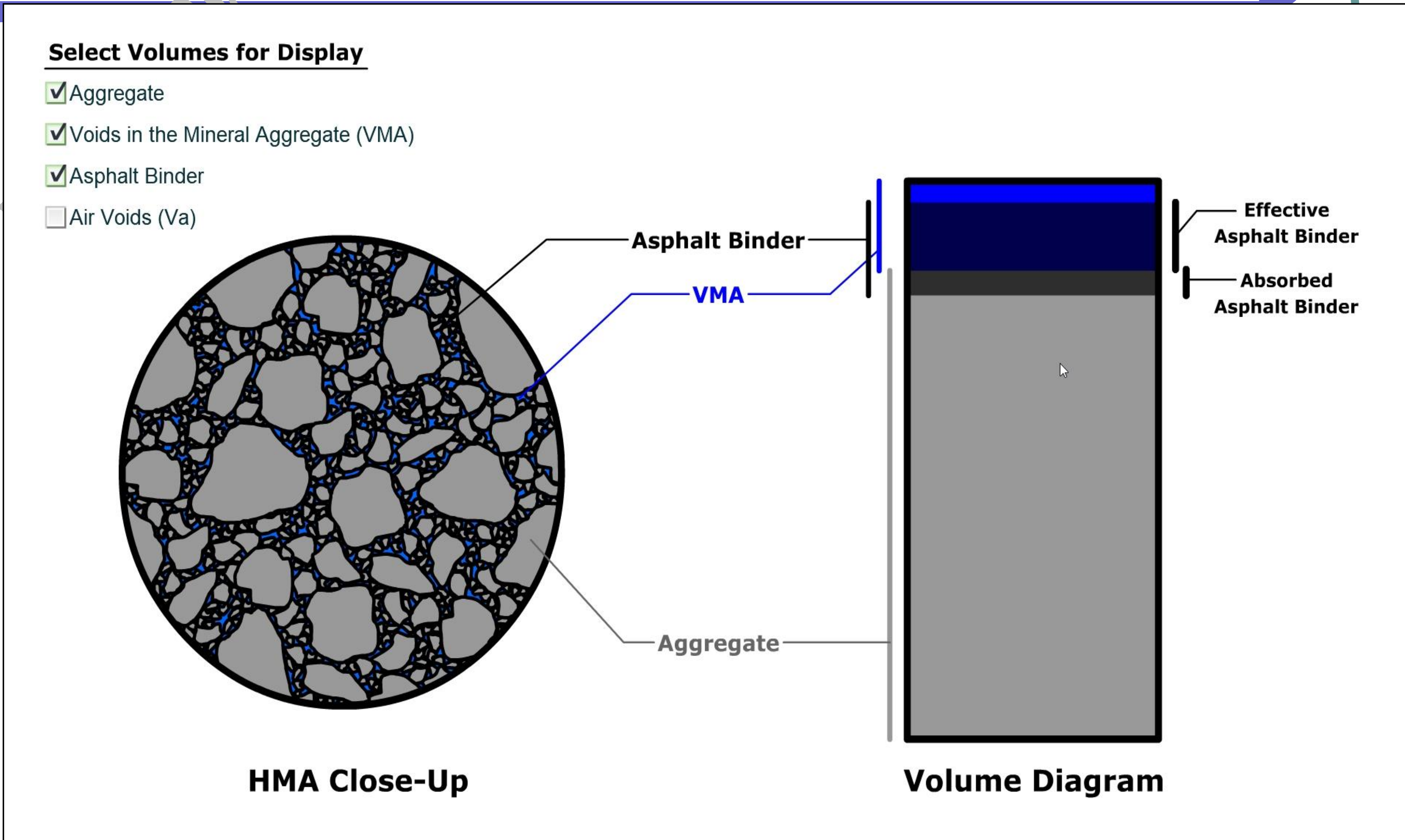

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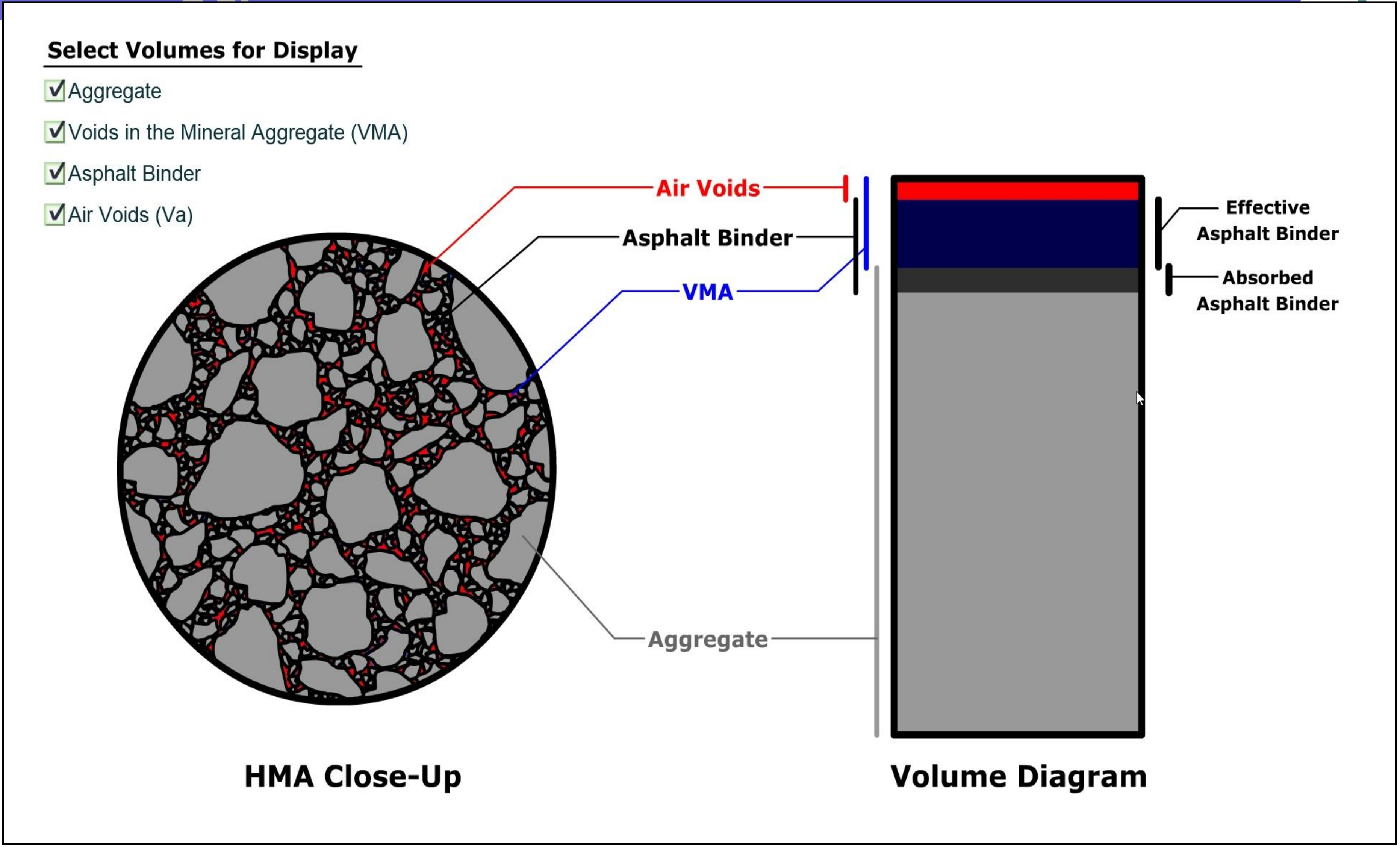

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Density & Void Analysis (Volumetrics)

مهم

حجم = كتلة / كثافة

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

اصغر منه sb بسبب فراغات

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

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

فراغات الاسفلت

أو V ba = vsb - vse

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

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

عشانه نحسب حجم إذا معروف عندي mass و SG

% Air Voids

VTM

Part 2

كمية فراغات موجودة بين الـ particles اللي مغطية بالإسفلت

- 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

مفروض ما يكون عنا فراغات عالية لأنه بتخلي يدخل هواء وماء فبتعمل مشاكل

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

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

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

مهم

من دي بقرام

3 ≤ %Vair ≤ 8

صار عندك نسبة اسفلت في نسبة VTM

Density of Compacted Mix

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

توتل حجم

max density

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

Vmm

كل حجم ماعدا فراغات الهوائية

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

Voids In Mineral Aggregates (VMA)

هي حجم فراغات موجودة بين ركام والي رح تتعبى اسفلت وهوا

- 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.

لما تكون VMA قليلة معناها ديمومة معرضة لمشاكل لانه بتهل لما تكون مساحة اقل من الاسفلت الفعال
فرح تتأثر سريعة تأثر بالعوامل الجوية

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

(P_s →) نسبة وزنية

او من رسمه

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

Voids In Mineral Aggregates (VMA)

- VMA represents the void space between aggregate particles.

* الاسفلت موجود يعطيني cover لا وجوه ويأثر على الرابطة بينهم

- 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.

* بكون عندي كمية اسفلت منيحة بحيث يعمل coating ويحافظ عليه ديمومة

- 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.

عشان صعب نحققها نوعا ما فصار عندي min value

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

اشياء تؤثر على VMA :-

Minor :- ① نوع الاسفلت ، يعني مثلاً إذا استخدم binder الـ viscosity العالية فبكون عندها ممانعة أكبر لعملية compaction فبولد فراغات

② كمية الاسفلت :- لما تكون كمية عالية بكون على حساب فراغات فلتر على خليط و إذا كان قوامه وكميته مناسبة فيساعد على عملية compact وبقلل فراغات ، كمية اسفلت لازم تكون optimum .

③ لما تبرد مرارة بصير اسفلت more viscosity فبزيد VMA

برضه agg بأثر بحيث إذا استخدمت agg تكون ابعاده متساوية بزيد ممانعة compaction فبزيد 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

Major : العملية compaction، كلما عملت زيادة بغير قيمة VMA

وتدرج agg اله التركيب حاله VMA

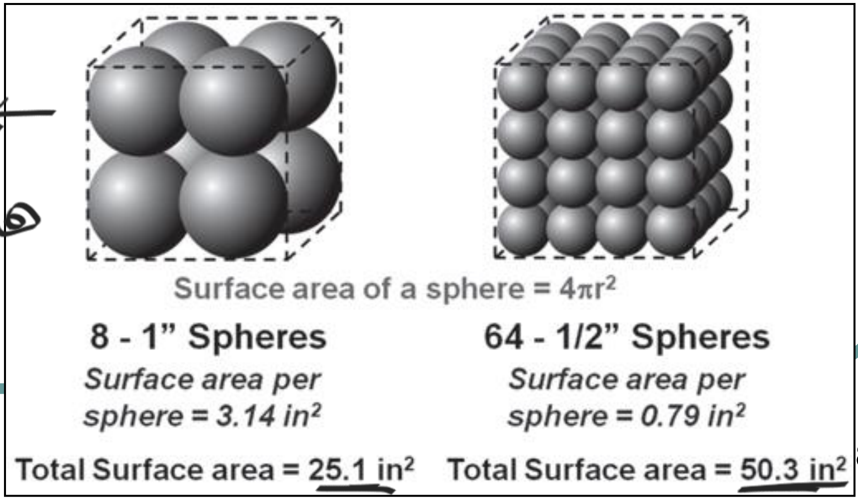
← إذا نستخدم تدرج مش dens فلًا معناه يكون في فراغات اكثر فبزيد VMA وفي حال استخدمت dense يكون نسبة فراغات اقل

Effect of Aggregate Nominal Max Size on VMA

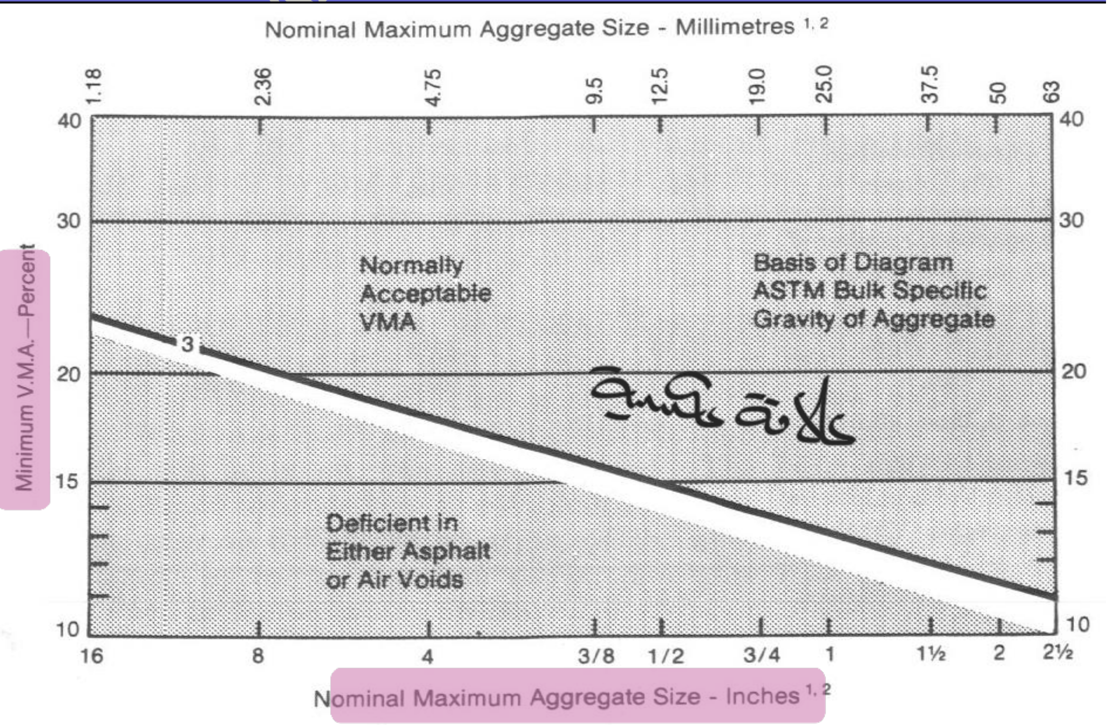
حجم يوجد بأعلى كمية VMA الطوبة ، لما يقل حجم بزيد مساحة سطحية

- 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.

كلما صغر حجم particle زادت مساحة سطحية ←
هاد يعني بحاجة كمية اسفلت زيادة لتغطية مساحة و
VMA أكبر



Effect of Aggregate Nominal Max Size on VMA



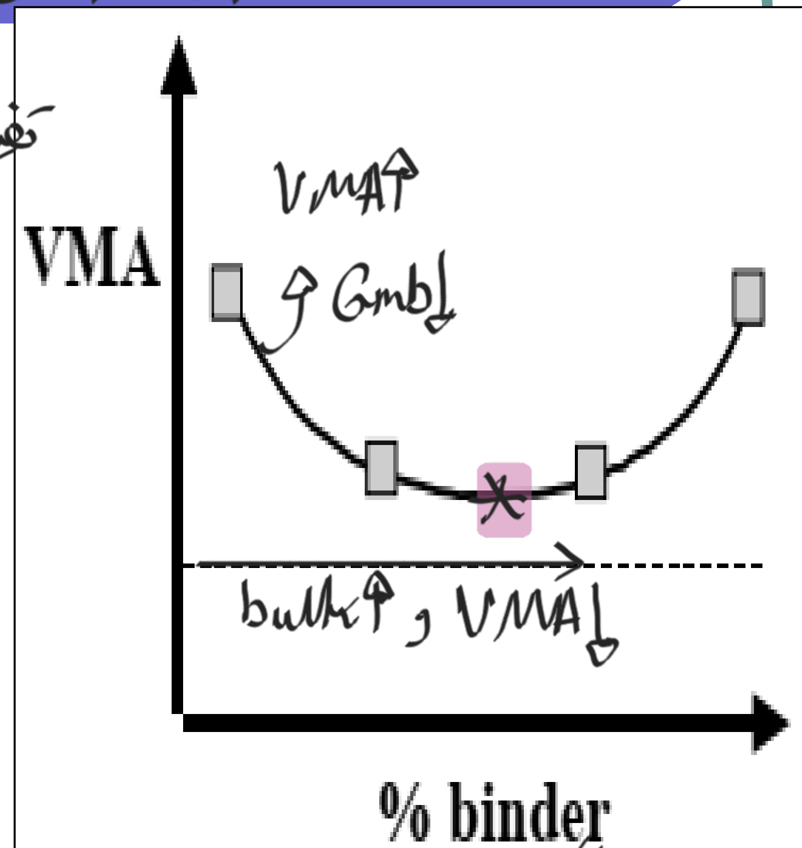
كل ما كانت ال partil اصغر كل ما كانت ال VMA اعلى

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)

يربط agg مع بعض

- 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

max Field

- 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

Part 3

هي تجربة مارشال مطلوب ارسم 6 رسمات

- 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

ارتفاع مطلوب 2.5 mm

Correction Factors		
Volume of specimen in cm^3	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

سماكة عالية ← ↑stable

إذا كانت سماكات أقل فلازم

ازدد stable

SHARDA UNIVERSITY

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

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

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

بالنسبة لـ Air void و VMA و VFA بنحسب

one value عن كل نسبة وقانونه هو سلايد 75 لـ

air void و VMA سلايد 77 و VFA سلايد

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بالنسبة لـ Measured stability معروض نعمل تصحيح

بناءً على ارتفاع عينة (بتكون اصلاً قايسين ارتفاع العينة

وعارفين any للارتفاع وطالعين تصحيح) فبضرب

رقم تصحيح بـ measured stability

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

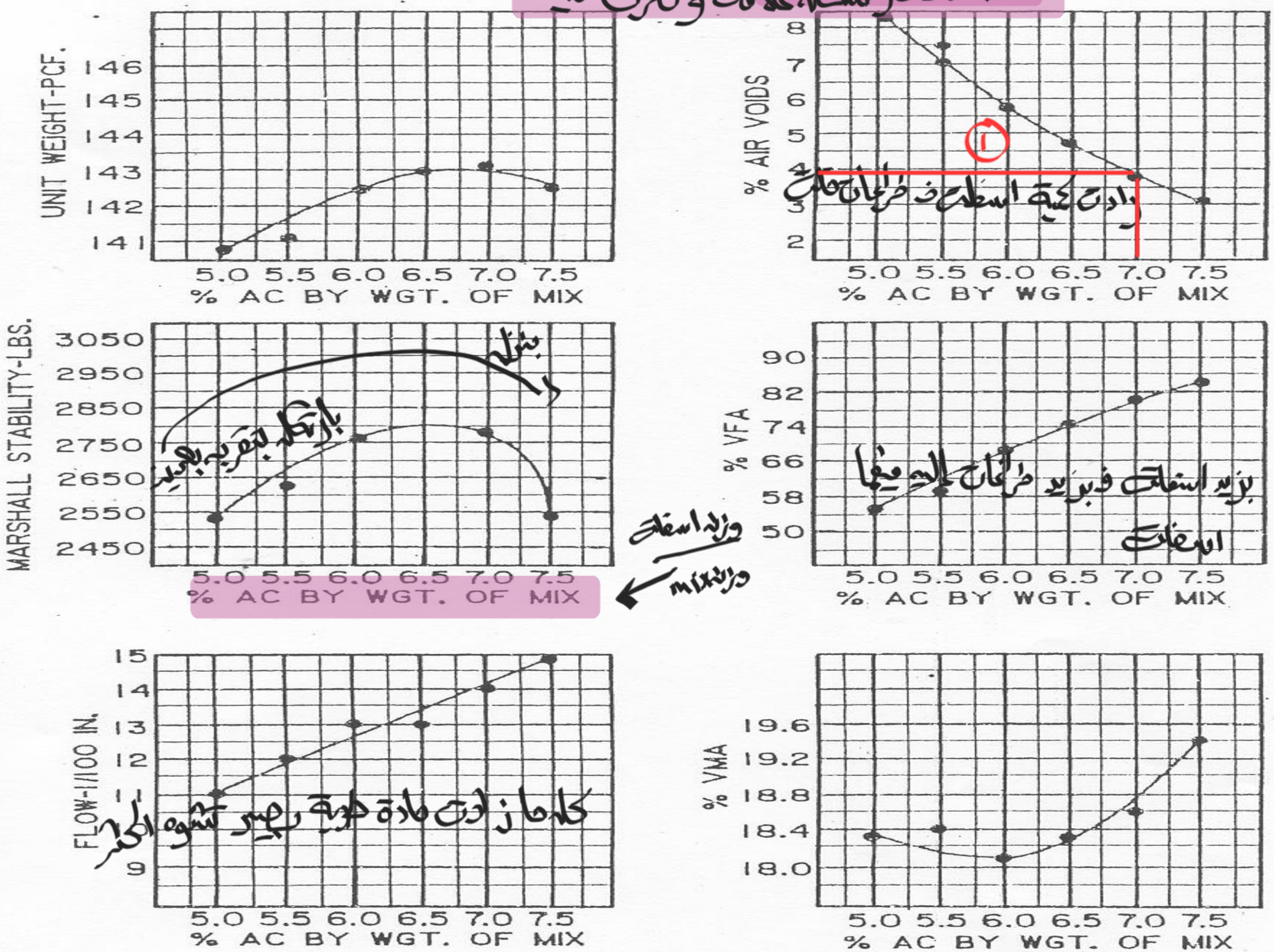
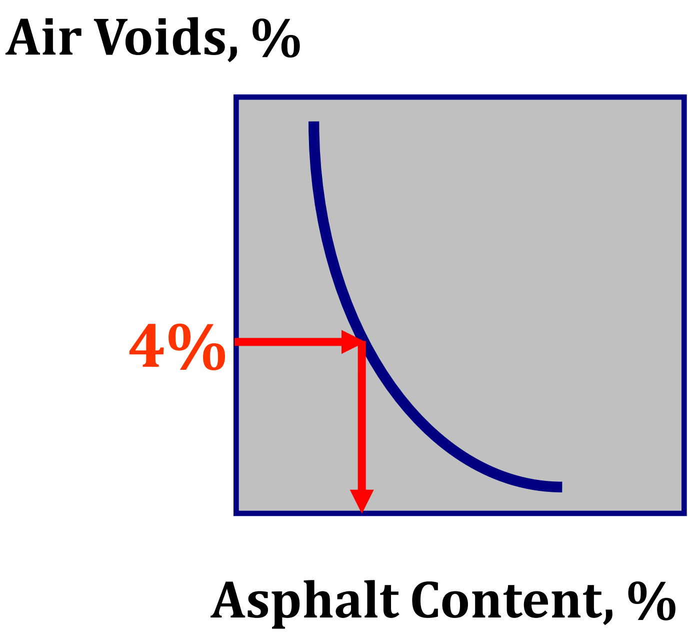


Figure 4–24. Graphical Illustration of HMA Design Data by Marshall Method

Determination of Optimum AC Content

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

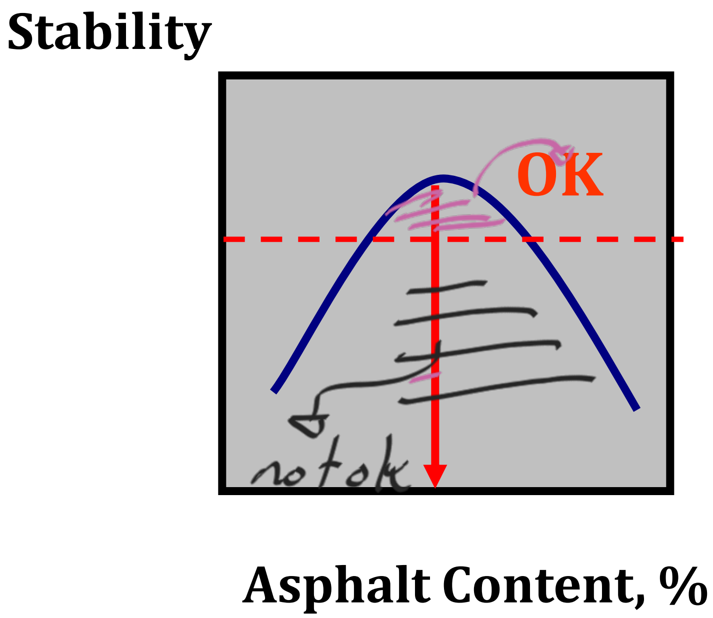
(NAPA) Procedure



Target optimum asphalt content =

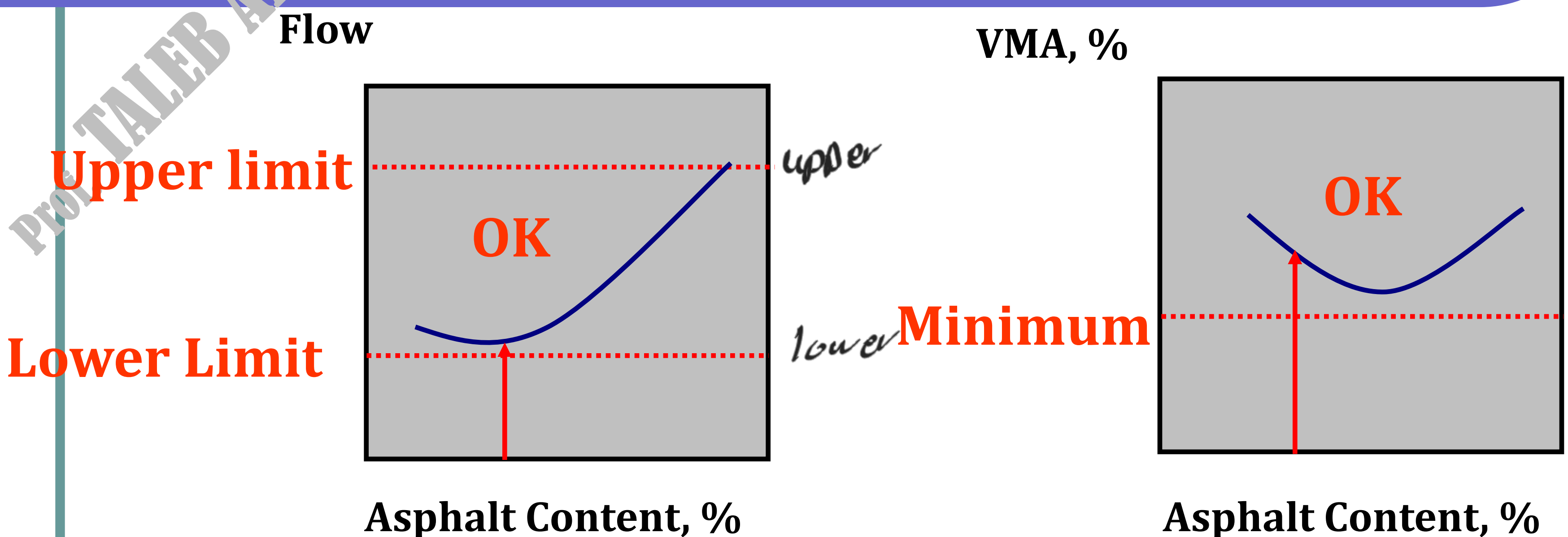
the asphalt content at 4% air voids

Marshall Design Use of Data NAPA Procedure



The target stability is checked

Marshall Design Use of Data
NAPA Procedure

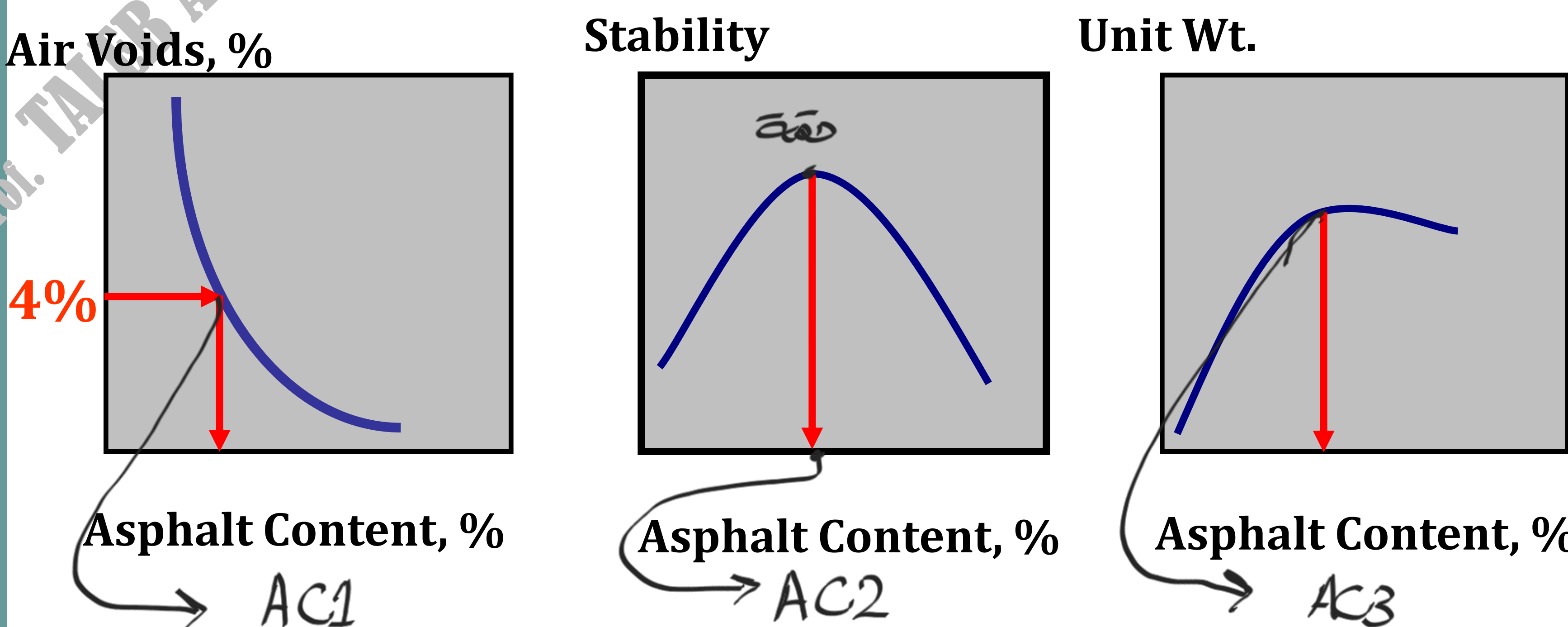


Use target optimum asphalt content to check if these criteria are met

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

*إذا كان في منهم عم طال بكون بحاجة اعدل mix

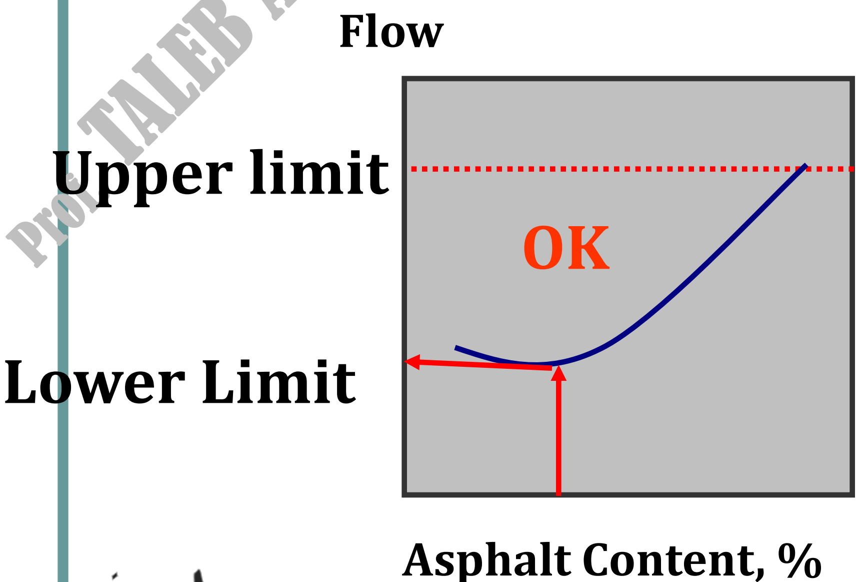
Marshall Design Use of Data
Asphalt Institute Procedure

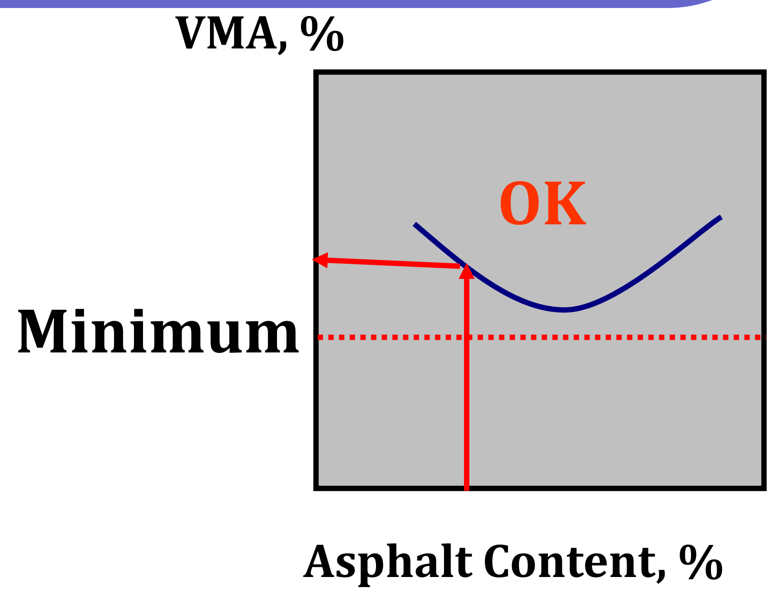


Target optimum asphalt content = average

بتوخذ range وبتطلع كل رسمات وبتحقق انهم بحققوا ال criteria

Marshall Design Use of Data
Asphalt Institute Procedure





بنشيك عالـ air void

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

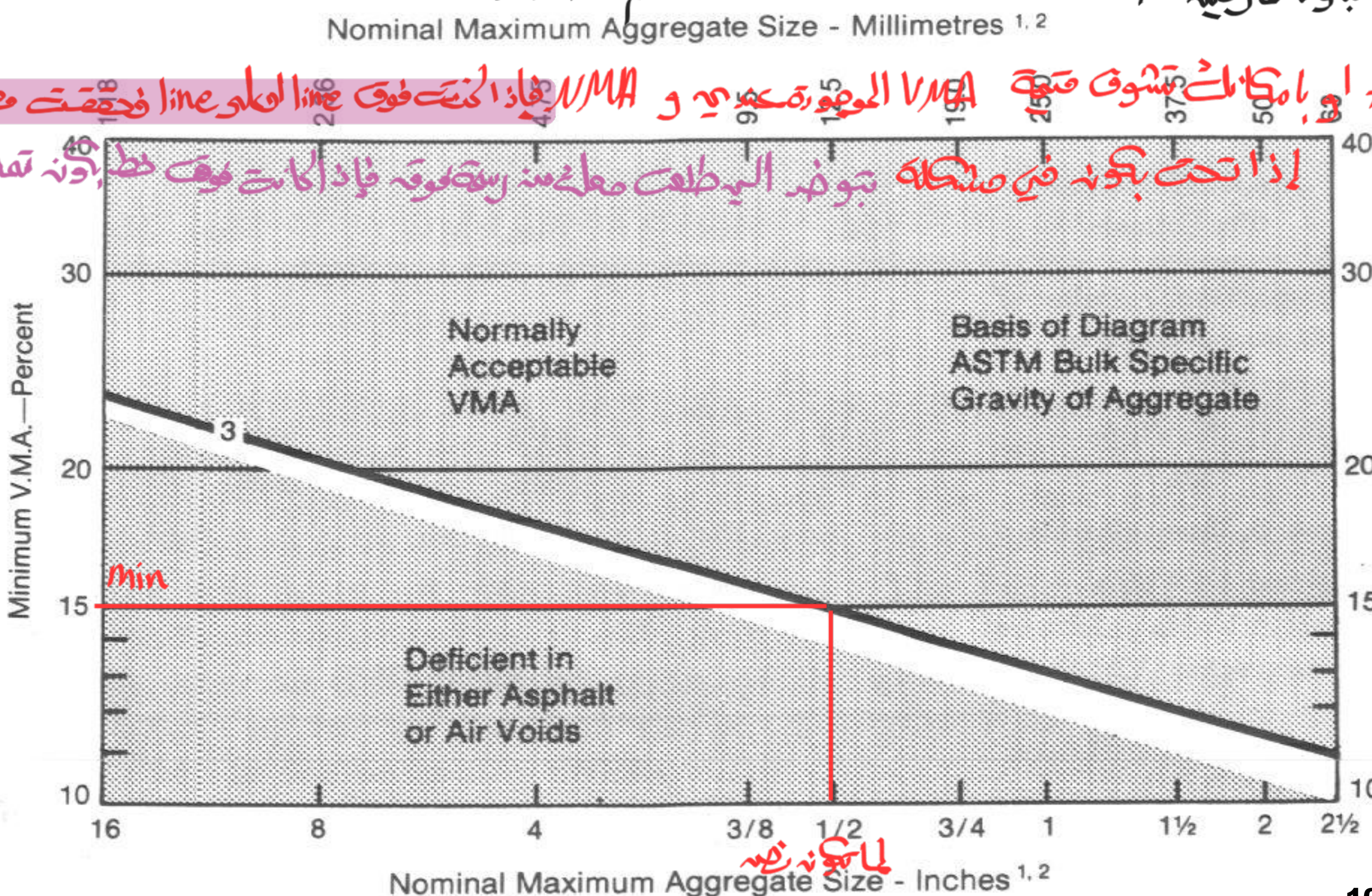
(If not - adjust slightly to meet all criteria if possible; else change gradation and repeat analysis)

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.)	min 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

$4\% = \frac{3+5}{2}$ افرض

Minimum VMA Requirements



Guidelines for Adjustments

طريقة تعديل

- 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

الحسقفت منه انه airvoid او VMA او low stability

① إذا بدي ازود VMA فبحط coarse agg

- VMA can be increase by adding more coarse aggregates.

