University of Babylon
College of Engineering
Department of Civil Engineering

Lectures of Highway Engineering

Forth Stage

01-Cross-Section Elements

02-Earthworks & Mass-Haul Diagram

03-Asphaltic Materials

04-Aggregate

05-Asphalt Paving Mixture

06-Drainage

07-Evaluation of Strength for Subgrade

08-Thickness Design of Flexible Pavement

09-Rigid Pavement

10-The Effect of type and amount of Filler on Asphalt Paving Mix

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Oct-2010

References:

1. Yoder; E. J. and M. W. Witczak, "**Principles of Pavement Design**", A Wiley-Interscience Publication, John Wiley & Sons Inc., U.S.A., 1975.
2. Yaug H. Huang, "**Pavement Analysis and Design**", Prentic Hall Inc., U.S.A., 1993.
3. Paul Croney and David Croney, "**The Design and Performance of Road Pavements**", McGraw Hill, U.S.A., 1998.
4. "**AASHTO Guide for Design of Pavement Structures 1993**", AASHTO, American Association of State Highway and Transportation Officials, U.S.A., 1993.
5. "**A Policy on Geometric Design of Highways and Streets 2001**", AASHTO, American Association of State Highway and Transportation Officials, U.S.A., 2001.
6. Oglesby Clarkson H., "**Highway Engineering**", John Wiley & Sons Inc., U.S.A., 1975.

01- Cross-Section Elements

1. Surface Type:
   - Asphalt concrete (flexible pavement).
   - Plan, simply reinforced & continuously reinforced concrete (rigid pavement).
   - Surface treatment → for shoulders.

   Choice depending on (اختيار نوع السطح يعتمد علي):

   a. Applied stresses (الاجهادات المسلطة).
   b. Environmental conditions (الظروف المناخية المحيطة).
   c. Available materials (المواد المتوفرة).
   d. Common practice (الخبرة الشائعة).
   e. Cost (الكلفة).

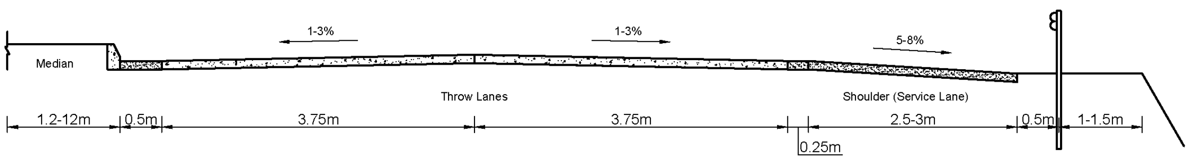
2. Cross Slop:

   0.01 – 0.03 "high type surface"

   0.08 "low type surface" → shoulders

3. Lane Width:
   - Standard = 3.65m
   - In practice = 3.75 m
   - +0.25m (at shoulders) & +0.5m (at median if <u>barrier curb is found</u>).

     Where +0.25m & 0.50m marginal strips.

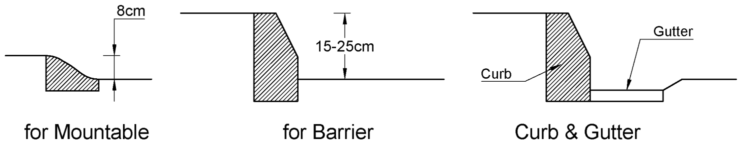


4. Shoulder: - Surface treatment

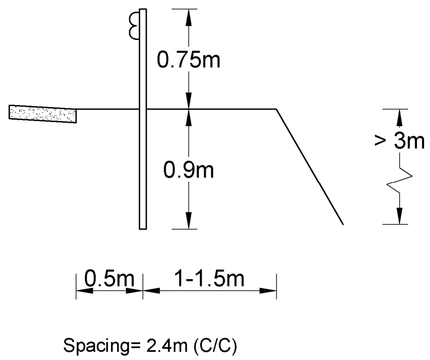
   Width = 2.5 - 3.0m

   Cross-slop = 5 - 8% = 0.05 - 0.08

5. Curbs:
   - Barrier (for pedestrian) (لا يمكن اجتيازه بالمركبات)
   - Mountable (يمكن اجتيازه بالمركبات)
   - Curb & Gutter (أنواع من الأرصفة تحوي نظام تصريف)



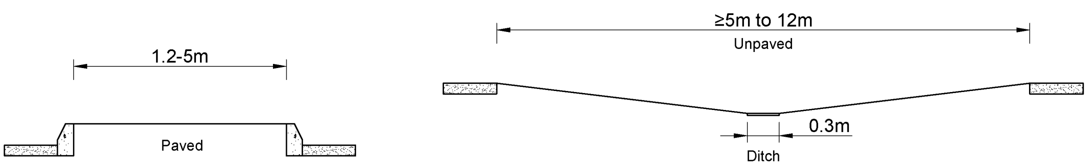
6. Guard rail (by sheet and column):



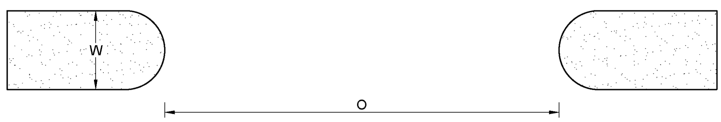
Used at hazardous points:
   - at high fill > 3.0m
   - steep grades (انحدار شديد)
   - sharp curvature (انحناء شديد)
   - sudden change in alignment
   - restricted sight (foggy ضبابي) (مناطق الرؤية المقيدة)
   - near rivers and lakes < 10 - 15m

7. Median:

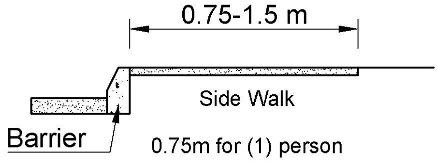
For:
   - Separating opposite flow
   - Future expansion



W (m)	O (m)
1.2	30
12	9



8. Side walk (طريق المشاة):

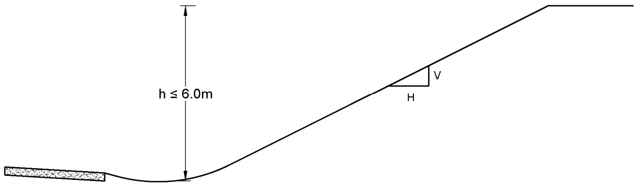


9. Side slop:

a. Cut slop:

- For normal soil (clay, silt, sand), & h ≤ 6.0m:

H:V = 2:1, … ..., 4:1 (favorable 4:1 المفضلة)



- For normal soil, & h > 6.0m:

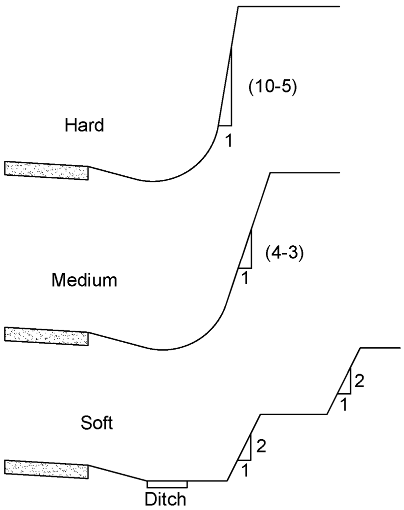
(has to be design according to slop stability theory)

- For rocky soil:

Hard (H:V) = 1:10 … 1:5

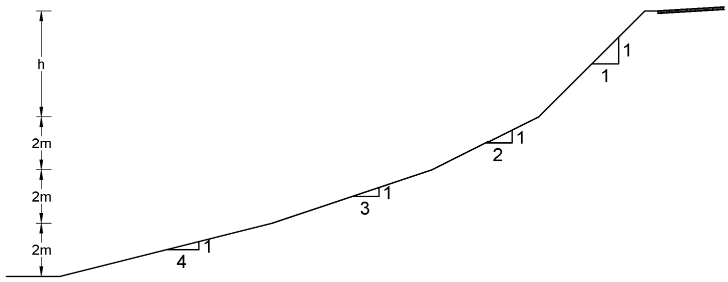
Medium (H:V) = 1:4 … 1:3

Sift (H:V) = 1:2 with steps

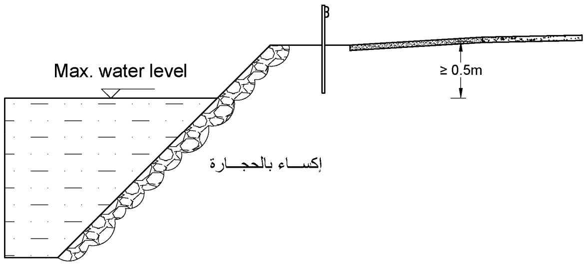


b. Fill slop:

أول ستة أمتار بالميل المبين بالشكل، والمتبقي (h) بالميل (1:1)



فـي حالـة وجـود مسـطح مـائي بجانـب الطريـق تكـون التفاصيل كما في الشكل



10. Vertical clearance:

For roads = min. 5.20m

For railway = min. 6.50m

For walkway = min. 2.50m

For main rivers = min. 6.50m

For other rivers = min. 3.50m

For high tension lines = min. 8.8 -10m

11. Right of way (محرمات الطريق) ≥ 80m

Freeway ≈ 200m

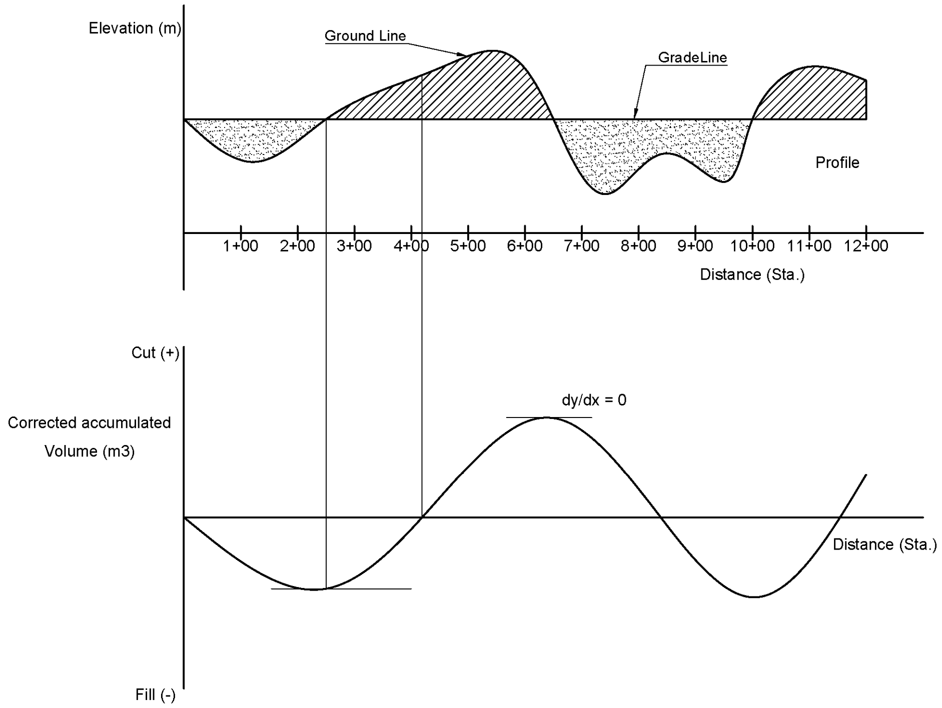
Highway ≈ 100m

Used for: future expansion (التوسع), safety (الأمان), maintenance (الصيانة).

02-Earthworks & Mass-Haul Diagram

Mass-haul diagram:

Continuous curve showing the relationship between the accumulated algebraic sums of corrected earthwork volume and distance for the purpose of minimizing the cost of excavating hauling & damping the materials (Soil).



- Rising → Cut
- Falling → Fill
- Steep slop → High cut or fill
- Zero slop → Change from cut to fill or vice versa.
- Zero value → Balance between cut and fill

Haul (النقل) = Volume (m^3) * Distance (sta.)

Haul distance:

The distance of moving the masses of soil from one place to another, in the process of earthwork.

Free haul distance (F. H. D.):

The distance within which there is a fixed price for excavating, hauling, and damping the materials regardless of the distance moved.

$$\text{Free haul charge} = \frac{\text{I.D}}{m^3}$$

Over haul distance (O. H. D.):

The distance beyond (F. H. D.) for which there is an additional price for each (m^3.sta.)

$$\text{Over haul charge} = \frac{\text{I.D}}{m^3.\text{sta.}}$$

$$\max.\text{O.H.D.} = \frac{\text{Borrow charge}}{\text{O.H.charge}}$$

Limit of economical haul distance (L. E. H. D.):

The distance beyond which it is more economical to waste and borrow rather than to pay for the cost of over hauling.

L. E. H. D. = F. H. D. + max. O. H. D.

A-B = F. H. D.

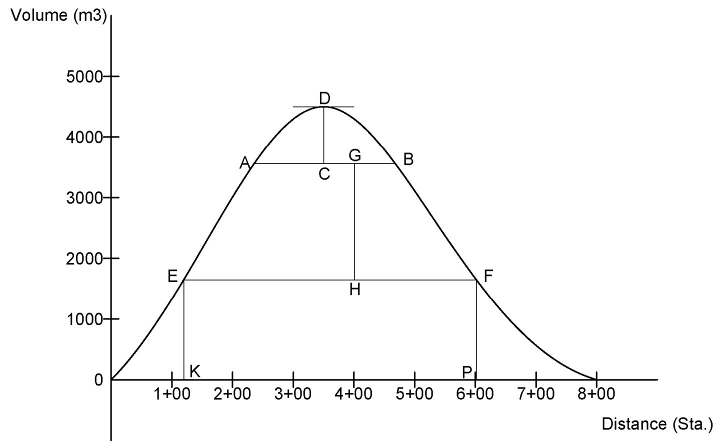
C-D = F. H. V.

E-F = L. E. H. D.

G-H = O. H. V.

E-K = West (W)

F-P = Borrow (B)

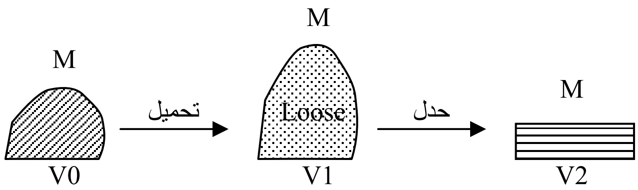


وكمثال ترسم العلاقة بين المسافة (بالمحطات) مع الحجوم المصححة المجمعة لقيم معينة بمقياس رسم معين للحصول على مخطط نقل الكتل ومنها، (A-B) هي مسافة النقل الحر ومقدارها للمثال حوالي (3Sta.) وحسب مقياس الرسم ترسم وتقاس المسافة من قمة المنحني للخط (A-B) وهي حجم الأتربة المنقولة بصورة حرة (F. H. V.). ثم نرسم الحد الاقتصادي لمسافة النقل (L. F. H. D.) وحسب مقياس الرسم فتكون المسافة (G-H) هي حجم التربة المنقولة بصورة مضافة بصورة مناسبة، أما الباقي تحت (E-F) فهي (W, B) الفائض والمستعار.

