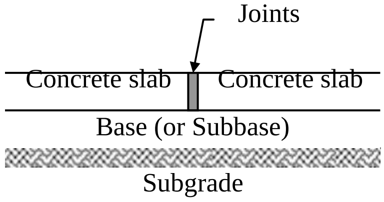
Rigid Pavement:



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

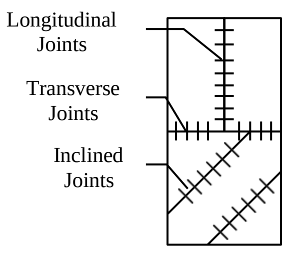
Rigid Pavement Characteristics:

- 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:

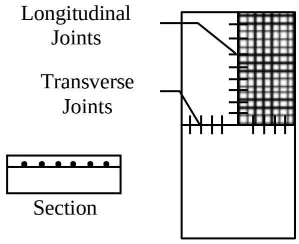
a) *Plain concrete pavement*:

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*:

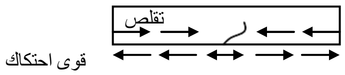
1. No joints except some expansion joints & may be some contraction joints
2. Heavy reinforcement (≈ > 0.6% of cross sectional area)
3. High cost
4. Used in very-weak subgrade & high traffic load

d) *Pre-stressed concrete pavement*:
1. Fewer joints
2. More expensive

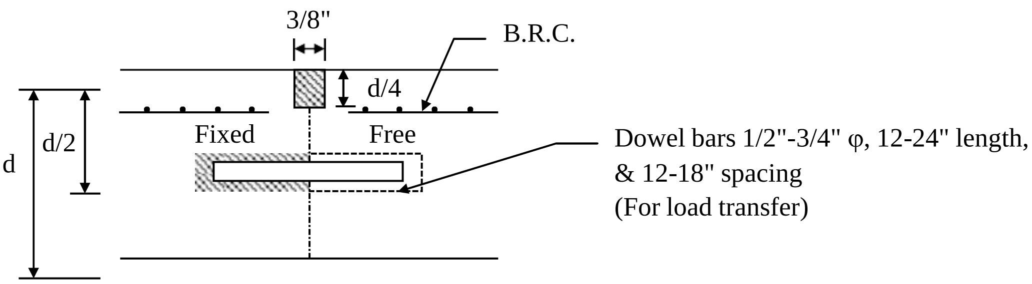
Type of Joints in Rigid Pavement:

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 بـين البلاطـة والتربة تحتها (Subgrade)، والتي تسبب فشل الطبقة.

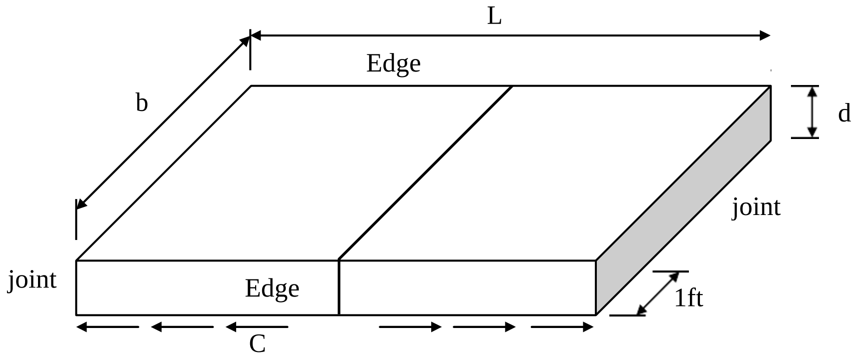


وتعالج بعمل أخدود يملأ بالماستك لمنع المياه من المرور، لمنع تأآسد حديد التسليح وتأثر طبقة التربة، والأخـدود يصنع منطقة ضعيفة لتحديد مسار الفشل.