② نقلل كمية الاسفلت (بس بدك تتأكد انك الجهة البعيدة بالوسة)

- 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. ← مجرد ما عدلت رح تتعدل void و رح تتحسن stability

Low Voids & Satisfactory Stability

بإمكاني ادخالها coarse

- 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 coarse aggregates.

← لما يكون عندي فراغات قليلة مع زيادة حركة traffic عليها ممكن تعمل نزيف

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

اول اشي بنحل مشكلة void

- Two steps can be carried out:

1- Adjust the voids (increase mineral filler).

- If stability is not improved

ممكن إذا عدلته مرة ثانية تتحسن stability

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).

خلطة تضل workable حتى لو بردت

- 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.

agg بعد تجفيفه + نشاط MC-30 + ماء

* يتم تحضيرها وهي ساخنة ويمكن استخدامها مباشرة أو تأخيرها لوقت ثاني

* استخدامها ممكن لما يكون ما عنده كميات كبيرة يتم تحضيرها بخلاطة مركزية

* فقد تستخدم طريقة مارشل في عملية تصميم ولكن يفضل استخدام low viscosity asphalt

* حرارة بدها تكون قريبة من حوالي 76° و يتم تنشيف aggregate عن طريق تسخينه نخلطه مع اسفلت

Cold-Mix, Cold-Laid Asphalt Concrete

- Emulsified asphalt and low viscosity cut back asphalt are used to produce this type. تم خلطه على درجة حرارة منخفضة
- They can be used after production or stockpiled for later use. مش بحاجة انشفها الا اذا كانت في رطوبة عالية
- 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)

Stablit / Flow

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

24/8

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

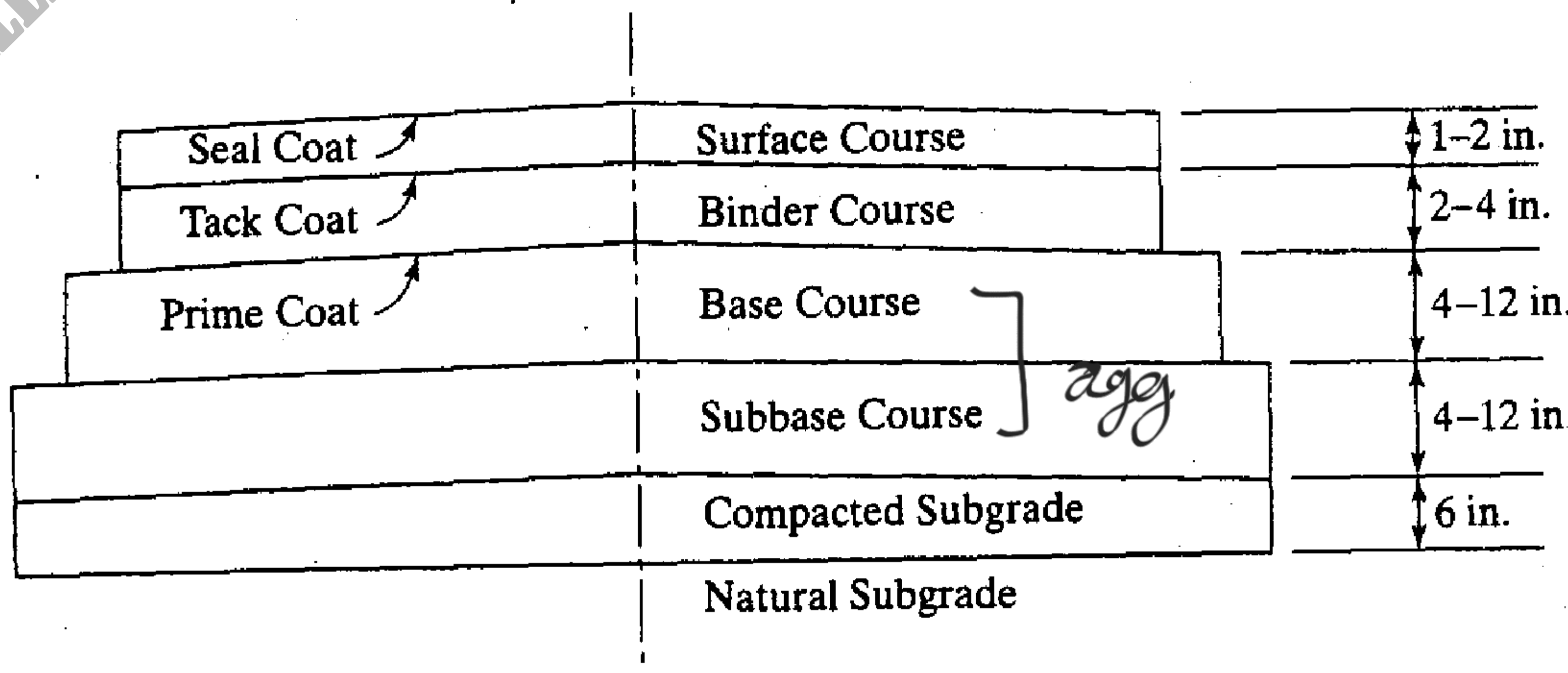


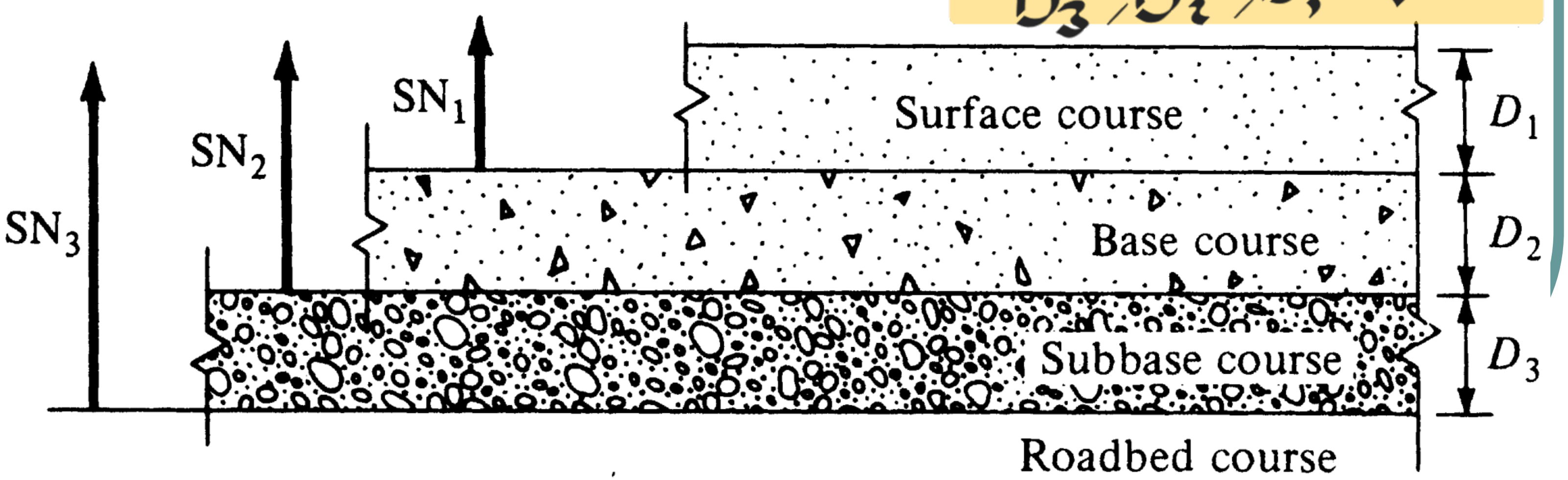
FIGURE 1.2

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 عملوا ديزاين للطرق السريعة

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. لقوا انه هاي سماكات مناسبة ↑

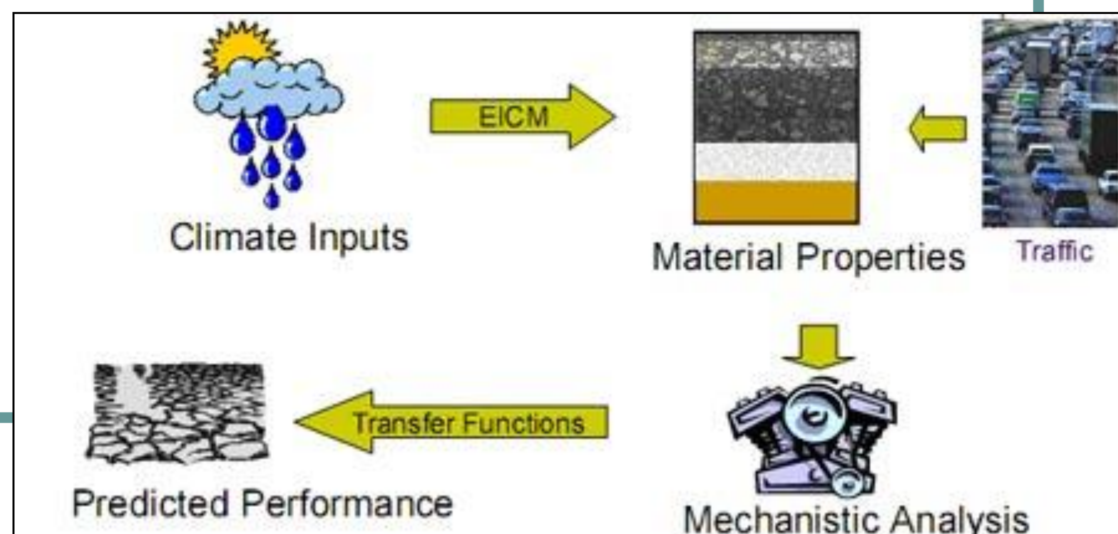
Empirical تجارب رح نعمل تجارب بيني

- 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

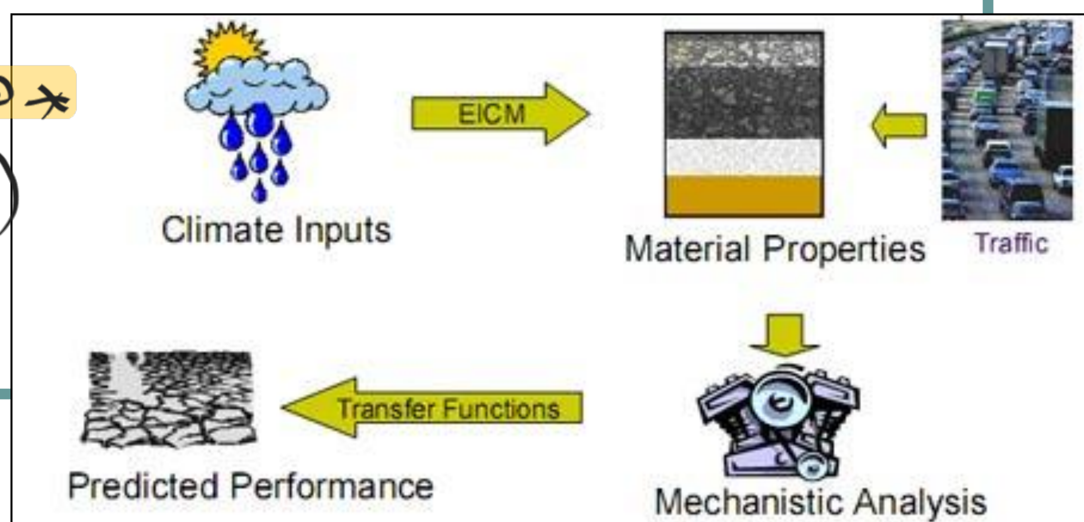
The phenomena are the stresses, strains and deflections within a pavement structure,

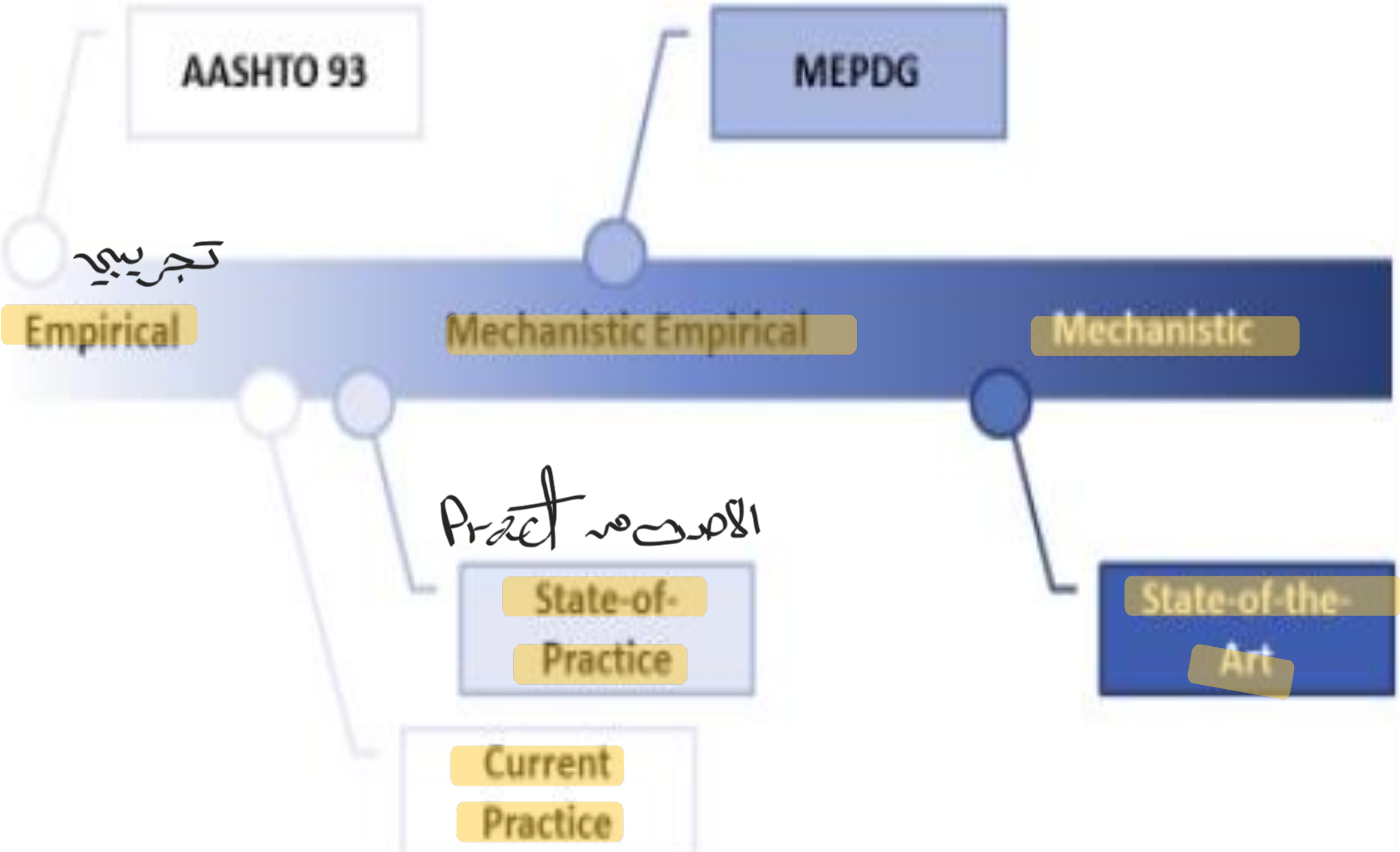
The physical causes are the loads and material properties of the pavement structure.

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

* هون معادلات بناء على ميكانيك فقط

(فيها تجريب)





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

Principles of Flexible Pavement Design

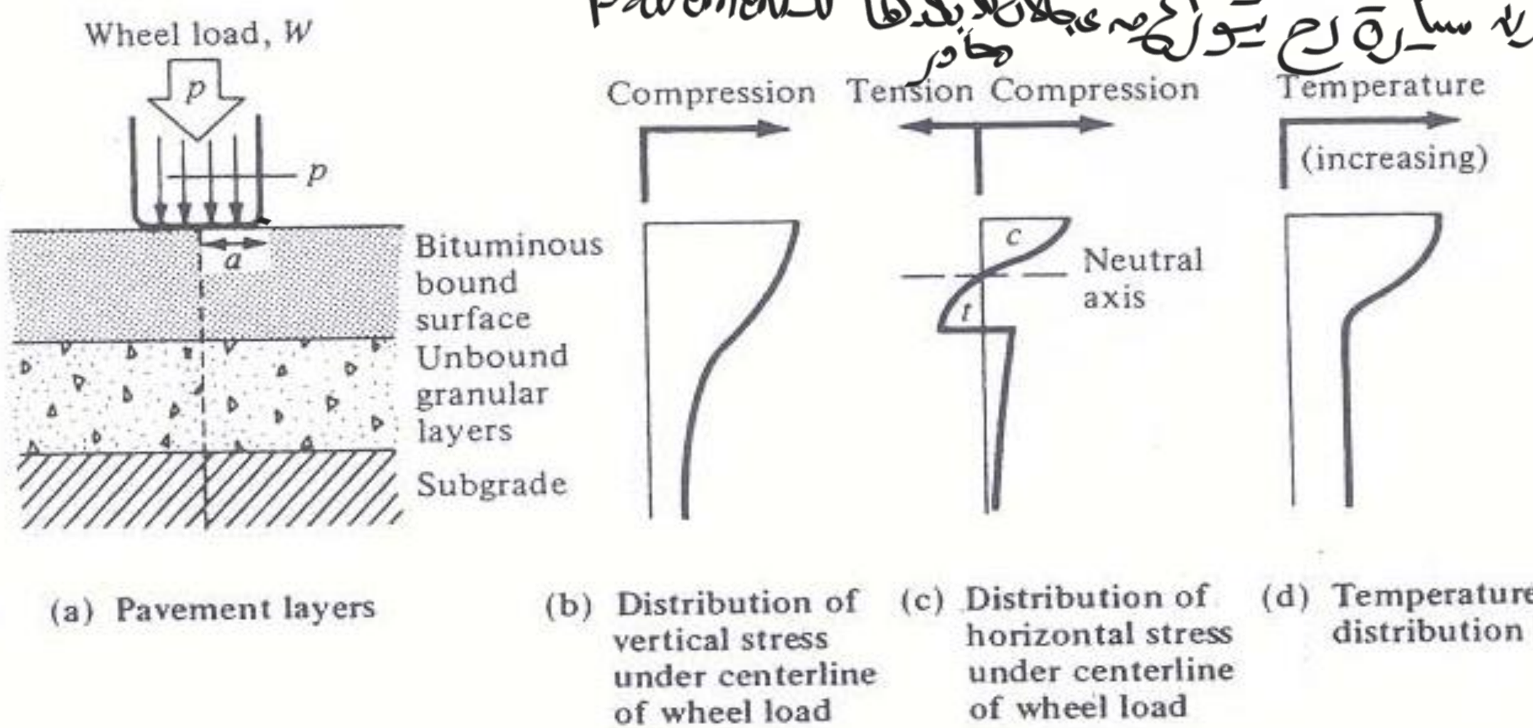
- Pavement structure is considered as a multilayered elastic system.
- Materials in each layers is characterized by certain physical properties (Mr, E,....).
- It assumes that subgrade is infinite in both the vertical and horizontal directions.
- Other layers are finite in the vertical direction and 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

مع حرارة تتمدد وتتقلص فممكن يصير خراب من حرارة

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



p = wheel pressure applied on pavement surface

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

c = compressive horizontal stress

t = tensile horizontal stress

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

Principles of Flexible Pavement Design

- The design of the pavement is therefore generally based on on strain criteria that limit both horizontal and vertical strain below those that will cause excessive cracking and permanent deformation.
- These criteria are considered in terms of repeated load applications.

طرق ديزاين

- Most commonly used methods:
  - Asphalt Institute Method
  - AASHTO method
  - California method

Elements of Thickness Design

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

عدد صادر بهمنا

Traffic Loading

- Pavement must withstand the large umber of repeated loads of variable magnitudes
- Primary loading factors: عدد المحاور، حجم الحمل load، عدد سيارات
  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.

هادا كله رح نحوله لـ

- 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 يؤثر 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

بيعنا الكواليتي

- 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.

اهم اشي

- CBR, Marshal stability, Resilient Modulus, Shear strength.
- Mr (psi) = 1500 CBR or Mr (Mpa) = 10.3 CBR

Figure 20.3 Spread of wheel load pressure through pavement structure

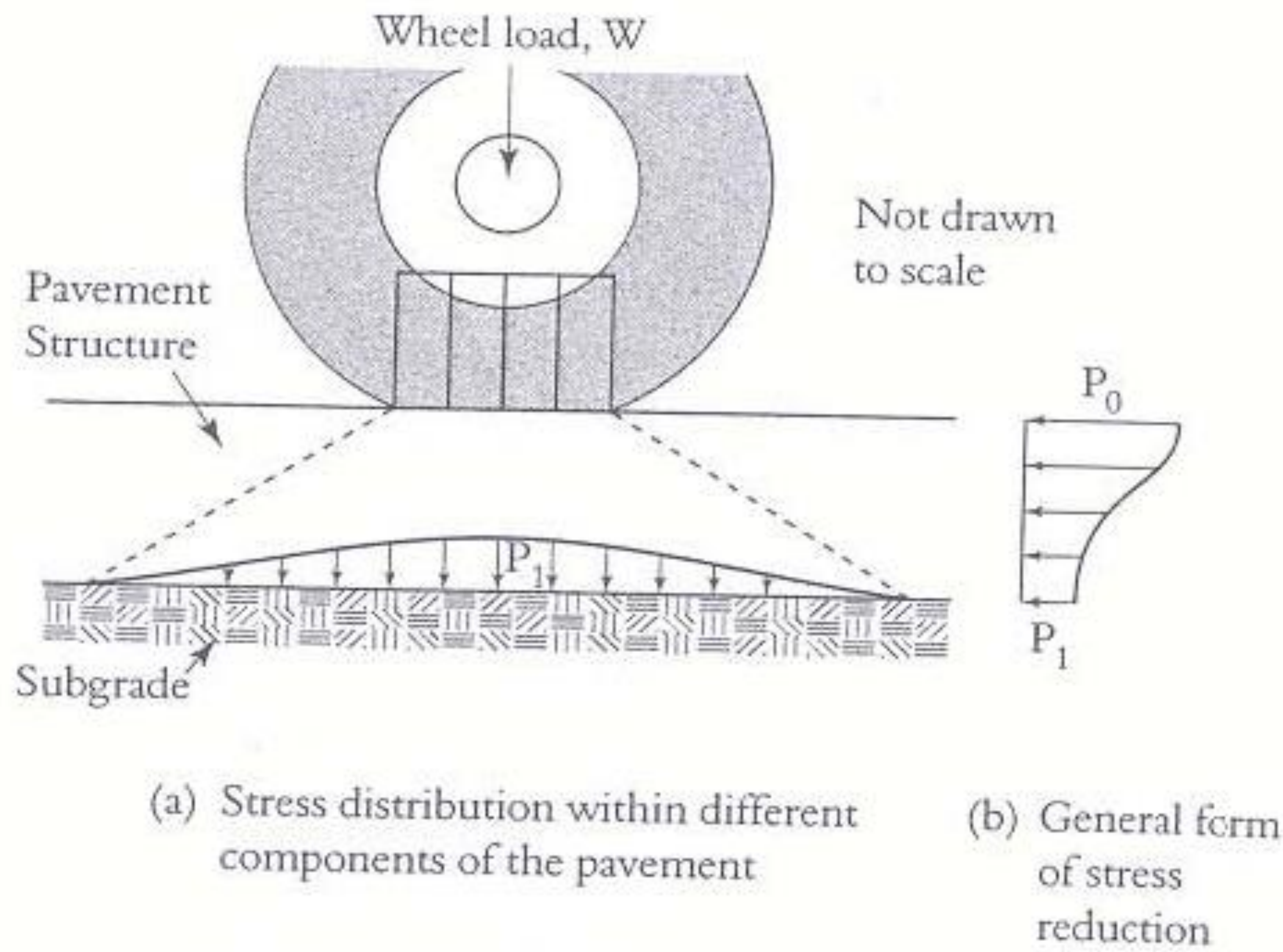


Figure 20.3 Soread of Wheel Load Pressure Through Pavement Structure

Figure 20.4 Tensile and compressive stresses in pavement structure

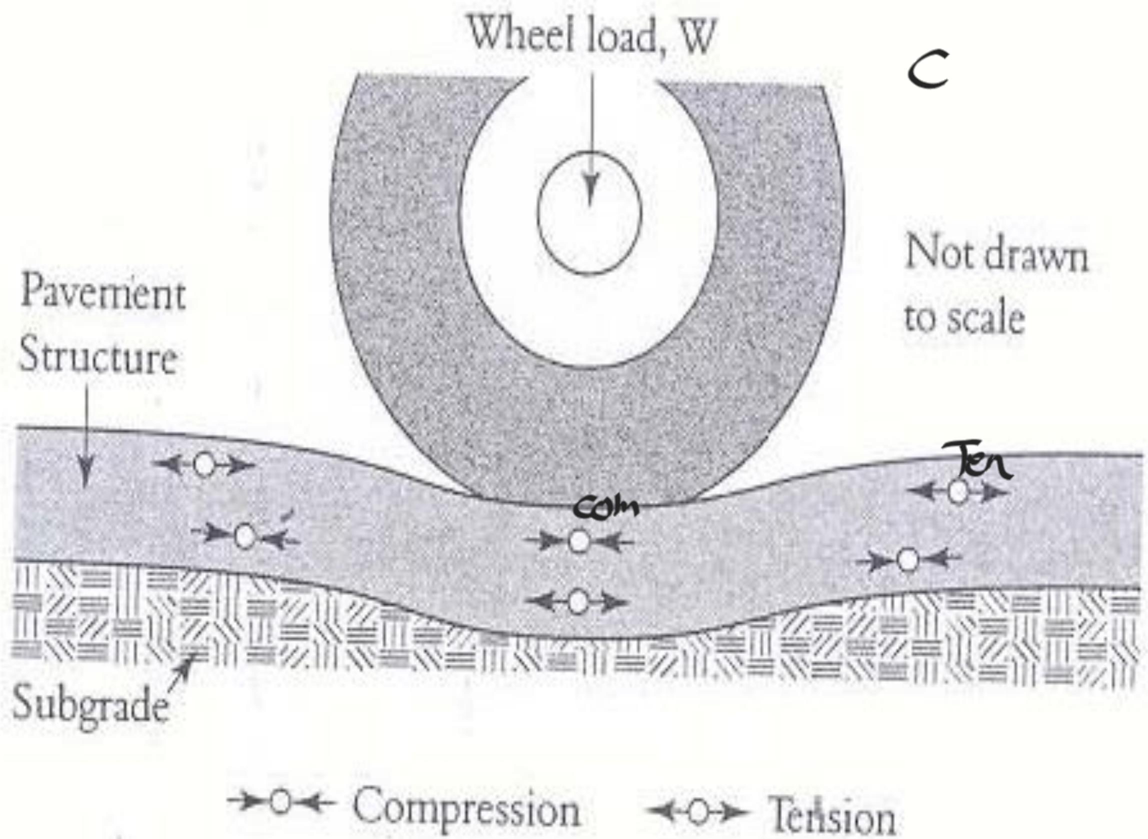
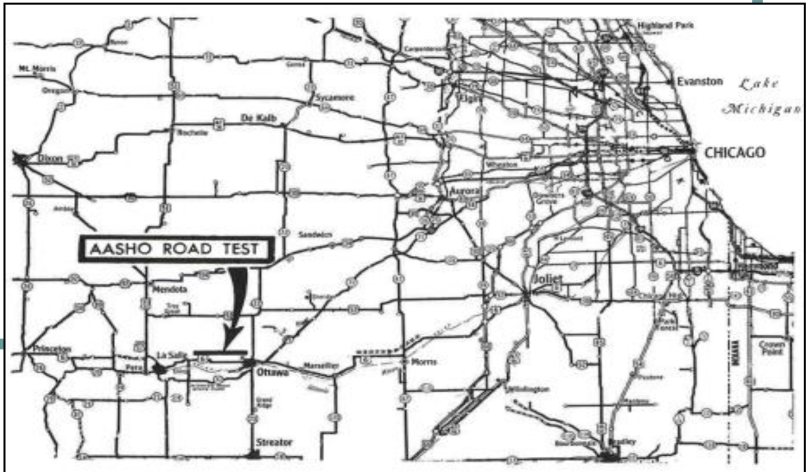


Figure 20.4 Schematic of Tensile and Compressive Stresses in Pavement Structure

AASHTO 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

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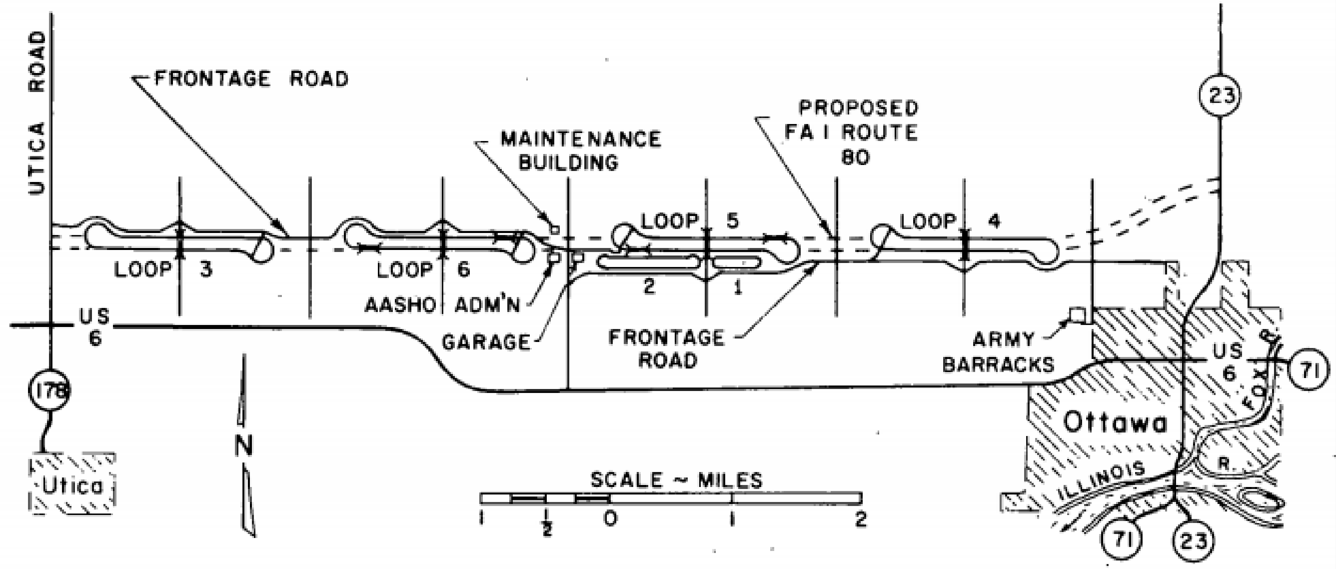


Figure 2. Layout of AASHO Road Test.

- 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).

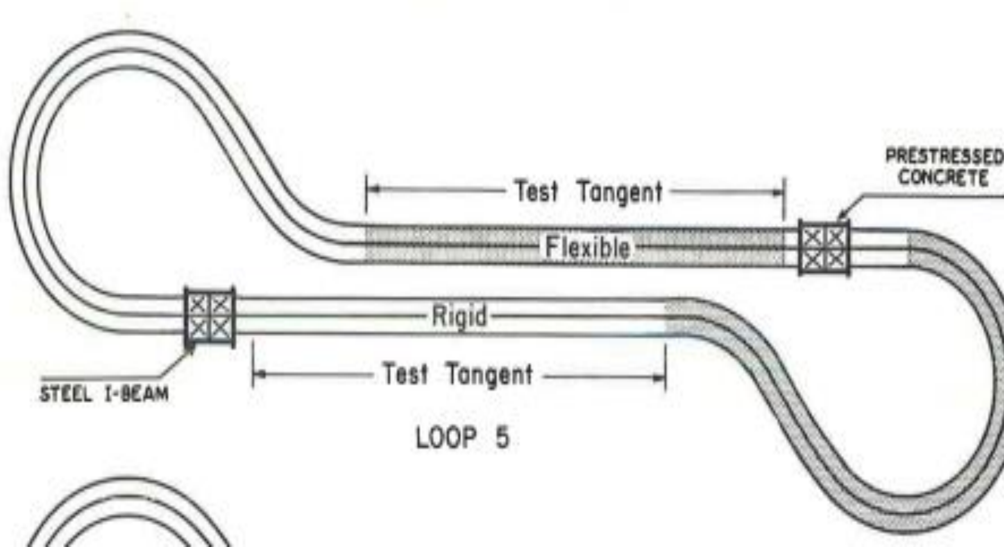
AASHTO 1993 Method/ Test Sections

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.