<u>Correction</u>:

* Sandy, Silty clay

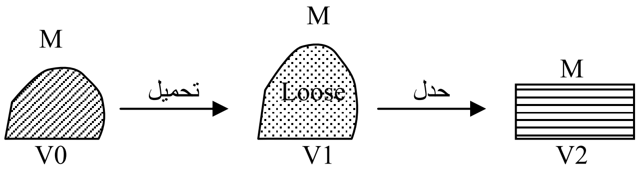
Shrinkage: 5 – 15 % ≈ 10%



V0 < V2 < V1

* Lime stone, Sand stone

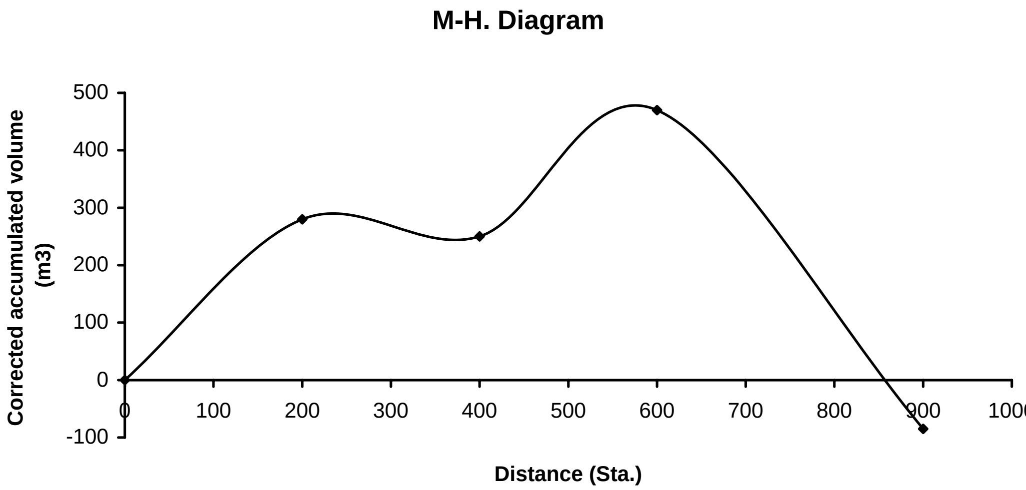
Bulking: 25 – 35 % ≈ 30%



V2 < V1
V2 > V0

Ex.:

Sta.	End Area (m^2)		Cut + (m^3)	(-) Shrinkage 10% (m^3)	Corrected Cut + (m^3)	Fill – (m^3)	Balance Vol. (m^3) (Cut-Fill)	Accu. Vol. (m^3)
	Cut	Fill						
0+00	4.0	2.6						0
			0.5*(4+2)*200 =600	600*0.1 =60	600-60 =540	0.5*(2.6+0)*200 =260	+280	
2+00	2	0						+280
			0.5*(2+1)*200 =300	300*0.1 =30	300-30 =270	0.5*(0+3)*200 =300	-30	
4+00	1.0	3						+250
			0.5*(1+7)*200 =800	800*0.1 =80	800-80 =720	0.5*(3+2)*200 =500	+220	
6+00	7	2						+470
			0.5*(7+0)*300 =1050	1050*0.1 =105	1050-105 =945	0.5*(2+8)*300 =1500	-555	
9+00	0	8						-85



03-Asphaltic Materials

Flexible Pavement Layers:

Axel Load

M. S. = (Marshall Stability)
C.B.R. = (California bearing reaction)

M. S. ≥ 8 kN ≈ 10 kN	Wearing (Surface) course	(Asphaltic concrete)
M. S. ≥ 7 kN	Level (Binder) course	(Asphaltic concrete)
	Base course	
M. S. ≥ 5 kN	- Asphaltic concrete	(Concrete)
C. B. R. ≥ 80%	- Crushed stone	(Stabilized mater) (asphalt, concrete, lime)
C. B. R. ≥ 35%	- Subbase course	(Sand-gravel)
C. B. R. ≥ 5% ≈ 10%	Compacted subgrade	
C. B. R. < 5% ≈ 4%	Natural subgrade	

Asphaltic Concrete:

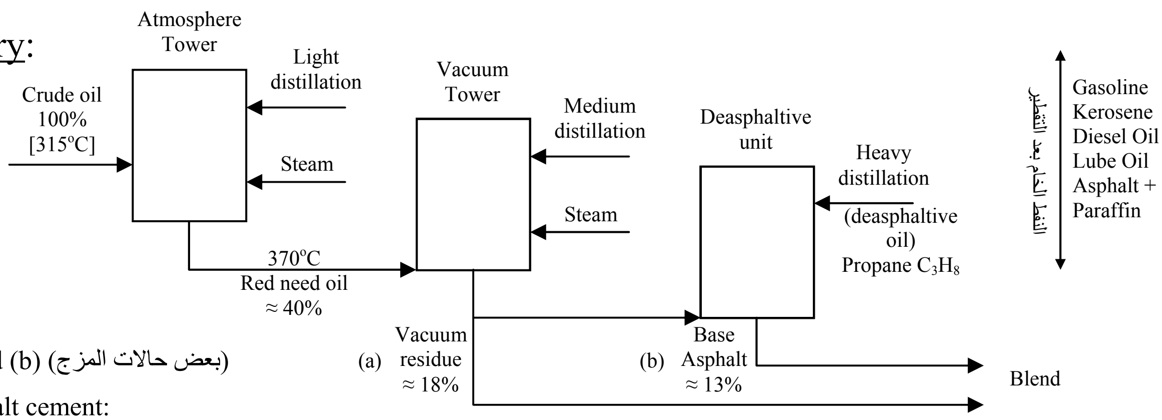
- Asphalt cement
- Coarse aggregate (crushed gravel) [1" – No.4 (No.10)]
- Fine aggregate (sand) [No.4 (No.10) – No.200]
- Mineral filler (cement or lime) [≤ No.200]
- Additives

Bituminous materials:

Mixture of hydrocarbons (C, H), liquid or semisolid in consistency, soluble in CS_2 & CCl_4

- Tar: produced by destructive distillation of coal (chemical change), cannot found in nature, more susceptible to temp. & more toxis.
- Asphalt: produced by fractional distillation of petroleum (physical change), natural (lakes, rocks) or manufactured, less susceptible to temp. & less toxic.

Dura refinery:



Blending (a) and (b) (بعض حالات المزج)
to produce asphalt cement:

1 (a) + 1 (b) → AC (40-50)

1.8 (a) + 1 (b) → AC (60-70)

Manufactured Asphalt

- Asphalt Cement
- Liquid (Cut-back) Asphalt
- Emulsified Asphalt

A) Asphalt Cement:

a. Penetration grade:

انتاج قليل	40-50 50-60 60-70	Less durable (قليل الديمومة) Less flexible (لدونة قليلة)	(Thermal Cracking)
	85-100 120-150 200-300	More temperature susceptible (permanent deformation)	(Rutting)

b. Viscosity grade:

Absolute viscosity (Dynamic): By Poise ($\frac{dyne * sec.}{cm^2}$)

$$\tau_{(\text{shear stress})}\left(\frac{\text{dyne}}{\text{cm}^2}\right) = \eta(\text{Abs.Vis.(Poise)}).\left[\frac{d\gamma(\text{shear strain})}{dt(\text{time(sec.)})}\right] \leftarrow \text{rate of shear strain}\left(\frac{1}{\text{sec.}}\right)$$

	Viscosity grade		Penetration grade
قليل الانتاج	AC-40	Abs. Vis. @60^{o}C = 40*100=4000 poise	> 20
مهم	AC-20	2000 poise	> 40
	AC-10	1000 poise	> 70
	AC-5	500 poise	> 120
	AC-2.5	250 poise	> 200

<u>Asphalt cement requirements (AC-20 [40-70])</u>:

1. Basis of grading (Consistency) (القوام)
   - Abs. Viscosity @60^{o}C = (1600 – 2400) poise

   (Gs = 1.01 – 1.05)
2. Temperature susceptibility (حساسيتها للحرارة):
   - Penetration (فحص الغرز): (ST. condition – min. 40 (40-70) 1/10mm

   Penetration after thin film oven test, retained pen. > 55% & (mass loss < 0.75%)
   - Kinematics viscosity @135^{o}C → Min. (210) Centistokes

   (Stokes = 100 Centistokes) (Stoke = Poise/Density)

3. Oxidative hardening (التصلب بسبب الاكسدة):
   - Abs. viscosity @60^{o}C after thin film oven test → Min. (10000) Poise
4. Homogeneity (التجانس):
   - Ductility after thin film oven test → Min. (20cm)

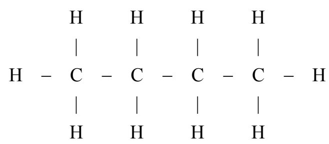
   Ductility before thin film oven test → (≥ 100cm)

   @25^{o}C (5cm/min.)
   - Solubility in Trichloro-Ethelin → Min. (99%)
5. Safety:
   - Flash point → Min. (232^{o}C)
   - Softening point → (52 – 60^{o}C)

<u>Chemical components (AC)</u>:

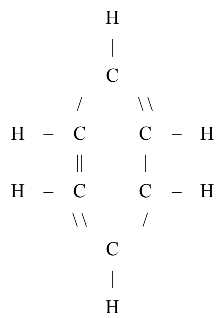
- Aliphatic hydro carbons (Chain)

  Light molecular weight



- Aromatic hydro carbons (Rings)

  Heavy molecular weight



Chemical Components:

وجد أن تركيب عينة من الاسفلت هو:

$[C_{89}\ H_{104}\ S_3\ N_2\ O_2]$

وتختلف أنواع الاسفلت في نسب هذه العناصر وتتراوح ضمن الحدود الآتية:

C = 70 – 85 %, H = 7 – 12 %, S = 1 – 7 %

O = 0 – 5 %, N = 0 – 1 %

		Fractional Components of AC	Role	(Durability) Reactivity to O_2
Asphaltene	1	Asphaltene	Bonding agent (القوام)	Low
Maltenes	2	Nitrogen bases	Peptizing agent (يساعد على اندماج الاسفلتين بالاجزاء الاخرى)	High
	3	First acidaffines	Solvent (مواد مذيبة تساعد على احتواء المواد الاخرى)	High
	4	Second acidaffines	Solvent (مواد مذيبة تساعد على احتواء المواد الاخرى)	Low
	5	Paraffin	Gelling agent (عامل مخثر)	Very low

B) Liquid (cut-back) Asphalt:

Asphalt cement + solvent (for temporary liquefaction)

a. Rapid Curing (R.C):

AC (85-100) + Gasoline

RC-70 (الاكثر شيوعاً)	للمناطق الحارة	Kinamatic Vis. @60oC = 70-2*70 centestok
RC-250	للمناطق الباردة	
RC-800		
RC-3000		

Used as **Tack Coat**: Thin film of asphalt applied (immediately before paving) between 2-paved layers (0.2-0.5 litter/m^2)

b. Medium Curing (M.C):

AC (120-150) + Kerosene

MC-30	
MC-70 (الاكثر شيوعاً)	Tight Surface (مساحات صغيرة)
MC-270 (الاكثر شيوعاً)	Open Surface (مساحات كبيرة)
MC-800	
MC-3000	

Used as **Prime Coat**: Film of asphalt applied (before 24hr of paving) between unpaved & paved layers (1.0-0.5 litter/m^2)

c. Slow Curing (S.C):

AC (200-300) + Oils

SC-70	For stabilizing earth works (لتثبيت الأعمال الترابية)
SC-250	
SC-800	
SC-3000	

C) Emulsified Asphalt:

Dispersing of asphalt particles in water in presence of emulsifying agent

AC (non-polar) + Water (polar $H^{+}OH^{-}$) + surface active agent (emulsifier)

* الإسفلت مادة غير متأينة، الماء مـادة متأينـة، المـادة المسـاعدة تمـنح ذرات الإسفلت قطبيـة لتكون مستحلبة في الماء

* بعض المواد المساعدة تضيف شحنات موجبة أو سالبة أكبر من الثانيـة والتـي تسمح في الحصـول علـى بعض الخواص للمادة المستحلبة

For:

1. Possibility of mixing with aggregate at normal temperature.
2. Water is safer and cheaper.

تستعمل المستحلبات عند المزج مع الركام لأنها توفر:

1. امتزاج الإسفلت بسطح الركام
2. إزالة الماء الموجود في فجوات الركام

* يحتوي سطح الركام على شحنات قطبية معينة لذلك اختيار نوع العامل المسـاعد يسـاعد علـى إيجـاد تـرابط بين الإسفلت وحبيبات الركام بصورة أفضل، كما في المخطط أدناه:

Emulsifying agent
- Type (Quality)
  - Anionic Emu. Asp. → With lime stone (+)
  - Cationic Emu. Asp. → With Quartz & Silica (-)
- Quantity

Quantity	Anionic Emu. Asp.	Cationic Emu. Asp.
Rapid setting As (tack coat)	RS-1 & RS-2	*CRS-1 & CRS-2
Medium setting As (prime coat with coarse agg.)	MS-1, MS-2 & MS-h	CMS-2 & CMS-2h
Slow setting As (prime coat with fine agg.)	SS-1 & SS-1h	CSS-1 & SCC-1h

* C في بداية الرمز معناه أن الشحنة سالبة (-)

Setting: coalesance (separation) of asphalt from water

Note:

(2) more viscose than (1) (أكثر لزوجة)

(2h) harder asphalt (residue) (المتبقي بعد تبخر الماء) than (2)

(1h) harder asphalt (residue) than (1)

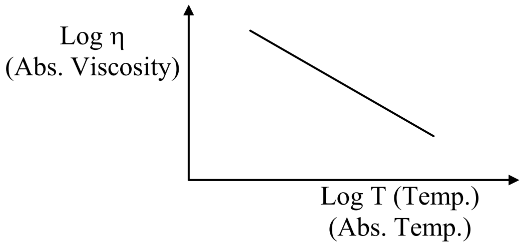
Important properties of Asphalt:

1. Hardening with time (Oxidation, Volatilization of light components)

زيادة الصلابة بمرور الزمن بسبب التأكسد وتبخر المواد المذيبة الخفيفة

2. Thermoplastic materials (Consistency varies with temperature)

مادة مرنة بالحرارة (اللدونة تتغير بتغير الحرارة) ومقياس اللدونة هي اللزوجة (η)



3. Rheological materials (Stress-Strain behavior is time depending)

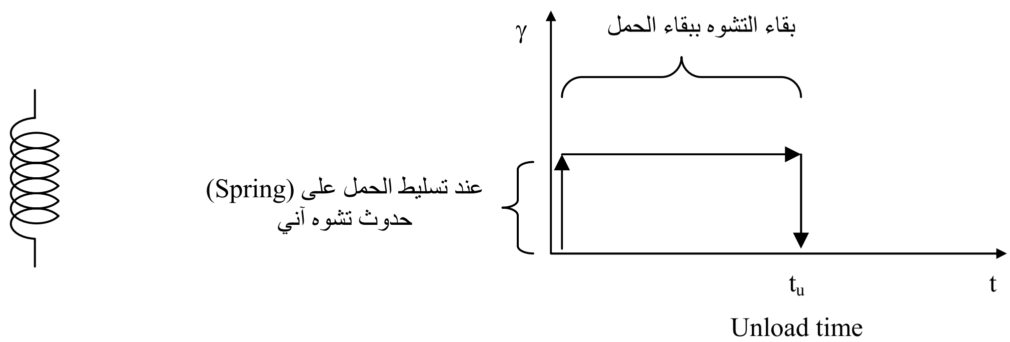
هناك علاقة بين الاجهاد والانفعال مع الزمن، ولدراسة وتمثيل تصرف المواد الاسفلتية التي هي وسط بين المواد اللدنة والمواد اللزجة يجب دراسة تصرفات المواد البلاستيكية واللزجة. وكما يأتي:

Elastic materials:

- Stress-strain in time independent.
- No permanent deformation (all recoverable after unloading).
- Instantaneous deformation while loading.
- Follow Hook's low.

  τ (shear stress) = G (shear modulus) * γ (shear strain)
- "Spring" may represent such behavior.

  τ = constant



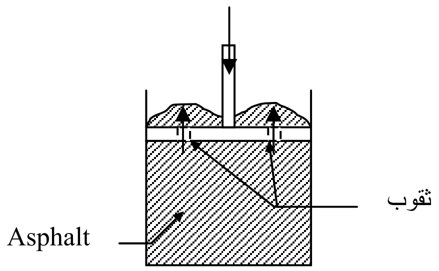
Viscous materials:

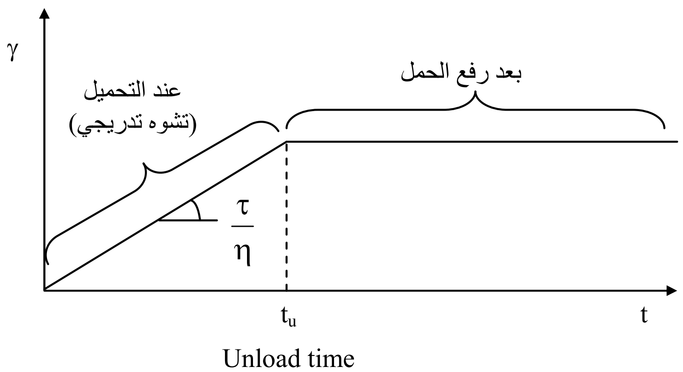
- Stress-Strain is time dependent.
- No immediate deformation.
- No recovery of deformation (all deformation are permanents).
- Follows Newton's law.

  τ (shear stress) = η(abs. vis.) $\frac{d\gamma}{dt}$ (rate of shear strain)

- Dash-pot may represent such behavior.

  τ = constant





But Asphalt may be viscoelastic material.