B. R. C. Design:

توضـع طبقـة مـن التسـليح (B.R.C.) فـي الجـزء الأعلـى مـن طبقـة التبلـيط لمقاومـة اجهـادات الشـد (Tensile stresses) المتولدة بسبب تغير تدرجات الحـرارة، وتكـون لطبقـة التبلـيط بـين المفاصـل (علـى جـانبي الأخدود)، وأسلوب حساب آمية التسليح آما يأتـي:



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

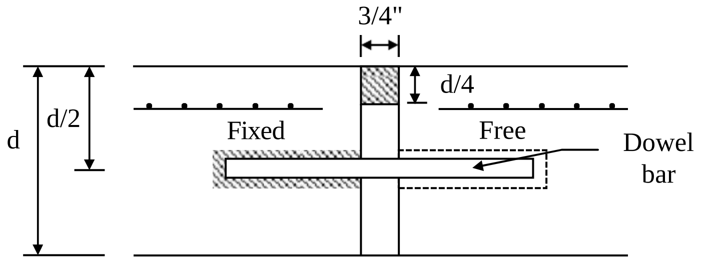
$L/2 * 1 * W * C = As * f_s$

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

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

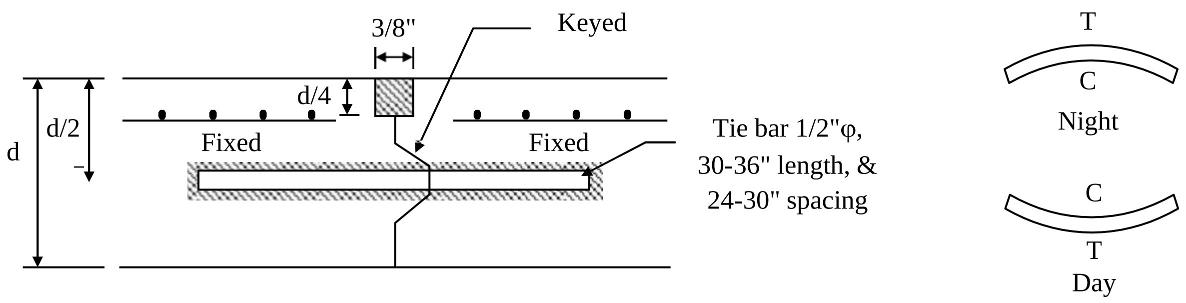
2) *Expansion Joints*: provide a clear spacing along the depth to relieve excessive compressive stresses due to rise in temperature.

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



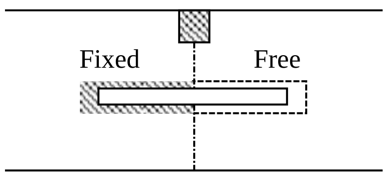
- Difficult in construction & maintenance
- Needed when casting in cold season, near structure, & for materials with high coefficient of thermal expansion
- Contraction joints used as expansion joints

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

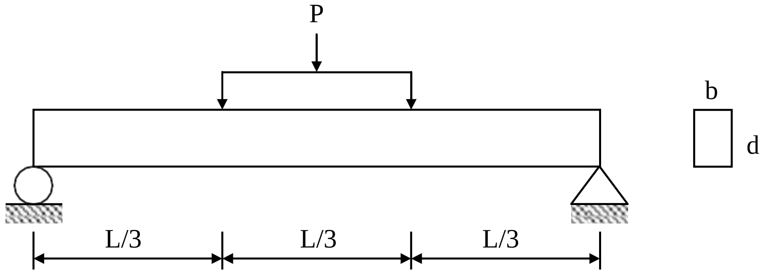
c) M. R. (f_r): Modulus of rupture (for third-point loading) (psi)

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

Where:

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

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



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

$$= 600 - 750 \text{ psi}$$

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

إذاكانت (ΣF ≥ 100%) فيجب تكبير "d" وإعادة التصميم.

إذا كانت (ΣF ≤ 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)

$F = \frac{\overline{N_{act.}}}{N_{all.}} *100\%$ …(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 كانتd المستخرجة بمقدار أقل أو أآبر 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"