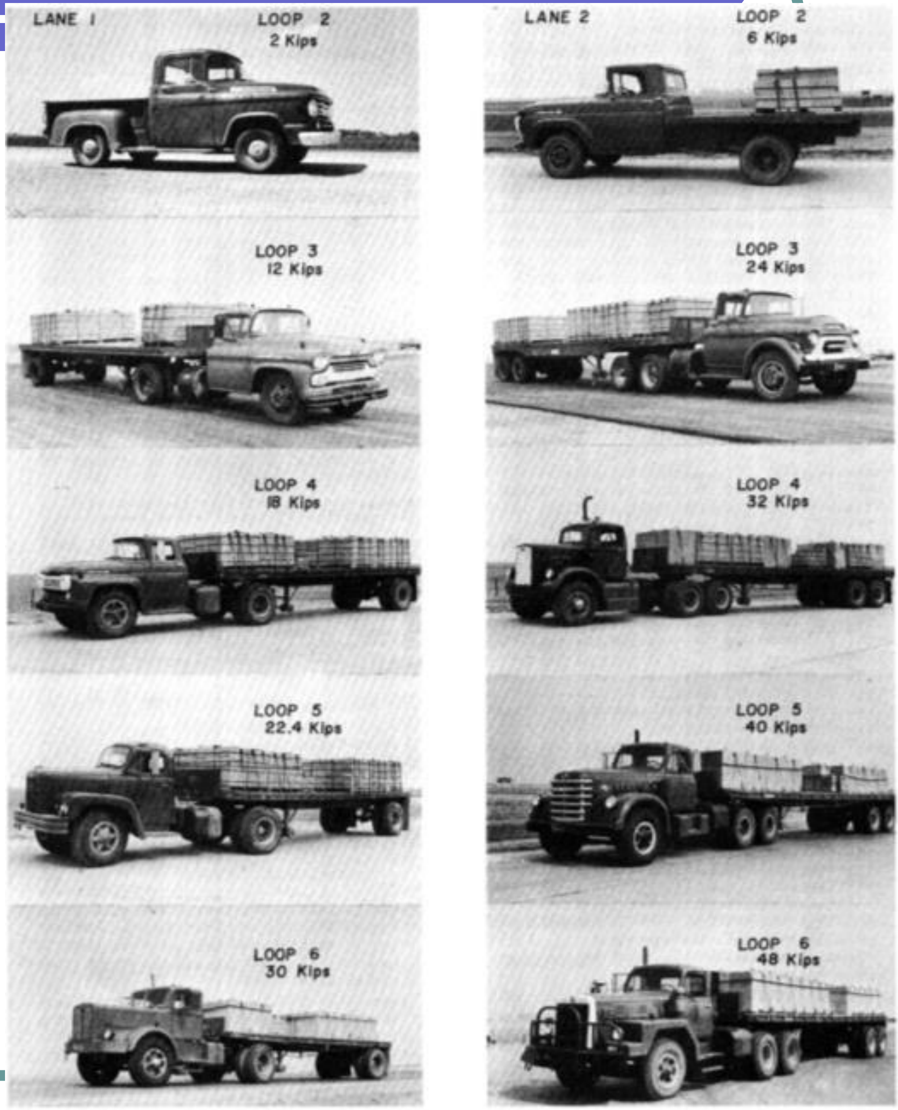


FIGURE 3 AASHO Road Test truck traffic.

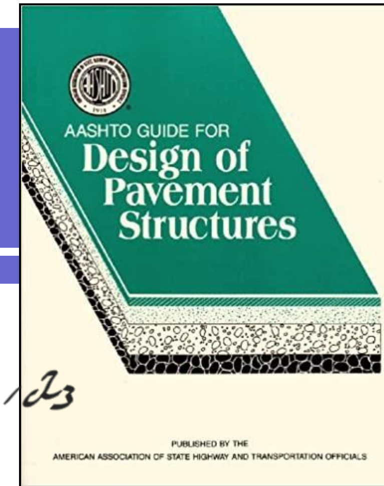
AASHTO Method/ Introduction

- 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 (<u>Current version)</u>
  - Mechanistic-empirical approach (AASHTO ME) [Under development]

AASHTO Design Method/ Design Considerations



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

← Material: إذا كوالتي الها جيدة وعالية رح تقلل سماكة

أما إذا ضعيفة فرح تنعكس بزيادة السماكة رح نشوف

انه الها دخل ب CBR and E وبناء عليها رح يكون

عندي a_1, a_2, a_3

← Environmental: كذلك الها تأثير هاي اخدنا تأثيرها

ب PSI ورح نشوف تأثيرها على subgrade

← Drainge: لازم يكون عندي طبقة تصريف ورح

نطلع m_1, m_2 ، ما عنا m_1 لانه طبقة الاسفلت لازم تكون

عازلة

← Reliability: الاعتمادية، رح تنعكس تقني على الديزاين

(رح يكون عندي سماكة ممتازة)

Pavement Performance

- Structural and functional performances.
- <u>Structural performance:</u> 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.
- <u>Functional performance</u>: 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

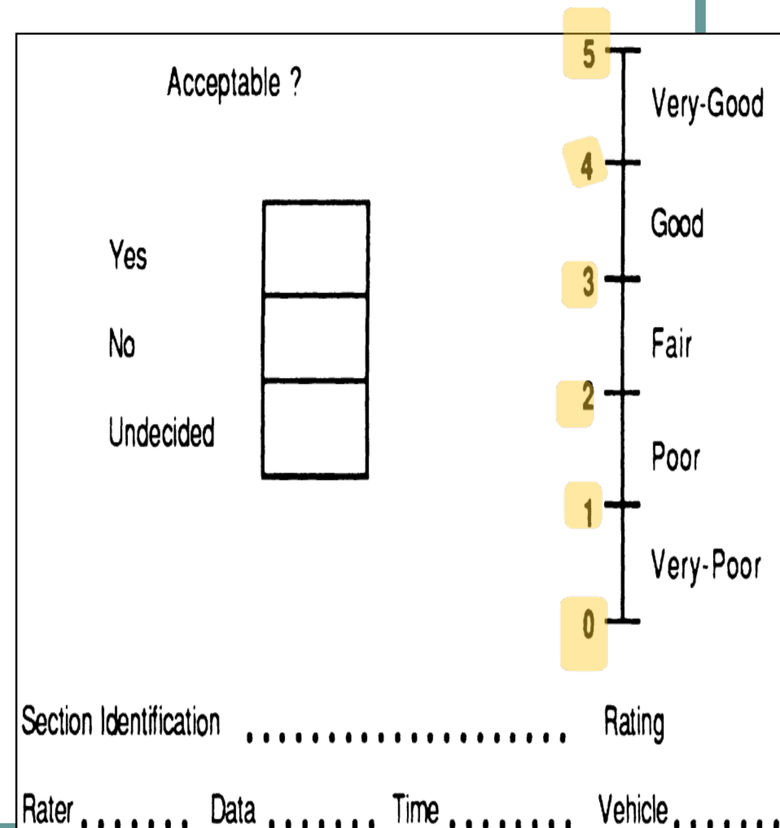
- It involves the measurement of the behavior of the pavement under traffic and its ability to serve traffic at some instance during its life.
- The evaluation is systematic but subjective.
- Evaluated by rating of the riding surface by individuals who travel over it.
- Can be evaluated also by means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



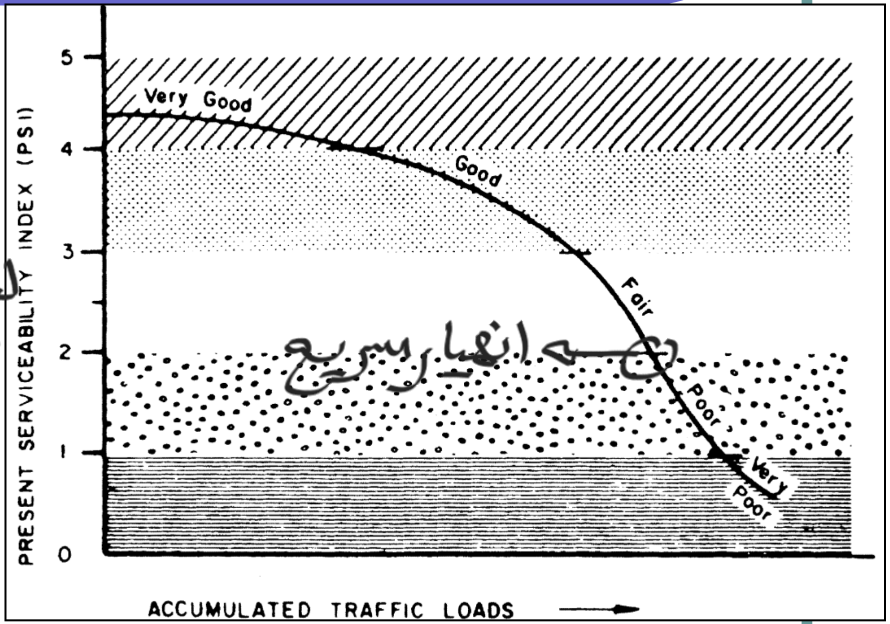
Serviceability

- 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. 4.5 For Rigid
  - AASHTO recommends that each agency determine more reliable levels for Pi based on existing conditions.



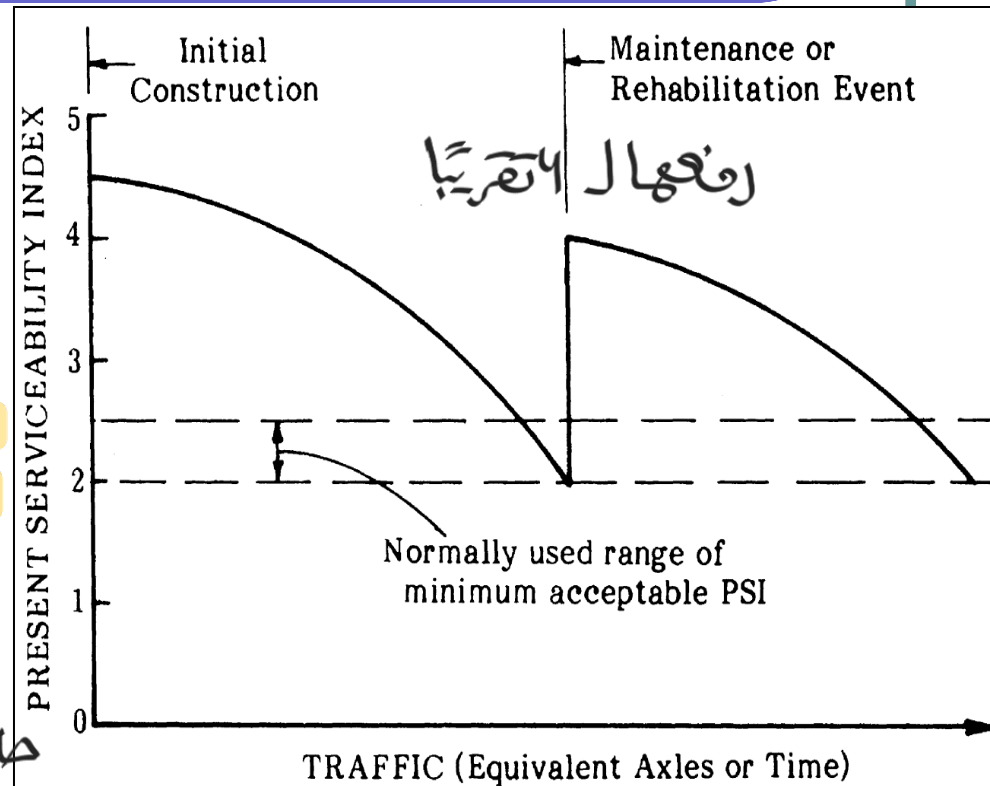
حالة الرصفات مع الوقت

Δ PSI

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

اهم اشي

- 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.*

*راح نحول كل Traffic لـ محور واحد وزنه 18000

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

عجال اثنين جنب بعض ومسافة بينهم بسيطة

زي سيارات (محوريه)

Single Axle

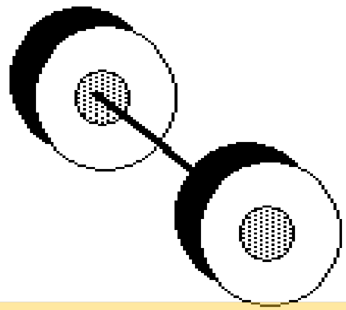
محورين قراب لبعض

Tandem Axle

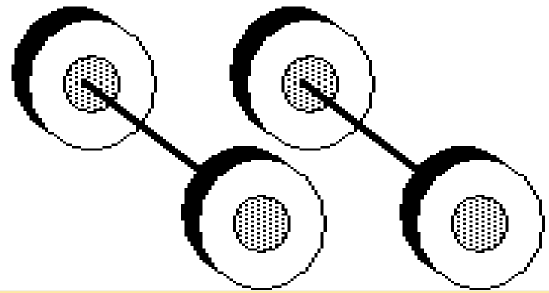
ثلاث عجلات

Tridem Axle

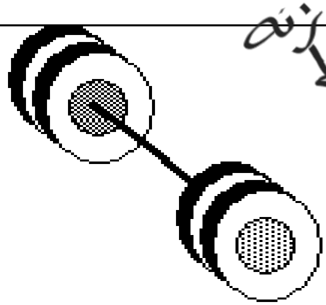
Traffic Load/ Tire and Axle Configuration



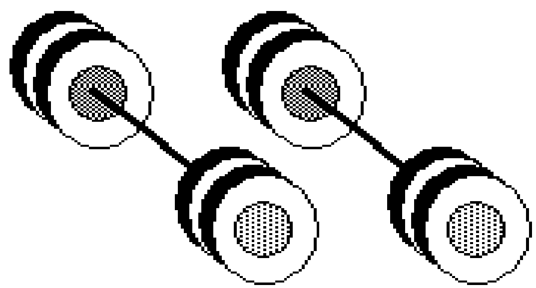
Single Axle with Single Tires



Tandem Axles with Single Tires

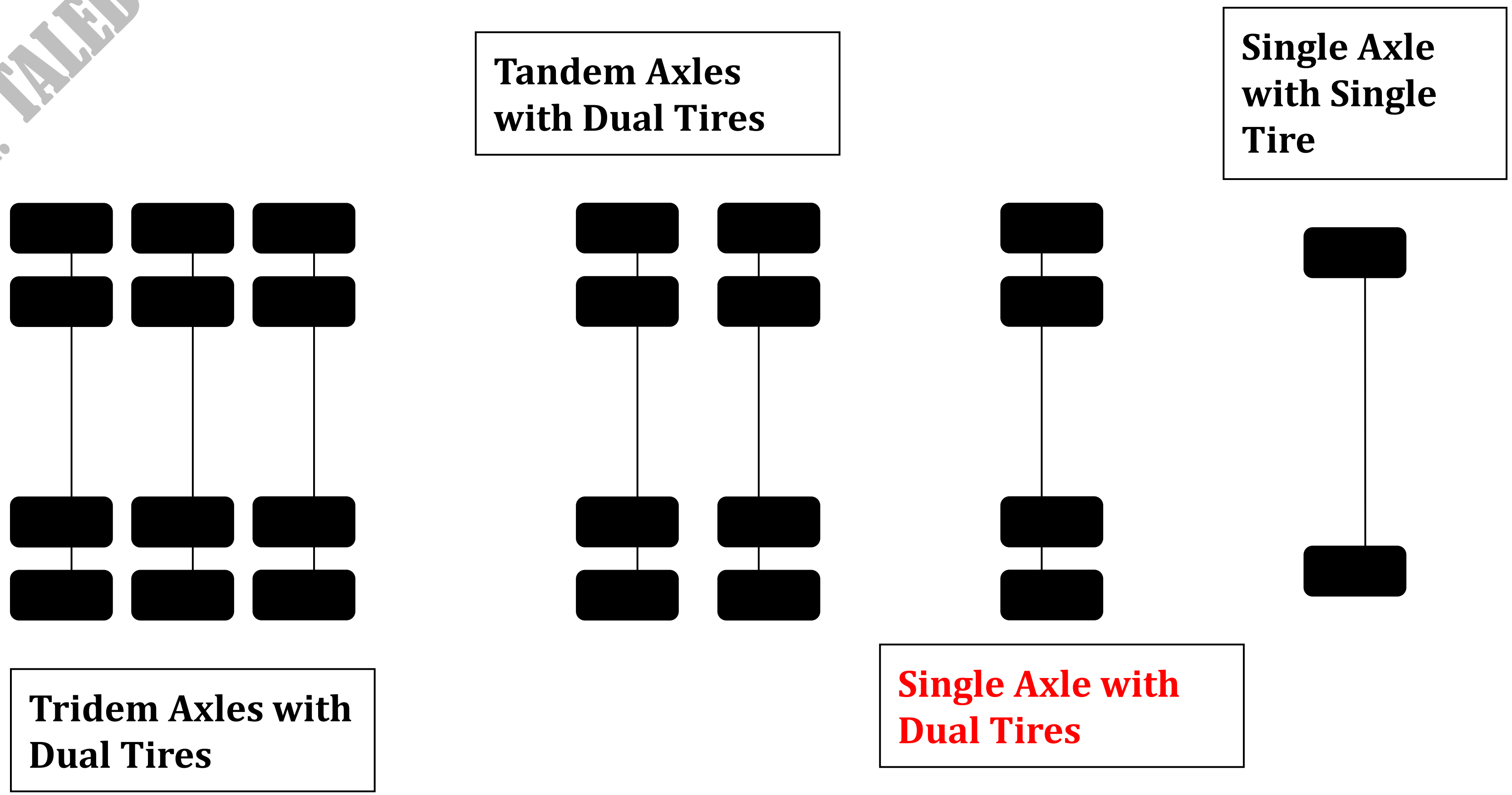


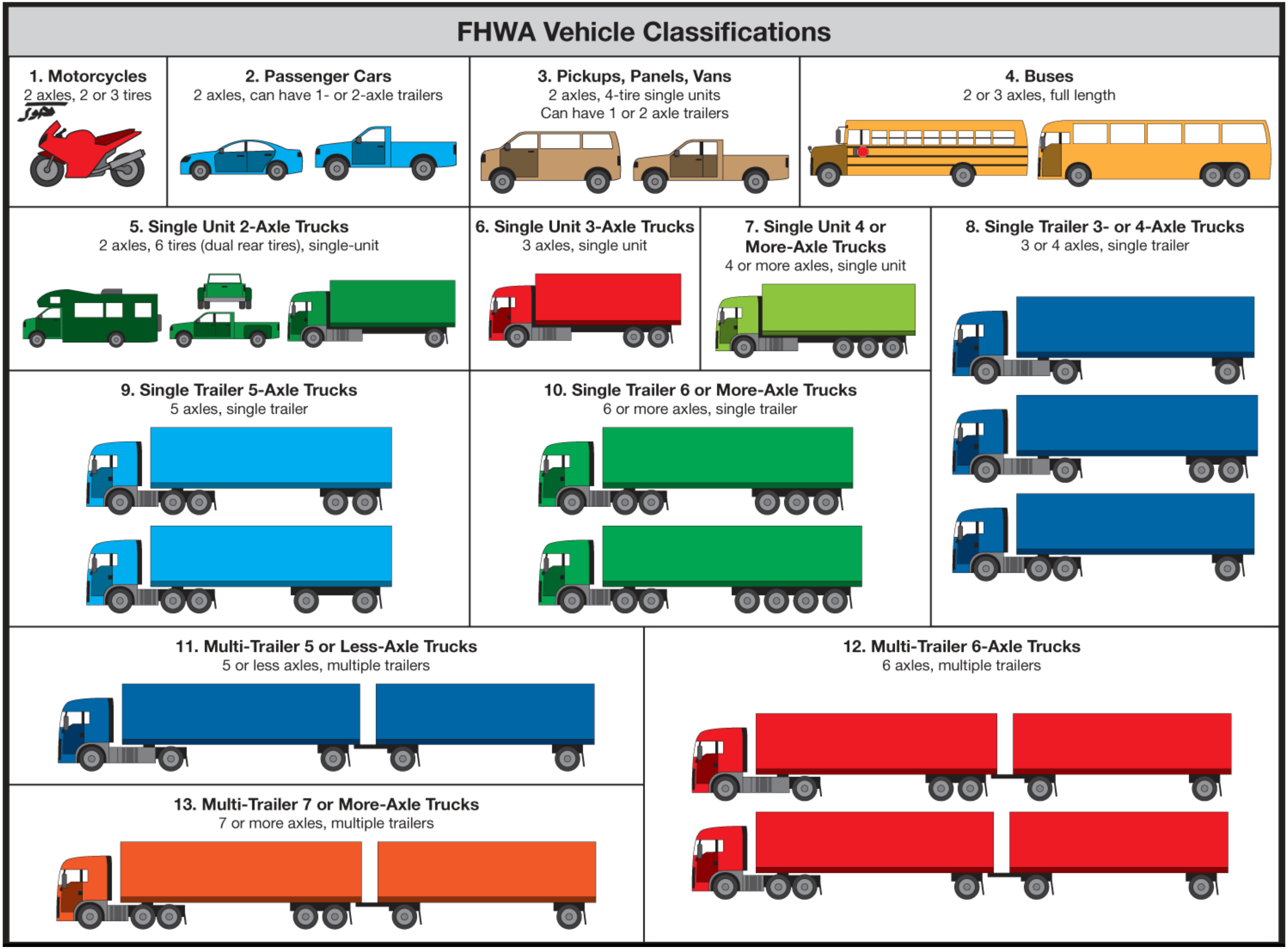
Single Axle with Dual Tires

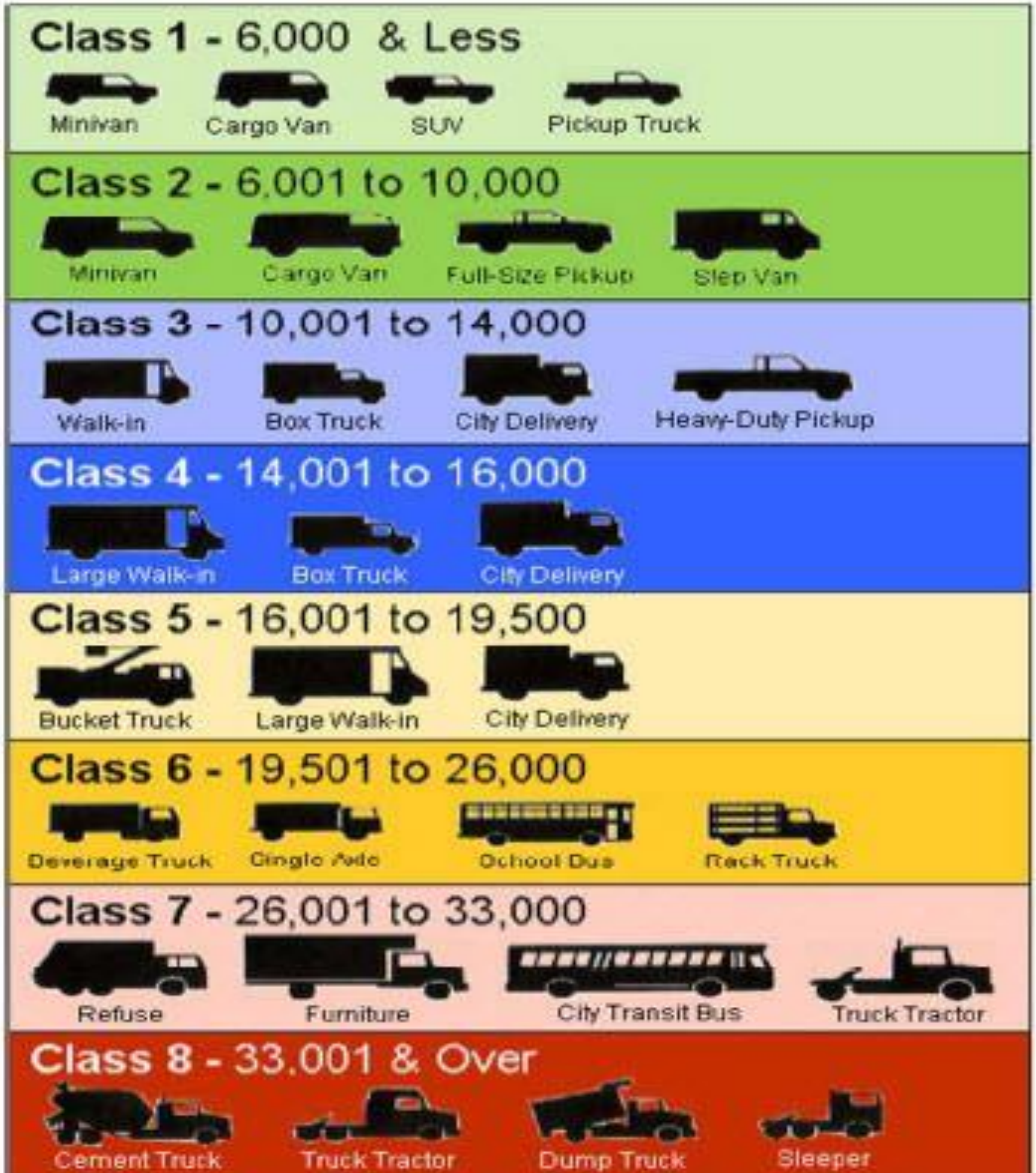


Tandem Axles with Dual Tires

Axle & Wheel Configurations




FHWA Vehicle Classifications
1. Motorcycles
2 axles, 2 or 3 tires
2. Passenger Cars
2 axles, can have 1- or 2-axle trailers
3. Pickups, Panels, Vans
2 axles, 4-tire single units
Can have 1 or 2 axle trailers
4. Buses
2 or 3 axles, full length
5. Single Unit 2-Axle Trucks
2 axles, 6 tires (dual rear tires), single-unit
6. Single Unit 3-Axle Trucks
3 axles, single unit
7. Single Unit 4 or More-Axle Trucks
4 or more axles, single unit
8. Single Trailer 3- or 4-Axle Trucks
3 or 4 axles, single trailer
9. Single Trailer 5-Axle Trucks
5 axles, single trailer
10. Single Trailer 6 or More-Axle Trucks
6 or more axles, single trailer
11. Multi-Trailer 5 or Less-Axle Trucks
5 or less axles, multiple trailers
12. Multi-Trailer 6-Axle Trucks
6 axles, multiple trailers
13. Multi-Trailer 7 or More-Axle Trucks
7 or more axles, multiple trailers


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 <u>that is of primary concern.</u>

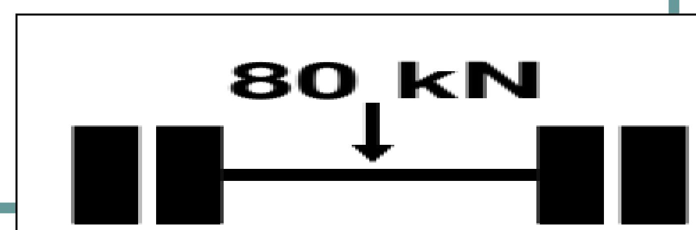
Repetition of Wheel Load Cont.

- 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 بقاس رح منسوزنه بوزنة ٥ بنقارن بكمية الخراب
  - 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: نتيجة axi اللي هو عند ال load
load

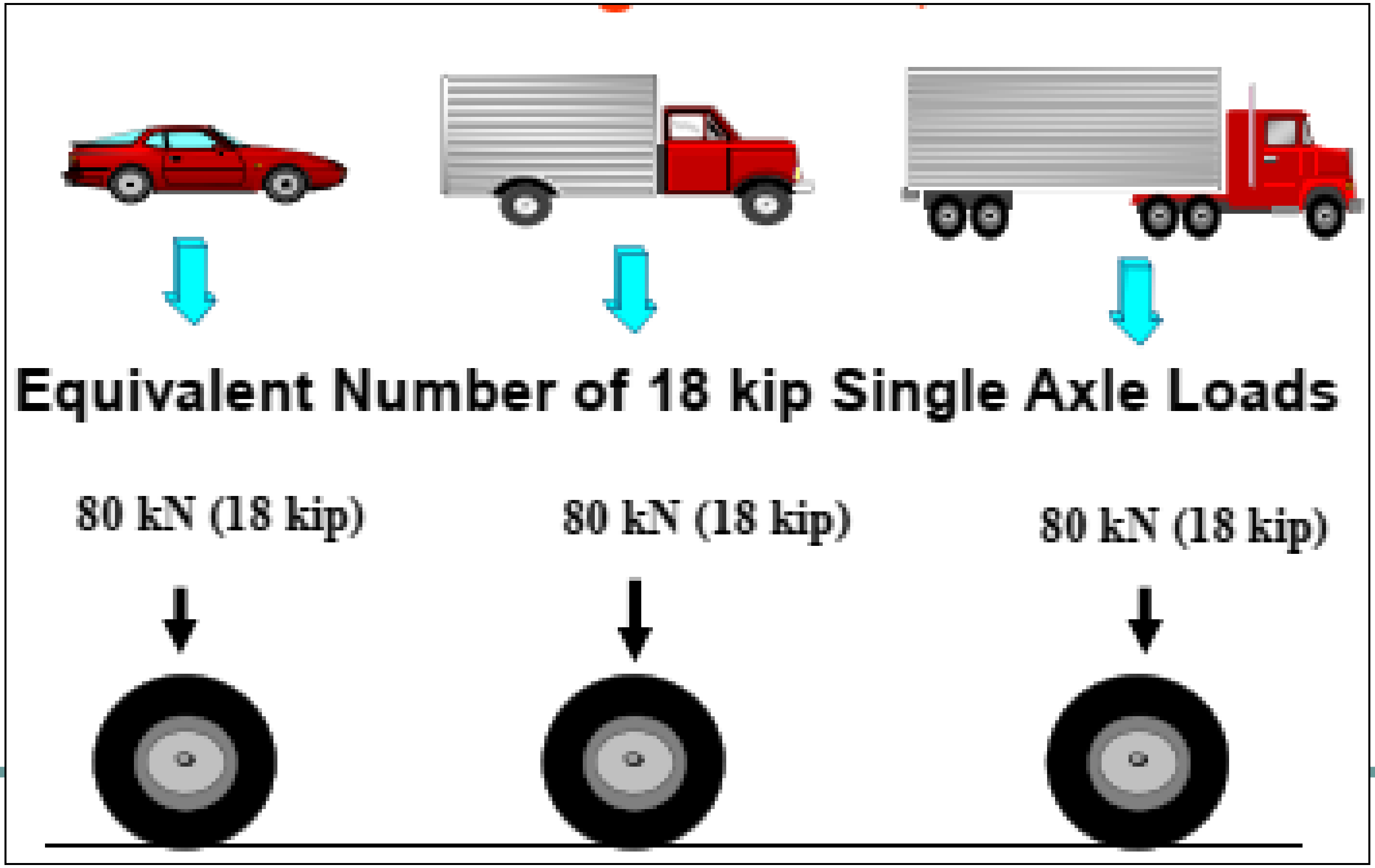


Traffic Load Determination

- 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 عدد مركبات

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

توزيع مركبات و شاحنات في امريكا

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

شوارع كبيرة

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

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

<u>If the axle load is unknown</u>, 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.

لازم اعرف وزنة محور

في حال ما اعطى axil load رح نستخدم البديل Truck factor

*إذا كان معطيني TF فمباشرة بضربه بعدد السيارات لحساب ESAL

*كيف نحسب TF في حال طلب قيمته؟

لازم يكون معي اوزان

← بنروح للجدول وبنجيب لكل محور factor (ممنوع تقريب)

← بعدها بنجمع factor كلهم

لما يكون عندي اكثر من نوع فـ TF هو عبارة عن مجموع axil load factor

Total # of v

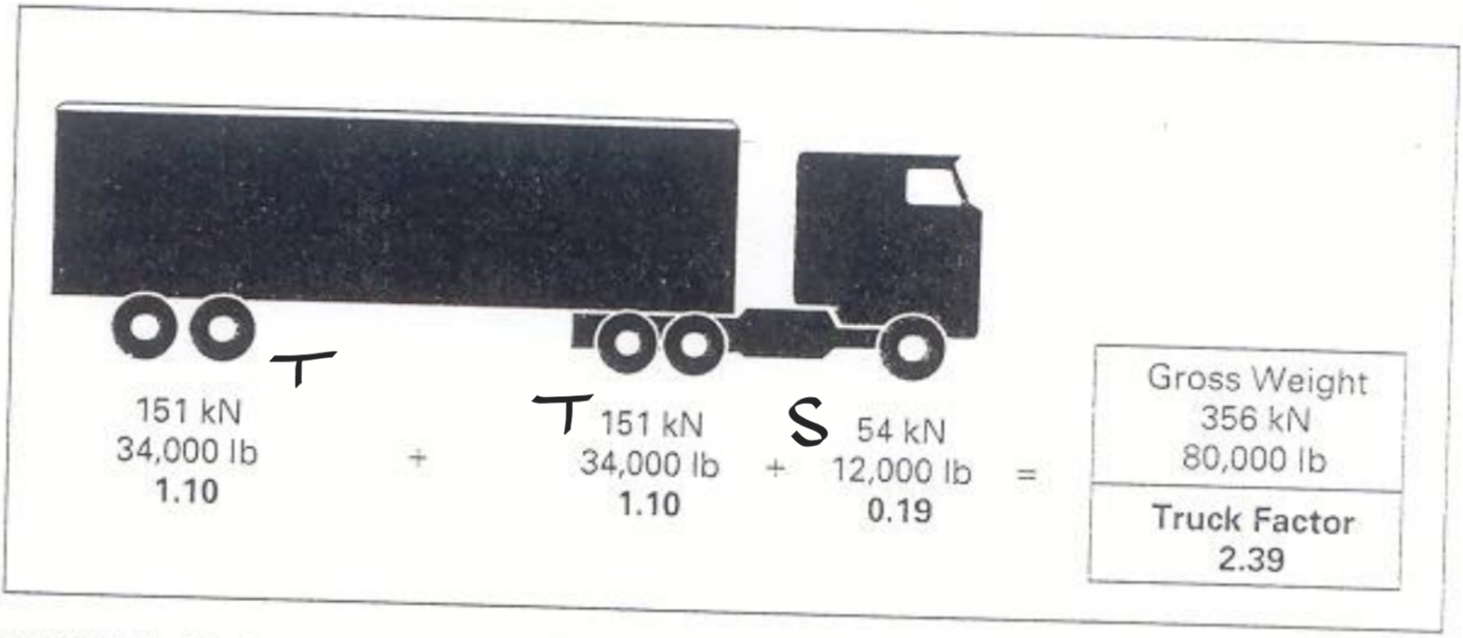


FIGURE 16-8 Load-equivalency factors and the truck factor for a single-tractor semitrailer truck. (Courtesy the Asphalt Institute.)