وللتعبير عن هذه الحالة هناك مجموعة من الموديلات الرياضية:

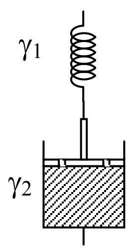
By Maxwell model:

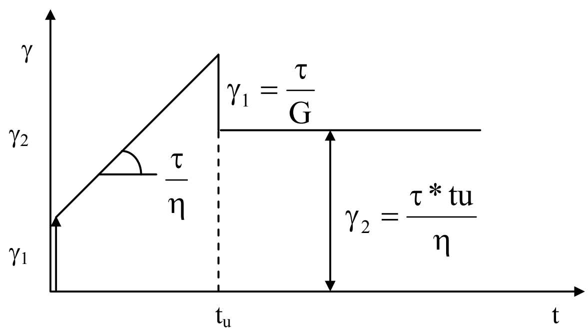
$$\tau = \eta \frac{d\gamma \leftarrow \gamma_2}{dt \leftarrow tu}$$

$$\gamma_2 = \frac{\tau * tu}{\eta}$$

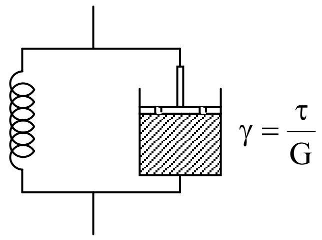
$$\gamma_{total} = \gamma_1 + \gamma_2$$

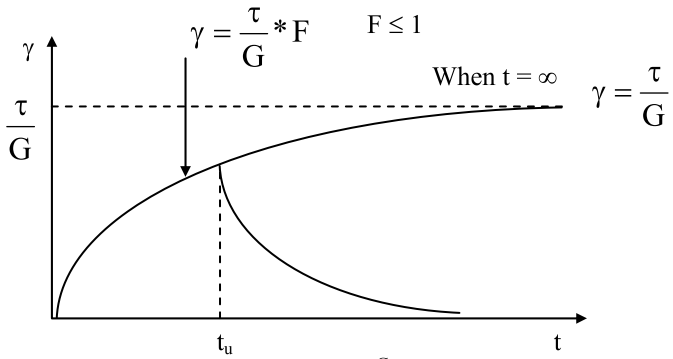
$$\gamma_{total} = \frac{\tau}{G} + \frac{\tau}{\eta} * t \leftarrow \text{Anytime}$$





By Kelvin or Voight model:





$$\gamma = \frac{\tau}{G}\left(1 - e^{-\frac{G}{\eta}t}\right)$$

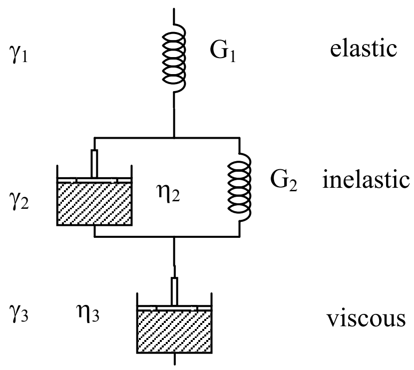
$$F = 1 - e^{-\frac{G}{\eta}*t}$$

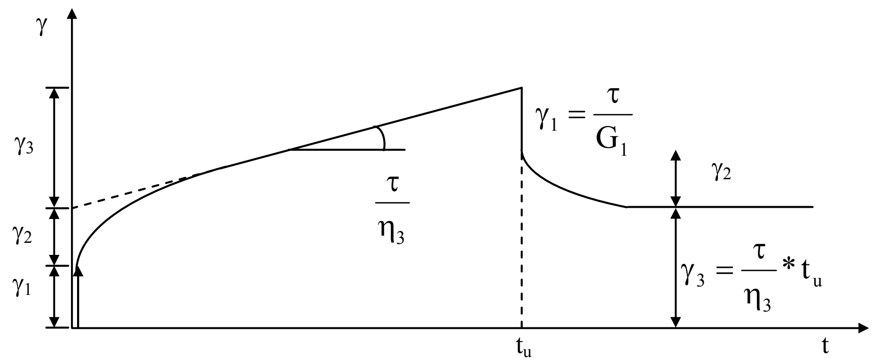
No instantaneous deformation

No permanent deformation

But related elasticity

By Burger (4-element) model [of asphaltic material]:





For loading curve:

$$\gamma = \frac{\tau}{G_1} + \frac{\tau}{G_2}\left(1 - e^{-\frac{G_2}{\eta_2}t}\right) + \frac{\tau}{\eta_3} * t$$

ملاحظة:

لطبقات التبليط المرنة يكون فيها قسم من التشوه وقتي يرجع بسرعة وقسم آخر يرجع بمرور الزمن والقسم الثالث صغير أو قليل الحدوث يكون فيها دائمي. (القسم الثالث يحدث غالباً في جانب الممر الخارجي للطريق حيث الأحمال المرورية البطيئة والثقيلة وعدم كفاءة التبليط، وكذلك يحدث في مناطق الوقوف (Parking))

04-Aggregate:

Natural → Igneous (Granite)
→ Sedimentary (sand, gravel, sandstone, and limestone)
→ Metamorphic (Marble)

Industrial product → Slag (مخلفات أفران الحديد)
→ Clinker (مخلفات أفران الفحم)

Main desirable properties of aggregate:

1) *Inter particle friction (Mechanism of load transfer)*:

ميكانيكية انتقال الأحمال (الاحتكاك الداخلي)، ويمكن السيطرة عليه من خلال:

a. Surface texture (rough or smooth): Resistance to displacement
b. Particle shape (angularity) التزوّي (round, fractured, & cubical)

يقيم عن طريق:

Angularity No. (0-10%) = % voids in round (≈33%) - % voids in any shape

وكلما اقتربت القيمة من (10%) كلما كان الركام أفضل

c. Gradation التوزيع الحبيبي (dense, gap, & open graded)

يقيم عن طريق:

By Fuller (dense gradation) = $\frac{P}{100} = \left[\frac{d}{D}\right]^{1/2}$

Where:

D = diameter of max. size particle → (passing 100%); inch

d = size of opening for any sieve, inch

P = percent passing of that sieve.

وتستعمل المناخل في إيجاد حجم الحبيبات المطلوب وهي كما يلي:

2", 1.5", 1", 3/4", 1/2", 3/8", No.4, ….

No.4 معناها توجد أربعة ثقوب في الأنج المربع الواحد.

مثال: إذا كان المطلوب تصميم خلطة تحوي على ركام أكبر قطر فيه "1، فنستخرج بقية النسب من القانون أعلاه وكنا يأتي:

1" → 100%

1/2" → $P = \left[\frac{1/2"}{1"}\right]^{0.5} * 100 = 70\%$

3/8" → $P = \left[\frac{3/8"}{1"}\right]^{0.5} * 100 = 61\%$

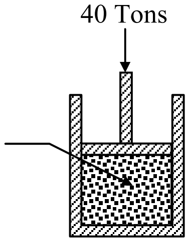
...الخ من المناخل.

2) *Durability* (الديمومة): The resistance to:

a. Crashing (الطحن أو السحق):

$$\text{Crashing Value} = \frac{\text{wt. of mat. passing No.7}}{\text{Original wt.}}$$

$\leq 12\%$ ($\approx 8\%$)



b. Degradation (التكسر بسبب التأثير الميكانيكي):

% of wear by L. A. Operation, (طريقة لوس أنجلس)

2.5kg (3/4"-1/2") + 2.5kg (1/2"-3/8") & Spheres (500 revolution)

$$\text{Degradation} = \frac{\text{wt. of mat. passing No.12}}{\text{Original wt.}} \leq 30\%$$

c. Disintegration (التكسر بسبب التأثير الكيميائي):

670 gm	(3/4" – 1/2")
330 gm	(1/2" – 3/8")
300 gm	(3/8" – No.4)
1300 gm	

* Soundness for 16-18 hours & drying Cycle
- By Na_2SO_4 (كبريتات الصوديوم) $\leq 12\%$
- By $MgSO_4$ (كبريتات المغنيسيوم) $\leq 18\%$

3) *Wet ability* (قابلية الترطيب): adhesion with asphalt, or resistance to stripping of asphalt film from aggregate in the presence of water.

a. Mechanical interlock: (التأثير الميكانيكي)

- Rough surface texture. (سطح خشن)
- Porous aggregate.

(مسامية سطحية عالية ولكن غير مؤثرة على القوة، لضمان تداخل الإسفلت وعدم انفصاله بالماء)

- No surface coating. (إزالة الأتربة المحيطة بالركام)

b. Chemical reactivity: (التأثير الكيميائي)

Basic minerals (of aggregate) المواد الأولية (الركام)	+	Acidic portion (of asphalt) مواد حامضية (في الإسفلت)	→	Compound not soluble in water مركب غير ذائب في الماء

c. Interfacial tension: (الشد السطحي بسبب الشحنات)

- Hydrophobic aggregate (water-hating) (غير مألوف للماء)
- Hydrophilic aggregate (water-loving) (يألف الماء)

والمفضل منها غير المألوف للماء. أغلب الركام العراقي من النوع الثاني (أليف للماء) لذلك يجب مراعاة ذلك.

Aggregate combination (blending) & separation to meet Job Mix requirement:

الركام الطبيعي غالباً لا يكون ضمن المواصفات الخاصة بالتدرج، لذلك نحتاج إلى عملية دمج و/أو فصل لتدرجات الركام للحصول على تدرج مقارب لمعادلة الخلط:

1. Discarding the over size.

(إبعاد الحجوم الأكبر من الحجم الأقصى للركام)

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

(فصل الركام إلى جزئين أو أكثر في منطقة الخلل)

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

(إعادة دمج الأجزاء بنسب مئوية مناسبة لتتلائم ومواصفات التدرج) (منتصف المواصفة)

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

(إضافة ركام ناعم (مواد مالئة) عند الحاجة)

Ex.:

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

Sol.:

طريقة الحل:

1. إزالة الحجم فوق الحجم الأقصى (Discard Oversize): نلاحظ أن الحجم الأقصى للركام ضمن المواصفات ("3/4) لذلك يجب إزالة الحجوم بين ("1-"3/4) أي جعل المار من المنخل ("3/4) (100%) وتصحيح تدرج باقي المناخل.

2. بعد المرحلة الأولى نحدد بداية الخلل في أي من المناخل، ونلاحظ أن منطقة الخلل مع المواصفات هي عند المنخل ("3/8) وكمية المار (67) وهي متجاوزة للمواصفة (60-40)، لذلك يتم فصل المقادير عند المنخل ("3/8) والذي فيه الخلل إلى مجموعتين ثم يتم المزج بنسب بمحاولة وخطأ للوصول للنسب المناسبة لتصحيح التدرج.

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

إذا كانت نسبة المالئ (4.5) =(1) مثلاً أي ان الركام لا يحويعلى مواد ناعمة من البداية ولا يمكن تصحيحه بإعادة التوزيع بل بإضافة (filler).

(1) Sieve size	(2) Specifications	(3) (C)	(4) (D) Filler	(5) 97% C + 3% D
1"	100	100	100	100
3/4"	100	100	100	100
1/2"	95 – 65	83	100	83.5
3/8"	60 – 40	50	100	51.5
No.4	40 – 24	33	100	35
No.10	30 – 20	26	100	22.25
No.40	20 – 10	16	100	18.5
No.80	10 – 5	8	100	10.75
No.200	5 – 3	1	100	4

Ex.:

Sieve	Stock (A) Passing	Stock (B) Passing	Stock (C) Passing	Specification
1"	100			100
1/2"	63			70 – 85
No.4	19	100		40 – 55
No.10	8	92		30 – 42
No.40	5	55	100	20 – 30
No.80	3	36	97	12 – 22
No.200	2	3	88	5 – 10

Sol.:

طريقة الحل:

تكون طريقة الحل بطريقة المحاولة والخطأ بفرض نسب مزج ومقارنتها مع منتصف المواصفة، وغالباً نبدأ بالنخل (No.200) ونفرض له نسبة صغيرة للكومة ذا المحتوى العالي من (Passing)، أي بما أن للكومة (C) نسبة المار من المنخل (No.200) يساوي (88) والمواصفة (5-10) فيجب إعطاءها نسبة قليلة وإعطاء نسب أكبر للكومتين (A, B)

Sieve	Stock (A) Passing	Stock (B) Passing	Stock (C) Passing	Specification	Mid Specification	Passing %
1"	100			100	100	100
1/2"	63			70 – 85	77.5	76
No.4	19	100		40 – 55	47.5	47
No.10	8	92		30 – 42	36	38
No.40	5	55	100	20 – 30	25	25
No.80	3	36	97	12 – 22	17	18
No.200	2	3	88	5 – 10	7.5	7
نسب المزج	65%	30%	5%			

05-Asphalt Paving Mixture:

يجب أن تتوفر عدد من الخواص التي تحدد كفاءة الأسفلت:

Function:

- Smooth riding quality surface. (نعومة سطحية لضمان نوعية سير مناسبة)
- Safety. (الأمان)
- Load carrying median. (يمكن تحمل الأحمال المرورية المسلطة المتوقعة)

Note:

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

Desirable properties:

1) *Stability (الثبات)*: resistance to permanent deformation.

(مقاومة الخليط للتشوه الدائمي)

Affected by:

- Frictional resistance (المقاومة الناتجة من الاحتكاك): rough surface texture (of aggregate), optimum asphalt content, & dense gradation with compaction.
  (خشونة الركام، نسبة الاسفلت المثلى، تدرج كثيف مع الرص)
- Cohesion (التماسك): reology of asphalt, adhesion with aggregate, & surface area of aggregate (filler 3-8%).
  (كلما نزداد مساحة الركام يزداد التلاصق بينه وبين الأسفلت لذلك نسبة المالئ مهمة في زيادة الثبات)
- Inertia of pavement: speed of vehicles, concentration of load, & axle load.
  (سرع المركبات، تركيز الأحمال، والحمل المحوري)

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

(مقاومة التجوية أوالتعرية (الهواء يسبب التأكسد Oxidation، الماء والمواد النفطية تسبب فصل المواد Stripping) ومقامة التأثير الاتلافي للسير)

Affected by:

- % of asphalt (نسبة الاسفلت)
- Gradation (dense or open) (التدرج)
- Degree of compaction (درجة الحدل)

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

(مقاومة الكلل، قابلية التمدد لمرات متعددة بدون حدوث تكسر)

4) *Skid resistance (مقاومة التزحلق)*: ability to provide safe coefficient of friction.

(أمكانية توفير معامل احتكاك آمن)

Affected by:

- % of asphalt. (نسبة الاسفلت)
- Gradation. (التدرج)

5) *Imperviousness (عدم النفاذية)*: (الانغلاقية أو عدم وجود مسامات)

6) *Workability (قابلية التشغيل)*: ability to provide smooth shaping of the finished pavement.

Affected by:

- Balanced portion of materials (أجزاء متناسبة من المواد)
- Efficient equipments.

Job Mix formula:

1. Selection of aggregate quality & gradation with in specification limits.

   (اختيار الركام من الناحية النوعية والتدرج ضمن المواصفات القياسية)
2. Selection of asphalt cement grade.

   (اختيار نوعية الاسفلت، ويكون لين لضمان قابلية التشغيل والمطاوعة وصلب لمنع التشوه الدائمي (الثبوتية))
3. Selection of optimum asphalt cement.

   (اختيار نسبة الاسفلت المثلى، تكون كمية كافية لضمان الديمومة والمطاوعة ولا تؤثر على الثبوتية والاحتكاك الداخلي)

Mix Design Methods:

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

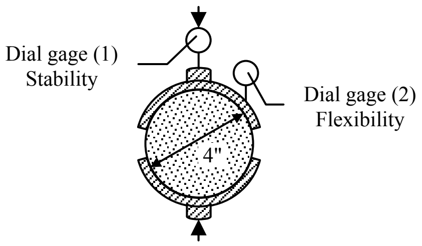
Marshall Method:

(Max. size of aggregate 1")

Stability: maximum load resistance of standard specimen (4" dia. & 2.5" height) when tested in the direction of diameter, at 60^{o}C at the rate of 2"/min.

(Stability ≥ 800 kg)

ثباتية مارشال: وهي مقاومة أكبر حمل مسلط على نموذج قياسي ("4"x2.5) عند تسليطه باتجاه القطر وبدرجة حرارة (60^{o}C) وبمعدل تحميل (2"/min.)



ملخص طريقة العمل للتجربة: ملئ القالب بالمزيج الساخن بدرجة حرارة المزج (160^{o}C) ثم تركها لتبرد لدرجة (100-105^{o}C) ثم تتم عملية الرص وذلك بمطرقة قياسية بمعدل :

75 blow/end (tire pressure = 200psi)

or 50 blow/end (tire pressure =100psi)

ثم تترك لمدة (24hr) لضمان زوال التشوهات الوقتية بسبب الرص، ثم تفحص بجهاز مارشال بدرجة حرارة الفحص.

Flexibility (Flow): the deformation (strain) corresponding to the max. load resistance of the standard specimen. (2 – 4 mm)

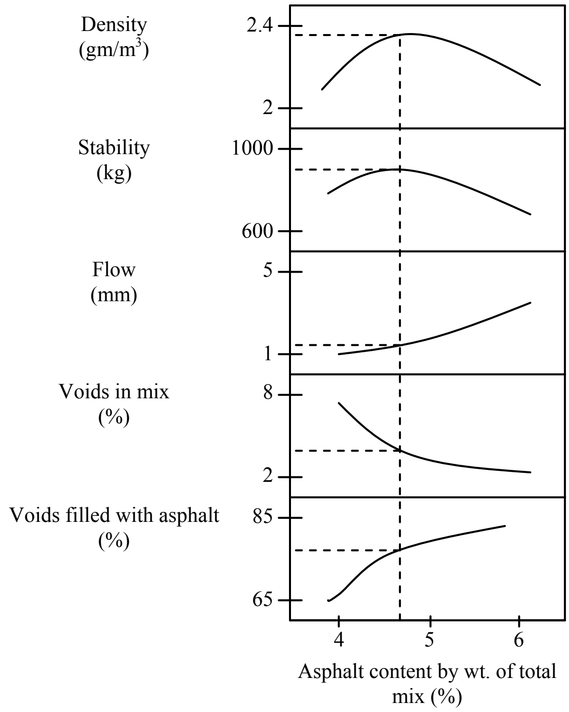
Durability: density – voids analysis.

% of air voids (3 – 5)% or (3 - 7)% in total mix.