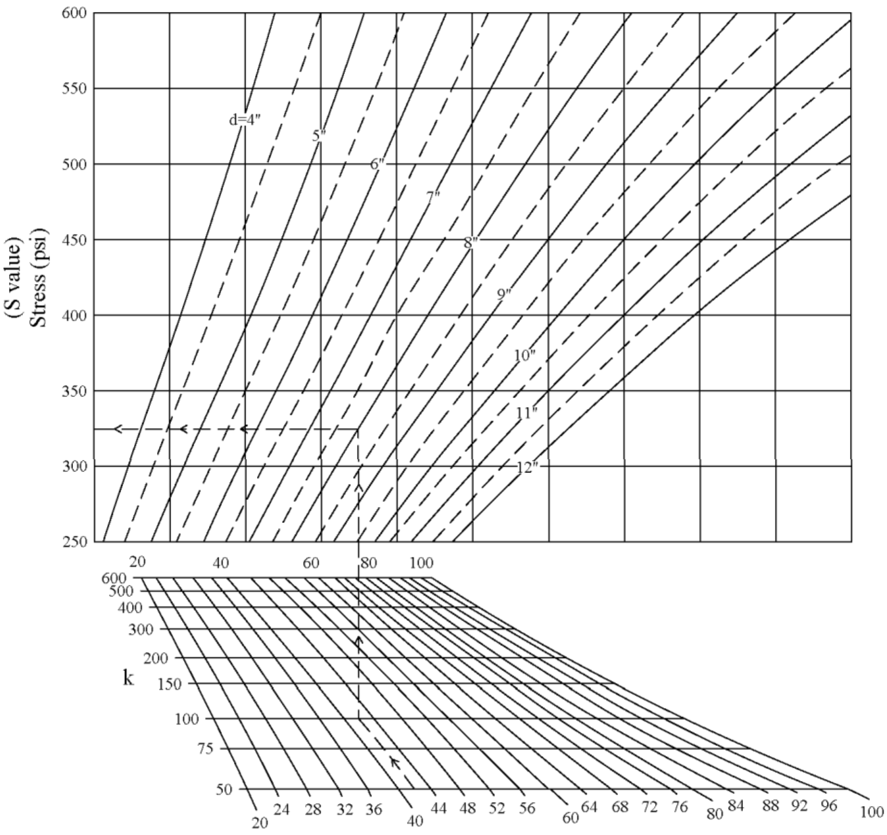
Table 17.1. Stress Ratios Allowable Load Repetitions
Yoder, P.603

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

Figure 17.2, Yoder, P.604



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

Table 4.10 AASHO Equivalence Factors – Rigid Pavement

(Yoder, P.166)

Single Axle, $\rho_t = 2.0$

Axle Load	D – Slab Thickness (in)					
(kips)	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	D – Slab Thickness (in)					
(kips)	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)

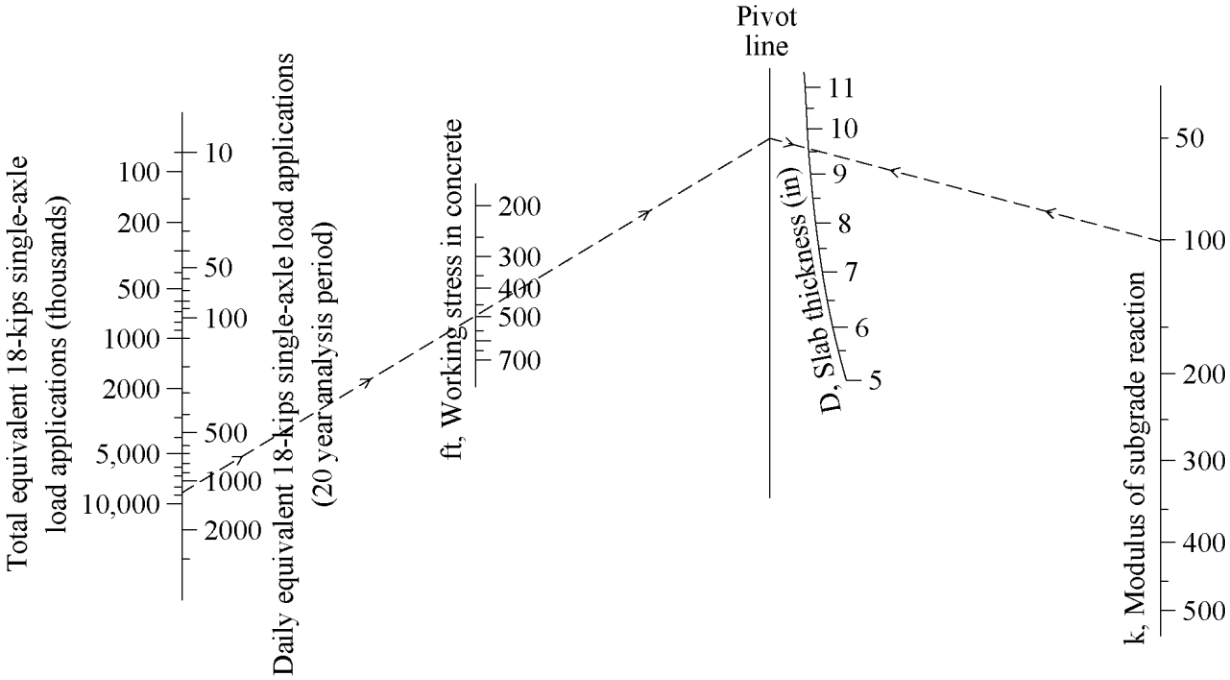
(Yoder, P.167)