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

مثلاً هون :-

عندي 34000 ← 1.095 Tandem

وعند 12000 ← 0.189 single

[TF = 1.095 + 1.095 + 0.189] هاد يعني السيارة تكافئ 2.39

فإذا عندي 1000 سيارة ← $2.39 * 1000$

← لو بدي احسب الـ 1000 سيارة الـ TF رح نضرب 1000 ب TF و

اقسم على 1000 رح تكتشف انه TF متساوية سواء الـ 1000 أو الـ 1

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.

← لما يكون عندي مجموعة سيارات مختلفة فهو نروح نجمعهم ونقسم
على مجموع عدد السيارات

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

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

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

*Including full-trailer combinations in some states.

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

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

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

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

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

(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.

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

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

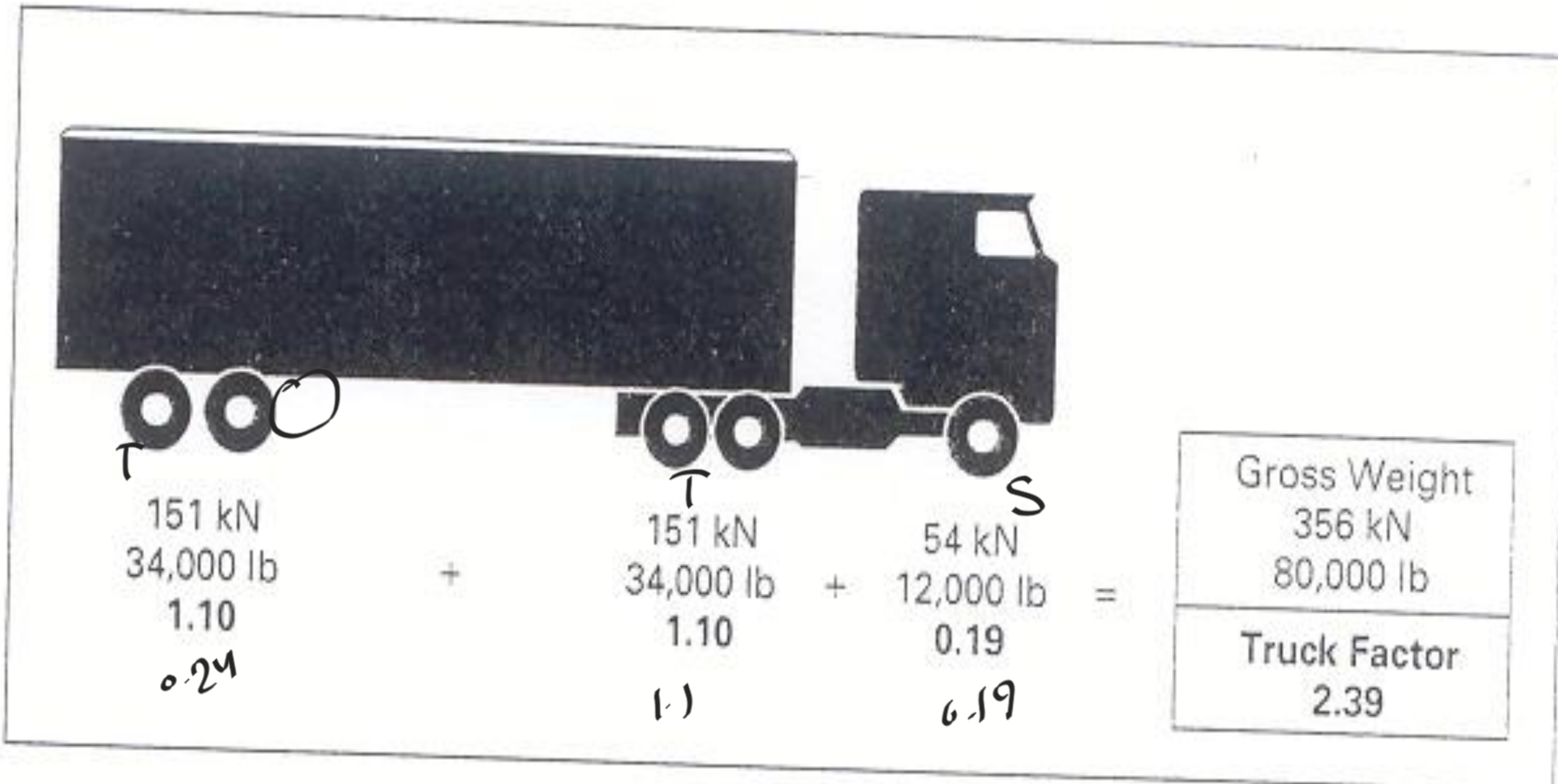


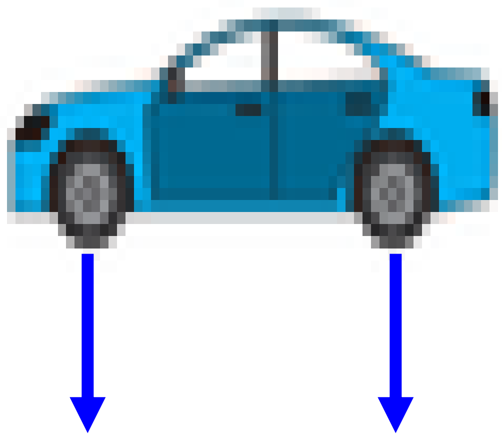
FIGURE 16-8 Load-equivalency factors and the truck factor for a single-tractor semitrailer truck. (Courtesy the Asphalt Institute.)

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)



2000 ib

2000 ib

LEF for single axle = 0.0002

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

1000 ib ≡ ; pt=2.5

Axle Load (kips)	Pavement Structural Number (SN) 1	2	3	4	5	6
2000 ≈ 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

0.0004

$$\text{Truck factor } (Tf) = \frac{\Sigma(\text{Number of axles} \times \text{LEFs for each axle})}{\text{Number of vehicles}} = \frac{\Sigma(2\times0.002)}{1} = 0.004 \text{ per vehicle}$$

هاد جدول مشعام وبكون معطي قيمة $S_N + P_t$

وزنة محور الواحد = 2000 / عندي محورين

$2 * 0.0002 = 0.0004$ ⁖

مكافئة للمحور الواحد

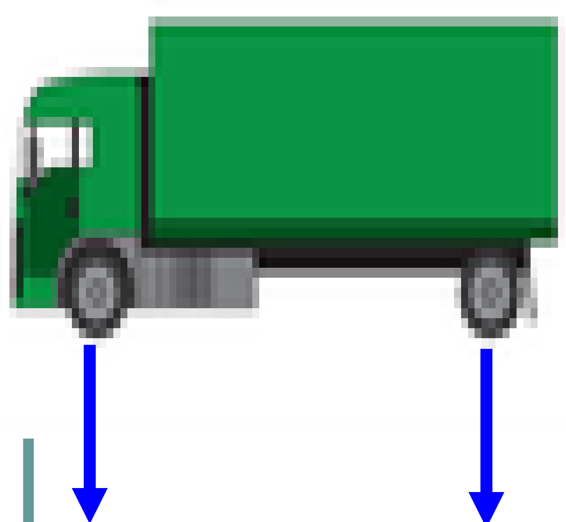
لو عندي مثلاً 10000 سيارة رح نضرب $0.0004 * 10000$

مكافئة لـ 10000 سيارة

← لو قيمة المحور مش متساوية رح نحسب كل وحدة لحال بعدين اجمعهم

← بلاحظ انه معطي وزنة المحور ونوعه

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

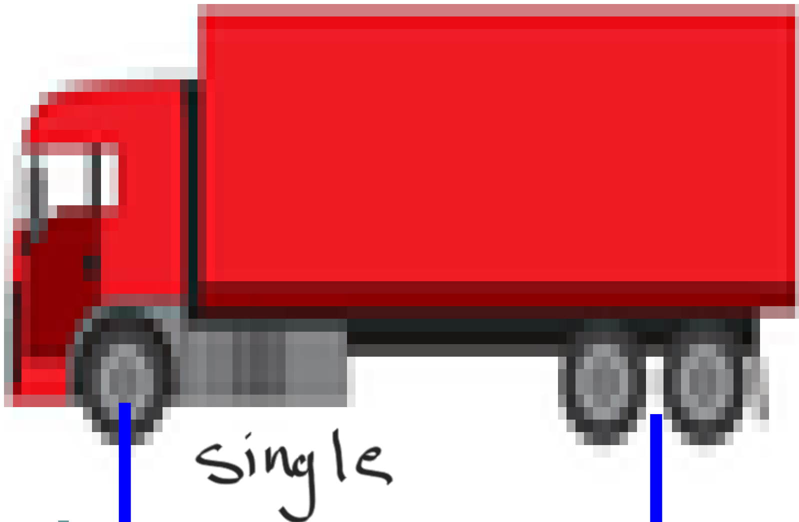
Axle Load (kips)	Pavement Structural Number (SN) 1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591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

2 * 0.010 * عدد شاحنات

TF = 100% (2 * 0.01) * / 1000 — يوجد في 1000 سيارة

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

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



10,000 ib

22,000 ib

Tan

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

$$Truck\ factor(Tf) = = \frac{\sum (1 \times 0.088 + 1 * 0.18)}{1} = 0.264\ per\ vehicle$$

لو عندي 1000 (عددهم)

1000 * 0.088 * 1 ← for single

1000 * 0.18 * 1 ← for tandem

equ = مجموع الاثنين

لو كان عندي 1000 وطلب حجم TF لل mix

$$\frac{1000 * (TF_1)}{1000}$$

Specified Maximum Gross Weight For Trucks

الجامعة الهاشمية
The Hashemite University

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 الاجمالي 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	263
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).

احنا لما نصمم بجوند 20 سنة تقريبًا وبدنا نشبه لاشي

هو growth ممكن يزيد عندي Traffic خلال 20 سنة

فلازم نحسب حسابها لانه احنا رح نستخدم تبع بعد 20 سنة

للديزاين :: عندي اشياء لازم احددها ① Design period

② Traffic growth factor

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:

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

معطى

j: Rate of growth.

t: Design period (yrs).

Growth Factors

Table 20.6 Growth Factors

ما بزيد growth يعني مقطع نضربه بعدد السنوات

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,

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

انتبه

رقم تبع سنة وحدة

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)

- $F_d = D \times L$

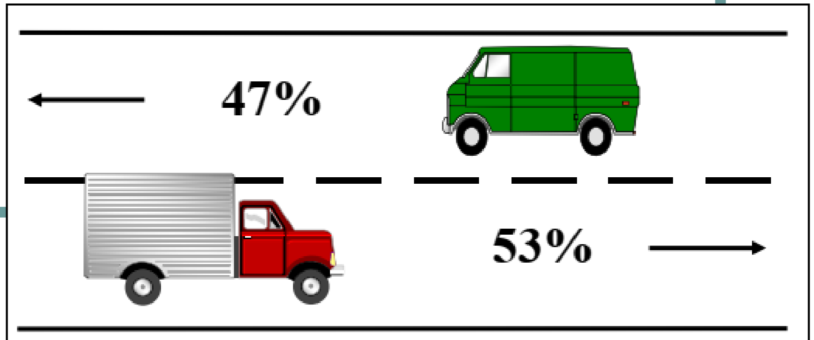
احنا بنحكم السايد واحد بنسميه Lane وبناءً عليه بتوزعوا باتجاه مسارب

  - (D): is the directional distribution factor
  - (L): L is the lane distribution factor
- D: represent Percentage of trucks traffic traveling in one direction.

إذا مسرب واحد بيكون 100%

- D usually assumed to be 0.5 unless the traffic in two directions is different.

Design for worst case!!



Lane Distribution Factor (L)

جهة وحدة

- Design lane: اسوء واصعبه حمل
  - 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).

هادبس ← 100

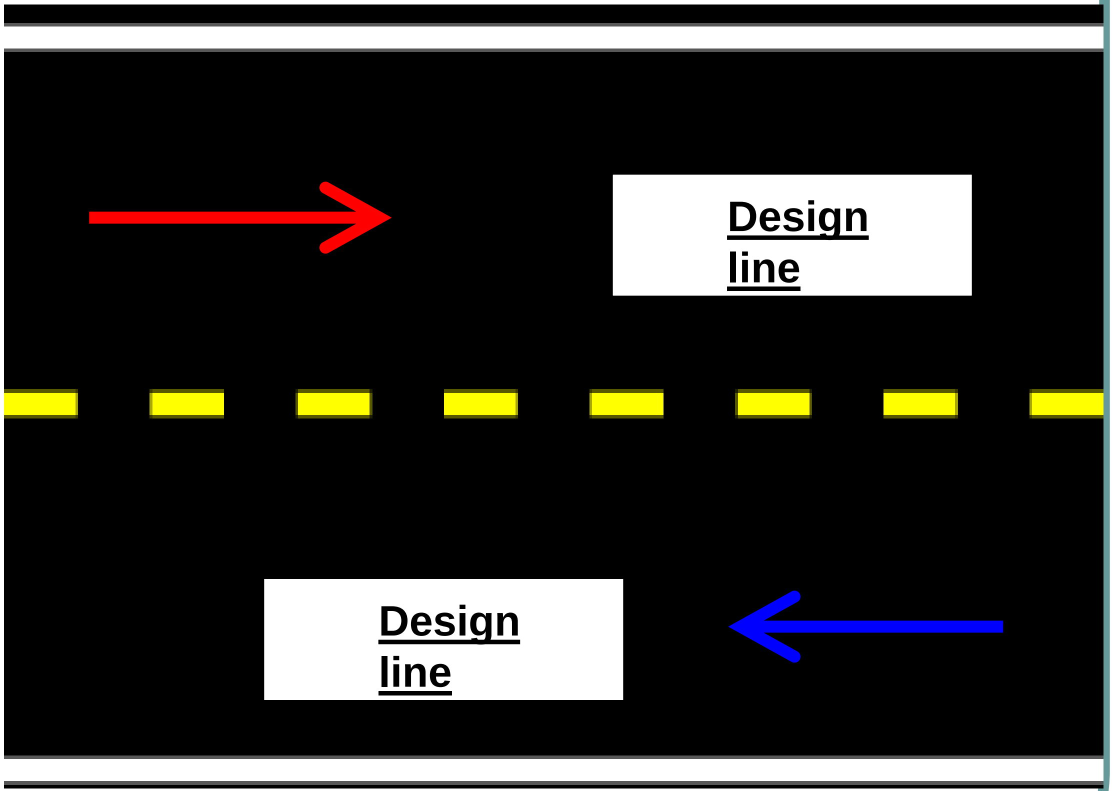
لا lane

Design for worst case!!

على مسارب بنفصل 50, 50

Lane Distribution

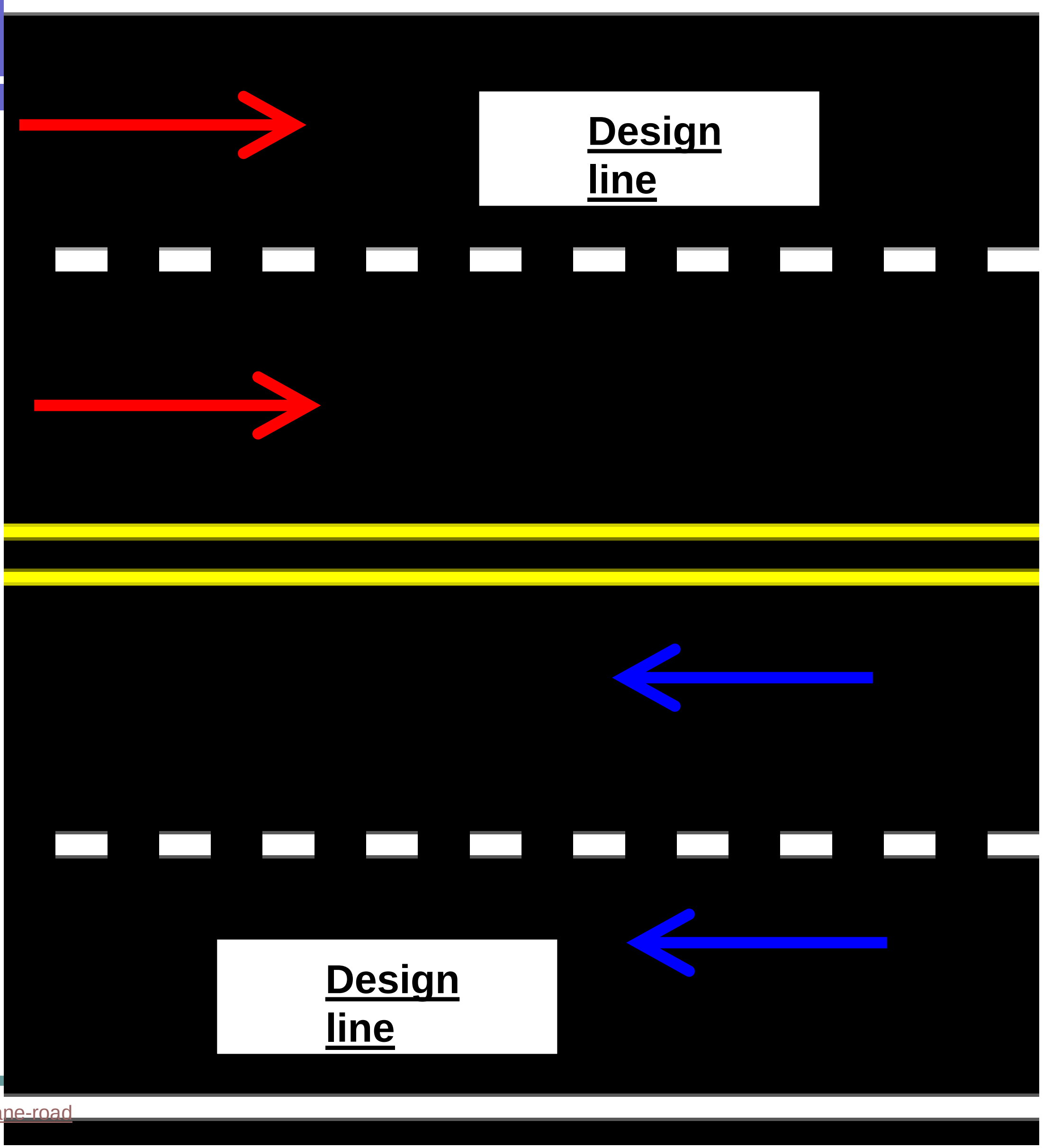
- For two-lane highways,
  - The lane in each direction is the design lane, so the lane distribution factor is 100%
  - Design lane: Lane expected to receive the severe service



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)*

تومات

*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.

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

عدد سيارات خلال 20 سنة

$ESAL_i$: ESAL for axle category i

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

(F_d): Design lane factor

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

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

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

Total ESAL Calculation Cont.

When truck factors are used

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

$ESAL_i$: ESAL for axle category i

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

(F_d): Design lane factor

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

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

Total ESAL Calculation Cont.

When truck factors are used

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

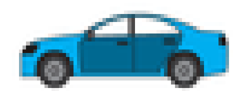
from i =1 to n

n= number of truck categories

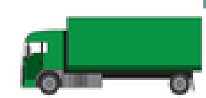
ESAL : ESAL for all vehicles during the design period.

ESAL Example

- An 8-lane divided highway is to be constructed on a new alignment. Traffic volume forecast indicates that AADT in both direction during the first year of operation will be 12,000 with the following vehicle mix:



- Passenger cars (1000 lb/axle) = 50%



- 2-axle single unit trucks (6000 lb/axle) = 33%
- 3-axle single unit trucks (10,000 lb/axle) = 17%

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

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

ESAL Example

Solution

- Growth Factor = G_{jt} ***= [(1 + j)^t - 1]/ j = [(1 + 0.04)^{20} - 1]/ 0.04 = 29.78 (or see Table 20.6)***
- ***% truck volume on design lane = 45 (assumed, Table 20.7)*** ← يكون معطى بالامتحان
- ***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***

6000 * 0.45 * 29.78 * 2 * 0.0002 * 365 = 1173.93

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

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							
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						365	
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.

الـ Subgrade هو النسبة النا فاونديشن ، لانه إذا

قدرته تحمله كويسة رح يخفف عن سالكات

* اهم خاصية للتربة هي Mr

← اوجدوا انه Mr تتغير مع الوقت فمثلاً في فترات فيها

رطوبة عالية رح تكون Mr قليلة ولما يكون تجمد Mr تزيد

و خلال فترة الصيف بترجع للطبيعي

Roadbed Soils (Subgrade Materials)

صعب تحدد قيمة معينة لل Mr لا نها معقدة و متغيرة على طول السنة

- 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***

   تتأثر بـ Mr بعلاقة عكسية
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.

1) تحسب Mr للتربة خلال شهر مرة أو مرتين يعني خلال السنة بكون عشي 12 أو 24 قراءة لل Mr

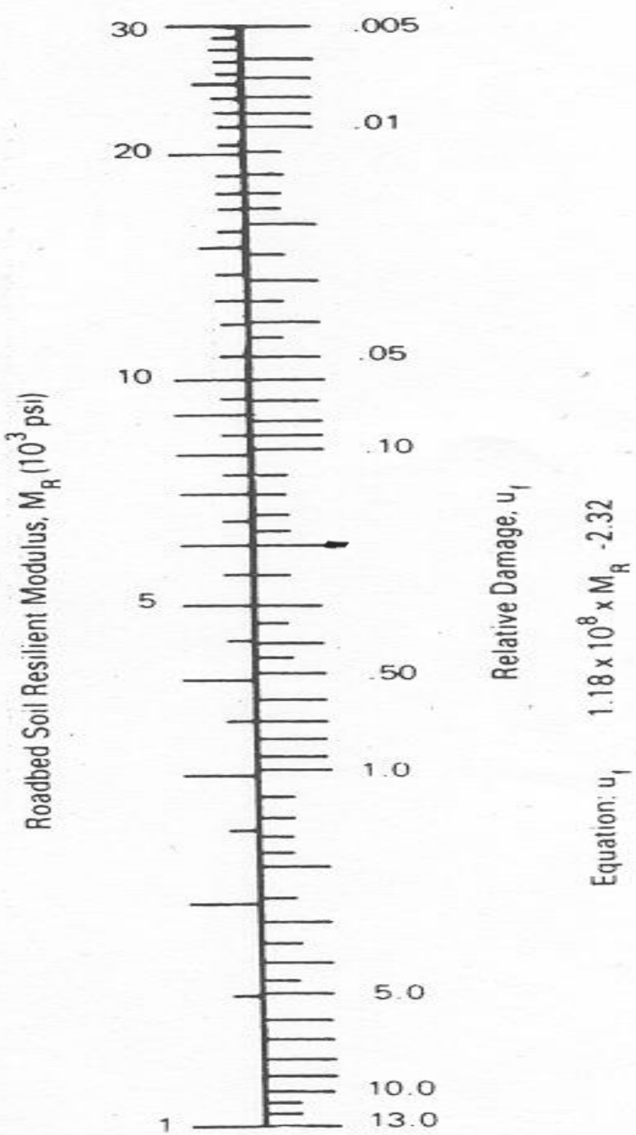
2) نطلع relative damage (وعلاقته عكسية مع Mr)

3) نوخذ avg لل relative damage

4) من avg ارجع احسب Mr

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:** بتجيب عينات من تربة واعمل تجارب على نسب رطوبة مختلفة
  - Develop a relationship between
    - Resilient modulus
    - Subgrade moisture content
  - For example :
    - at 25% moisture content, Mr is 9500 Psi

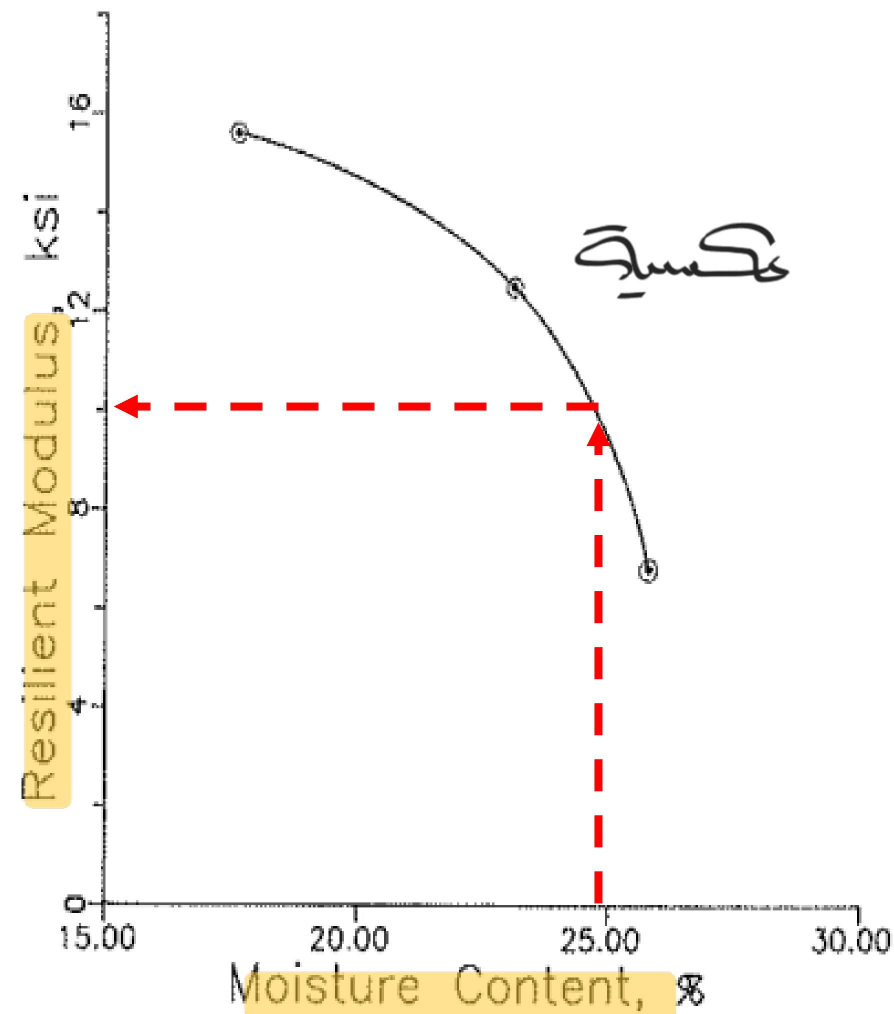


FIGURE 12 Moisture content-resilient modulus relationship for soil used in example.

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPORTATION RESEARCH RECORD, 1989

Determination of Effective Roadbed Soil Resilient Modulus

- **Step 2:** نسبة الرطوبة خلال كل شهر

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%

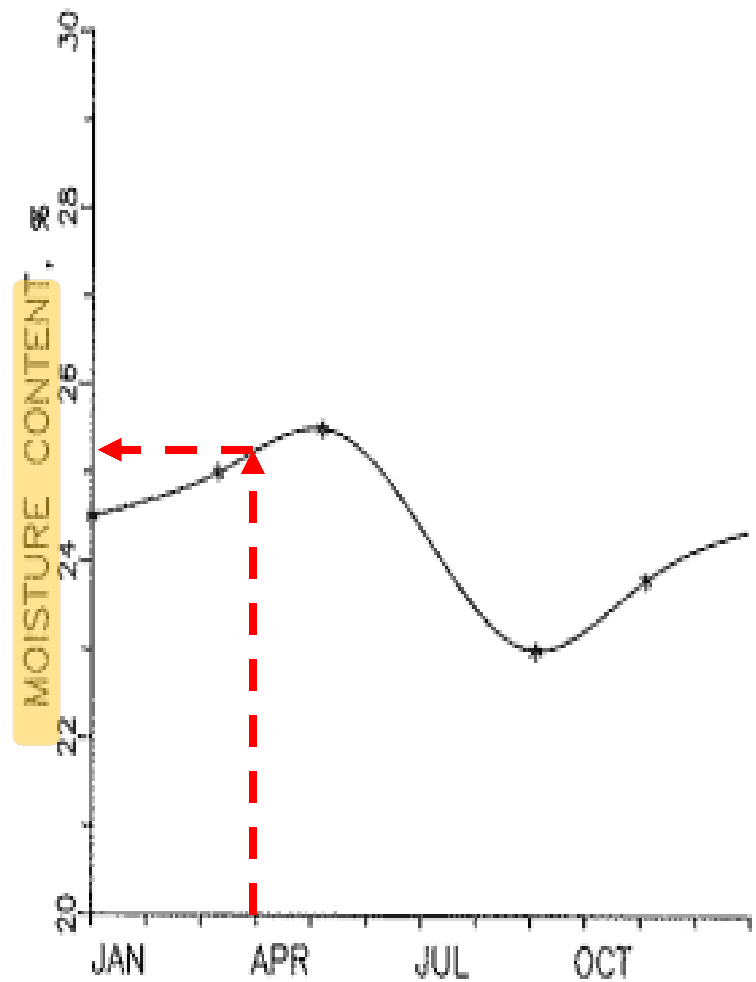


FIGURE 13 Seasonal moisture variation used in example.

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

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

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Determination of Effective Roadbed Soil Resilient Modulus

- **Step 4:**

  - Select a relative damage factor for each resilient modulus (U_f)

  - $U_f = 1.18 \times 10^8 \times Mr^{-2.32}$

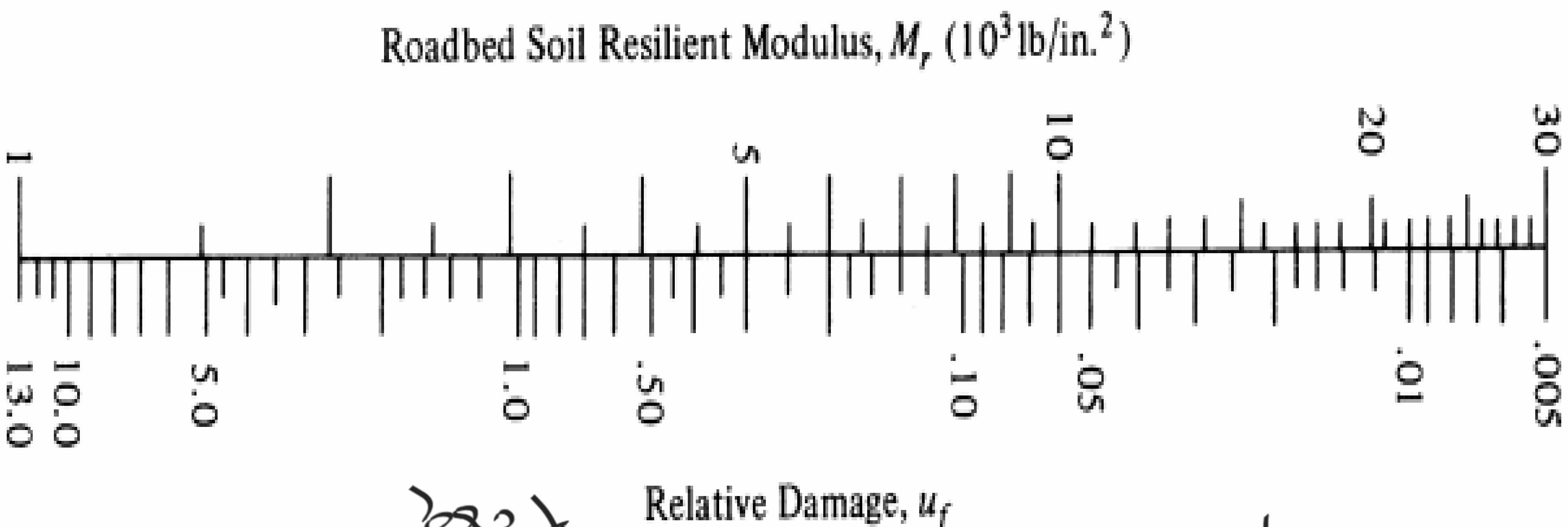
  - For the frozen subgrade (January),

    - The resilient modulus would be high resulting in a low relative damage

      - For practical purposes, a damage value of 0.0 is assigned

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Determination of Effective Roadbed Soil Resilient Modulus



Equation $u_f = 1.18 \times 10^8 \times M_r^{-2.32}$

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

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Determination of Effective Roadbed Soil Resilient Modulus

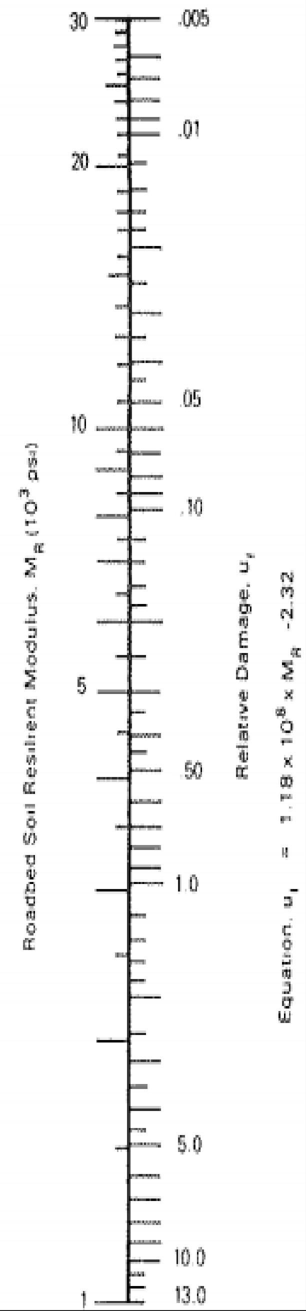
Step 6.

- 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



Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Example

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

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

- Determine
  - The effective resilient modulus of the subgrade

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

layer coeffient رح نستخدم

- 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)

كلما كان a الأكبر كان احسن

- Is a measure of the relative effectiveness of a given material to function as a structural component of the pavement.

لازم يكون عندي معلومة عن E

- 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**).