ترسم العلاقة بين نسبة الاسفلت في المزيج مع العوامل (الكثافة، ثبوتية مارشال، المرونة، نسبة الفجوات، ونسبة الفجوات المملوءة بالاسفلت).
ثم يتم اختيار النسبة المثلى من الاسفلت بحيث تحقق قيم لهذه العوامل ضمن المواصفات القياسية لطبقة التبليط المطلوبة. وذلك بإيجاد نسبة الاسفلت المقابلة لما يأتي:

1. أكبر قيمة للكثافة (Max. Density)
2. أكبر قيمة للثبات (Max. Stability)
3. عند نسبة فجوات (5%) (معدل القيمة)
4. نسبة الفجوات مملوءة بالاسفلت (75%) (معدل القيمة)

وبأيجاد معدل لنسبة الاسفلت أعلاه، يسقط المعدل على المنحنيات لايجاد قيمة كل عامل من العوامل، ويدقق مع المواصفة.
إذا لم تنطبق أحد المواصفات فهناك خلل في مواصفات وتحليل وخواص الركام أو الاسفلت.



<u>For surface course (wearing)</u>:

- % of asphalt (usually effective asphalt) = 4.5 – 6.5 % by wt. of total mix
- Stability at 60°C & 75 blows/end ≥ 800 kg
- Flow = 2 – 4 mm
- % air voids in total mix = 3 – 5 %
- % voids filled with asphalt = 70 – 85 %
- % voids in mineral aggregate V. M. A.% (min. =15%)
- Filler / Asphalt (max. = 1.4)
- Index of retained strength = $\frac{\text{comp.st.(Immersion)}}{\text{comp.st.(Dry)}} * 100\% \geq 70\%$
- Relative compaction = $\frac{\text{Field density}}{\text{Lab.density}} * 100\% \geq 96\%$

<u>Compaction of Pavement</u>:

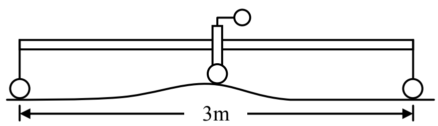
a) *Rolling edges & joints*: immediately after spreading (Tandem steel roller).

b) *Break down rolling*: as soon as the mix can bear roller (3-wheel roller).

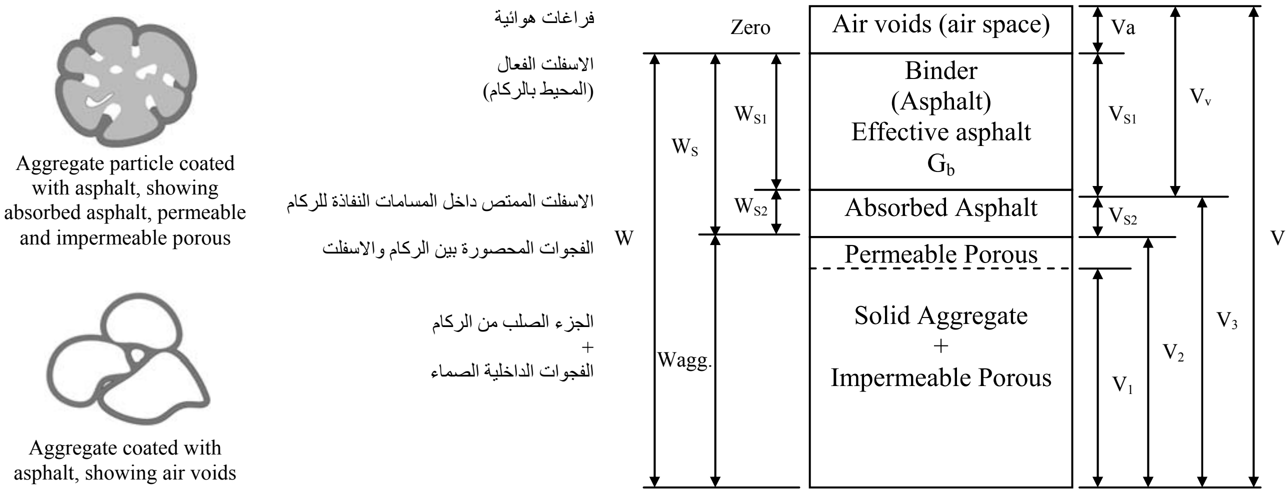
c) *Intermediate roller*: while the mix is still plastic (kinematics roller).

d) *Finish rolling*: mix still warm to eliminate tire marks (steel roller).

<u>Note</u>: Smoothness: (Irregularities) ≤ 3mm/3m



Analysis of Mixture (Mass-Volume Relationship):



Va = volume of air voids in total mix

Vs_1 = volume of effective asphalt

Vs_2 = volume of absorbed asphalt

V_1 = apparent volume of aggregate

V_2 = effective volume of aggregate

V_3 = bulk volume of aggregate

V = total volume of mixture

Vv = voids of aggregate (Voids in mineral aggregate)

- Bulk G_A = bulk specific gravity of combined aggregate = $\frac{W_{Agg.}}{V_3}$

$$= \frac{100}{\frac{\%course}{Gs(course)} + \frac{\%fine}{Gs(file)} + \frac{\%filler}{Gs(filler)}}$$

Ex.:

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

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

5% (No.200) Gs=3.15

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

- P_S = total % of asphalt (by wt. of total mix)
- P_A = % of aggregate (by wt. of total mix)

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

- In void less mix → max. theoretical sp. gr. of mix

(max. Gm by testing in the lab (ASTM-2041)

$$max.Gm = \frac{W}{V - Va}$$

- Effective $G_A = \dfrac{W_A}{V_2}$

$$= \frac{100 - P_S}{\frac{100}{Gm} - \frac{P_S}{Gs}}$$ (as sp. gr. of asphalt), where $V_2 = V-(Va+Vs_1+Vs_2)$,

Effective G_A constant property (independent of asphalt content)

من تجربـة مختبريـة يمكـن أيجـاد (max. Gm) (Theoretical) لنسبة مـن الاسـفلت لنوعيـة ركـام واسـفلت، ولايجـاد (max. Gm) لنسـب أخـرى مـن الاسـفلت يمكـن أيجـاد (effective G_A) ونطبـق القوانين الآتيـة لاستخراج قيم (max. Gm) (Calculated) دون إجراء تجارب أخرى.

- Actual $Gm = \dfrac{W}{V} = \dfrac{W_{air}}{W_{air} - W_{water}}$

Found by: Core from pavement, or compacted sp. gr. in lab

- Calculated max. $Gm = \dfrac{W}{V - Va} = \dfrac{100}{\frac{P_S}{Gs} + \frac{100 - P_S}{effective\,G_A}}$

- % air voids (in total mix) = $\dfrac{Va}{V} * 100\% = \dfrac{max.Gm - actual\,Gm}{max.Gm} * 100\%$

- % voids in mineral aggregate (V.M.A.%) = $\dfrac{Vv}{V} * 100\% = 100 - \dfrac{actual\,Gm * P_A}{bulk\,G_A}$

$Vv = V - V_3$, $W_{S1} + W_{S2} = W_S$, $W_S + W_A = W$

- Absorbed asphalt (% by wt. of agg.) = $P'_{S2} = \dfrac{W_{S2}}{W_A} * 100\%$

$$= \left[\frac{1}{bulk\,G_A} - \frac{1}{effective\,G_A}\right] * Gs * 100\%$$

$V_3 - V_2 = V_{S2}$, $\dfrac{V_{S2}Gs}{W_A}$, $\left(\dfrac{W_A}{V_3}, \dfrac{W_A}{V_2}\right)$

- Effective asphalt (% by wt. of total mix) = $P_{S1} = P_S - \frac{P'_{S2} * P_A}{100} = P_S - P_{S2}$

Where: P_{S2} = absorbed asphalt (% by wt. of total mix)

- % voids filled with asphalt = $\frac{V_{S1}}{Vv} * 100\%$

$= \frac{\text{actual Gm} * P_{S1}}{\text{actual Gm} * P_{S1} + Gs * \% \text{air voids}} * 100\%$

$Vv = Va + V_S$

Ex.: To prepare asphalt mixture as surface course, it is found the following:

a) For aggregate:

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

For course agg. Gs = 2.64

For fine agg. Gs = 2.67

For filler Gs = 3.10

b) For asphalt (40-50) → Gs = 1.04

c) For asphalt concrete contains 5% asphalt → max. Gm = 2.49

If the same above materials used to construct asphalt concrete layer with 5.7% asphalt. The core from layer has W_{air} = 1200gm, & W_{water} = 692gm. Check this layer?

Sol.:

Check: % air voids (3-5), V.M.A. = min. 15,

asphalt voids (70-85), effective asphalt (4.5-6.5)%, التقريب لثلاث مراتب

Bulk $G_A = \frac{100}{\frac{55}{2.64} + \frac{40}{2.67} + \frac{5}{3.1}} = 2.672$

Effective $G_A = \frac{100 - 5}{\frac{100}{2.49} - \frac{5}{1.04}} = 2.687$ (مقدرا ثابت بتغير نسبة الاسفلت)

For the layer with asphalt = 5.7%

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

Calculated max Gm = $\dfrac{100}{\dfrac{5.7}{1.04}+\dfrac{100-5.7}{2.687}}$ = 2.464

Check:

1) % V. M. A. = $100-\dfrac{2.362*94.3}{2.672}$ = 16.6% ≥ 15% $\therefore$OK

2) % air voids = $\dfrac{2.464-2.362}{2.464}*100\%$ = 4.1% (3 – 5)% $\therefore$OK

3) absorbed asphalt (by wt. of agg.)

$$=\left[\frac{1}{2.672}-\frac{1}{2.687}\right]*1.04*100\% = 0.23\%$$

$\therefore$ effective asphalt concrete = P_{S1} = $5.7-\dfrac{0.23*94.3}{100}$ = 5.48% (4.5-6.5)% $\therefore$OK

4) % voids filled with asphalt

$$=\frac{2.362*5.48}{2.362*5.48+1.04*4.1}*100\% = 75.2\%\ (70-85)\%\ \therefore OK$$

06-Drainage:

Proper drainage is important to ensure high quality pavement. Moisture in the subgrade and subbase layer can weaken these materials by:

1) Increasing pore water pressure.

2) Reducing the materials resistance to shear.

- Some soils expand when moist causing differential heaving.
- Moisture can cause stripping of aggregate.

Moisture Sources:

Rain water, runoff, and high ground water, which prevented by:

A) Surface Drainage:

By removing all water that is present on surface and shoulder, by these primary means, to prevent water infiltration and accumulation:

1) *Impermeable Mix*:

Air voids in total mix <7%, by proper compaction and minor cracks in the mix should be sealed.

2) *Slop*:

Cross slop =2% and using curb with gutter (in urban and suburban highways) or road side ditches (in rural highway cut).

3) *Grade*:

Use grade ≥ 0.5% for curb with gutter or side ditches to allow flow to central collection point.

B) Subsurface Drainage:

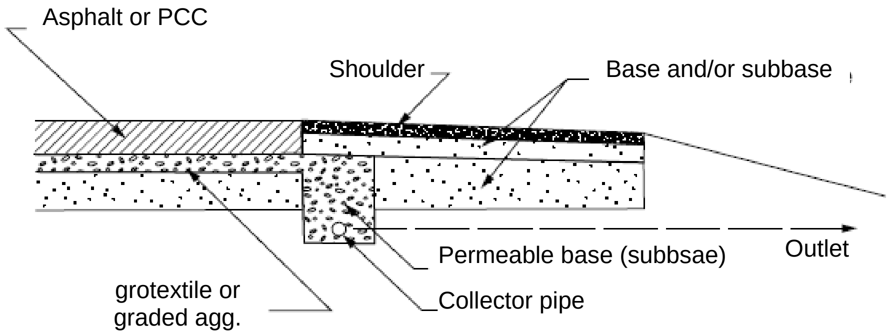
Is concerned with removing water, typically the result of high water table or wet weather which can accumulate under the pavement structure by two chief means:

- Gravity flow: (in mix with air voids above 7%) and through cracks.
- Capillary rise: (in the fine grained soil).

1) *Minimize water infiltration into the pavement structure*: by providing proper road side drainage and minimizing air voids in the mix.

2) *Provide surface drainage*: consist of three base elements:

- A permeable subbase to provide for rapid removal of water which enters the pavement structure.
- A method of conveying the removed water, by using a base sloped towards a drainage ditch.
- A filter layer (such as geotextile, graded aggregate) to prevent the migration of fines into the permeable base from subgrade.



07-Evaluation of Strength for Subgrade:

* **C. B. R.**: California Bearing Ratio, for subgrade in "Flexible Pavement".

$$C.B.R._{0.1"} = \frac{P_{0.1"}(psi)}{1000(psi)}$$

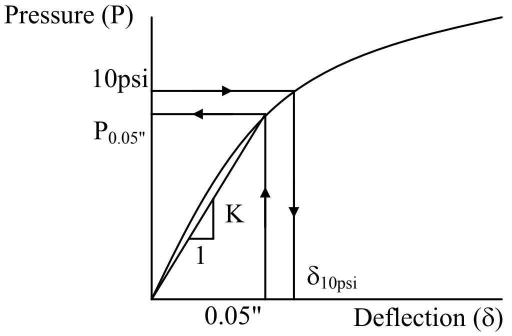
$$C.B.R._{0.2"} = \frac{P_{0.2"}(psi)}{1500(psi)}$$

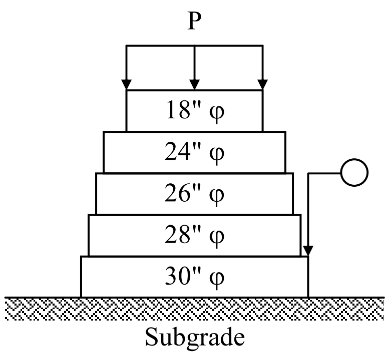
Whichever is grater

* **K**: Modulus of subgrade reaction, for subgrade in "Rigid Pavement"

By Westagard: $R = K * \delta$

Where: R = reaction (applied stress), δ = deflection





تجرى التجربة موقعياً من خلال تحميل صفائح ذات أقطار مختلفة (المبينة أعلاه)، ويقرأ التشوه ويرسم منحني ومنه نستخرج قيمة (K)، وهناك طريقتين:

As:

$$K(pci) = \frac{P_{0.05"}}{0.05"}$$

Or sometime: $K = \frac{10(psi)}{\delta_{10psi}}$

في حالة عدم امكانية استخدام بعض الصفائح في التجربة بسبب ضيق المساحة، ويمكن استخدام أقطار أخرى وتصحح النتائج:

For the sheets & deflection:

Depend on K with 30" φ base plate

For $K_{40"\varphi} = 0.8\ K_{30"\varphi}$

$K_{20"\varphi} = 1.5\ K_{30"\varphi}$

By AASHTO class.:

Clayey sand	A-7	→	K = 50 – 150 psi
Gravel	A-1	→	K = 400 – 500 psi

For soft subgrade:

إذا كانت (K) قليلة جداً (تربة ضعيفة)

Partial or full replacement with better soil, as granular material, with cohesive soil (more frictional resistance), or by soil stabilization.

استبدال جزئي او كلي بتربة أفضل (خلط التربة الضعيفة بتربة قوية)، أو استخدام تقنيات تثبيت التربة.

08-Thickness Design of Flexible Pavement:

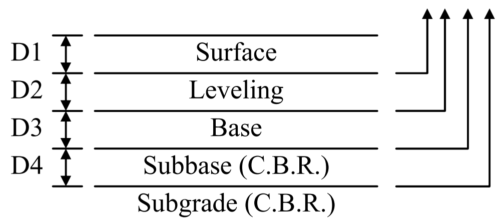
By different methods [due to: methods pf traffic analysis, failure definition (structural & users), evaluation of properties, & environmental effects].

1) AASHO (AASHTO) Guide method.

2) T. A. I. method (The asphalt institute method).

3) N. C. S. A. (National Crushed Stone Association).

AASHTO method:



D or h = f (W_{t18}, ρ_t, S, & R)

SN = f (S, R)

Note: h (for each layer) > max. size of agg. * 2

Where:

a) W_{t18} = Equivalent (18kips) (≈8.2ton) single axle applications.

W_{t18} = f (axle type, axle load magnitude, ρ_t, design life, & SN)

$W_{t18} = \Sigma$ T*A*F

Where:

T = Future trucks / Day / Direction = (Future ADT * %Truck * D.D)

A = Axle / Truck

F = Damage factor

b) ρ_t = Terminal Serviceability:

Lowest serviceability allowed at the end of design period before resurfacing or reconstruction.

By:

Arbitrary scale (named present serviceability index: 5 for best riding quality, and 0 for worst)

ρ_t = 2.5 for main highway

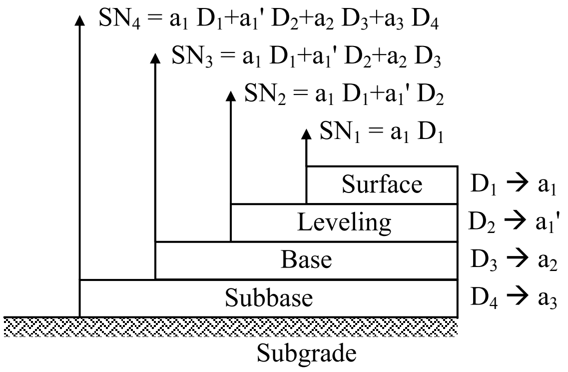
ρ_t = 2.0 for secondary highway

c) S = Road bed support value

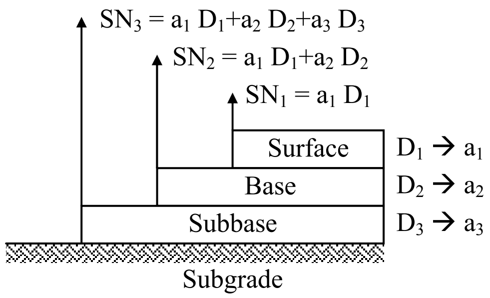
d) R = Regional factor

e) SN = Structural number:

Index number derived from analysis of traffic (W_{t18}), road bed support number (S), regional factor (R) [from monograph], which may be converted to thickness of various layers by using suitable layer coefficient.