Single Axle, $\rho_t = 2.5$

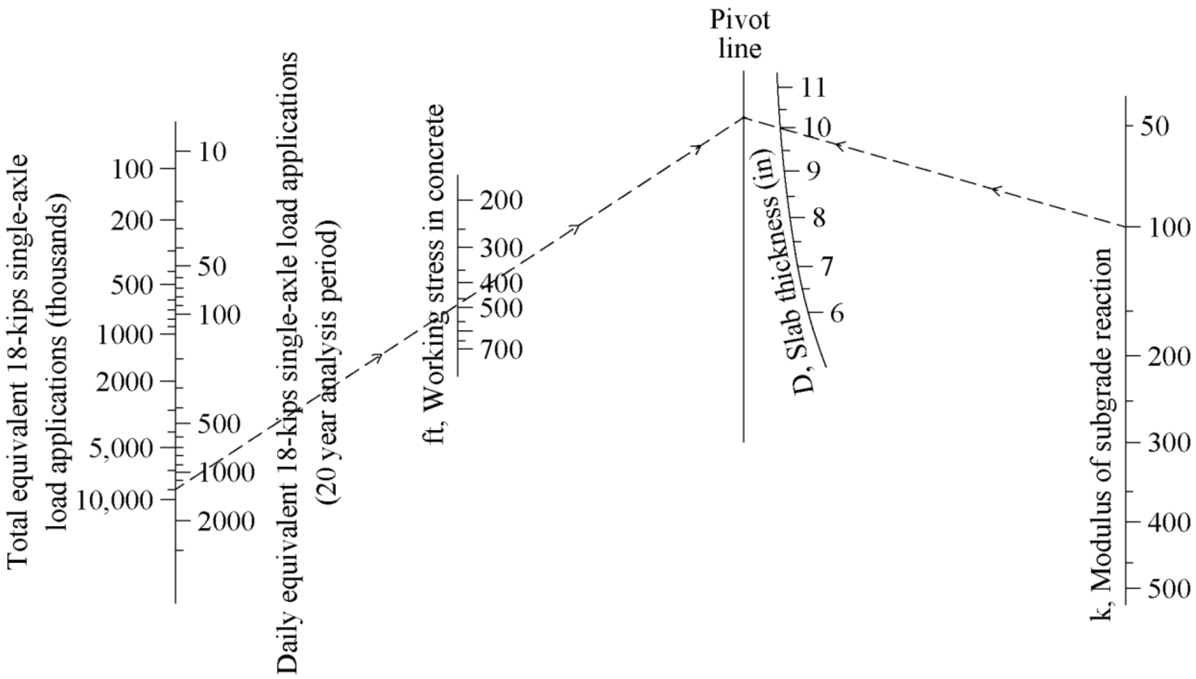
Axle Load (kips)	D – Slab Thickness (in) 6	7	8	9	10	11
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
4	0.003	0.002	0.002	0.002	0.002	0.002
6	0.01	0.01	0.01	0.01	0.01	0.01
8	0.04	0.04	0.03	0.03	0.03	0.03
10	0.10	0.09	0.08	0.08	0.08	0.08
12	0.20	0.19	0.18	0.18	0.18	0.17
14	0.38	0.36	0.35	0.34	0.34	0.34
16	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