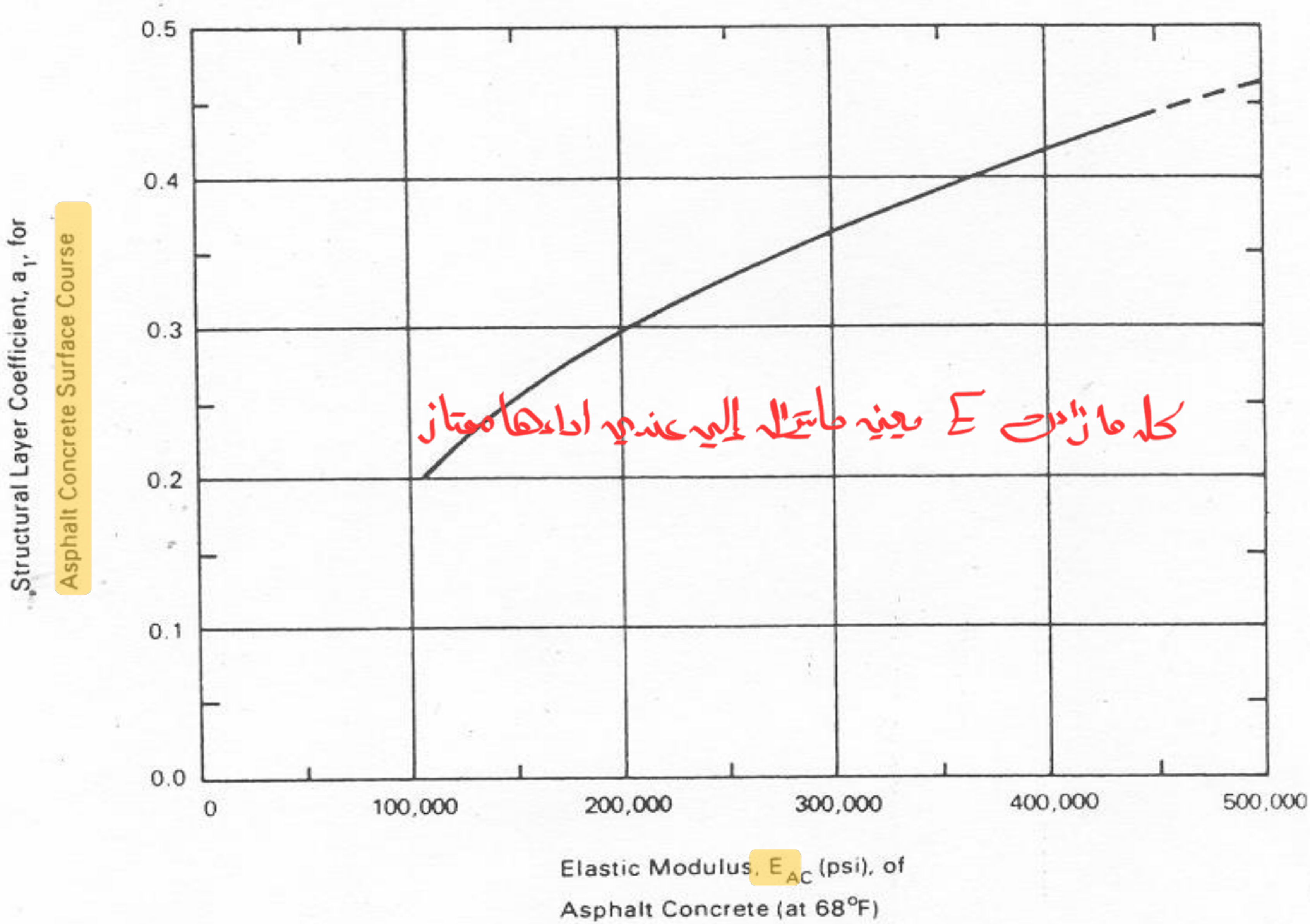
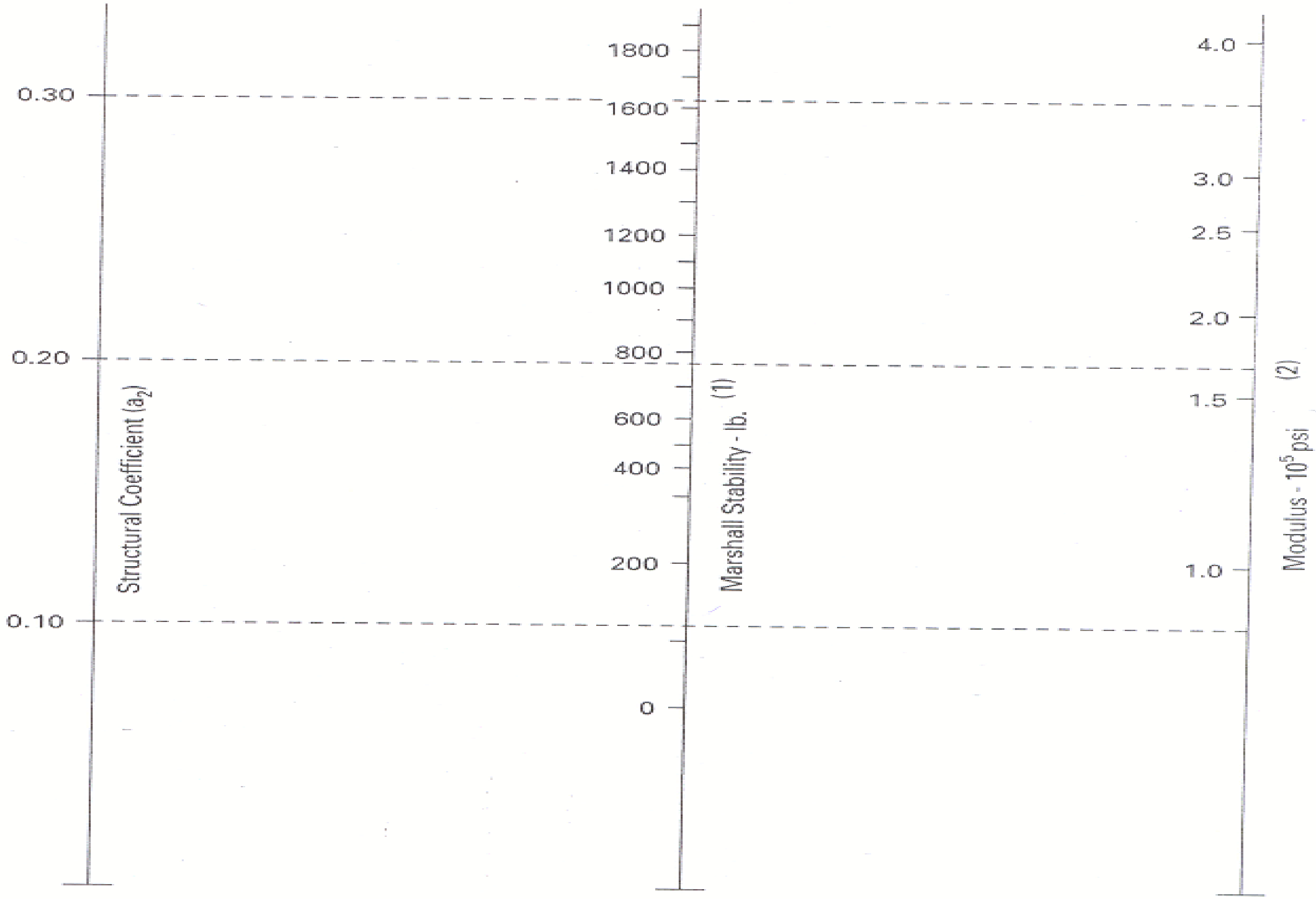
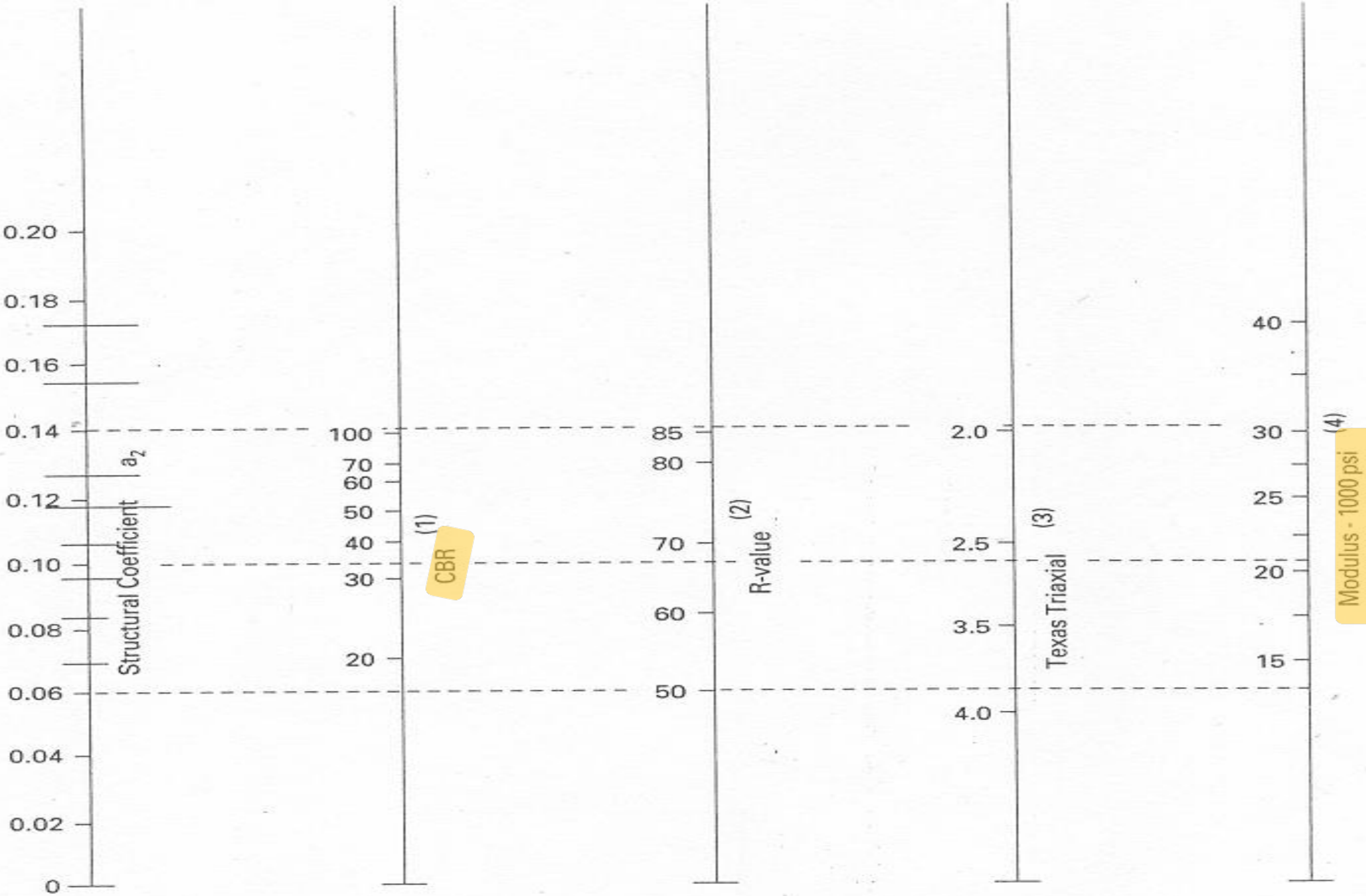


FIGURE 16-13 Chart for estimating structural layer coefficient of dense-graded asphalt concrete based on the elastic (resilient) modulus. (Courtesy American Association of State Highway and Transportation Officials.)



(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.)



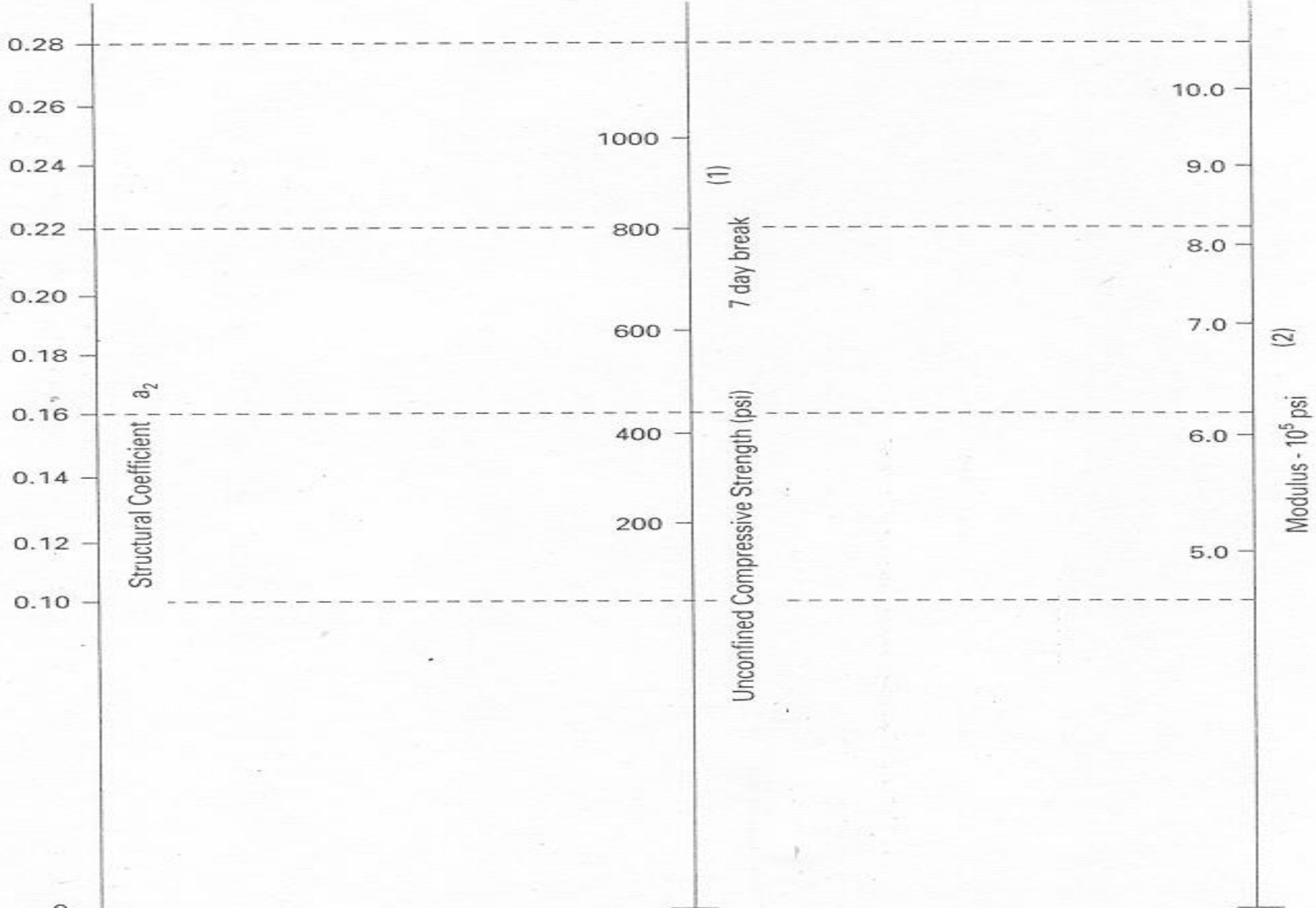
(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on NCHRP project *(4)*.

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.)

untreated ← بس base عادي ما عليه مواد العادية

(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

اصلاً احنا حسابه ب ΔPSI و Mr

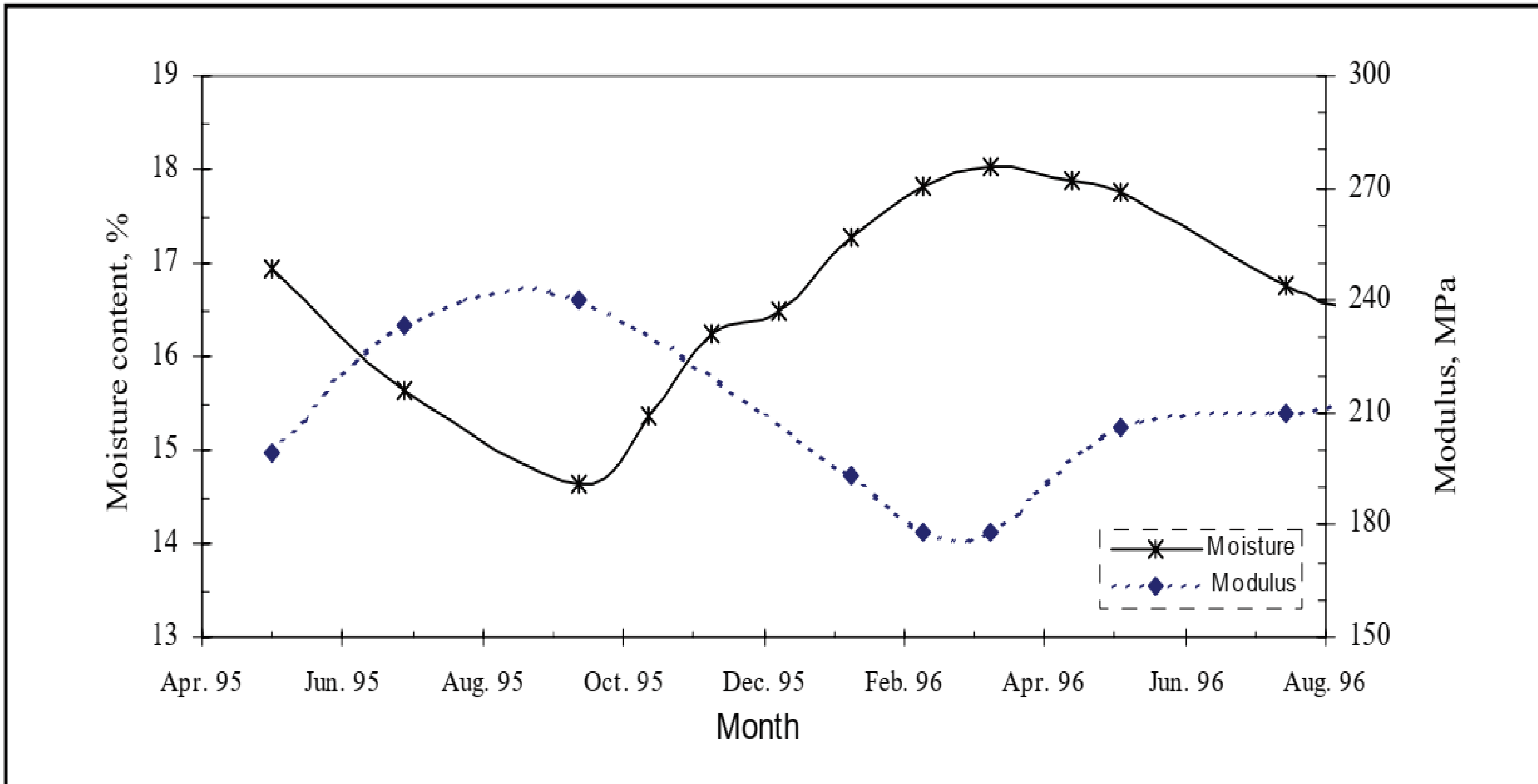
- Temperature and Rainfall are the two main environmental factors used in evaluating pavement performance in the AASHTO method.
- Effect of temperature includes:
  - Stresses induced by thermal action.
  - Changes in creep properties.
  - Effect of freezing and thawing on subgrade soil.
- Effect of rainfall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

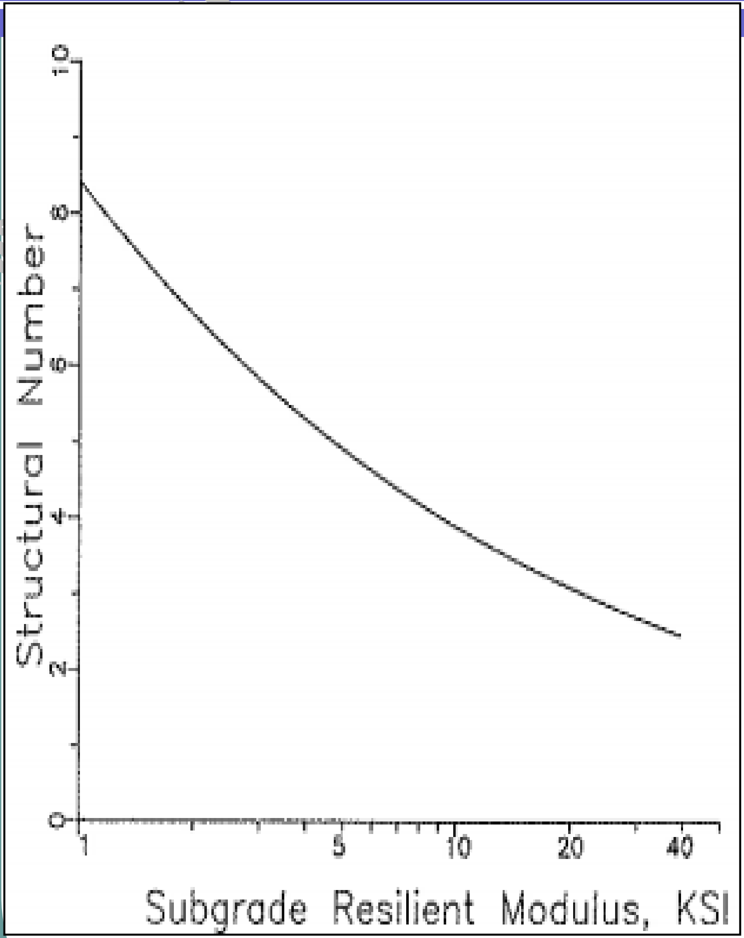
Subgrade Mr Seasonal Variation

Moisture content effects on Mr

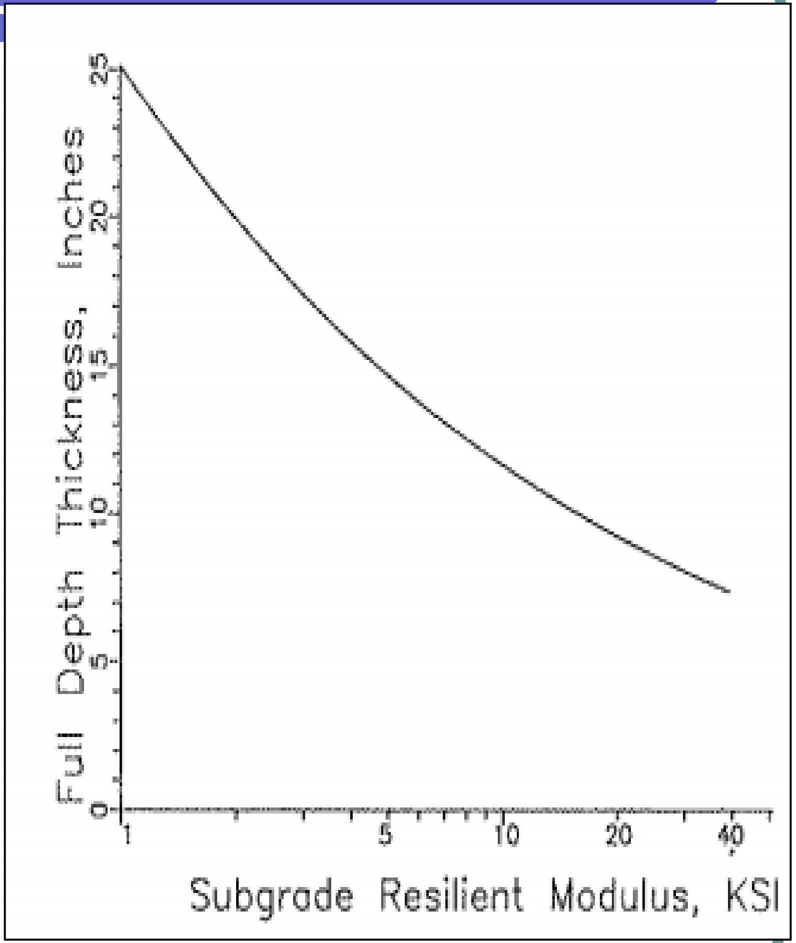


Roadbed Soils (Subgrade Material)

Effects of Mr on AASHTO 1993 Design



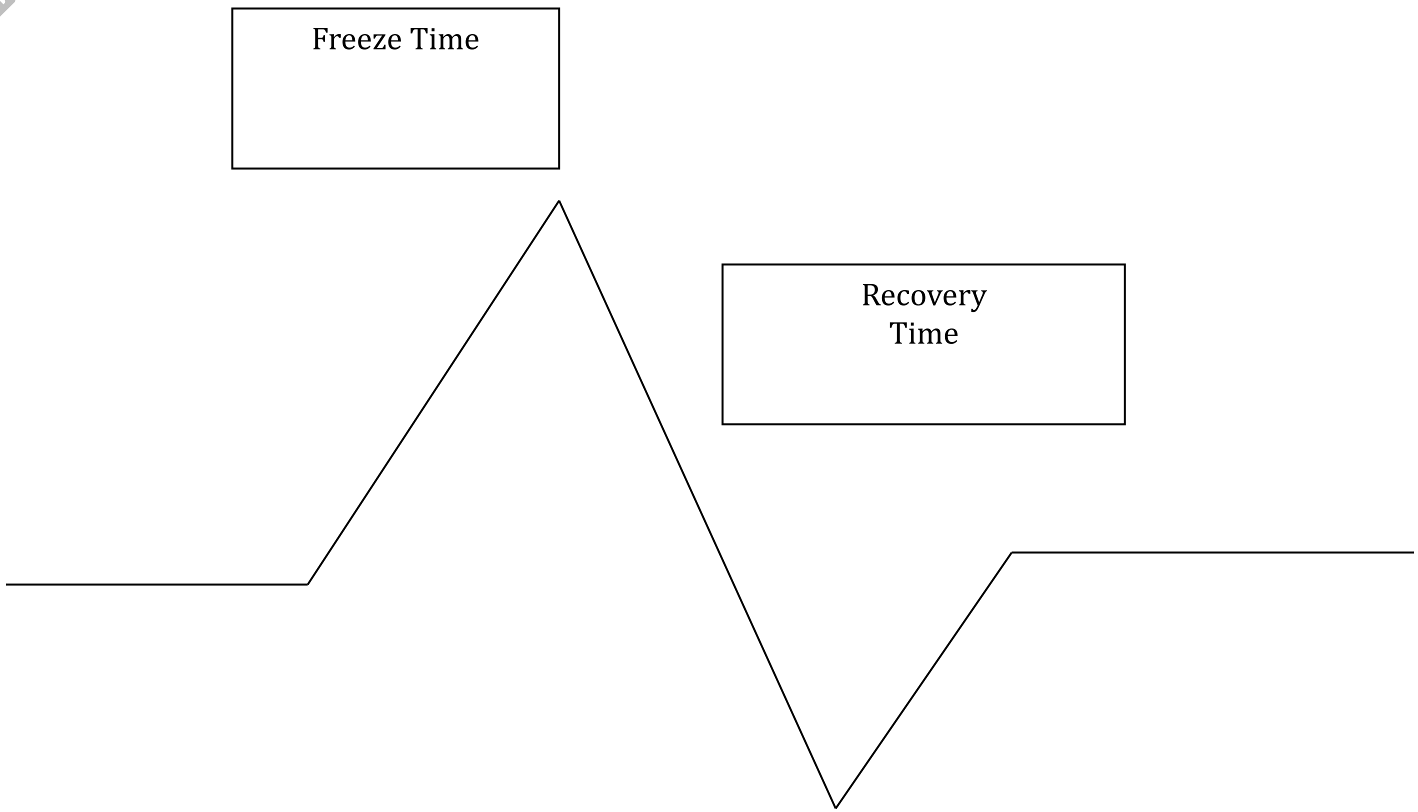
Effect of subgrade resilient modulus on design structural number



Effect of subgrade resilient modulus on design thickness

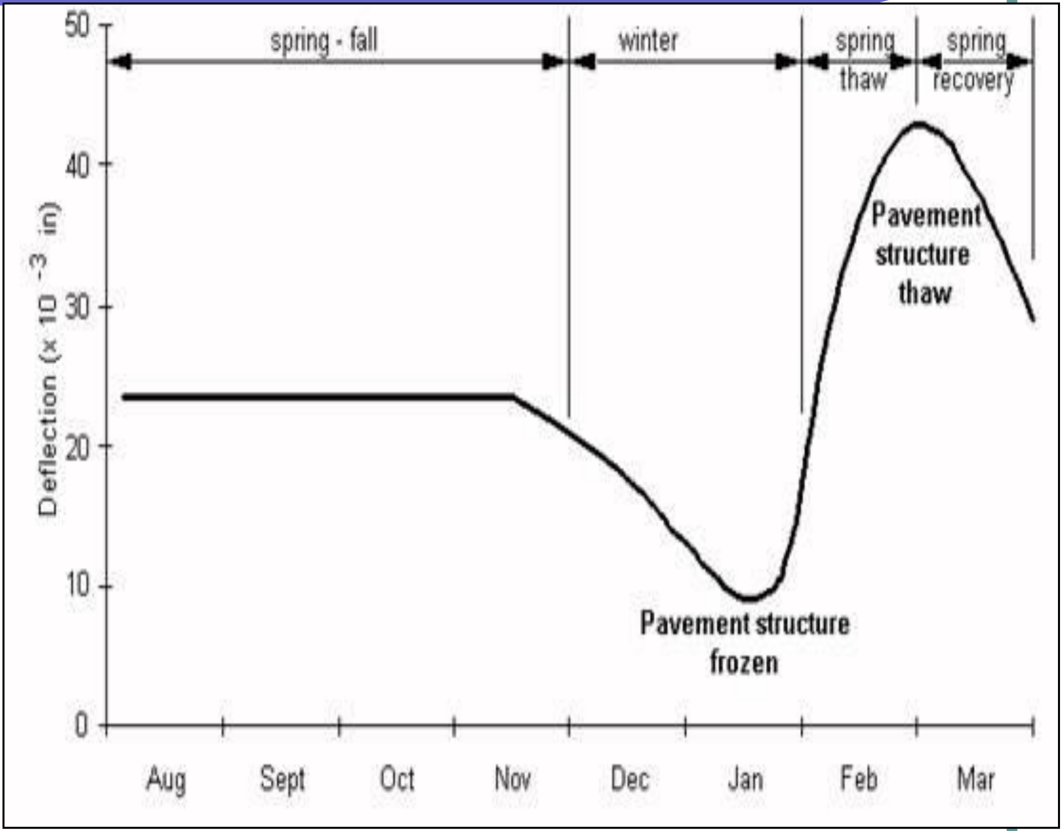
Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Subgrade Mr Seasonal Variation



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

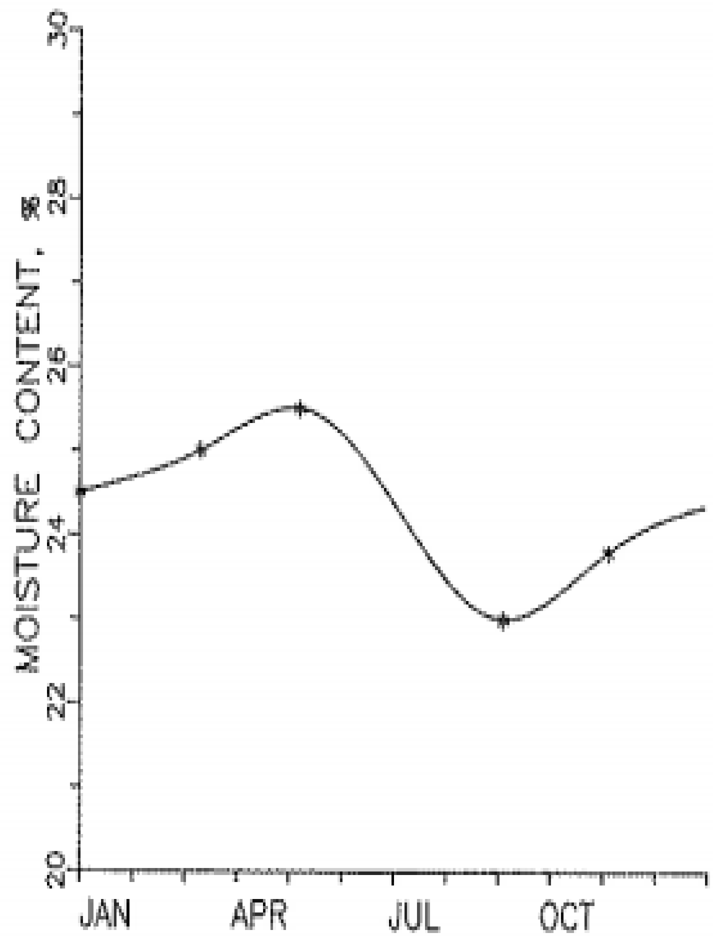


FIGURE 13 Seasonal moisture variation used in example.

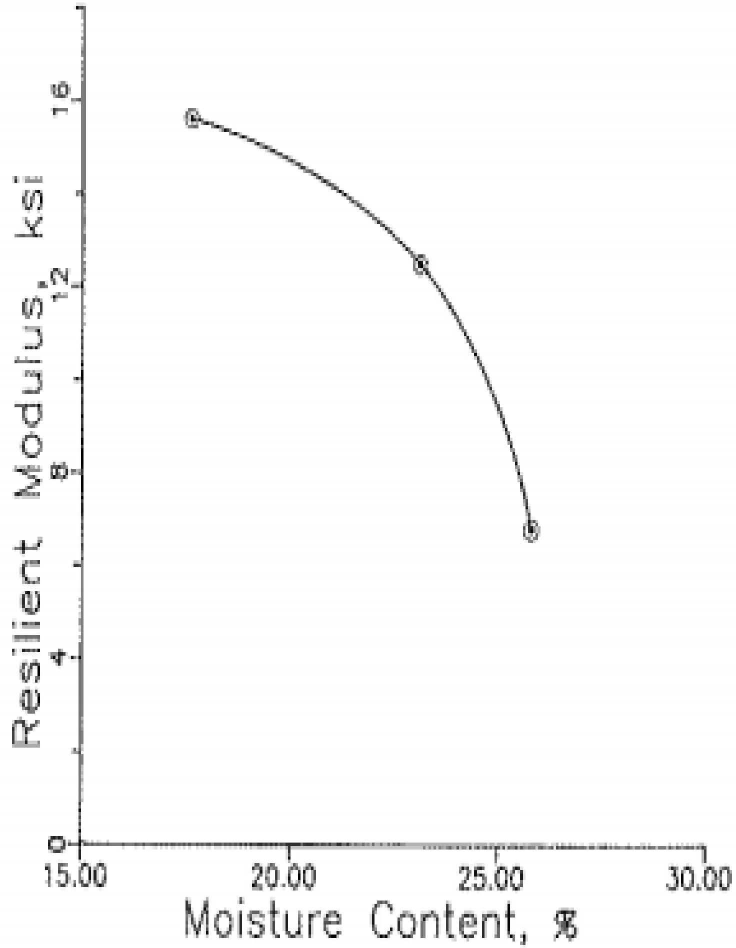
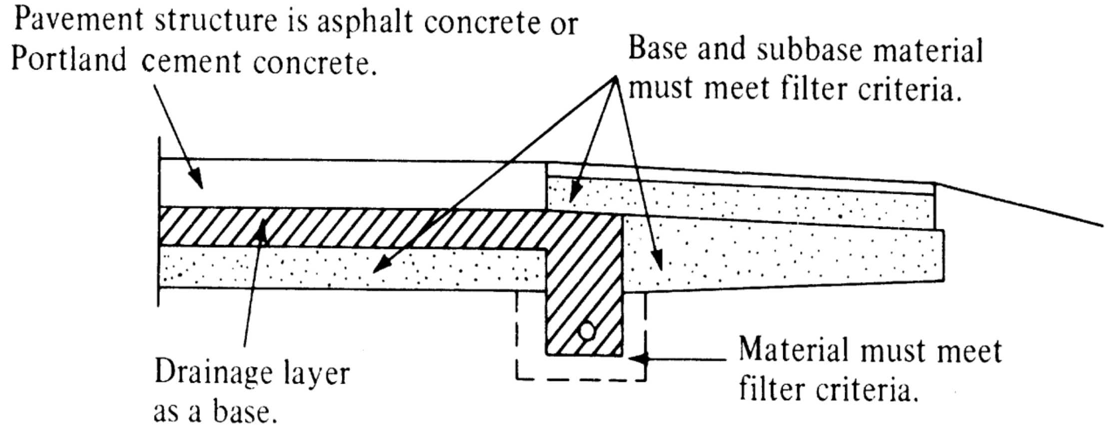


FIGURE 12 Moisture content-resilient modulus relationship for soil used in example.