Case (2) Ideal Arrangement



Case (1) General

ملاحظة: ($SN_1 = a_1 D_1$) المطلوب (D_1) نستخرج (SN_1) من المخططات (P.509) و(a_1) من المخطط (P.514) نجد (D_1) بالانج ويقرب لأقرب نصف ("0.5").

For case (1) General:

a_1 = Layer coefficient for Surface — D_1 = Thickness of Surface (inch)

a_2 = Layer coefficient for Base — D_2 = Thickness of Base (inch)

a_3 = Layer coefficient for Subbase — D_3 = Thickness of Subbase (inch)

Design monographs and tables: Yoder (Table 4.9 P.164, 165), (Fig. 15.1 P.509), (Table 15.1 P.510), (Fig. 15.3 P.514, 515), (Fig. 15.5 P.516)

Ex.:

A main rural highway has been built or designed for (200) daily 18-kips single axle load repetition. Regional factor (R) = 1.2 & the characteristics of pavement materials as following:

Subgrade	→	C. B. R. = 5%	(Plastic clay)
Subbase	→	C. B. R. = 20%	(Sand-gravel)
Base	→	C. B. R. = 80%	(Crushed stone)
Surface	→	$E = 4.3*10^5$ psi	(Asphalt concrete)

Sol.:

From graph (P.514, 515)

Surface	$a_1 = 0.42$	(Modulus E = 4.3)
Base	$a_2 = 0.13$	(C. B. R. = 80%)
Subbase	$a_3 = 0.095$	(C. B. R. = 20%)

$SN_1 = a_1 D_1$

$W_{t18} = 200$

From graph (P.516)

قيم (C. B. R.) للطبقة التي قبلها

S_1 (@ 80% C.B.R.) = 8.5 → $SN_1 = 1.95$

S_2 (@ 20% C.B.R.) = 6.2 → $SN_2 = 2.82$

S_3 (@ 5% C.B.R.) = 4 → $SN_3 = 3.78$

$SN_1 = a_1 D_1$

$1.95 = 0.42*D_1$ → $D_1 = 4.64"$ use $D_1 = 5"$

$SN_2 = a_1 D_1 + a_2 D_2$

$2.82 = 0.42*5 + 0.13*D_2$ → $D_2 = 5.54"$ use $D_2 = 6"$

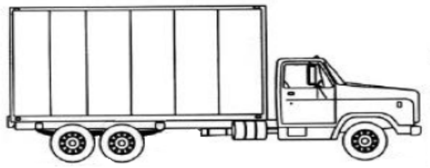
SN3 = a1 D1 + a2 D2 + a3 D3

$3.78 = 0.42*5 + 0.13*6 + 0.045*D_3$ → $D_3 = 9.47"$ use $D_3 = 9.5"$

H.W.:

Secondary highway, ADT (1994) = 400vph, truck = 40%, D. D. = 50%, annual rate of traffic growth = 6%, design life = 20 years, wet (saturated road bed).

Truck type:



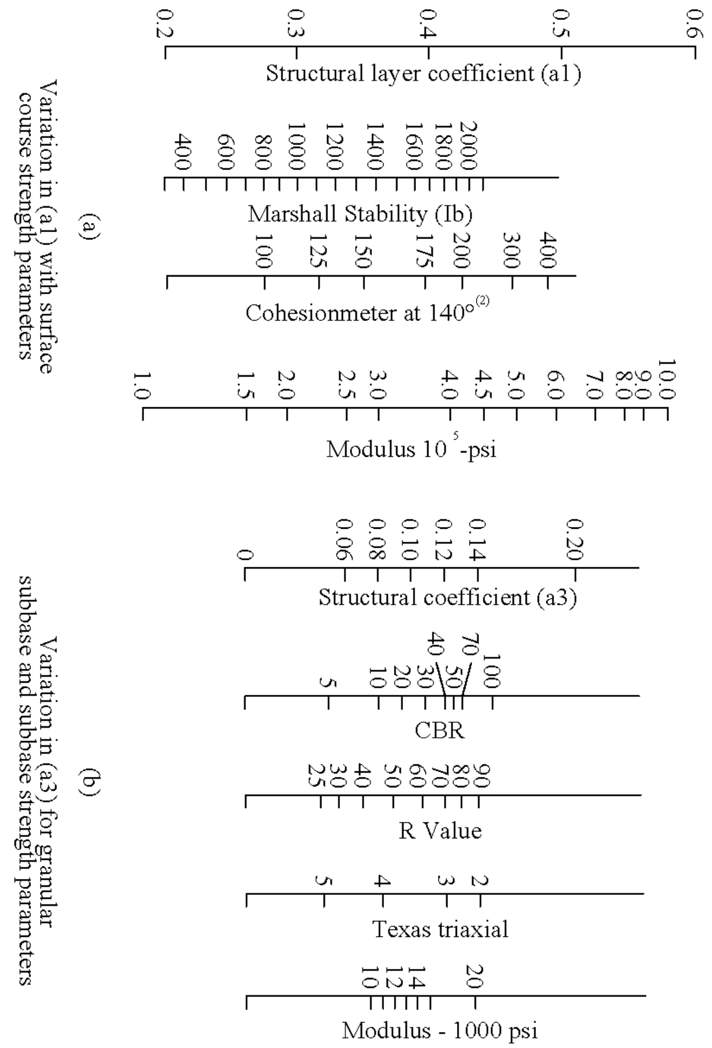
Materials	Properties	
Asphalt concrete wearing course	M. S.	≥ 800 kg
Asphalt concrete leveling course	M. S.	≥ 700 kg
Crushed stone base	C. B. R.	80 %
Subbase	C. B. R.	30 %
Subgrade	C. B. R.	2%

Determine thickness of layers in (cm)

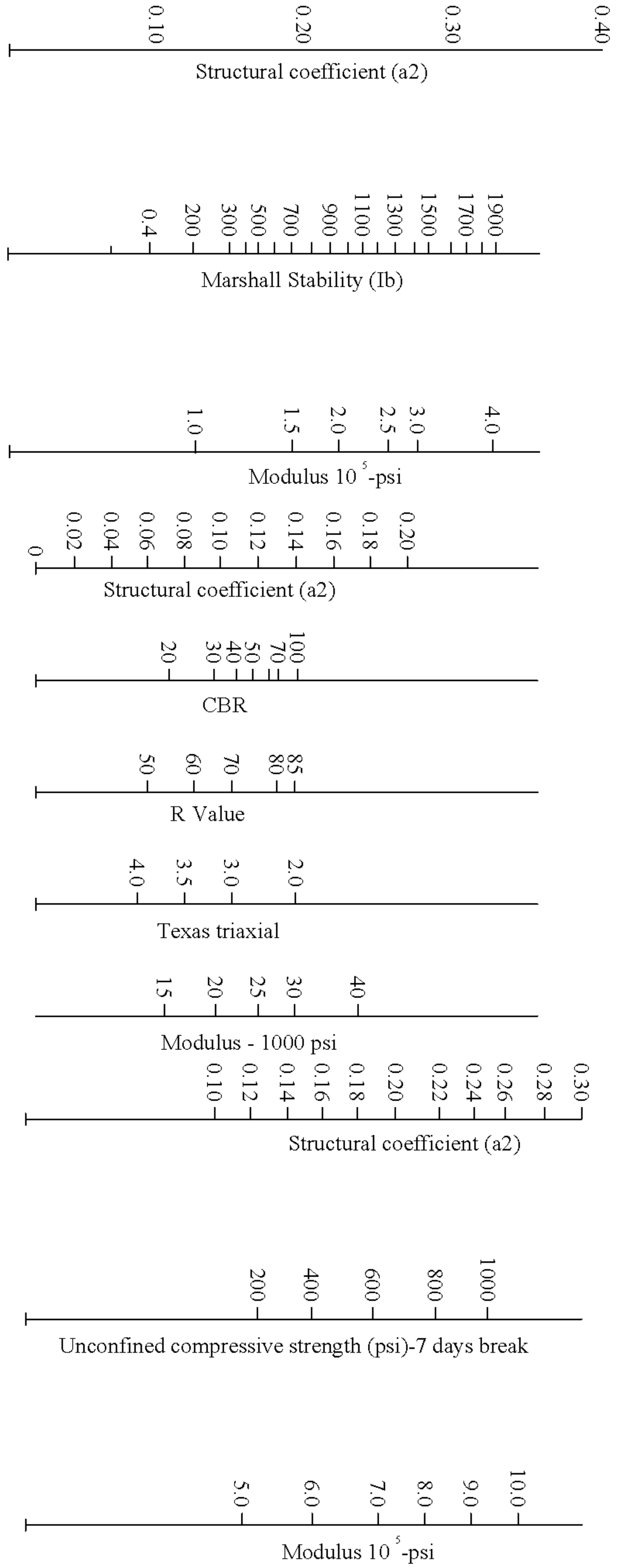
Note: let D_1 = 8 cm

Ans.: D1 = 8cm (3"), D2 = 11cm (4.5"), D3 = 12cm (5"), D4 = 57cm (22.5")

1kg = 2.20462 lb



(Yoder, Fig. 15.3, P.515)



(c)
Variation in (a2) for bituminous-treated bases with strength parameters

(d)
Variation in granular coefficient (a2) with base strength parameters

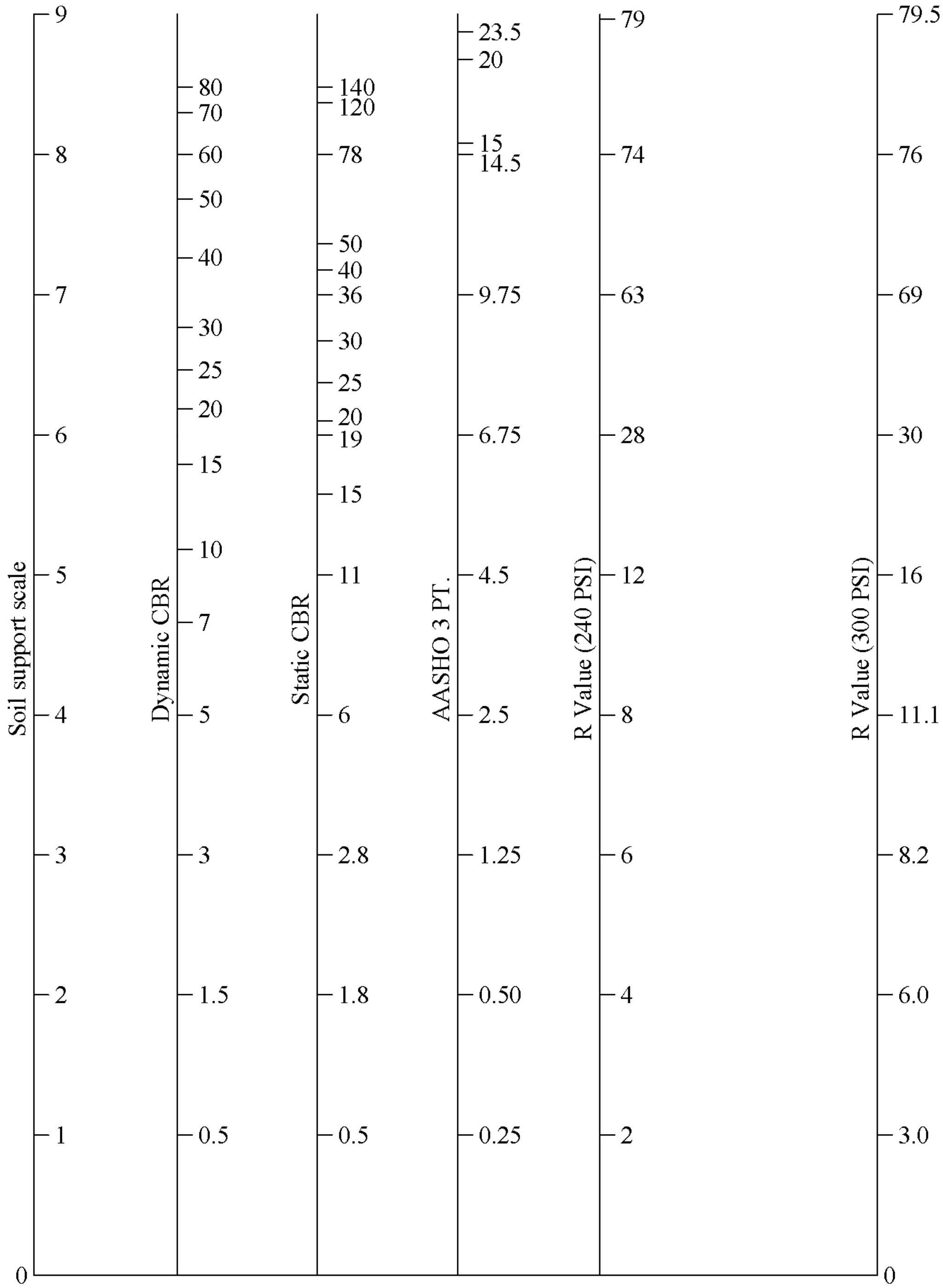
(e)
Variation in (a2) for cement-treated bases with base strength parameters

(Yoder, Fig. 15.3, P.515)

Regional Factor

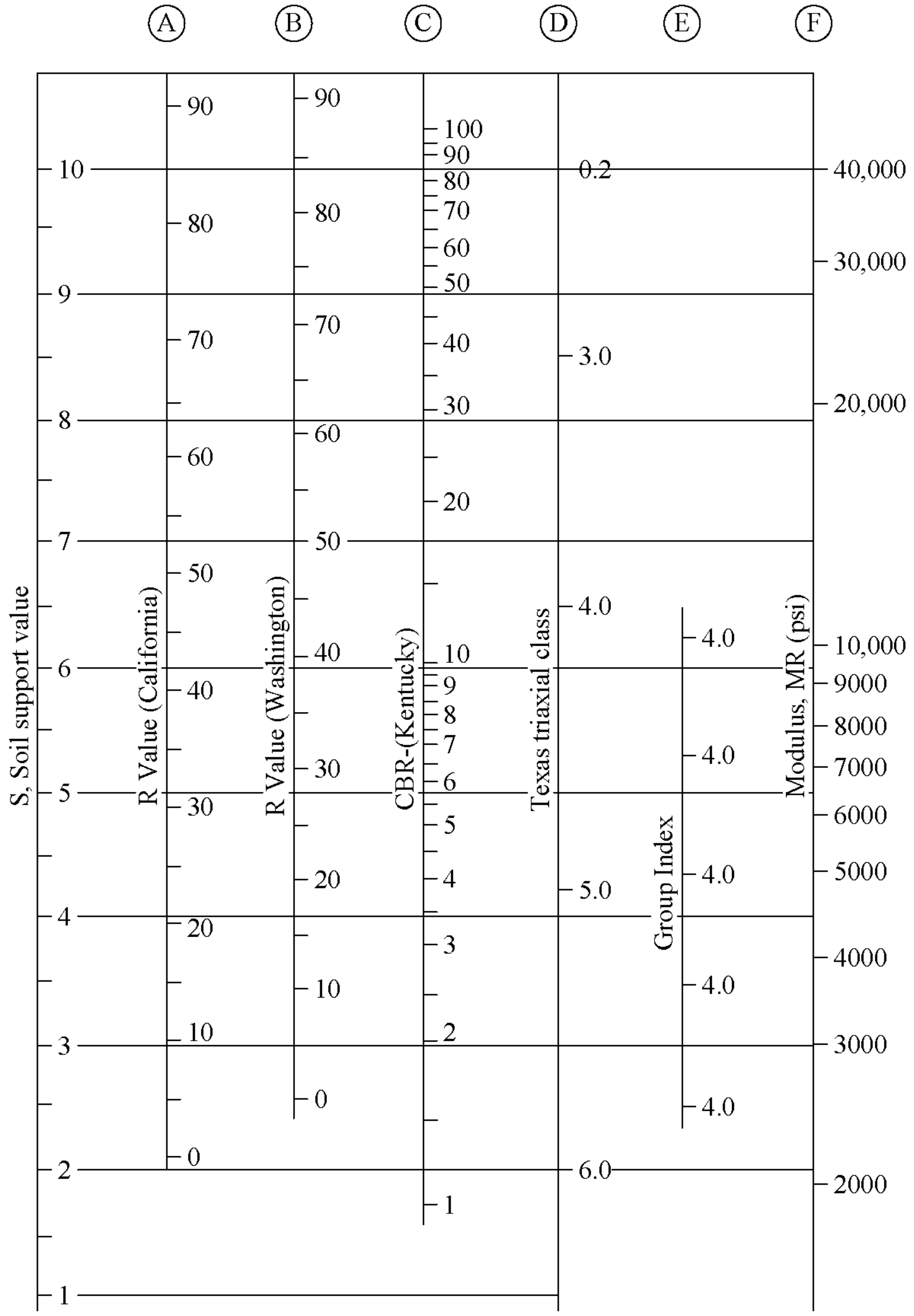
(Yoder, Table 15.1, P.510)