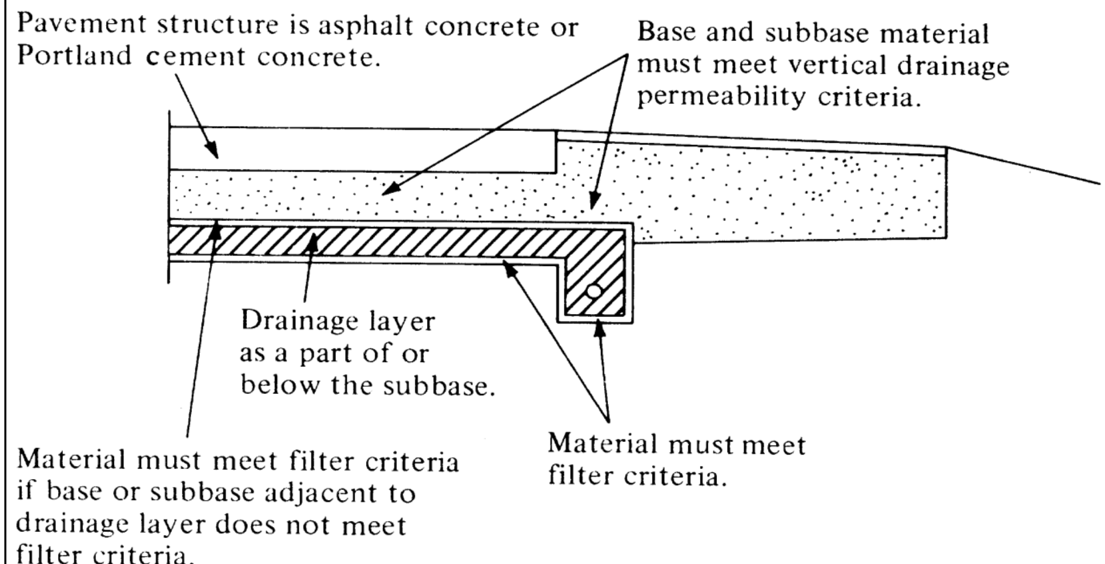
Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

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 معناها m_1

- 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.

كم نسبة الوقت الي بده يكون في pavment بحالة

- 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

Quality of Drainage	*Percent of Time Pavement Structure Is Exposed to Moisture Levels Approaching Saturation*			
	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 : كم أنت متأكد اعتمادية ، بحيث كل ما طلبت اعتمادية عالية رح ينعكس على التصميم

مين ممكن يخرب الثقة ؟! انت بتفرض انه كل ما تستخدم

الي فحصتها تكون تمام ولكن انت ما فحصت كل حبة فممكن يصير عندي variation in materials , وبرضه ممكن construction

فرح يكون مناطق اتدمكت بشكل جيد ومناطق لا ، وممكن chance variation in traffic ممكن تكون اخترنا G غلط

So safety factor رح يكون عندي ز ي

Reliability

- The level of reliability to be used for design should increase with the increase of كل ما زاد مهم بزيد ال reliable
  - The volume of traffic.
  - Difficulty of diverting traffic.
  - Public expectation of availability. ← توقعات مستوى عالي

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

Functional Classification	Recommended Level of Reliability: Urban	Recommended Level of Reliability: 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).

كل ما كان الشارع مهم نرفع safety factor

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.

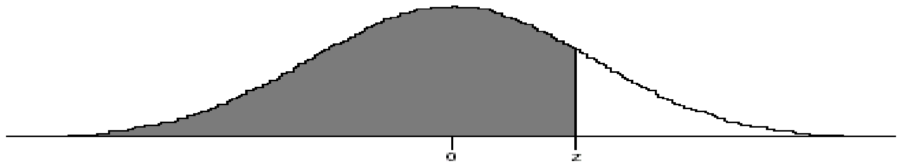
Table 19.8 Standard Normal Deviation (Z_R) Values Corresponding to Selected Levels of Reliability

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

100 ماعندي

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.

الهدف نوجد SN التي تكون كافية لحمل الأحمال المتوقع

Basic Design Equation

المعادلة محفوظة

The basic design equation given in the 1993 guide is

Reliability — إلي بشرعية

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

$$+ 2.32 \log_{10} M_r - 8.07$$ [redacted]

ESAL

subgrade

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
$\Delta PSI = p_i - p_t$

بنوجد SN بنوجد thickness (d_1, d_2, d_3)

Structural Number (SN)

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

NOMOGRAPH SOLVES:

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

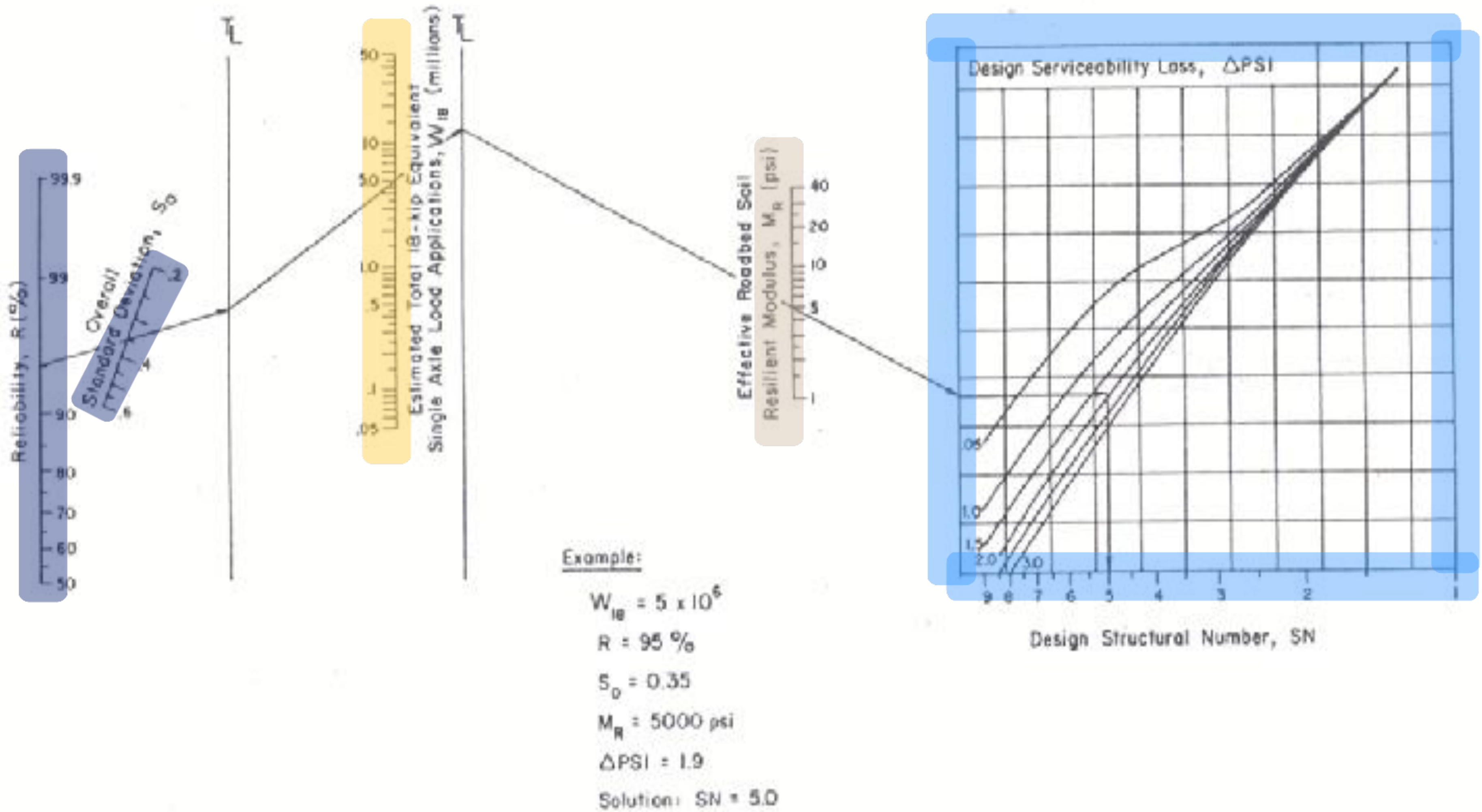


FIGURE 16-11 AASHTO design chart for flexible pavements based on using mean values for each input. (Courtesy American Association of Highway and Transportation Officials.)

طريقة استخدام chart:- ببلش ب قيمة R% بعدها

S_o وبنزل الخط لل TL بعدها بنشوف قيمة W (ESAL)

نلاحظ انه 10^6* ونمد الخط لل TL بعدها قيمة M_r ونلاحظ

انها 10^3* وبعدها نوصل الخط للمربع وبنمد خط افقي لحد

قيمة ΔPSI وبنزل عاموديًا لايجاد قيمة SN/ لو عندي ΔPSI

مش موجودة بنرسم خط موازي بينهم

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.

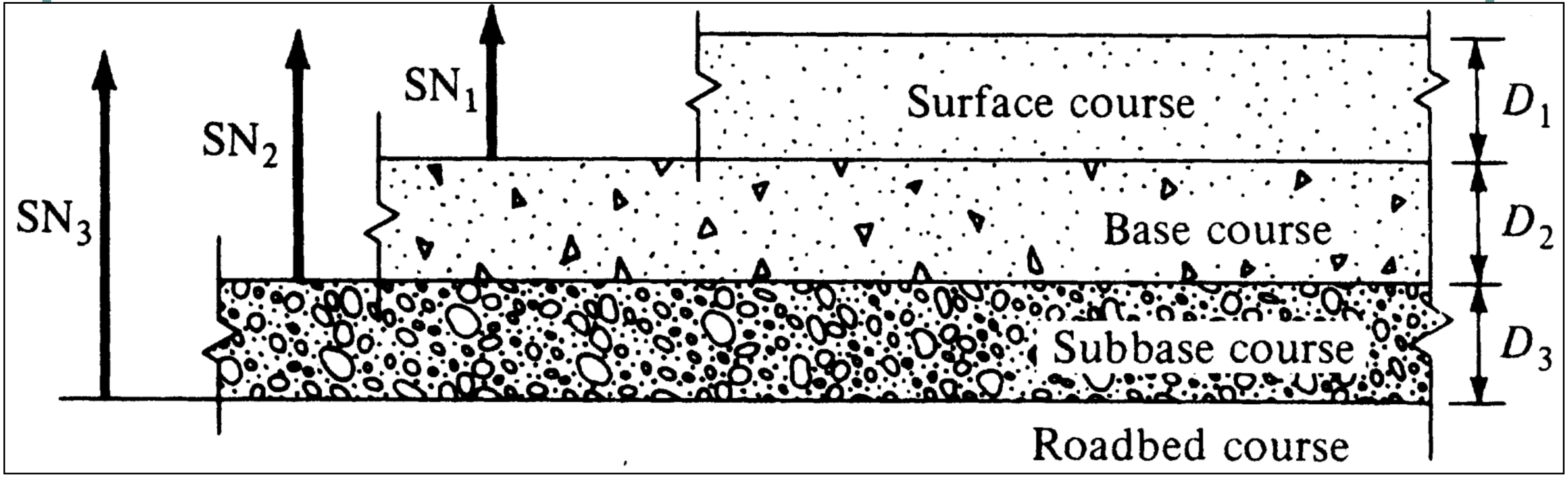
Structural Number (SN)

There are three type of **SN** :

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



Design steps

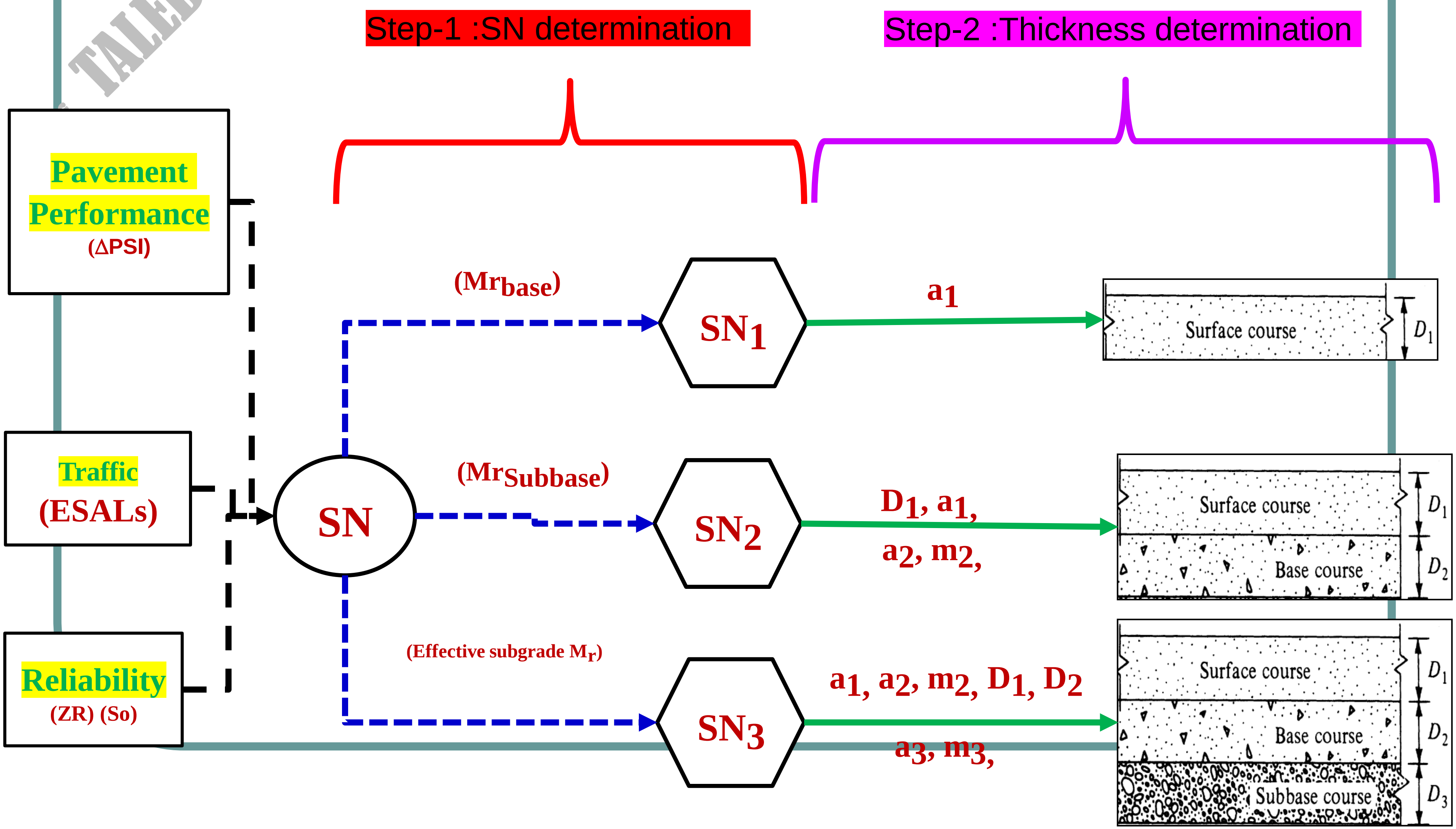
- ***Step -1:***
  - Determine the Structural Number (SN) for pavement layers

    كم عدد بـ سماكة لأحمي طبقة base

    - 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

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



Step -1:

Determination of Pavement Layers Structural Numbers (SNs)

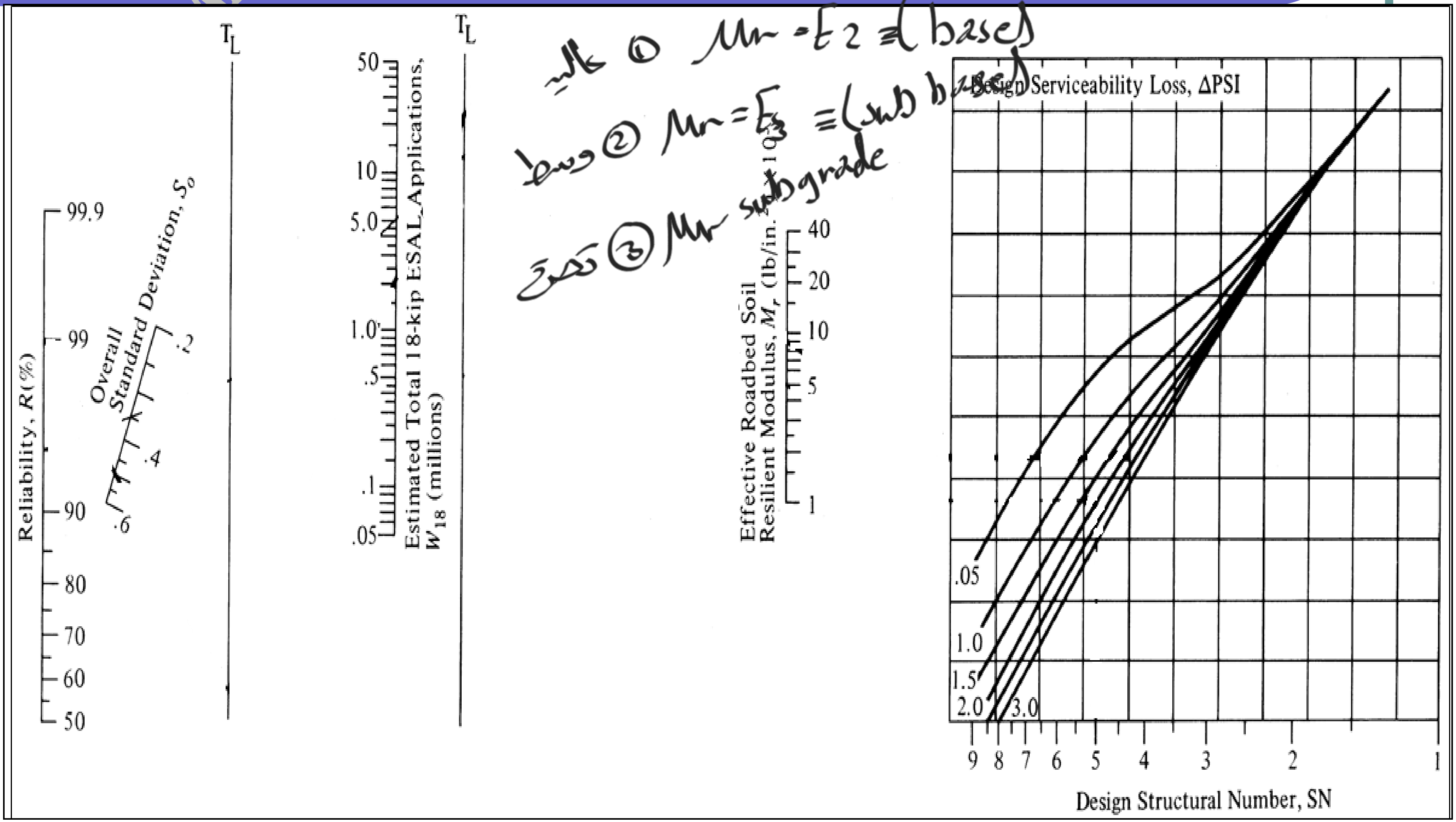
SN Determenation

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

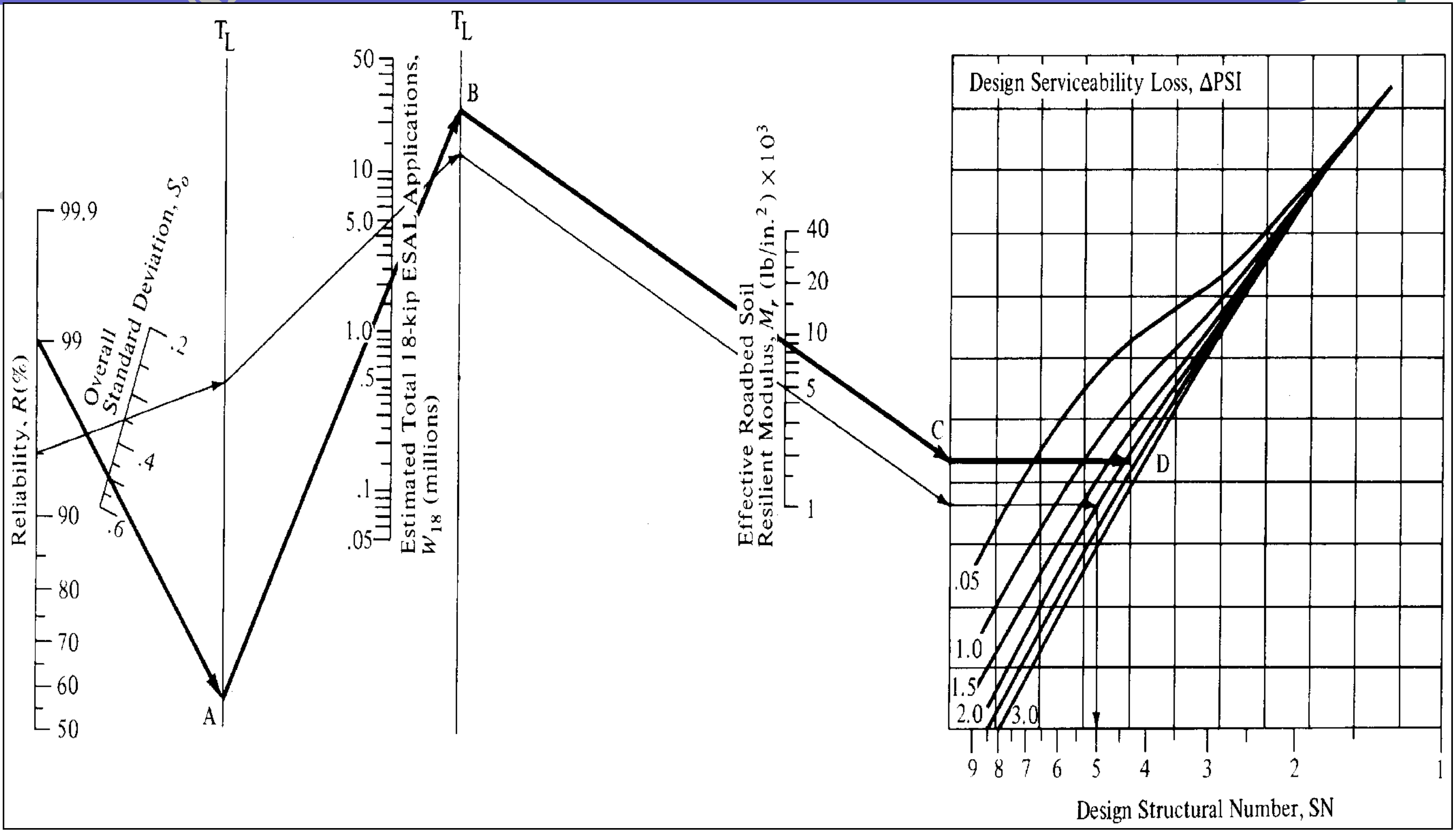
- W_{18} = predicted number of 18,000-lb (80 kN) single-axle load applications
- Z_R = standard normal deviation for a given reliability
- S_o = overall standard deviation
- SN = structural number indicative of the total pavement thickness

- $\Delta PSI = p_i - p_t$
- p_i = initial serviceability index
- p_t = terminal serviceability index
- Mr = resilient modulus for Base, subbase, and effective subgrade layers lb/in^2

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:

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

①

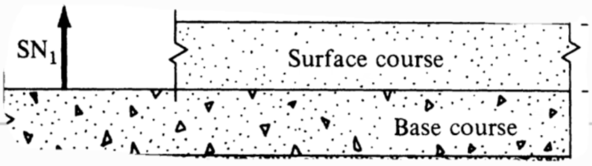
2. The computed thickness D_1 is usually rounded up to the nearest one-half inch.
3. In addition for purpose of practicality and economy, certain min. thicknesses are recommended (***Table 20.18 in Text and 16.8 in Ref***).
4. The rounded value of (D_1) will be used in the preceding calculations as (D_1").

بشكل عام احنا اعنا طبقة فاونديشن هي subgrade و Mr كانت

للـ subgrade فعشان اطلع D_1, D_2, D_3 رح نجزء الحل

(1 رح نفرض انه فقط عندي surface وتحتها base فقط

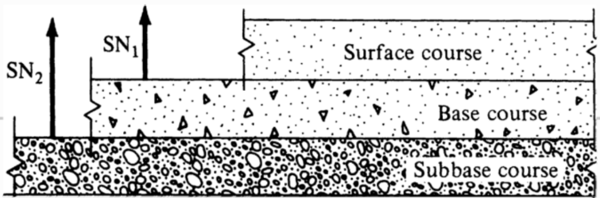
base يعني فاونديشن هو base هيك



بنطلع D_1 هاي بكون اسمها SN_1

(2 رح نفترض انه D_1 صارت معروفة وصار عندي sub base

هي فاونديشن هيك بنوجد D_2



بكون اسمها SN_2

(3 بعدها بنوجد D_3 وبكون فاونديشن هو subgrade

بكون اسمها SN_3

نلاحظ انه R و S_0 ثابتين بكل حالات فقط متغير

عنا هو M_r فبالحالة الاولى لما نفرض انه طبقة

الاسفلت موجودة على Base course بتكون M_r تبع subgrade

ساوي base = E_2 بتكون M_r عالية نسبيا

والحالة الثانية لما استعملنا SN_2 بتكون M_r تبع

subgrade ساوي subbase = E_3 بتكون اقل من الاولى

والحالة الثالثة لما استعملنا SN_3 بتكون M_r تبع

subgrade

عنا الشي الثاني minimum لل D_1 و D_2 فلازم قبل نروح نحسب D_2 نتأكد

من قيمة min لل D_1 إذا كانت القيمة اقل من min بنوخذ min

إذا اكبر بنوخذها للقيمة ونكمل ب D_1 الي اعتمدتها لحساب D_2

ونفس الاشي نشيك على D_2 ونعتمدو ونطلع D_3 ، دائما تقرب للأكبر نص

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:

ماعندي min للـ D_3

دائمًا تقرب للأكبر نص

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

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

Example 1 (20.8 in text)

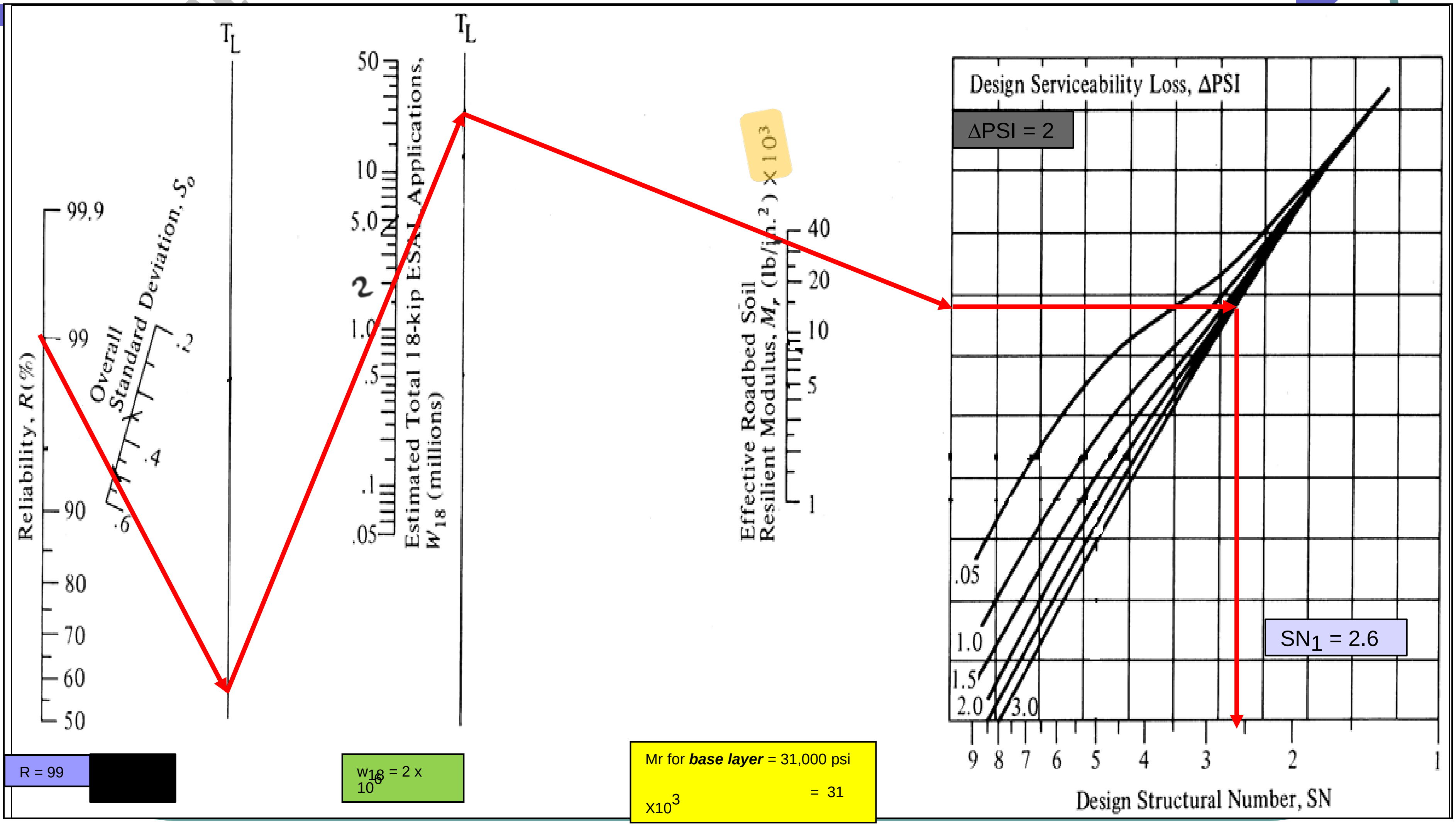
- A flexible pavement for an urban interstate highway.
- ESAL = $2x\ 10^6$
- It takes about a week for water to be drained from within the pavement.
- The pavement structure will be exposed to moisture levels approaching saturation for 30% of time.
- Resilience modulus of asphalt concrete = 450,000 psi.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

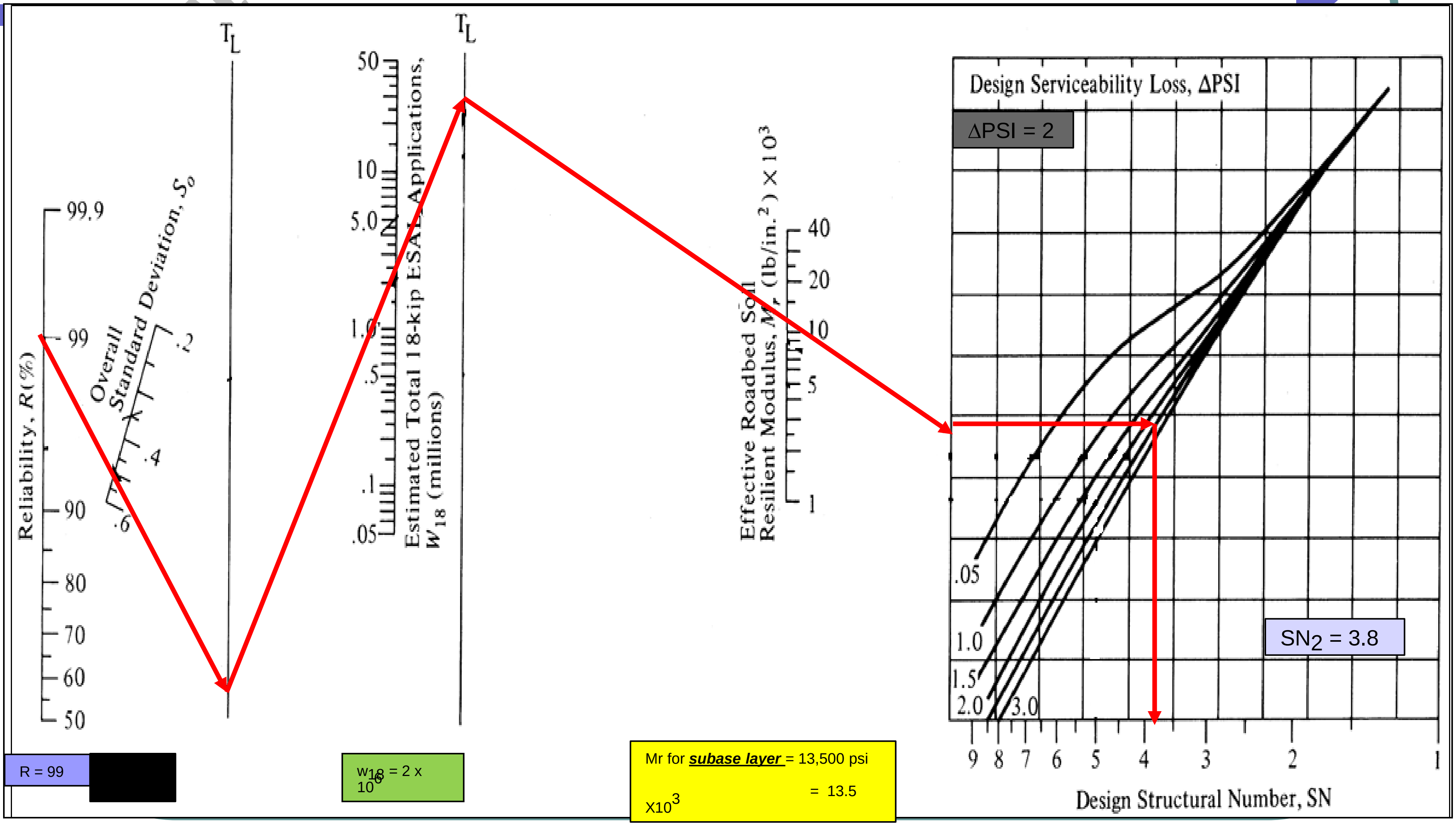
Determination of SN_1 (to protect base layer)