Condition	R value
Roadbed materials frozen to depth of 5in or more	0.2 – 1.0
Roadbed materials dry, summer and fall	0.3 – 1.5
Roadbed materials wet, spring thaw	4.0 – 5.0

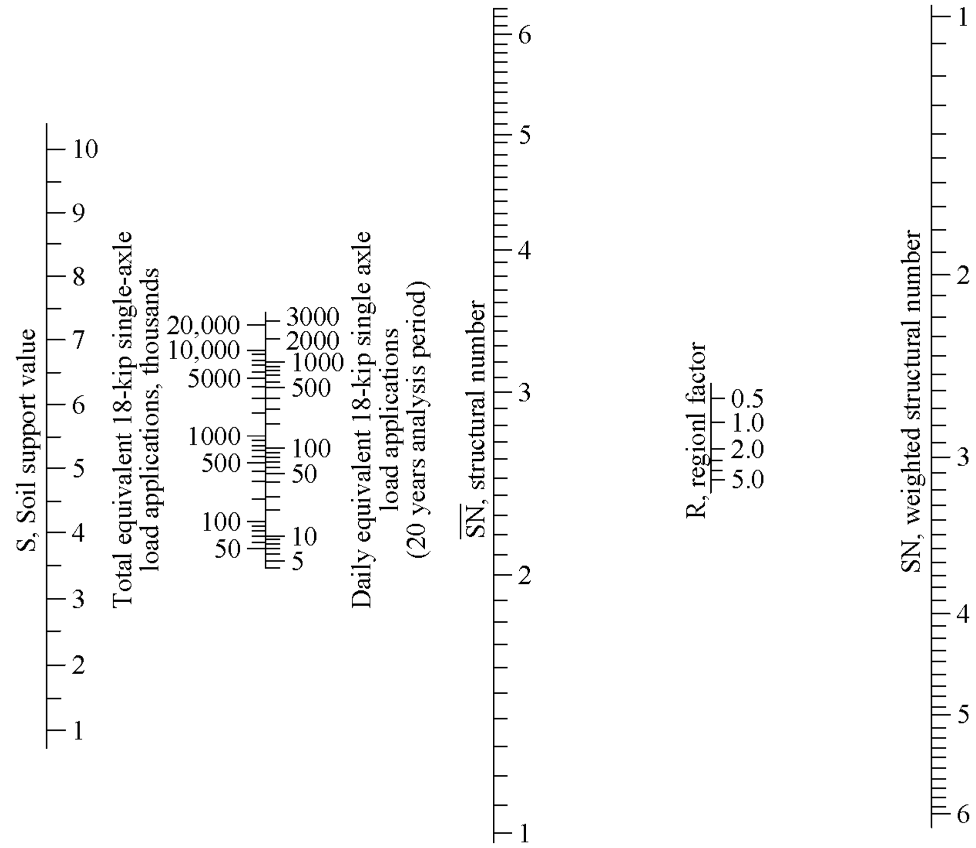


Soil suport value correlations

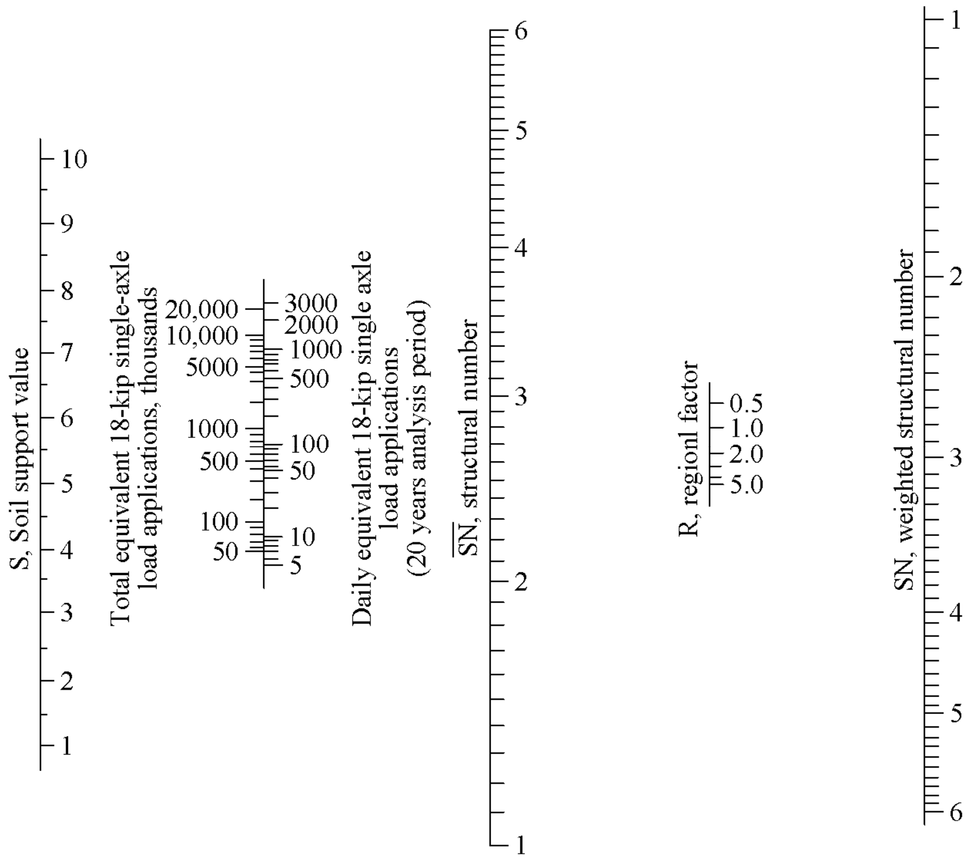
(Yoder, Fig. 15.5, P.516)



(Yoder, Fig. 15.5, P.517)



Design chart for flexible pavements, ρt = 2.0



Design chart for flexible pavements, ρt = 2.5

(Yoder, Fig. 15.1, P.509)

Table 4.9 AASHO Equivalence Factors – Flexible Pavement

(Yoder, P.164)

Single Axle, $\rho_t = 2.0$

Axle Load (kips)	Structural Number, SN					
	1	2	3	4	5	6
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
4	0.002	0.003	0.002	0.002	0.002	0.002
6	0.01	0.01	0.01	0.01	0.01	0.01
8	0.03	0.04	0.04	0.03	0.03	0.03
10	0.08	0.08	0.09	0.08	0.08	0.08
12	0.16	0.18	0.19	0.18	0.17	0.17
14	0.32	0.34	0.35	0.35	0.34	0.33
16	0.59	0.60	0.61	0.61	0.60	0.60
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.59	1.56	1.55	1.57	1.60
22	2.49	2.44	2.35	2.31	2.35	2.41
24	3.71	3.62	3.43	3.33	3.40	3.51
26	5.36	5.21	4.88	4.68	4.77	4.96
28	7.54	7.31	6.78	6.42	6.52	6.83
30	10.38	10.03	9.24	8.65	8.73	9.17
32	14.00	13.51	12.37	11.46	11.48	12.17
34	18.55	17.87	16.30	14.97	14.87	15.63
36	24.20	23.30	21.16	19.28	19.02	19.93
38	31.14	29.95	27.12	24.55	24.03	25.10
40	39.57	38.02	34.34	30.92	30.04	31.25

Tandem Axle, $\rho_t = 2.0$

Axle Load (kips)	Structural Number, SN					
	1	2	3	4	5	6
10	0.01	0.01	0.01	0.01	0.01	0.01
12	0.01	0.02	0.02	0.01	0.01	0.01
14	0.02	0.03	0.03	0.03	0.02	0.02
16	0.04	0.05	0.05	0.05	0.04	0.04
18	0.07	0.08	0.08	0.08	0.07	0.07
20	0.10	0.12	0.12	0.12	0.11	0.10
22	0.16	0.17	0.18	0.17	0.16	0.16
24	0.23	0.24	0.26	0.25	0.24	0.23
26	0.32	0.34	0.36	0.35	0.34	0.33
28	0.45	0.46	0.49	0.48	0.47	0.46
30	0.61	0.62	0.65	0.64	0.63	0.62
32	0.81	0.82	0.84	0.84	0.83	0.82
34	1.06	1.07	1.08	1.08	1.08	1.07
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.76	1.75	1.73	1.72	1.73	1.74
40	2.22	2.19	2.15	2.13	2.16	2.18
42	2.77	2.73	2.64	2.62	2.66	2.70
44	3.42	3.36	3.23	3.18	3.24	3.31
46	4.20	4.11	3.92	3.83	3.91	4.02
48	5.10	4.98	4.72	4.58	4.68	4.83

Table 4.9 (Continued)

(Yoder, P.165)

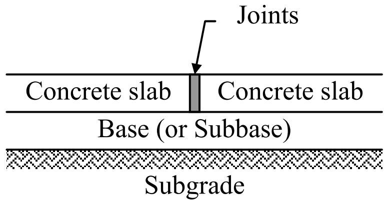
Single Axle, $\rho_t = 2.5$

Axle Load (kips)	Structural Number, SN					
	1	2	3	4	5	6
2	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002
4	0.003	0.004	0.004	0.004	0.003	0.002
6	0.01	0.02	0.02	0.01	0.01	0.01
8	0.03	0.05	0.05	0.04	0.03	0.03
10	0.08	0.10	0.12	0.10	0.09	0.08
12	0.17	0.20	0.23	0.21	0.19	0.18
14	0.33	0.36	0.40	0.39	0.36	0.34
16	0.59	0.61	0.65	0.65	0.62	0.61
18	1.00	1.00	1.00	1.00	1.00	1.00
20	2.61	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
30	10.31	9.55	7.94	6.83	6.97	7.79
32	13.90	12.82	10.52	8.85	8.88	9.95
34	18.41	16.94	13.74	11.34	11.18	12.51
36	24.02	22.04	17.73	14.38	13.93	15.50
38	30.90	28.30	22.61	18.06	17.20	18.98
40	39.26	35.89	28.51	22.50	21.08	23.04

Tandem Axle, $\rho_t = 2.5$

Axle Load (kips)	Structural Number, SN					
	1	2	3	4	5	6
10	0.01	0.01	0.01	0.01	0.01	0.01
12	0.02	0.02	0.02	0.02	0.01	0.01
14	0.03	0.04	0.04	0.03	0.03	0.02
16	0.04	0.07	0.07	0.06	0.05	0.04
18	0.07	0.10	0.11	0.09	0.08	0.07
20	0.11	0.14	0.16	0.14	0.12	0.11
22	0.16	0.20	0.23	0.21	0.18	0.17
24	0.23	0.27	0.31	0.29	0.26	0.24
26	0.33	0.37	0.42	0.40	0.36	0.34
28	0.45	0.49	0.55	0.53	0.50	0.47
30	0.61	0.65	0.70	0.70	0.66	0.63
32	0.81	0.84	0.89	0.89	0.86	0.83
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

09-Rigid Pavement:



Function of Base (or Subbase):

1) Drainage purpose

2) Reduce the effect of subgrade volume change on concrete layer

3) Prevent pumping of fines through joints & edges

4) Increase "K" modulus of subgrade reaction

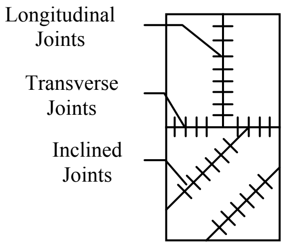
Rigid Pavement Characteristics:

- Can resist unlimited loading
- Minor defects are not reflected.
- More skid resistance, safe.
- More economical for same projects at certain location.
- Concrete layer is less thickness than other layers.

Rigid Pavement Types:

a) *Plain concrete pavement*:

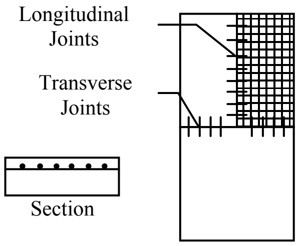
1. No reinforcement except of using tie bars
   (for longitudinal joints)
2. Closer spacing between contractions joint
   (as transverse joints)
3. Inclined joints may be used
   (for better load transfer)
4. Very limited use



b) *Simply reinforced concrete pavement*:

1. Temperature (wire-mesh, B. R. C.) reinforcement between joints to control cracking (close to the upper surface)
2. Dowel bars across transverse joints

3. Tie bars across longitudinal joints to control warping
4. Wider spacing between joints (from 3-6m to 12-14m)
5. Widely used



c) *Continuously reinforced concrete pavement*:

1. No joints except some expansion joints & may be some contraction joints
2. Heavy reinforcement (≈ > 0.6% of cross sectional area)
3. High cost
4. Used in very-weak subgrade & high traffic load

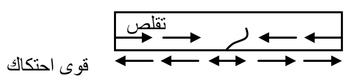
d) *Pre-stressed concrete pavement*:

1. Fewer joints
2. More expensive

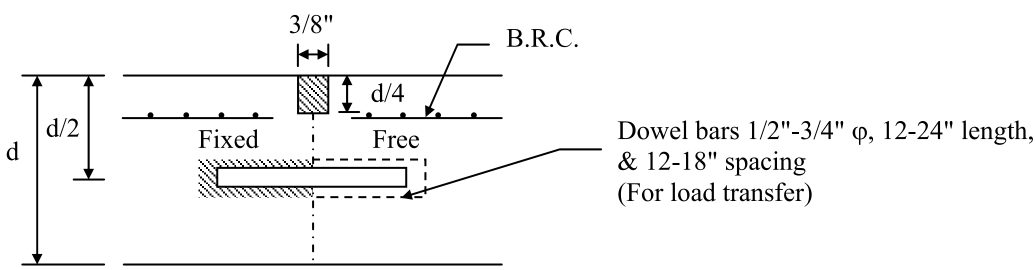
Type of Joints in Rigid Pavement:

1) *Contraction joints*: to relieve excessive tensile stress due to drop in temperature.

مفاصل الشد: للتخلص من اجهادات الشد الناتجة من انخفاض درجة الحرارة، والناتجة من الاحتكاك بين البلاطة والتربة تحتها (Subgrade)، والتي تسبب فشل الطبقة.

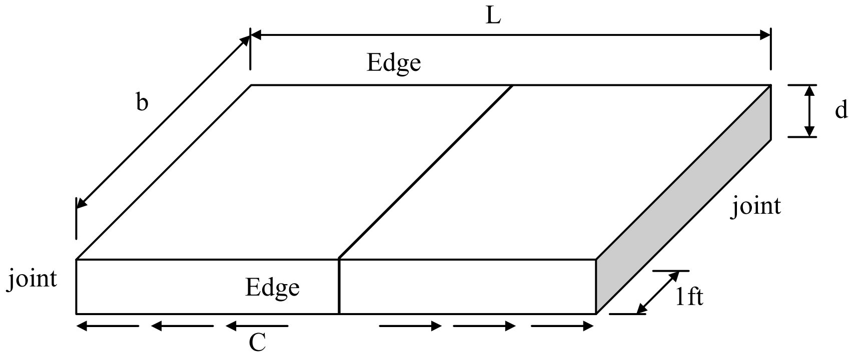


وتعالج بعمل أخدود يملأ بالماستك لمنع المياه من المرور، لمنع تأكسد حديد التسليح وتأثر طبقة التربة، والأخدود يصنع منطقة ضعيفة لتحديد مسار الفشل.



B. R. C. Design:

توضع طبقة من التسليح (B.R.C.) في الجزء الأعلى من طبقة التبليط لمقاومة اجهادات الشد (Tensile stresses) المتولدة بسبب تغير تدرجات الحرارة، وتكون لطبقة التبليط بين المفاصل (على جانبي الأخدود)، وأسلوب حساب كمية التسليح كما يأتي:



L = Allowable spacing for contraction joint (for longitudinal reinforcement), (ft)

b = Slab width, (ft)

C = Coefficient of friction (1 – 2 use 1.5)

γ = Unit wt. of concrete (pcf)

d = Slab thickness (ft)

Friction resistance = Allowable tensile strength

Friction resistance = Concrete tensile strength + Steel tensile strength

$(L/2 * b * d) * \gamma * C = b * d * f_{tc} + As * f_s$

For one unit of width use b =1ft

For safety assume concrete tensile strength ($b * d * f_{tc}$) = 0

f_{tc} = Allowable tensile strength of concrete ≈ 400 psi

f_s = Allowable tensile strength of steel ≈ 25000 psi

As = Area of steel (in^2/ft)

$W = d * \gamma$

where: W = Weight of 1ft^2 of slab

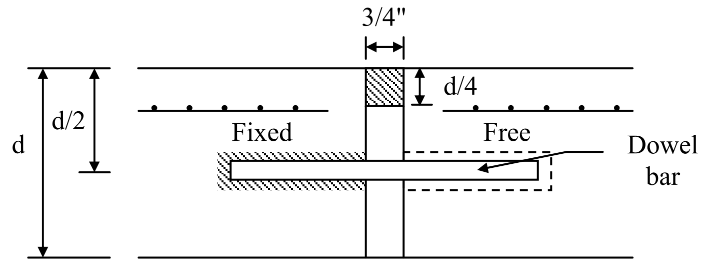
$L/2 * 1 * W * C = As * f_s$

$$As = \frac{L * W * C}{2F_S}$$

للتسليح بالاتجاه الطولي (L) تكون المسافة بين مفصلين، أما للتسليح بالاتجاه العرضي (L) تكون المسافة بين حافتي الطريق (edge to edge) أي (b).