Follow the red line

Example 1 solution

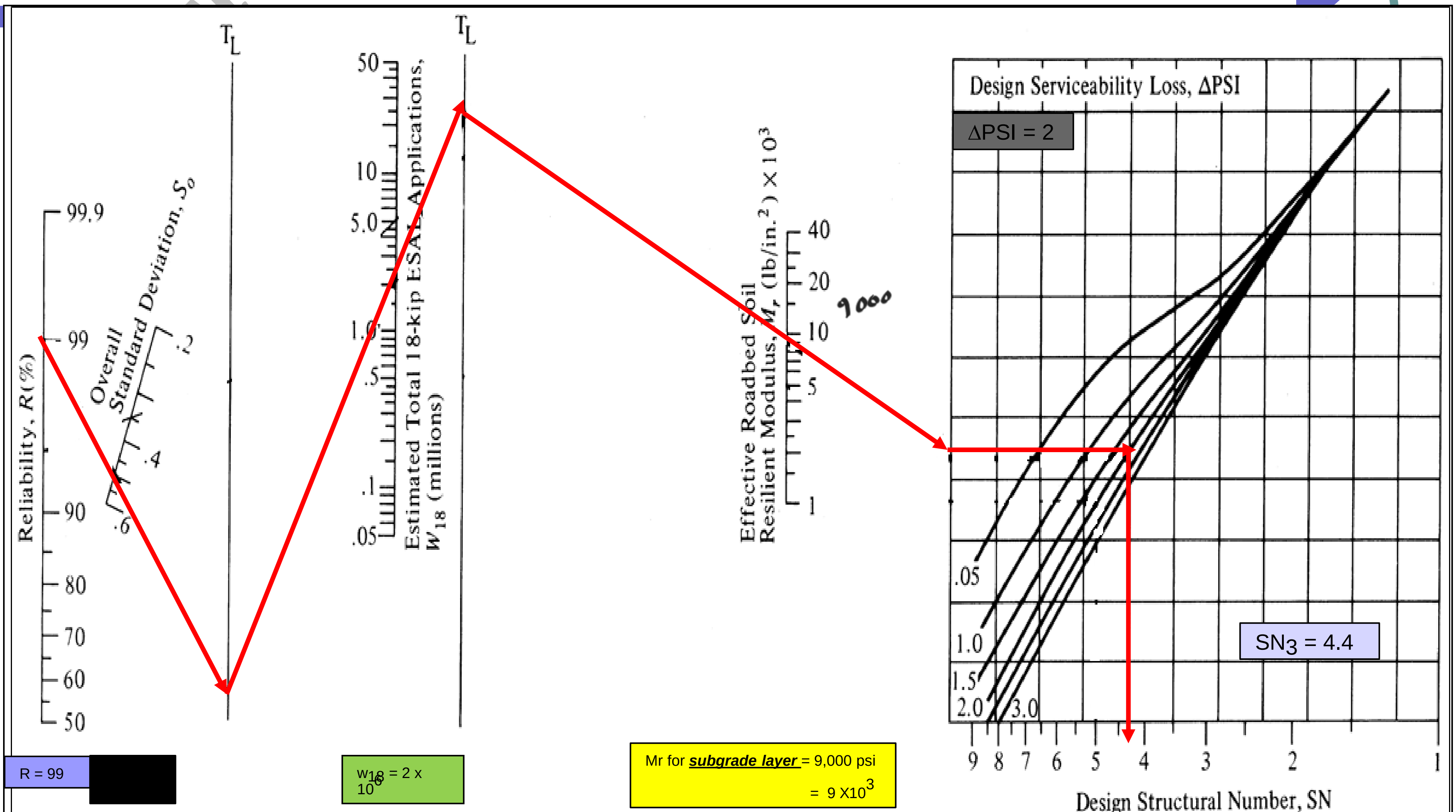
Determination of SN_2 (to protect subase layer)



Follow the red line

Example 1 solution

Determination of SN_3 (to protect Subgrade layer



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

بالامتحان نعتمد هاي

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

هاي حسب كتاب

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)

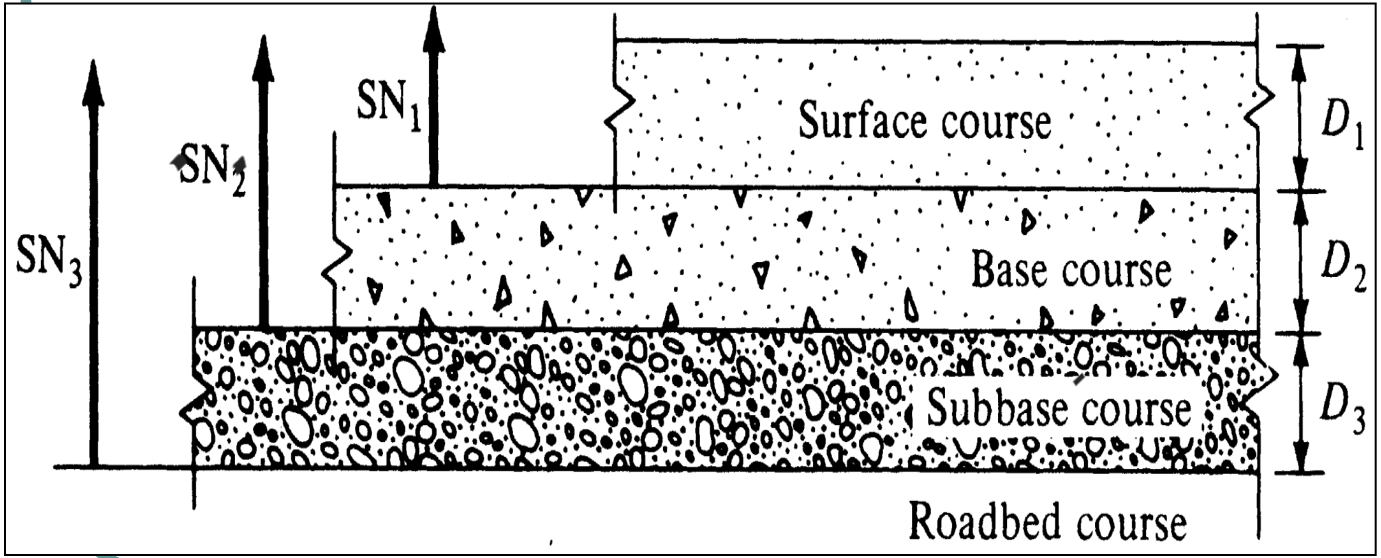
- $D_3 \geq \frac{SN_3 - a_1 \times D_1^{**} - a_2 \times D_2^{**}}{a_3 m_3} = \frac{4.4 - 0.44 \times 6.0 - 0.14 \times 10.5}{0.1 \times 0.8} = \frac{.29}{0.08} = 3.625$

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.

حالات خاصة

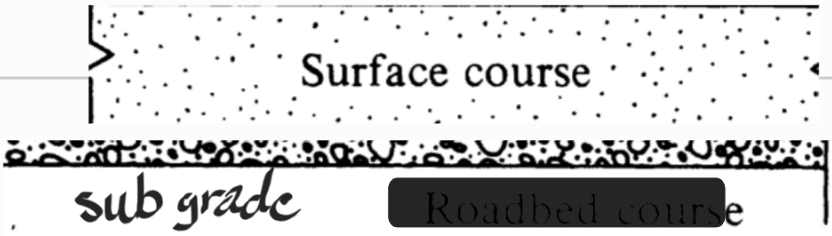
①

لو كان عندي Full depth وهي عبارة عن subgrade واسفلت

لو سؤال كان Full depth رح يكون فاونديشن subgrade

رح يكون عندي SN_3

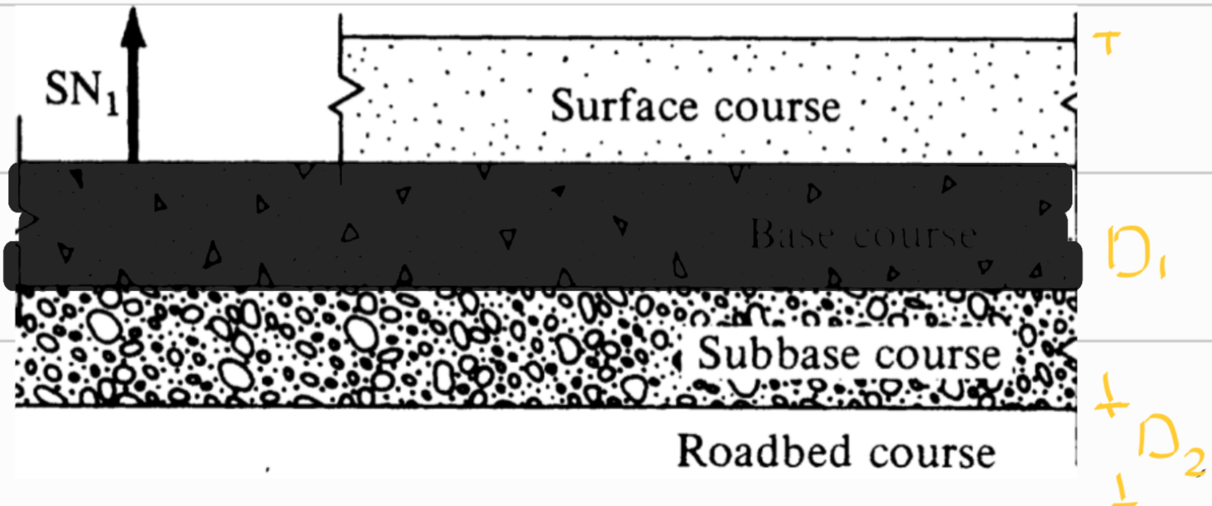
$SN_3 = a_1 D_1$ يعني



$$\frac{SN_3}{a_1} \le D_1$$ (الاسفلت رح يتحمل الكل)

لو حذفنا طبقة مثلاً الـ base او خواص الخامة فيه زي

subbase يعني صار كأنه طبقة واحدة



طبقة اسفلت فاونديشن subbase يعني استعملت $M_r = E_3$

يكون: $\frac{SN_2}{a_1} \leq D_1$ ← بيكون حسب فاونديشن

لما نطلع D_2 بيكون فاونديشن subgrade رح نستعمل الـ M_r

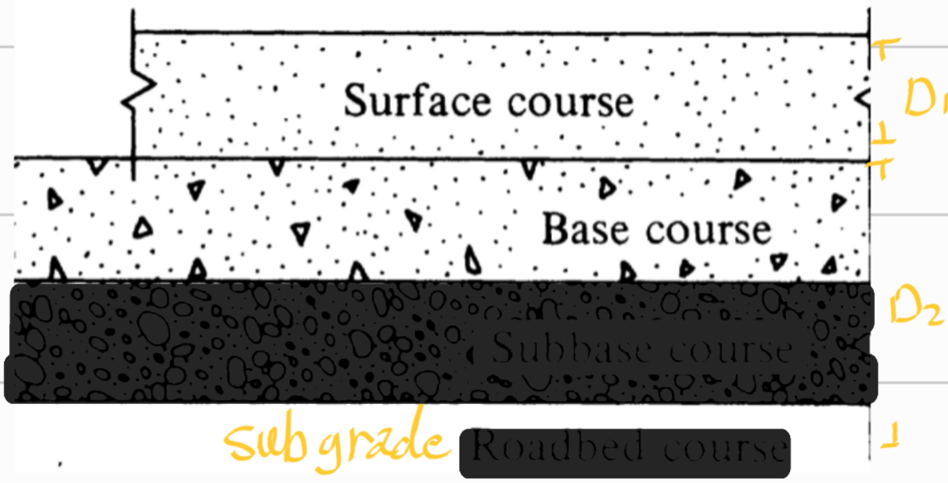
subgrade: يكون $\frac{SN_3}{a_2} \leq D_2$ ($SN_3 = a_1 D_1 + a_2 m_2 D_2$)

③

لوشلت subbase وخليت base ف بتضل SN_1 نفس ماهي

وبتصير الو بعدها SN_3 بتطلع D_2 سماكة base رح

نستخدم SN_3



السر هو أي SN نستخدم :

:

$SN_1 \longrightarrow E_2$

$SN_2 \longrightarrow E_3$

$SN_3 \longrightarrow M_r$

نهاية الشابتر☆

Pavement Materials & Design (110401466/2104011466)
Hot Mix Asphalt Production and Placement

Instructor:

Prof. TALEB M. AL-ROUSAN

محاضرة اون 1

HMA Manufacturing

تم ادخال aggregate واسفلت بنسبة معينة وخلطها

مصنع صغير

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

* يتم تصنيع بهاي المحطة (الخلطات الاسفلتية)

- 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.

وحدات النقل

* بدخل مواد الأولية (الحصمة)

عنده فوائد

- Preparation of the paving mixture at a central plant offers the advantages of:

سيطرة بدقة على الكميات

  - More careful proportioning of the ingredients.
  - More uniform and thorough mixing with consequent production of more uniform mixtures.

طريقة خلط بعطينا اكثر تجانس فيقلل مشاكل

  - Less dependence on favorable weather conditions. ← الاعتماد على طقس ما بأثر على الخلطة
  - Use of more viscous bituminous materials.

يتم استخدام ولما يكون اللزوجة عالية بكون بحاجة تسخين اكثر

Central Mixing Plants

مجموعة من اشكال

- 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.

Portable :- يكون الخلاطة المركزية مكونة من اجزاء صغيرة مركبة على

عجلات خلف سيارة تعطي Plant لمكانه انه يكون سهل نقلها

الاكثر شيوعًا

Semi - Portable :- ممكن نفك القطع ونحملها على

شاحنات (قطار) ويعاد تركيبها بس توصل الموقع ، الاكثر شيوعًا

Stationary :- يكون ثابت بحيث يكون باقيا في مكانها

ولا يتم نقلها (في مشاريع طويلة الامد)

Types of Central Mixing Plants

الانواع

- **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.*

(خزانات شكلها زي صوامع طويلة يخزن فيها الأسفلت)

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.

كلفة تشغيلية

رح يعطوني تقريبًا نفس الكوالتي لـ HMA و ما في فرق

بطبيعة المنتج (نوعية) ولكن الفرق بينهم انه batch

رح تعمل خلطة وحدة في كل مرة أما drum إنتاج الاسفلت

بكون متواصل

Batch Plants :- الكمية صحيحة والاوزان المناسبة للـ agg والاسفلت

رح يتم اضافتها للخلاط اوحدة الخلاط) بحيث فكرة انه بندخل مكونات الخلطة الوحدة

بعدها بفرغها وبرجع اضيف كمية جديدة من الماتيريال

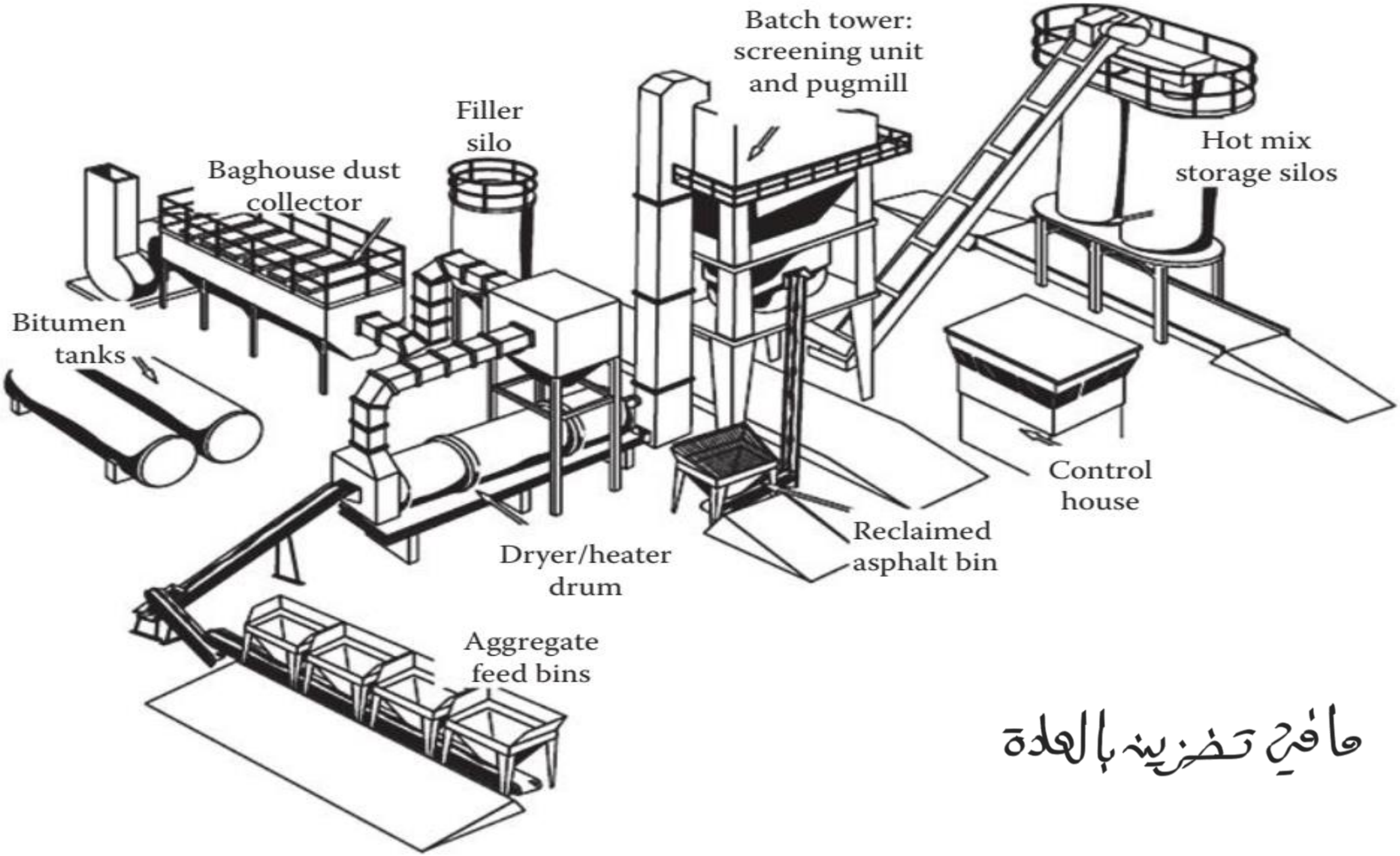
Drum mix Plants :- يتم استخدام النسب المناسبة من agg باستخدام

حزام ناقل ابوحدها تيريال بشكل مستمر) بحيث بكون مجموعة من agg ، بكونحنا

drum بوحد agg وبنشفها و يخلطها مع كمية مناسبة من الاسفلت

اختيار النوع بكون بناءً على الامور العملية

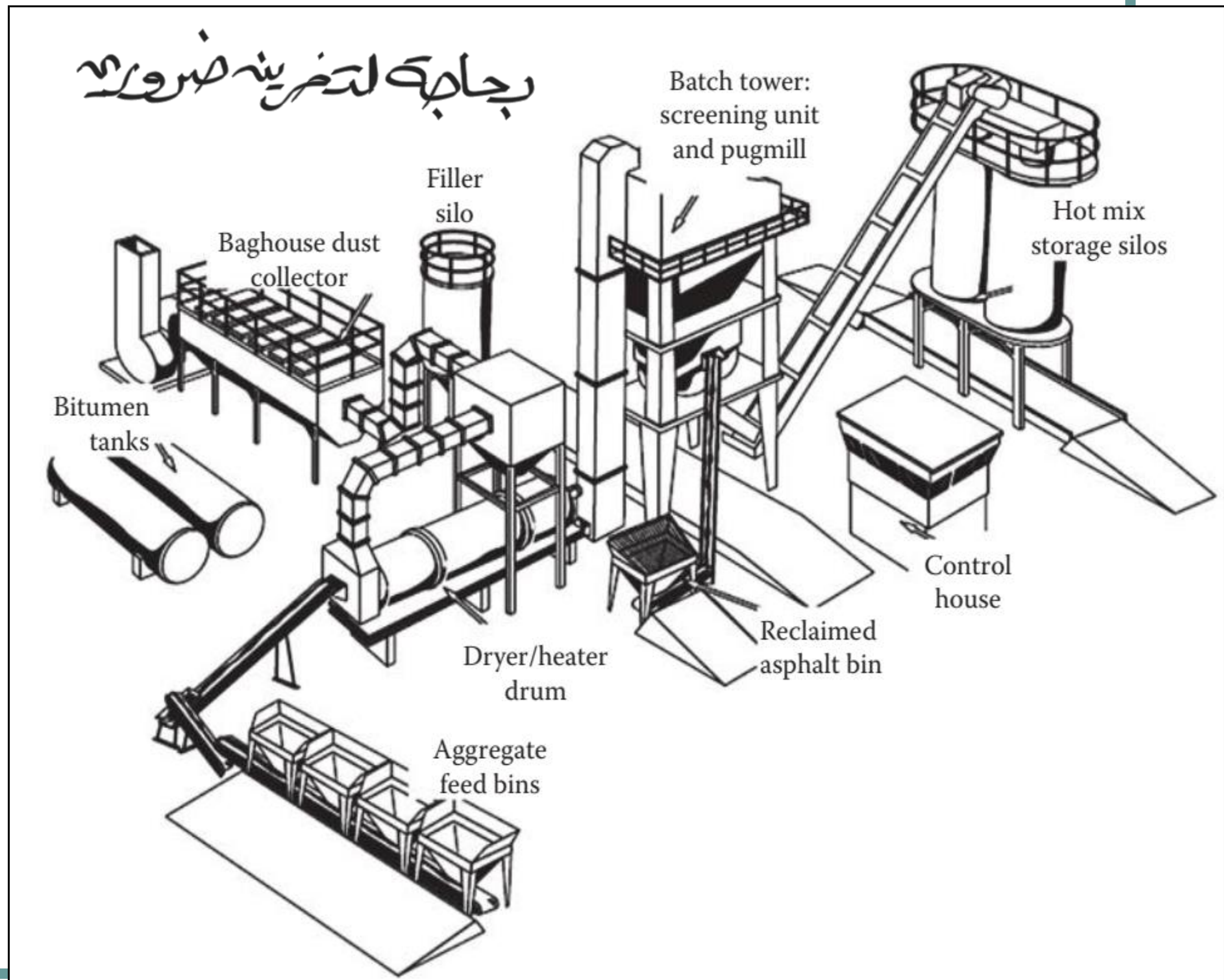
Batch Plant



مافي تخزين بالعادة

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

وظائف

تخزين agg و الاسفلت

- Aggregate and asphalt storage.

تجفيف agg

- Aggregate drying.
- Dust collection, air pollution control.

توزين agg

- Aggregate and asphalt proportioning.
- Mixing.
- Mixture discharge/storage.

اخراج خليط او تخزينه

Aggregate Storage

ننتبه لموضوع تصريف ماء

تأمين ماتيريال المطلوبة

- 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

كل صومعة فيها نوع من انواع [illegible]

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

يتم تجميعها

بالماء عشان ما يلوث الهوا

Asphalt Storage

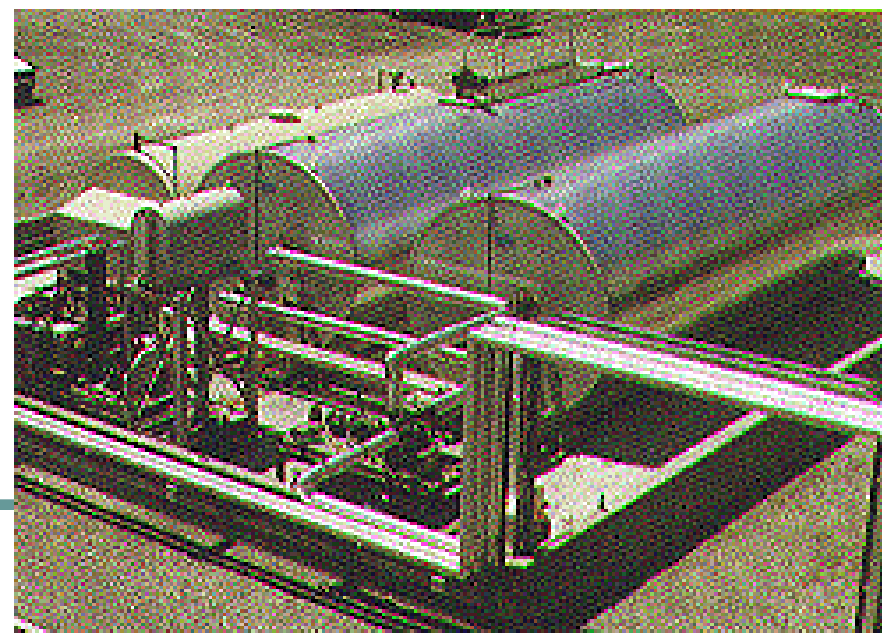
بتكون هاي خزانات جواها كهربية بحيث انها تسخن وتعطيني درجة حرارة مطلوبة

- 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.

لازم يكون فيها معايرة

بحيث تعطيكم كميات المتبقية

Asphalt Storage Tanks



Control Facility

منشآتها يتم تحكم بمجموعة عمليات

- Plant operations are monitored
  - تحكم بمعدل تزويد agg
  - Aggregate feed rate (s)
  - معدل كمية الاسفلت
  - Asphalt feed
  - تحكم بالحارقة
  - Burner control
- Truck loading

تحكم بتحميل سيارات

Batch Plant

هي خلاطة التي تعمل خلطة وحدة

Batch Plants / Features

بنشف الحصى بعدها نحسب وزنه

- Aggregates dried, separated by size.

نجمعهم باستخدام أوزان مختلفة من كل size

- Aggregates recombined by weight in weigh hopper.

بنحطهم على جزء الذي يتم به الخلط

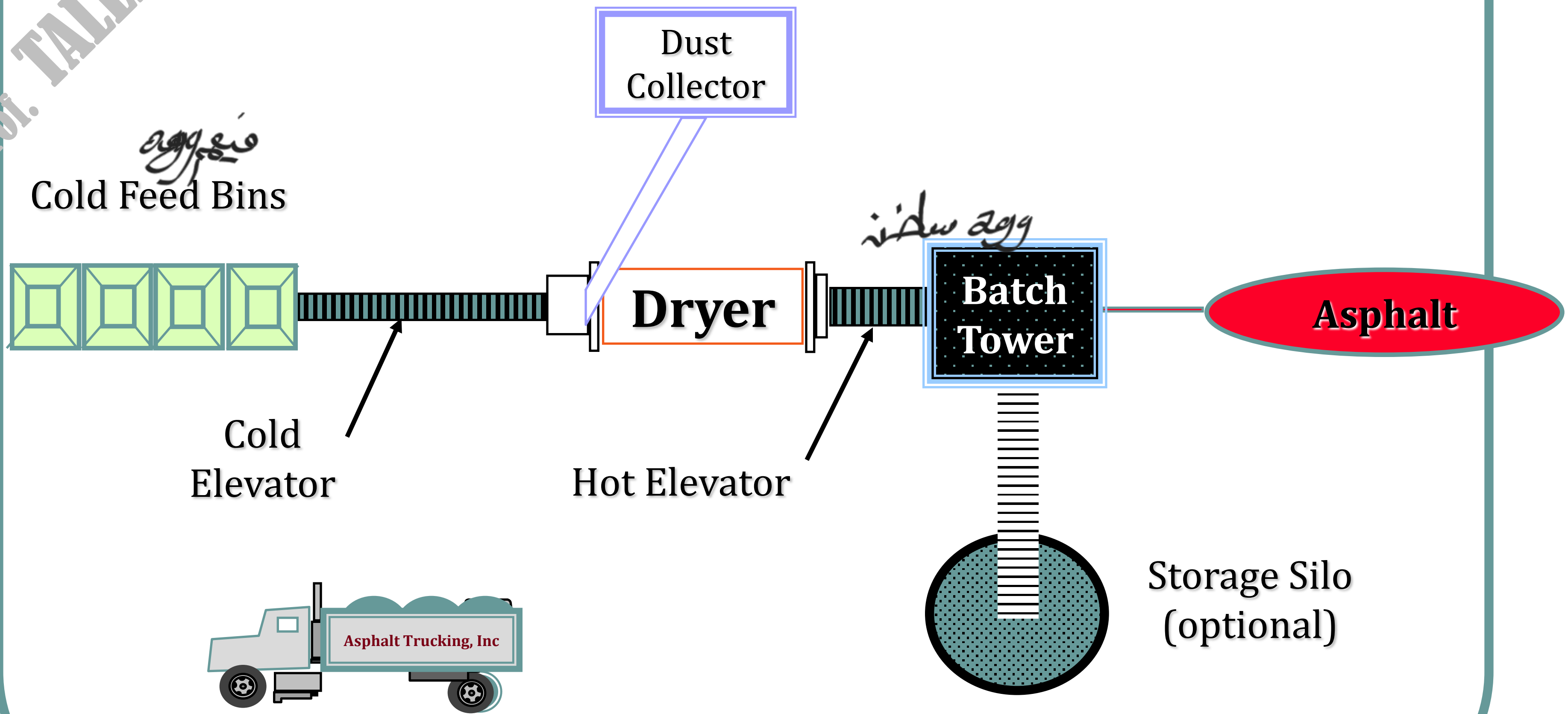
- Aggregates introduced into pugmill, briefly mixed.

رح نحط بعدها الأسفلت بدرجة حرارة عالية

- Asphalt introduced by weight, mixed with aggregates.
- Completed HMA discharged or stored.

اما بنخرج الخلطة على سيارات أو صومعة تخزينية

Batch Plant Layout



Batch Plant/ Asphalt Delivery System

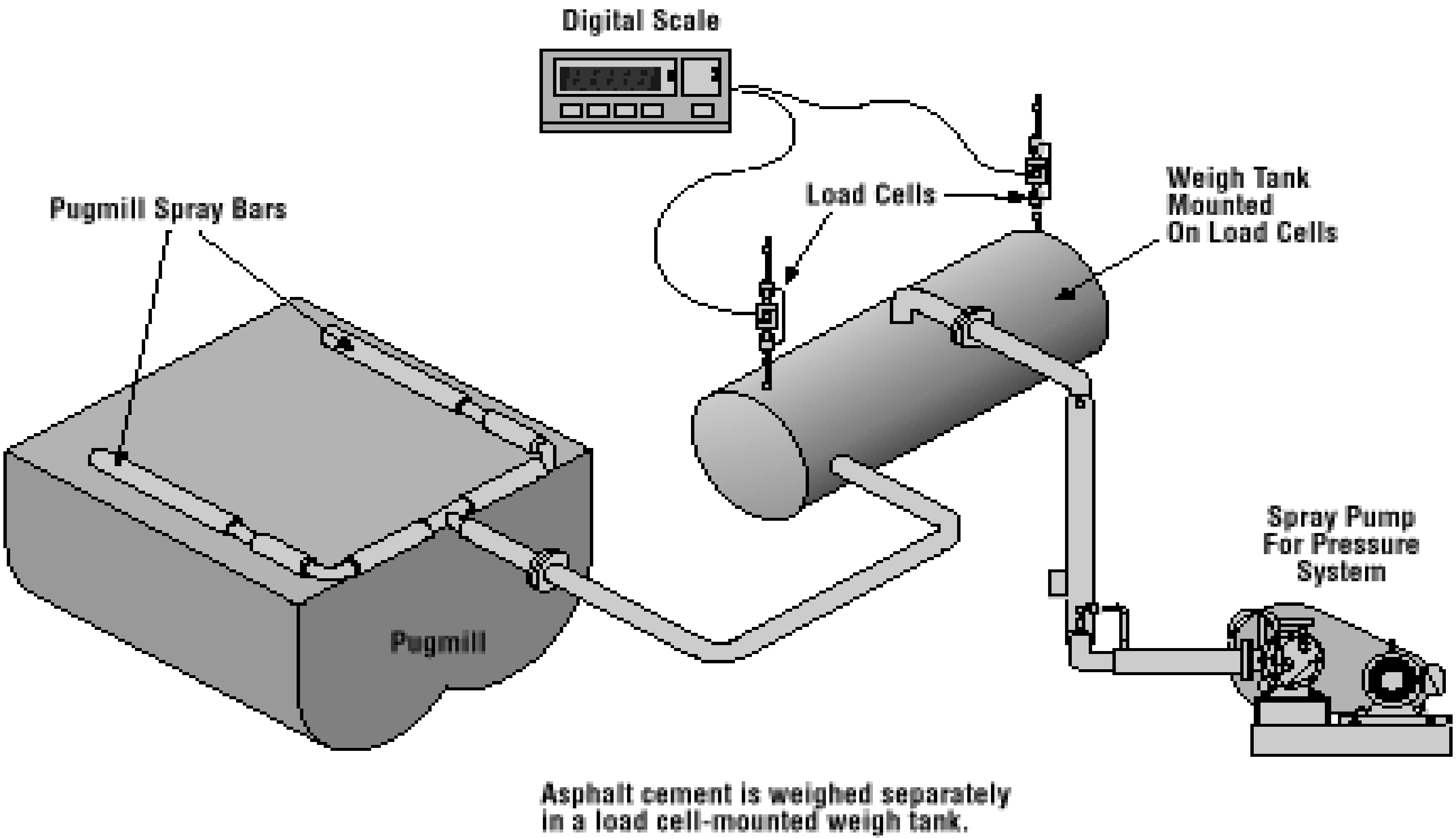


Figure 4.35 Asphalt Weighing and Delivery System in a Batch Plant (Courtesy of GenTec)

Batch Plant Typical Mixing Cycle

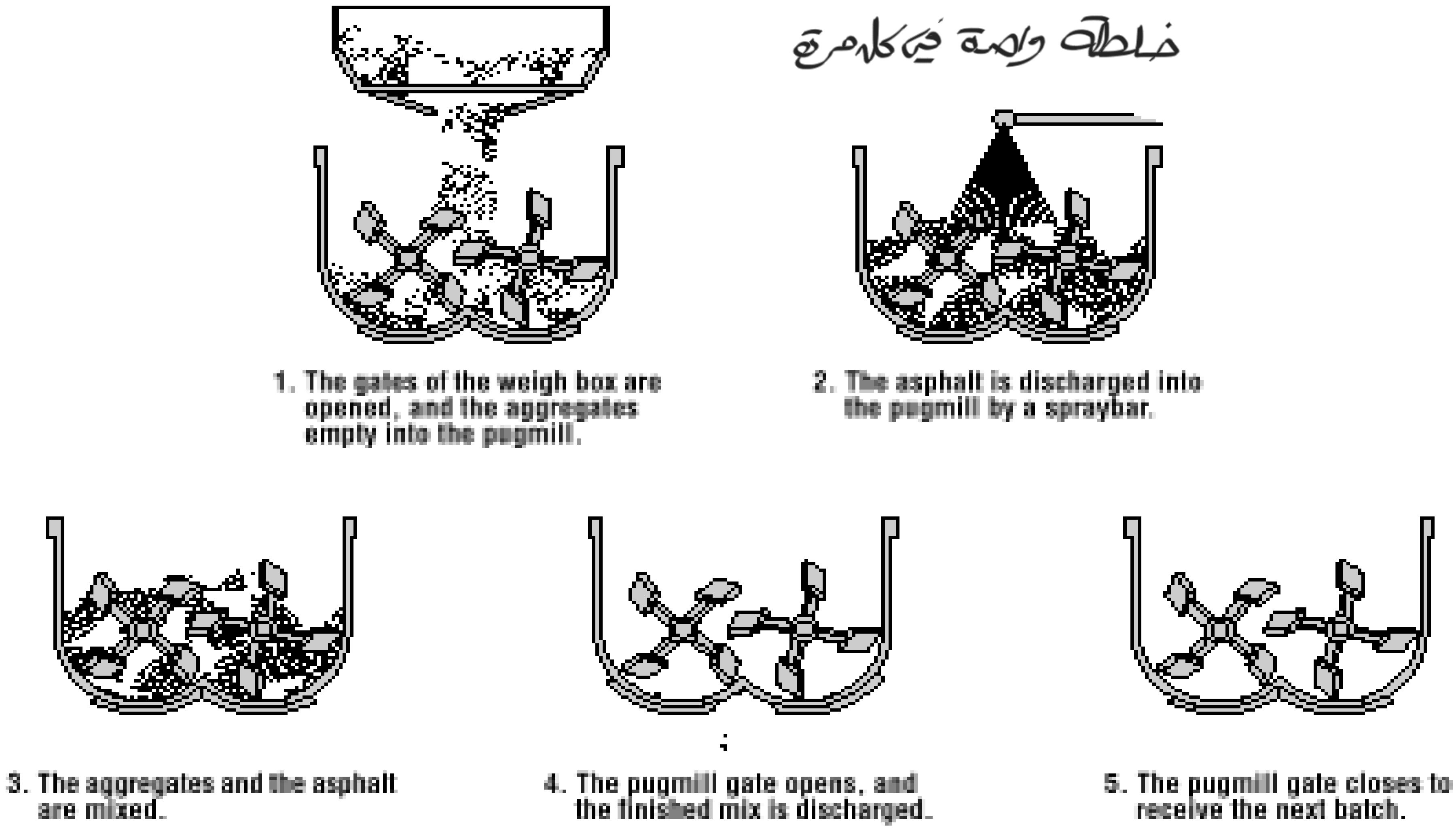


Figure 4.39 Steps in a Typical Batch Plant Mixing Cycle

Drum Plants

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

Drum Plant Layout

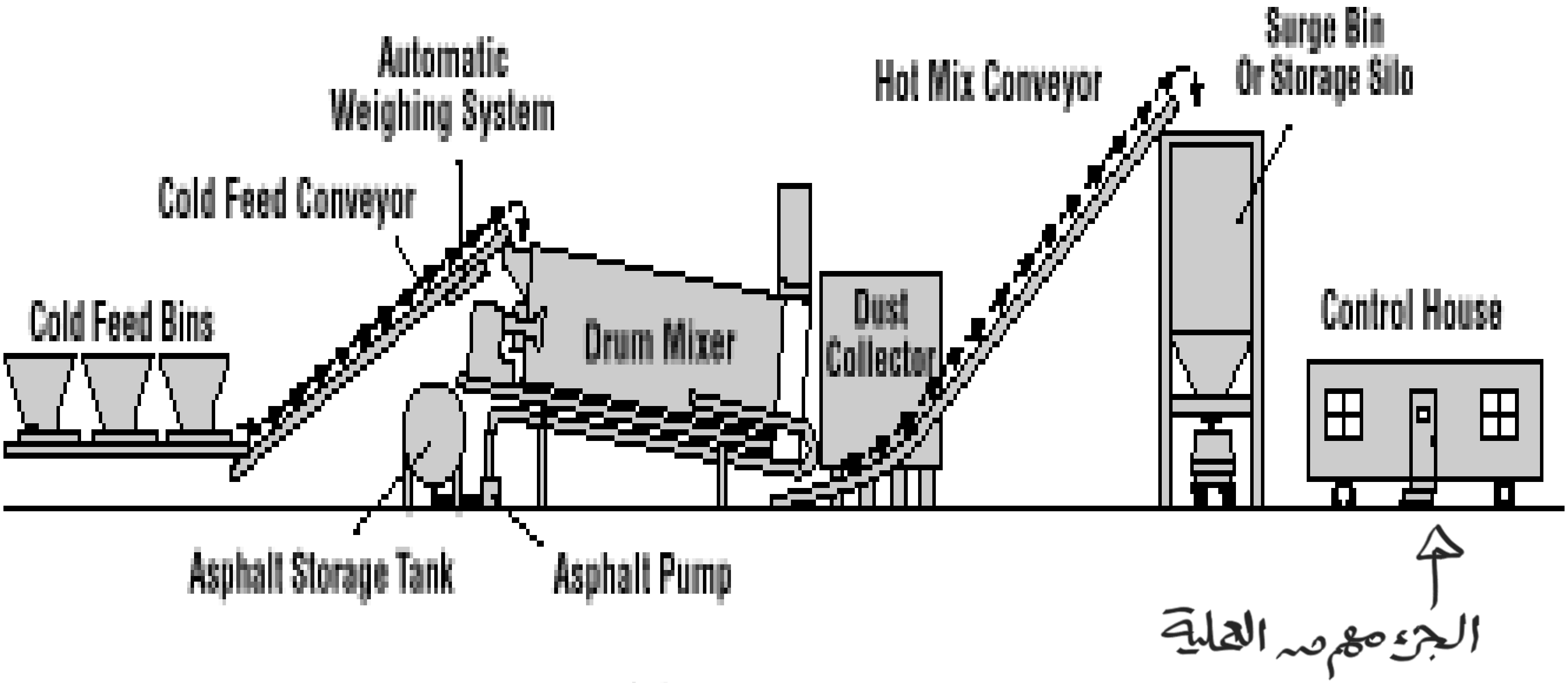


Figure 4.43 Basic Drum Mix Plant

Drum Plant-Knippa, Texas

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.

عملية النقل بتحسين بعد تجهيز الخليط في الخلاطة يتم استخدام عدة

طرق للنقل ، فعملية التوصيل تتضمن ان تتصل بال Track و

بعدها توزن (لتعرف الكميات المحملة أو توزن سيارة قبل وبعد

لمعرفة كم عدد محمل)

Asphalt Mixtures Transport

يفرغ الحمولة من نهايتها

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

اشهر طريقة لنقل الأسفلت لأنه موجودة بكثرة و
سهل تعامل معها ومتعددة الاشكال

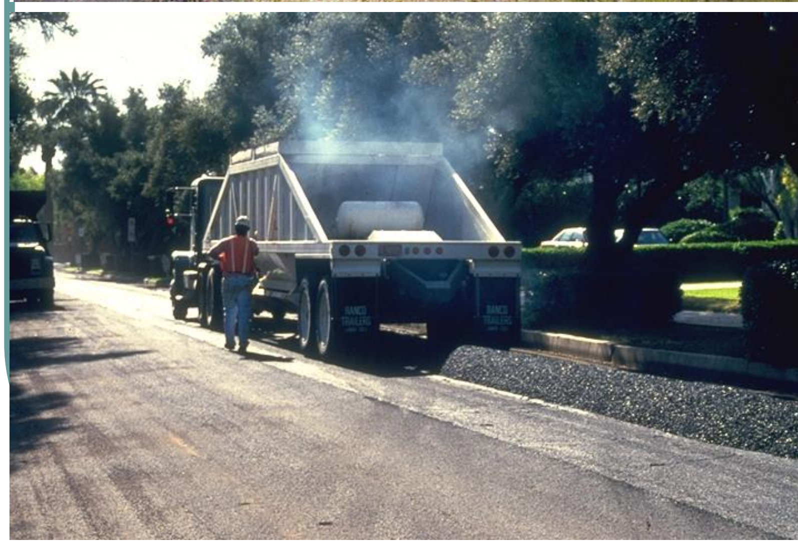
Asphalt Mixtures Transport

- **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

عملية فرد الاسفلت تتم عن طريق

Pavers

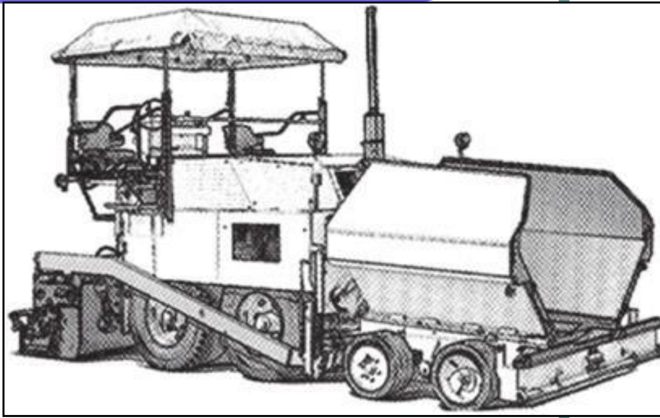
THE BASIC PRINCIPLE HAS NOT CHANGED MUCH

Asphalt Mixtures Laying/Paving

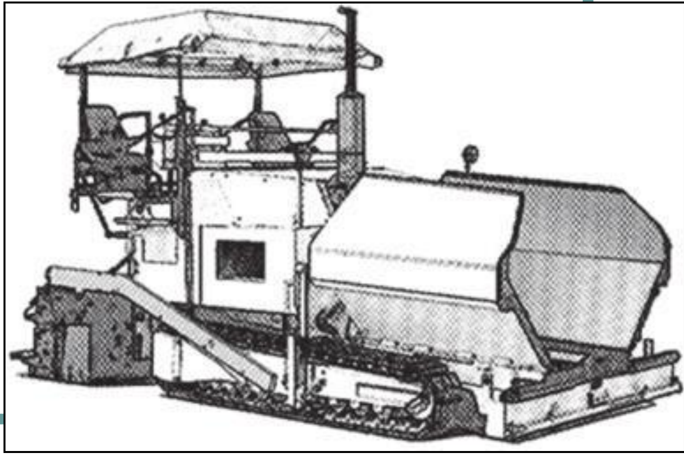
- Laying of the hot asphalt is carried out with special motorized units called pavers.
- Pavers are available in a wide variety of sizes capable of laying mats from as narrow as 1 m to up to 16 m wide.
- The minimum and the maximum range of paving width vary from one manufacturer's model to another.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

  The wheeled pavers → عجلات

  The tracked pavers. → جنزير



The wheeled pavers



The tracked pavers

التعبيد أو فرد الأسفلت يتم عن طريق جهاز اسمه Pavers

وهو متوفر بأحجام وأشكال مختلفة

- حسب موديل وحسب size وتصنيع بالطن range

Asphalt Mixtures Laying/Paving

كمية الاسفلت تضاف على جزء الامامي

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.

على التراكتور يشغل السيارة وهو جزء اللي بوخذ HMA و بنقله لمنطقة خلفية للPaver ويوزعها بتساوي

المرحلة الثانية

من الذي يعطيني العرض للناتج + سماكة معينة و
يعمل initial compaction

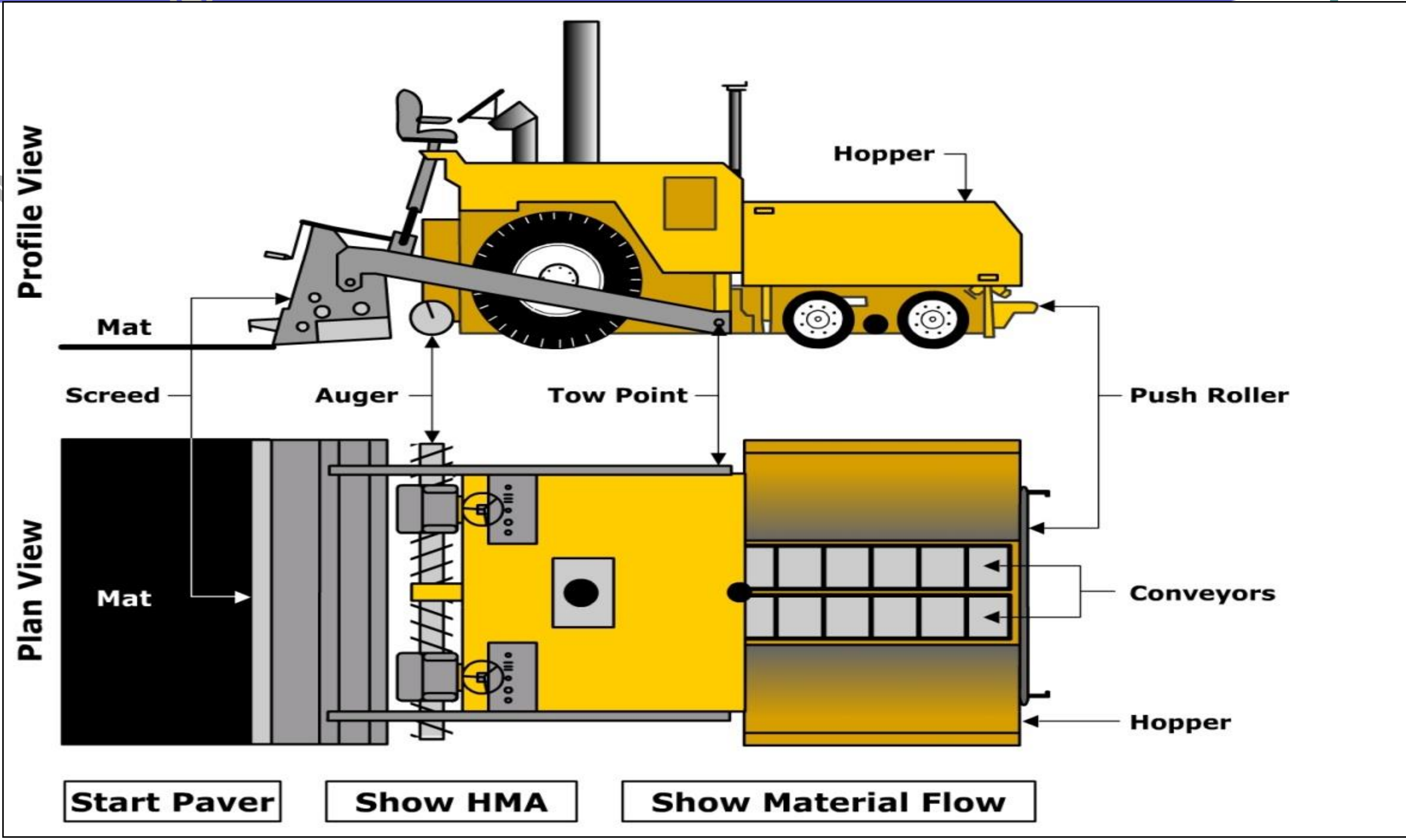
2- Screed

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

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

بكشطها ويعطيني العرض مناسب

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

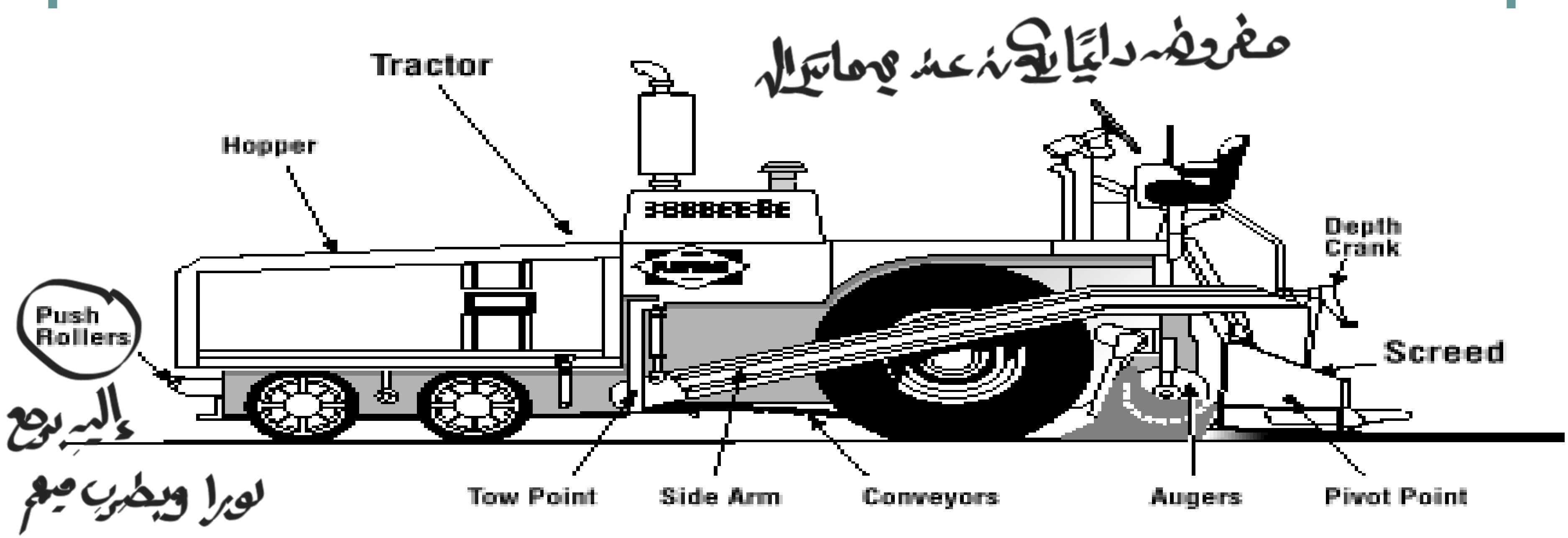
Paving Machine Components

- Tractor unit
- Screed
- Electronic grade controls

تحكم بالارتفاع (سماكة الطبقة)

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

قدرة في تحكم الارتفاع

- 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

يكون في عندي ادارة موقع بحيث اضمن انه دائماً عندي تزويد متواصل

- Maintain uniform resistance to face of screed!

  اغلب وقت مفروض Paver يظل شغال

  - Keep Paver in motion 75% of the time
  - Keep augers turning 85% of the time
- Coordinate mixture delivery, Paver speed and compaction operations.

ما يتأخر لما توصل على موقع وعملية Paver وفرد الاسفلت و compaction مفروض تنعمل بطريقة متناسقة

Placement

وضع الاسفلت أو فرد الاسفلت بالموقع

- **Placement Considerations:**

لازم ننتبه لمجموعة اشياء منها

سماكة طبقة

  - **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

صح اضمن انه ما يصير عندي تمزق بالطبقة فالمفروض تكون الها سماكة معينة

ومحددة [ما تكون قليلة كثير] ، تمزقات تظهر على شكل تشققات في الطبقة

السطحية ، فعلى الغالب عشان اضمن انه يصير عندي أي تشقق فبحاجة

تكون سماكة الطبقة اقل اشي ضعفين أو ٣ اضعافه ILMA .

رح يصير عندي مشاكل إذا كانت طبقة كثير رقيقة زي segregation و

مشاكل خشونة في السطح

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.

-8 longitudinal Joint الفرق ما بين الأسفلت القديم والجديد رح

يكون عندي فاصل طولي ، هاد معرض بده عناية مشددة بحيث

ما يصير عندي crack أو مشاكل ، مثلاً شغل يوم وشغل بعد يومين

طول رح يكون عندي فاصل طولي ، إذا ما انعملوا بشكل صحيح فهاد

الفاصل رح يكون منطقة فيها أي خراب

-8 Hand work الأماكن صعب يوصلها الأسفلت ف بحاجة نوصل

هاي الأماكن باستخدام العمال ، زي الأماكن اللي فيها تقاطعات

أو زوايا .

هاي الأماكن لازم نعتني فيها بعناية لأنه ممكن يصير فيها segregation

و ينتج عنها خشونة في السطح

Compaction

من اهم العمليات التي تحسب بالموقع

- 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.

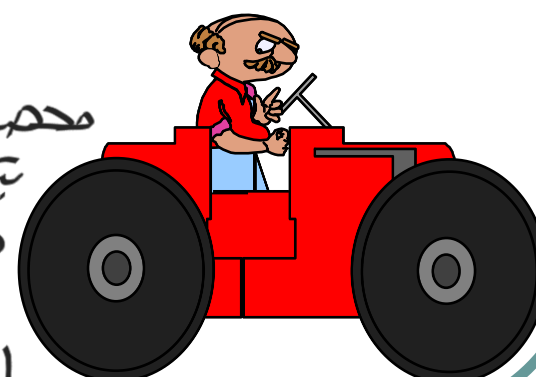
إذا ما انعمل compaction بطريقة صحيحة رح يضل عندي فراغات عالسطح رح يدخل فيها هواء وماء وتسبب مشاكل

- اثناء الدحل بصير عندي انو ما تيريال كلها تنضغط
- فراغات هوائية تقل و density رح تزيد
- رح تصير الطبقة افضل

* mass ماتتغير لكن حجم تغير (صغر)

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

بدي سطح كويس وبنفس الوقت تكون عندي نسبة فراغات مقبولة

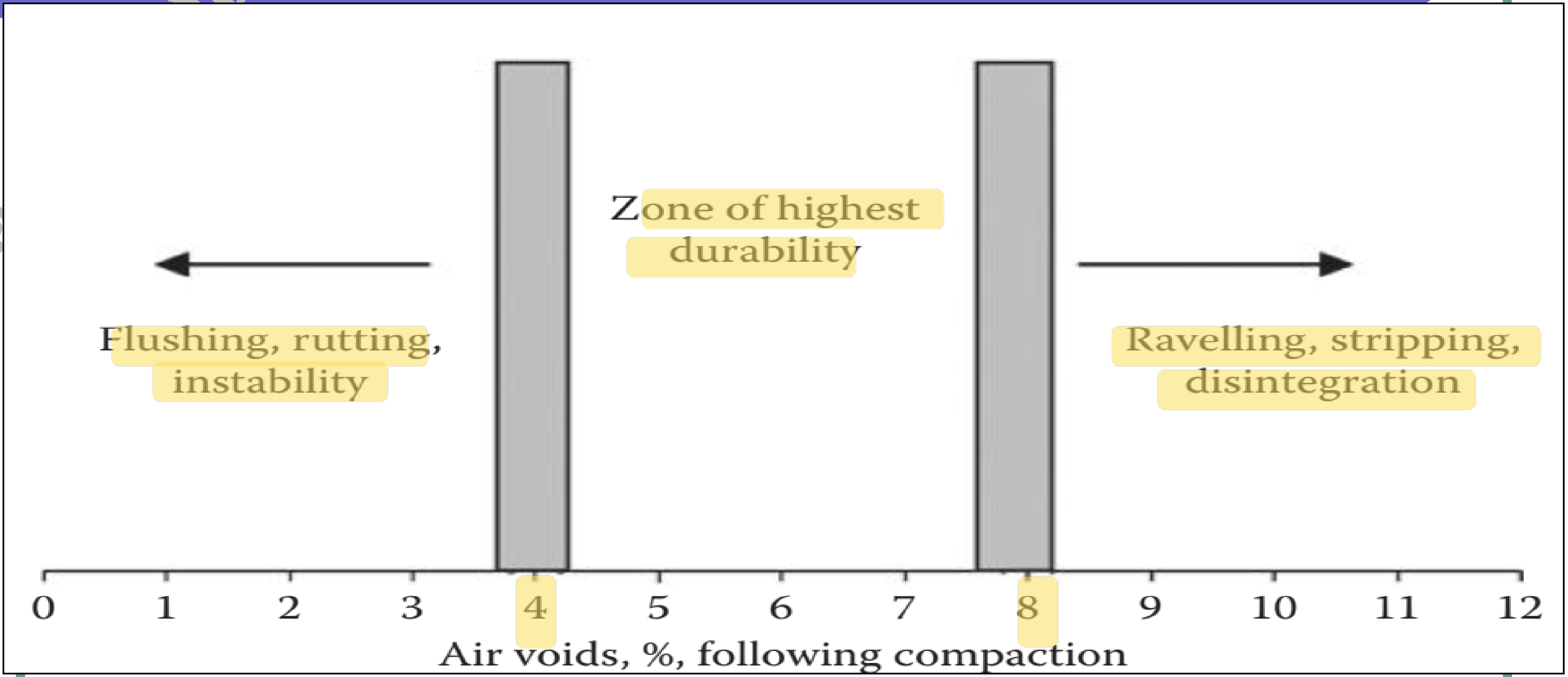
- The aim during compaction is to achieve an optimum void content and at the same time to ensure a smooth surface.

نسبة فراغات تكون قبل ما تنضغط مباشرة

- 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. ← هدفه انه توصل نسبة
- Air voids of less than 3.5% after compaction should be avoided, since rutting, flushing and instability of the mix will most certainly occur.

مفروض ما يوصل درجة عالية بعد ال compaction يعني اقل من 3,5٪ مرفوض

Compaction



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

Factors Affecting Compaction

محاضرة 2 اونه

- Mixture properties
  - *Aggregate*
  - *Asphalt*
  - *Mix Temperature*
- Base/subgrade support (confinement) support
- Ambient conditions ← ظروف محيطة
- Lift thickness: ← سماكة طبقة
  - *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

مدحلة

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.

موضوع compaction غالبًا بنعكس عن workabel فأي اشي بأثر على workabel بأثر على compactions

بعض الملاحظات :-

* إذا تكاملت مع dense حتكون workable اصعب شوي مش زي open

* كلما زادت الخلطة خشونة بتقل workable

* rounded و smooth هي عكس rough و angular يعني لما تكون شكلا partical مش angular فهاد بسهل حركة agg على بعض ومساحة سطحية اقل فبزيد workable

* زيادة natural sand بحسن workable (بتكون rounded, smooth)

* إذا كانت كمية filler قليلة كثير بتكون tender وإذا كان نسبة عالية بتكون gummy فبتكون معه مشاكل على workable

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.

* كمية الاسفلت موجودة بالخليط 2 بتأثر عله workable بحيث كل ما زادت كمية بكون workable افضل ولكن ممكن تأثر عله اشياء ثانية

* نوعية او grade الخاص ب bitumen ، إذا استخدمنا لزوجة عالية على الغالب هيكون بحاجة حرارة اعلى حتى تخلي لزوجة اقل و بساعد ب compaction

* مشان نحل مشكلة إلي فوق فبحاجة تكون حرارة compaction عالية

* العلاقة ما بين اللزوجة و حرارة عند درجتين حرارة

* إذا انخفضت حرارة المزيج عن °95 ما رح ينفع نعمل compaction

كل ما كانت حرارة اعلى كل ما كان compaction اسهل

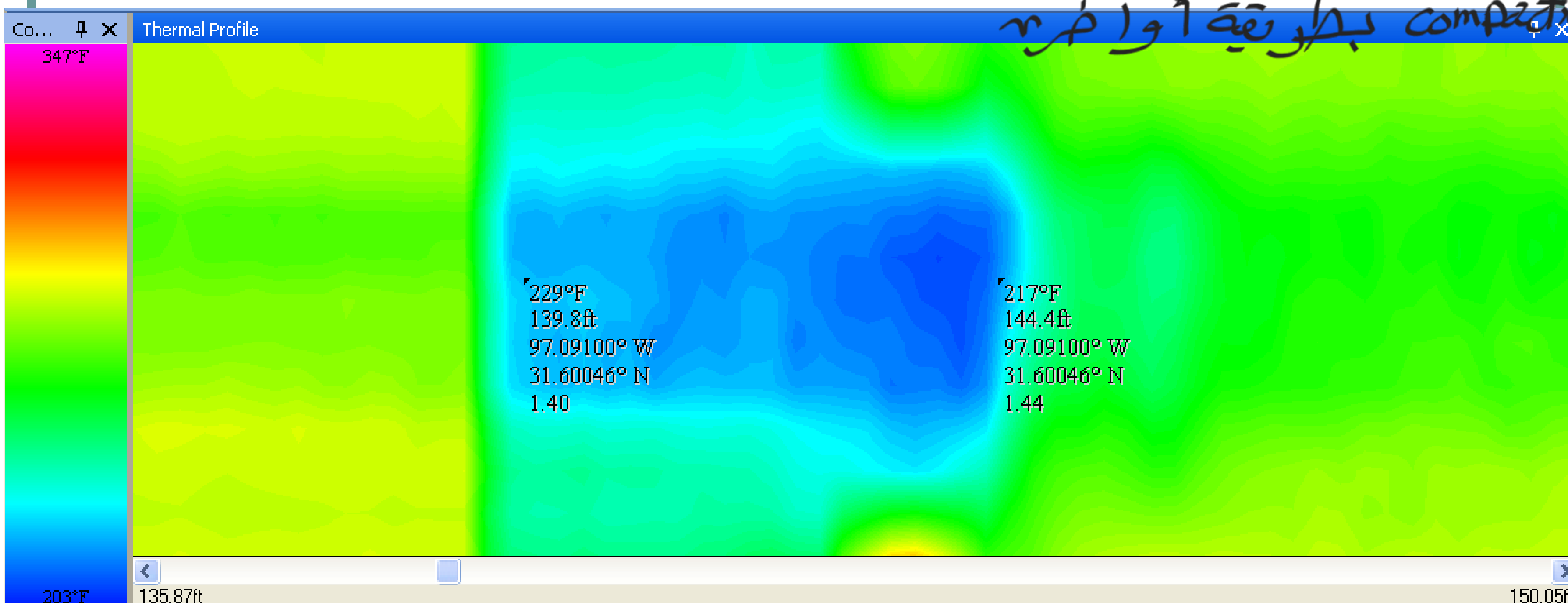
Factors Affecting Compaction/ Bitumen and Temperature

مشكلة الاماكن اللي فردنا فيها الاسفلت رح تكون فيها مراح متساوية

- 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.

معناته يكون سطحها ابرد مناطق داخلية وعلم غالب بأثرها

بطريقة أو اخرى compaction



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.

تأثير سي،

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.

- Environmental: إذا كانت درجة حرارة جو والاجواء محيطة لو عندي

مثلاً حرارة باردة او عندي رياح سرعتها عالية هاي رح تساعد انه الاسفلت

يبرد بسرعة ∴ بهاي حالة لازم اعمي عملية compaction بسرعة

- layer thickness: إذا كان عندي سماكات عالية للخليط على غالب

درجة حرارة رح تحافظ على حرارتها داخلية فترة اطول

* سماكة طبقة تأثر على سهولة الحصول على compaction المطلوب

* بشكل عام كل ما كانت طبقة اسمك كل ما كان compaction اسهل

بحيث كل ما زادت سماكة رح يحافظ على درجة حرارة المزيج بداخله

* مفروض سماكة الطبقات تقريبًا اكبر من 2inch نقسمهم لطبقتين

فإذا كانت طبقة كثير صغيرة بكون thin مفروض بحاجة اعمل

compaction بشكل سريع جدًا!

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 ← محدلة حديد غير رجاج
  - (b) vibrating steel-wheel rollers ← عجلات حديد
  - (c) pneumatic-tyre rollers ← عجلة كاوتشوك
  - (d) combination rollers ← واحد حديد وواحد كاوتشوك

حسب نوع مدحلة المستخدمة وبعضنا بالبداية بتكون مدحلة ثقيلة شوي

و Finish بصير بمدحلة اخف

← عملية compaction بتصير في site انه بمر مدحلة عدة مرات وهاد

بنسميه compaction effort

← عدد مرات الدحل بيعتمد على (test section) وبناءً عليه خبرة بتم تحديد

عدد مرات

Compaction Equipments

- Screed unit on paver بتعمل الدحل مبدأي
  - weight of screed ستكون نسبة فراغات حوالي 20% بعدها بدخل rollers
  - 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

مش للحفظ

- 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.

تحطه باتجاه paver لقدام مش لورا

Three-Wheel Static Roller

عجلات
ستيل

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

ما يلزق فيها بارتكل

- 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.

مشان نحصل compaction مناسب لطبقات الاسفلت لازم نتبع بعض الاشياء :-

* تدحل مباشرة بعد فردها الا إذا كانت درجة حرارة كثير عالية

* مرحلة الاولى بعد الفرد بكون اسمها break down

* لما يكون خليط ساخن وندحل مرحلة رح نحصل compaction مطلوب

* المرحلة المتوسطة ، رح تعطيني compaction زيادة وتقلل فراغات موجودة بين partel

* المرحلة الاخيرة :- مرات بكون مش المرحلة على طبقة سطحية لانه بها هي مرحلة بتحل على الخدوش والاثار

⟸ مفروض مايكون في تاخير بين مراحل

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.

* عدد المراحل المطلوب يعتمد على عرض المسرب

* عرض المرحلة على الغالب يتم اختياره تقريبًا $\frac{1}{3}$ عرض مسرب

* دائمًا نبدأ من نقطة منخفضة للأعلى

* مرحلة تمشي مرتين على نفس الخط

* بحاول يعمل overlap بحيث انه قديمة وجديدة يكون بينهم 20cm
(عشان ما أعطي فراغات)

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.

* عملية الطلاء إلي بدي اعمله بعتمد على سماكة طبقة ، إذا الحائط سميكة شوي رح نزيد مسافة الطول

* بداية بده يتم ترطيب سطح عشان ما ينزل الشي من الـHMA أو بارتكل يلزقوا بسطح آلة

* نحافظ على سرعة خلال عملية الطلاء

Rolling Pattern

- Speed & lap pattern for each roller
- No. of passes for each roller

بحددها نوعية مداحل وسماكة

- Min. temperature by which each roller must complete pattern

IMPORTANT:

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

ما يكون عندي paver سابق كثير مداحل

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

بعد تنفيذ الخلطة يجب مراقبتها وتتم من خلال عمل فحوصات
على الخلطة الاساسية التي تم انتاجها وتوصيلها للموقع

الفكرة انه نتأكد انه يكون الخليط إذا يحقق مواصفات أو
لأ ونضمن انه خلطة مركزية جيدة

Quality control of production and acceptance of asphalts mixtures

موجودة بالعقود: لكل كم افحصه

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

بعض المواصفات

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) طريقة الاستخلاص
- Ignition method. ← محرق
- Nuclear method.

In the first two methods,

يتم التخلص من الاسفلت داخل عينة بعدها [illegible]

- 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

بس بقدر احدد نسبة الاسفلت موجود

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.

مفروض تدرج يكون ضمن حدود المواصفة

Volumetric properties of the asphalt

- The volumetric properties of the asphalt such as air voids (1), voids in the mineral aggregate (2) and voids filled with bitumen (3) 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.

مفروض يكونوا ضمن مواصفات

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.

  شيك على حرارة وهي بالشاحنة

- For the acceptance of delivered product, the asphalt temperature is measured while the material is still in the arrived lorry. (شاحنة)
- Infrared thermometers are not advised to be used since readings are very sensitive (حساسة) to wind and moisture conditions and will certainly give erroneous results

  بستخدم ميزان حرارة عادي (اسفلت مش من حوله)

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% مطلوب
- The bulk density achieved after completion of rolling is usually determined using: نحفر بعدها
  - Extracted cores
  - Nuclear devices

اهمية موضوع compaction

- 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])

مشاكل

- 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
  من خلاله تقييم سماكة ولحساب الكلفة
  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)

خشونة السطح

- 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.

في مواصفات بتحدد

- Measurements are taken normally after completion of asphalt works, although daily measurements are not uncommon

تقدر نوخذ قراءات بعد نهاية العمل

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)."

يصير في خشونة زائدة وهاد بأثر لانه
بكون في فراغات وبتعمل مشاكل