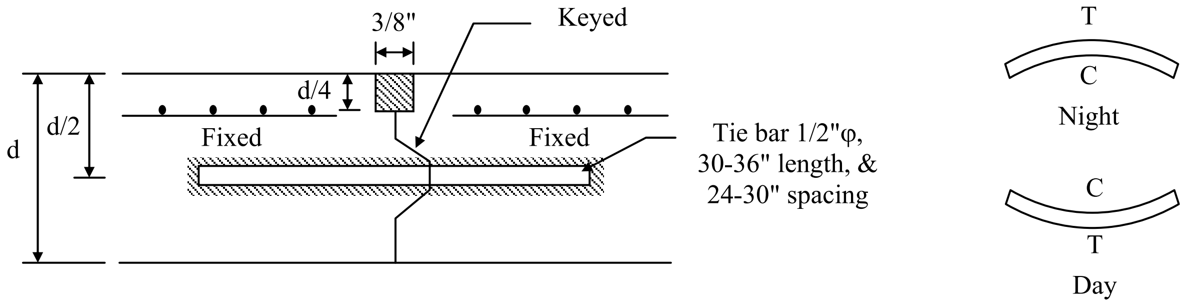
2) *Expansion Joints*: provide a clear spacing along the depth to relieve excessive compressive stresses due to rise in temperature.

مفاصل التمدد: ارتفاع درجة الحرارة تسبب التمدد، فالمعالجة بعمل أخدود أو فراغ على عمق طبقة التبليط لمنع إجهادات الانضغاط.



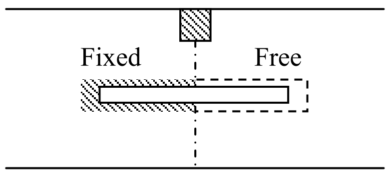
- Difficult in construction & maintenance
- Needed when casting in cold season, near structure, & for materials with high coefficient of thermal expansion
- Contraction joints used as expansion joints

3) *Warping joints*: to relieve tensile stresses due to warping because of difference in temperature between top and bottom of the slab (in night & day).



4) *Construction joints*: in some conditions.

مفصل إنشائي: ويستخدم في بعض الحالات (مثل نهاية وجبة عمل وبداية وجبة أخرى).



Thickness Design of Rigid Pavement:

Design methods:

1) PCA method (Portland Cement Association)

2) AASHO (AASHTO) guide method

1) ***PCA method***: depends on fatigue analysis under repeated loading.

h = f (axle type, axle load magnitude, No. of repetitions, M. R. (f_r), & K)

where:

h = thickness of concrete layer

Design steps:

a) Analysis of traffic:

$N_{act.}$: Actual No. of repetitions in 40-years period for each axle load.

Axles ≥ 16 kips – Single (المحاور أقل من 16 ومفردة تهمل)

Axles ≥ 30 kips – Tandem (المحاور أقل من 30 ومزدوجة تهمل)

$N_{act.}$ = T * A * 40 * 365

Where:

T = Future truck per day per direction

A = No. of axles per truck for certain axle load

b) Correction for impact:

Static axle load * 1.2 = corrected (dynamic) axle load

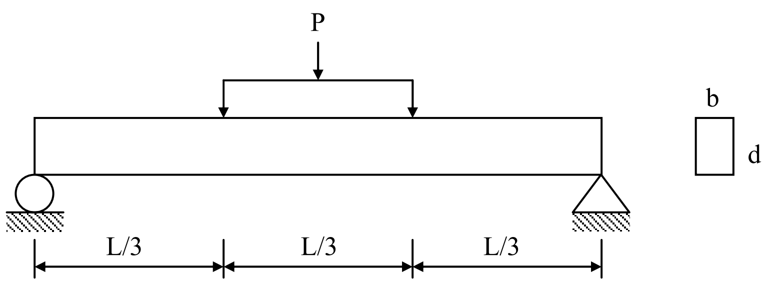
c) M. R. (f_r): Modulus of rupture (for third-point loading) (psi)

$$\sigma = \frac{M.C}{I}$$

Where:

$$M = \frac{P.L}{6},\ C = \frac{d}{2},\ I = \frac{b.d^3}{12}$$

$$\therefore\ M.R. = \frac{P.L}{b.d^2}$$



$$M.R. = 8 - 10\sqrt{f_c}$$

$$= 600 – 750 \text{ psi}$$

Where: f_c = Compression strength of concrete (psi)

d) K: Modulus of subgrade reaction

e) S: Actual load stress in pavement

Determine form design charts from either single or tandem axle, depend on:

- Corrected axle load
- K – value
- Suggested thickness of concrete layer "d"

f) SR: Stress ratio

$$SR = \frac{S}{M.R.}$$, for each axle load

g) $N_{all.}$: Allowable No. of repetitions of each axle load to account for fatigue in concrete pavement (depend on stress ratio SR)

Note: Unlimited repetitions for SR = 0.5 or less → ∞ vehicles

h) F: Fatigue percentage

$$F = \frac{N_{act.}}{N_{all.}} * 100\%$$, for each axle load

i) Σ F < 100%, for correct assumption of "d" value

إذا كانت ($\Sigma F \geq 100\%$) فيجب تكبير "d" وإعادة التصميم.

إذا كانت ($\Sigma F \leq 85\%$) فتبقى "d"،

أما إذا كانت أقل من (85%) فالتصميم غير اقتصادي أي نقلل "d" بمقدار ("1-0.5") وإعادة التصميم.

Design monographs and tables: Yoder (Fig. 17.2, 17.3, P.604, 605), (Table 17.1, P.603)

Ex.:

T = 60 trucks/day/dir, K = 150 psi, & M. R. = 650 psi

Axle type	Axle load (kips)	A' (No. of axles/100 trucks)
Tandem	45	0.1
	43	0.1
	41	0.1
	39	1.0
	37	0.9
	35	1.4
	33	1.8
	31	9.4
Single	21	3.2
	19	5.4
	17	6.1

Find concrete layer thickness "d" using P.C.A. method?

Sol.:

$N_{act.} = 60*(A'/100)*40*365$ …(1)

$SR = \frac{S}{650}$ …(3)

Corrected axle load = 1.2*axle load …(2)

$F = \frac{N_{act.}}{N_{all.}}*100\%$ …(4)

Assume d = 7"

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Axle type	Axle load	A' (No. of axles/ 100 trucks)	$N_{act.}$	Corrected axle load	S	SR	$N_{all.}$	F (%)
			(3)+eq.(1)	(2)+eq.(2)	Graph+(5)+K+d	(6)+eq.(3)	(7)+table	(4)+(8)+eq.(4)
Tandem	45	0.1	876	54	435	0.67	4500	19
	43	0.1	876	51.6	415	0.64	11000	8
	41	0.1	876	49.2	410	0.63	14000	6
	39	1.0	8760	46.8	390	0.60	32000	27
	37	0.9	7884	44.4	375	0.58	57000	14
	35	1.4	12250	42.8	350	0.54	180000	7
	33	1.8	15800	39.6	325	0.50	∞	0
	31	9.4	82400	37.6	310	0.48	∞	0
Single	21	3.2	28100	25.2	350	0.54	180000	15
	19	5.4	47400	22.8	325	0.50	∞	0
	17	6.1	53500	20.1	290	0.45	∞	0
							ΣF	96%

ΣF(%) = 96% < 100%

∴ d = 7" OK

2) ***AASHTO method***:

d (slab thickness) = f (ρ_t, No. of W_{t18}, K, & working stresses in concrete)

a) ρ_t: Terminal level of serviceability

2.5 for main highway

2.0 for secondary highway

b) No. of W_{t18}: No. repetitions of 18-kips single axle load

as:

W_{t18} = f (axle type, effective axle load, ρ_t, design life, assumed "d")

c) K: Modulus of subgrade reaction (pci)

d) Working stress in concrete = M. R. * 0.75

إذا كانت d المستخرجة بمقدار أقل أو أكبر من (0.5") من المفروض تعاد عملية التصميم

Design monographs and tables: Yoder (Fig. 17.4, 17.5, P.608), (Table 4.10, P.166, 167)

Ex.:

T = 60 trucks/day/dir, K = 150 psi, & M. R. = 650 psi

Axle type	Axle load (kips)	A' (No. of axles/100 trucks)
Tandem	45	0.1
	43	0.1
	41	0.1
	39	1.0
	37	0.9
	35	1.4
	33	1.8
	31	9.4
Single	21	3.2
	19	5.4
	17	6.1

Find concrete layer thickness "d" using AASHTO method? (assume ρ_t = 2.5)

Sol.:

$N_{act.}$ = 60*(A'/100)*40*365 …(1)

Corrected axle load = 1.2*axle load …(2)

Assume d = 7"

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Axle type	Axle load	A' (No. of axles/ 100 trucks)	$N_{act.}$	Corrected axle load	Equivalent factor	No. of W_{t18}
			(3)+eq.(1)	(2)+eq.(2)	(5)+Table	(4)*(6)
Tandem	45	0.1	876	54	10.61	9294.4
	43	0.1	876	51.6	9.23	8085.5
	41	0.1	876	49.2	7.85	6876.6
	39	1.0	8760	46.8	6.47	56677.2
	37	0.9	7884	44.4	5.21	41075.6
	35	1.4	12250	42.8	4.16	50960
	33	1.8	15800	39.6	3.296	52076.8
	31	9.4	82400	37.6	2.588	213251.2
Single	21	3.2	28100	25.2	3.796	10666.6
	19	5.4	47400	22.8	2.56	12134.0
	17	6.1	53500	20.1	1.65	88596
					ΣW_{t18}	559694 psi

ΣWt18 ≈ 560 ksi

Working stress = 0.75 * 650 = 487.5 psi

& K = 150 psi

From monograph:

d = 6.25" < $d_{assumed}$ (with more than 0.5") Not OK

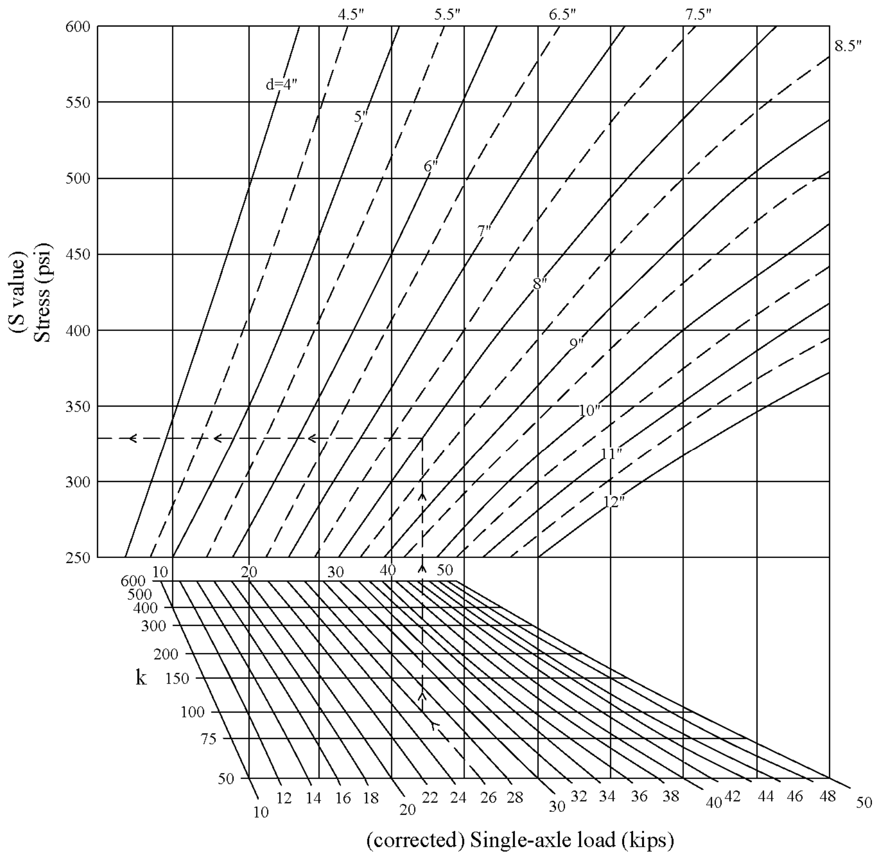
check (redesign) with d = 6.5"

Table 17.1. Stress Ratios Allowable Load Repetitions
Yoder, P.603

Stress Ratio S_R	Allowable Repetition N_{all} (Veh.)
0.51	400,000
0.52	300,000
0.53	240,000
0.54	180,000
0.55	130,000
0.56	100,000
0.57	75,000
0.58	57,000
0.59	42,000
0.60	32,000
0.61	24,000
0.62	18,000
0.63	14,000
0.64	11,000
0.65	8,000
0.66	6,000
0.67	4,500
0.68	3,500
0.69	2,500
0.70	2,000
0.71	1,500
0.72	1,100
0.73	850
0.74	650
0.75	490
0.76	360
0.77	270
0.78	210
0.79	160
0.80	120
0.81	90
0.82	70
0.83	50
0.84	40
0.85	30
NOTE: Unlimited Repetition for S_R = 0.5 or less	

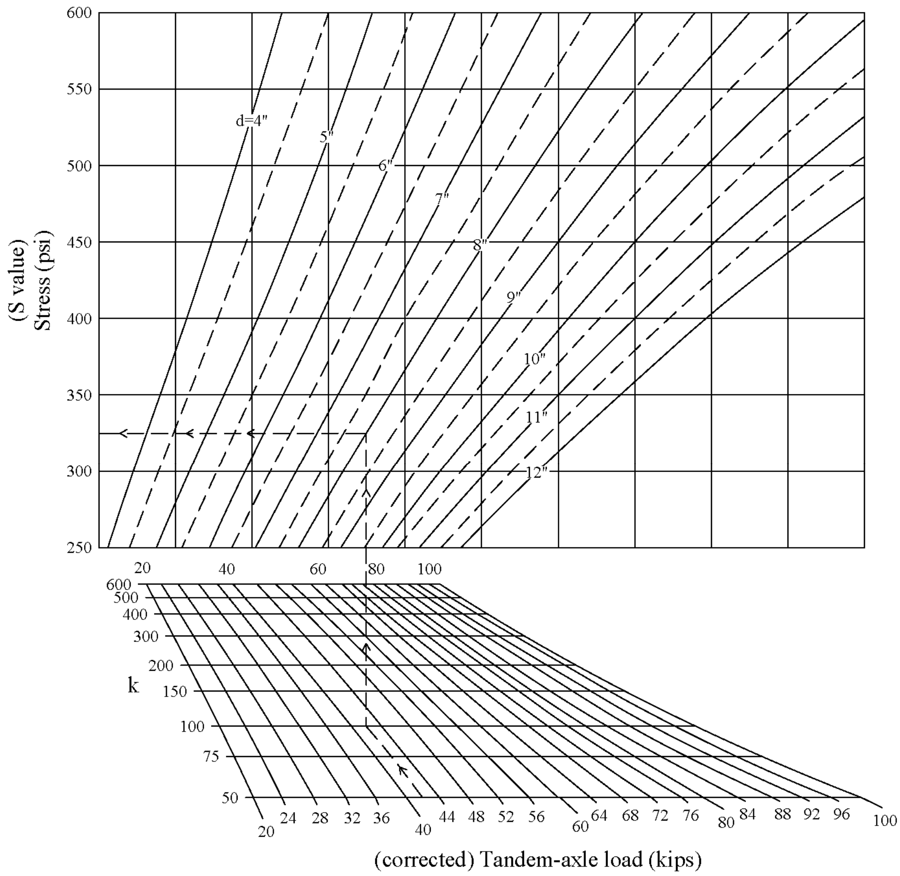
d = (7 – 9) in

Charts and Tables for Rigid Pavement Thickness Design by PCA Method



Design chart for single-axle truck loads (From Portland Cement Association)

Figure 17.2, Yoder, P.604



Design chart for tandem-axle truck loads (From Portland Cement Association)

Figure 17.3, Yoder, P.605

Table 4.10 AASHO Equivalence Factors – Rigid Pavement

(Yoder, P.166)

Single Axle, $\rho_t = 2.0$

Axle Load (kips)	D – Slab Thickness (in)					
	6	7	8	9	10	11
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
4	0.002	0.002	0.002	0.002	0.002	0.002
6	0.01	0.01	0.01	0.01	0.01	0.01
8	0.03	0.03	0.03	0.03	0.03	0.03
10	0.09	0.08	0.08	0.08	0.08	0.08
12	0.19	0.18	0.18	0.18	0.17	0.17
14	0.35	0.35	0.34	0.34	0.34	0.34
16	0.61	0.61	0.60	0.60	0.60	0.60
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.55	1.56	1.57	1.58	1.58	1.59
22	2.32	2.32	2.35	2.38	2.40	2.41
24	3.37	3.34	3.40	3.47	3.51	3.53
26	4.76	4.69	4.77	4.88	4.97	5.02
28	6.59	6.44	6.52	6.70	6.85	6.94
30	8.92	8.68	8.74	8.98	9.23	9.39
32	11.87	11.49	11.51	11.82	12.17	12.44
34	15.55	15.00	14.95	15.30	15.78	16.18
36	20.07	19.30	19.16	19.53	20.14	20.71
38	25.56	24.54	24.26	24.63	25.36	26.14
40	32.18	30.85	30.41	30.75	31.58	32.57

Tandem Axle, $\rho_t = 2.0$

Axle Load (kips)	D – Slab Thickness (in)					
	6	7	8	9	10	11
10	0.01	0.01	0.01	0.01	0.01	0.01
12	0.03	0.03	0.03	0.03	0.03	0.03
14	0.05	0.05	0.05	0.05	0.05	0.05
16	0.09	0.08	0.08	0.08	0.08	0.08
18	0.14	0.14	0.13	0.13	0.13	0.13
20	0.22	0.21	0.21	0.20	0.20	0.20
22	0.32	0.31	0.31	0.30	0.30	0.30
24	0.45	0.45	0.44	0.44	0.44	0.44
26	0.63	0.64	0.62	0.62	0.62	0.62
28	0.85	0.85	0.85	0.85	0.85	0.85
30	1.13	1.13	1.14	1.14	1.14	1.14
32	1.48	1.45	1.49	1.50	1.51	1.51
34	1.91	1.90	1.93	1.95	1.96	1.97
36	2.42	2.41	2.45	2.49	2.51	2.52
38	3.04	3.02	3.07	3.13	3.17	3.19
40	3.79	3.74	3.80	3.89	3.95	3.98
42	4.67	4.59	4.66	4.78	4.87	4.93
44	5.72	5.59	5.67	5.82	5.95	6.03
46	6.94	6.76	6.83	7.02	7.20	7.31
48	8.36	8.12	8.17	8.40	8.63	8.79

Table 4.10 (Continued)

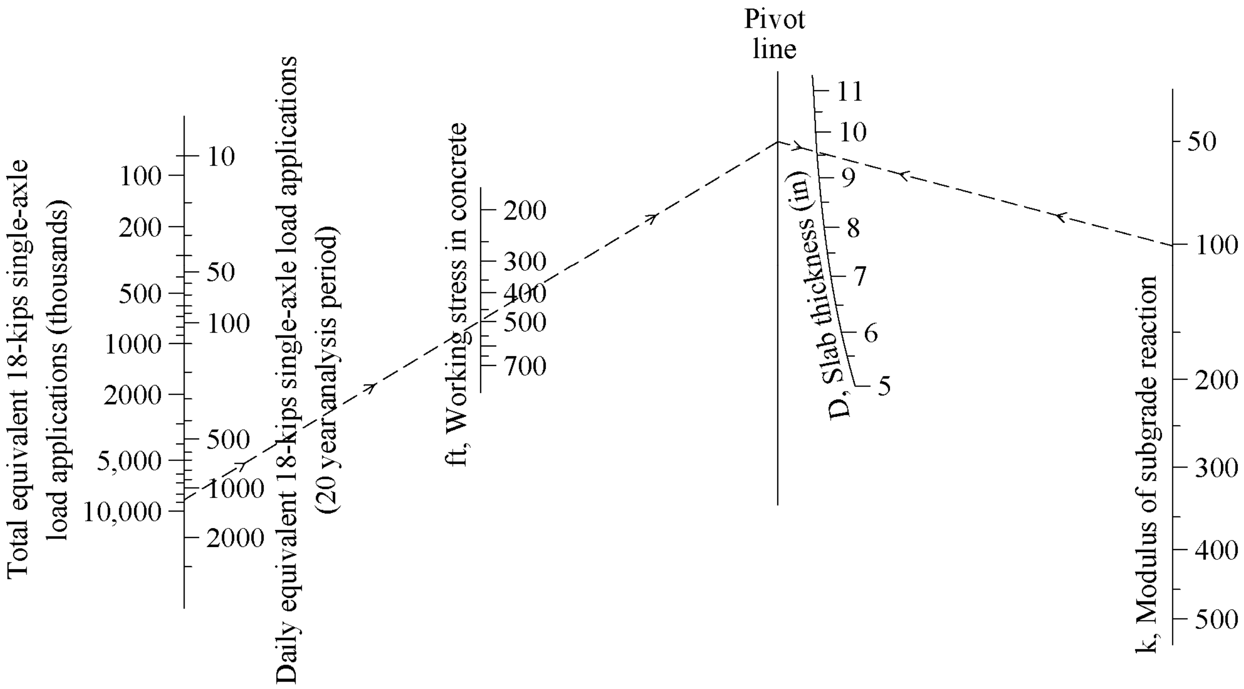
(Yoder, P.167)

Single Axle, $\rho_t = 2.5$

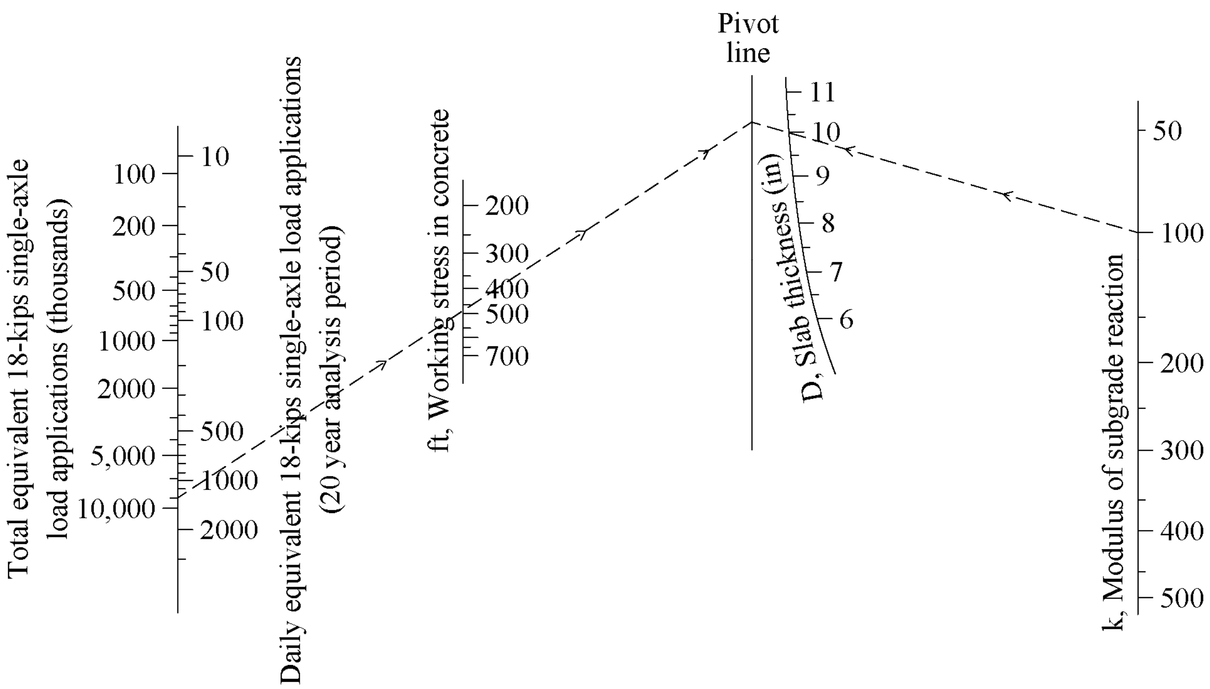
Axle Load (kips)	D – Slab Thickness (in)					
	6	7	8	9	10	11
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
4	0.003	0.002	0.002	0.002	0.002	0.002
6	0.01	0.01	0.01	0.01	0.01	0.01
8	0.04	0.04	0.03	0.03	0.03	0.03
10	0.10	0.09	0.08	0.08	0.08	0.08
12	0.20	0.19	0.18	0.18	0.18	0.17
14	0.38	0.36	0.35	0.34	0.34	0.34
16	0.63	0.62	0.61	0.60	0.60	0.60
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.51	1.52	1.55	1.57	1.58	1.58
22	2.21	2.20	2.28	2.34	2.38	2.40
24	3.16	3.10	3.23	3.36	3.45	3.50
26	4.41	4.26	4.42	4.67	4.85	4.95
28	6.05	5.76	5.92	6.29	6.61	6.81
30	8.16	7.67	7.79	8.28	8.79	9.14
32	10.81	10.06	10.10	10.70	11.43	11.99
34	14.12	13.04	12.94	13.62	14.59	15.43
36	18.20	16.69	16.41	17.12	18.33	19.52
38	23.15	21.14	20.61	21.31	22.74	24.31
40	29.11	26.49	25.65	26.29	27.91	29.90

Tandem Axle, $\rho_t = 2.5$

Axle Load (kips)	D – Slab Thickness (in)					
	6	7	8	9	10	11
10	0.01	0.01	0.01	0.01	0.01	0.01
12	0.03	0.03	0.03	0.03	0.03	0.03
14	0.06	0.05	0.05	0.05	0.05	0.05
16	0.10	0.09	0.08	0.08	0.08	0.08
18	0.16	0.14	0.14	0.13	0.13	0.13
20	0.23	0.22	0.21	0.21	0.20	0.20
22	0.34	0.32	0.31	0.31	0.30	0.30
24	0.48	0.46	0.45	0.44	0.44	0.44
26	0.64	0.64	0.63	0.62	0.62	0.62
28	0.85	0.85	0.85	0.85	0.85	0.85
30	1.11	1.12	1.13	1.14	1.14	1.14
32	1.43	1.44	1.47	1.49	1.50	1.51
34	1.82	1.82	1.87	1.92	1.95	1.96
36	2.29	2.27	2.35	2.43	2.48	2.51
38	2.85	2.80	2.91	3.04	3.12	3.16
40	3.52	3.42	3.55	3.74	3.87	3.94
42	4.32	4.16	4.30	4.55	4.74	4.86
44	5.26	5.01	5.16	5.48	5.75	5.92
46	6.36	6.01	6.14	6.53	6.90	7.14
48	7.64	7.16	7.27	7.73	8.21	8.55



Design chart for rigid pavements, ρt = 2.0. (From AASHO Interim Guide)
Yoder, Figure 17.4, P.608



Design chart for rigid pavements, ρt = 2.5. (From AASHO Interim Guide)
Yoder, Figure 17.5, P.608

10-The Effect of type and amount of Filler on Asphalt Paving Mix

First:

The role of the filler in the mix is very complex:

1. Serves as an inertic materials in the mix.
2. Serves as an active materials in the mix.

(due to its fineness and surface characteristics).

a. Specific Surface (S.S.) (m^2/kg).

b. Surface Activity (S.A.) (Shape Factor).

c. Absorption.

* F/A (filler/Asphalt) ratio should be decreased as S.S. increases.

* S.A.: Capacity of filler particles to absorb AC.

And it increases as the irregularity increases (roughness and angularity)

* More absorption è decrease in free AC.

Second:

1. Behavior of filler/AC (mastic) and asphalt paving mixture can be explained by physical-chemical properties of filler at the filler-AC interface.
2. H.L. (Hydrated Lime) have the highest geometric irregularity and high surface activity è higher consistency (low penetration, high softening point, low ductility) for mastics and higher strength in mix.
3. Rapid deterioration of mix occurred with non-active filler (after 4 days of immersion at 60^{o}C water) and H.L.

Exhibits a superior durability potential with mix sensitivity to the immersion periods (as an active filler). [by E. Marshall St. Loss%, H.L. 5%, LSD (Limestone Dust) (15%)]

4. The use of Portland cement as filler increase the fatigue life of the mix.

Third:

1. The type and amount of filler used in asphalt paving mix is are of the most important factor that influence distress. (permanent deformation, low temp. cracking, fatigue cracking, and moisture damage).

2. Limestone dust (L.D.) (3, 5, 7)%, Hydrated Lime (H.L.) (5%), Cement (C.I.) (5%).

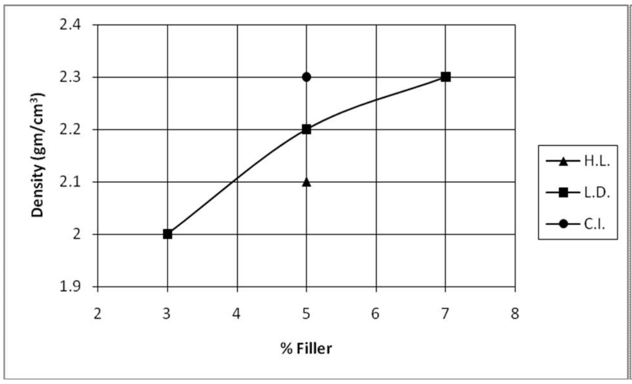
- Marshall Stiffness = Stability / Flow (kg/mm) (Sp. 4"x2.5")
- Compressive Strength = Max load / Cross-Section Area (kg/cm^2) (Sp. 4"x4")
- Indirect tensile strength = $\frac{2.Pu}{\pi.t.D}$ (kg/cm^2)

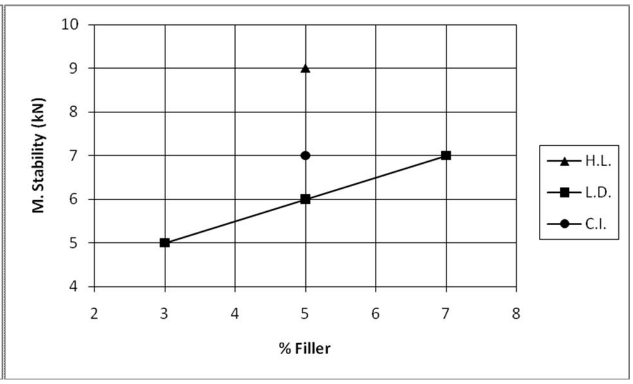
3. There is an optimum filler content for every type, satisfying most of asphalt paving mixture requirements for (strength, durability, workability).

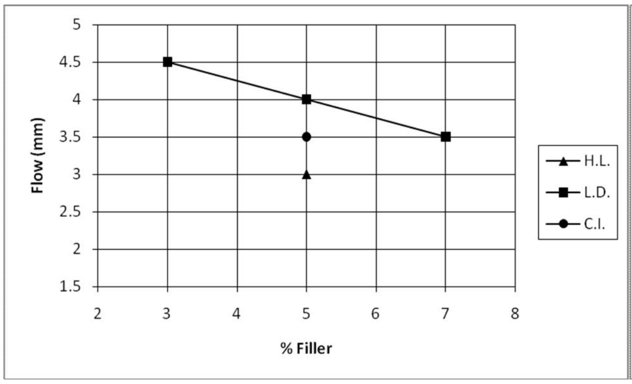
Shape Factor = 2.30 à H.L. (sp=2.30) à S.S. = $750 m^2/kg$

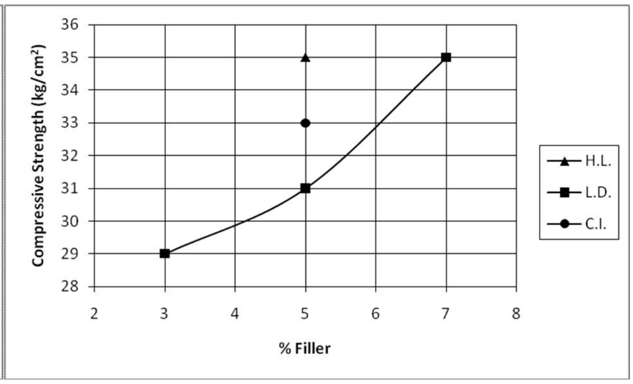
Shape Factor = 1.30 à L.D. (sp=2.88) à S.S. = $260 m^2/kg$

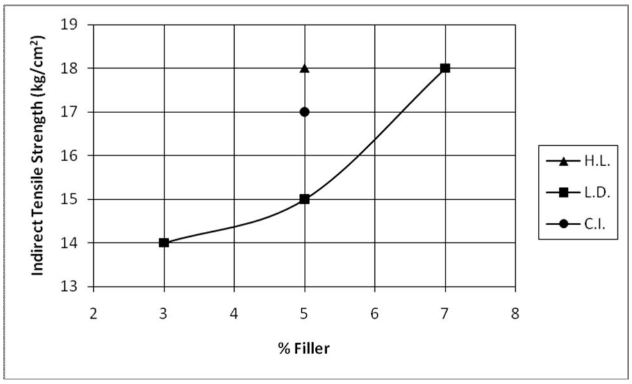
C.I. (sp=3.10)






Flow (mm)
% Filler
H.L.
L.D.
C.I.


Compressive Strength (kg/cm²)
% Filler
H.L.
L.D.
C.I.


Indirect Tensile Strength (kg/cm²)
% Filler
H.L.
L.D.
C.I.