AASHTO Rigid Pavement Design

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1. Introduction

Empirical design based on the AASHO road test:

- Over 200 test sections JPCP (15' spacing) and JRPC (40' spacing)
- Range of slab thickness: 2.5 to 12.5 inches
- Subbase type: untreated gravel/sand with plastic fines
- Subbase thickness; 0 to 9 inches
- Subgrade soil: silty-clay (A-6)
- Monitored PSI w/ load applications – developed regression eqn's
- Number of load applications: 1,114,000

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2. General Design Variables
   - Design Period
   - Traffic – what changes? (EALF Table 6.7)
   - Reliability
     - Based on functional classification
     - Overall standard deviation (S_0=0.25 – 0.35)
   - Performance criteria
     - $\Delta PSI = PSI_0 - PSI_t$
3. Material Properties

3.1 Effective Modulus of Subgrade Reaction (k)

Need to convert subgrade M_R to k:

1. Without Subbase
2. With Subbase
3. Shallow bedrock

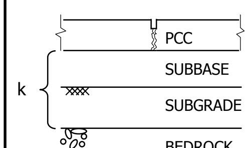
3.1.1 Pavement **Without** Subbase

If there is no Subbase, AASHTO suggests:

$$k = \frac{M_R}{18.8}$$

- Correlation based on 30-in plate-load tests
- k value becomes too high because k=fnc(1/a)
- More accurate k if plate test was run w/ bigger plates; too expensive & impractical

3.1.2 Pavement **With** Subbase



If subbase exists, need to determine the composite modulus of subgrade reaction (k)

3.1.2 Pavement **With** Subbase (cont.)

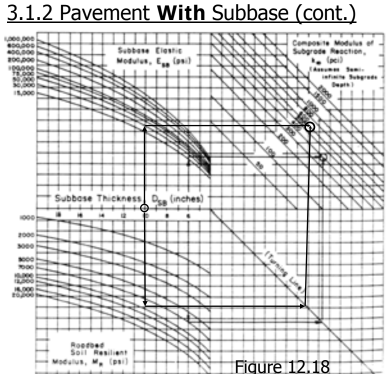


Figure 12.18

Example:
Subbase thickness=10"
Subbase modulus=30,000 psi
Subgrade M_R=10,000 psi

To get k:
Cut across the E_{SB}
Cut across M_R to the TL
Vertically meet other line
Read k-value

k=600pci

3.1.3 Rigid Foundation @ Shallow Depth

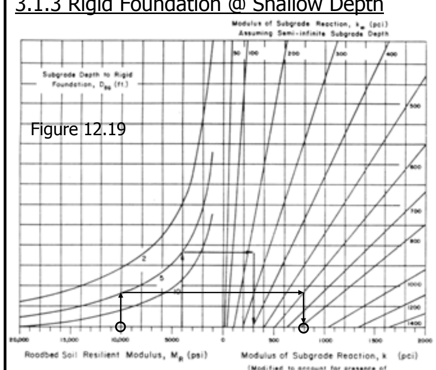


Figure 12.19

If bedrock is within 10ft, it will confine the material (subgrade) and will produce a higher k.

Example:
Rigid depth=5'

From prev. page:
Subgrade M_R=10,000 psi
k_∞ = 600 pci

k = 800pci

3.1.4 Effective Modulus of Subgrade Reaction K_{eff}

Equivalent modulus that would result in the same damage if seasonal variations were taken into account (similar to flexible design)

$$u_r = \left(D^{0.75} - 0.39k^{0.25}\right)^{3.42}$$

Month	k	u_r
1	500	33.5
2	450	32.5
.	.	.
.	.	.
n	xxx	yy.y

$$\bar{u}_r = \frac{\sum u_r}{n}$$

3.1.5 K_{eff} Example

Figure 12.18 Figure 12.19

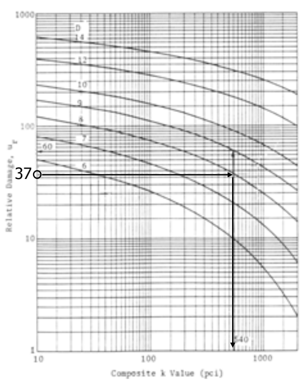
Month	Subgrade Modulus, M_R (psi)	Subbase Modulus, E_{SB} (psi)	Composite k-value, k_∞ (pci)	Rigid Foundation, k (pci)	Relative Damage, u_r
Jan	12,000	30,000	700	-	31.84
Feb	12,000	30,000	700	-	31.84
Mar	7,000	30,000	400	-	43.45
Apr	7,000	30,000	400	-	43.45
May	10,000	30,000	550	-	36.73
Jun	10,000	30,000	550	-	36.73
Jul	10,000	30,000	550	-	36.73
Aug	10,000	30,000	550	-	36.73
Sep	10,000	30,000	550	-	36.73
Oct	10,000	30,000	550	-	36.73
Nov	10,000	30,000	550	-	36.73
Dec	10,000	30,000	550	-	36.73
				Σu_r	444.41

3.1.5 K_{eff} Example (cont.)

$$\bar{u}_r = \frac{\sum u_r}{n} = \frac{444.41}{12} = 37.03$$

D = 8in

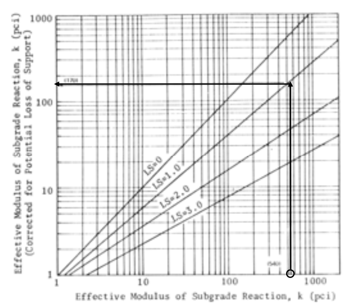
Figure 12.20



k_{eff} = 540pci

3.1.6 Loss of Support (LS)

- Reduction of k_{eff} by a factor LS to account for erosion and/or differential soil movement
- Best case scenario, LS=0 (Slab is in full contact with subbase)



k_{eff} = 540pci
LS = 1.0
Fig12.21

k_{actual} = 170pci

3.1.7 Table for Estimating K_{eff}

Trial Subbase: Type GRANULAR
Thickness (inches) 6"
Loss of Support, LS 0.5

Depth to Rigid Foundation (feet) > 10' *
Projected Slab Thickness (inches) 9
(*) IF<10' THEN FILL IN (5)

(1) Month	(2) Roadbed Modulus, M_R (psi)	(3) Subbase Modulus, E_{SB} (psi)	(4) Composite k-Value (pci) Fig. 12.18	(5) k-Value (pci) on Rigid Foundation Fig. 12.19	(6) Relative Damage, u_r EQUATION
Jan.	20,000	100,000	1,300		37
⋮	⋮	⋮	⋮	⋮	⋮
Dec.	15,000	100,000	1,000		43
				Summation: Σu_r =	534

Average: $\bar{u}_r = \frac{\Sigma u_r}{n} = \frac{534}{12} = 44.5$

Effective Modulus of Subgrade Reaction, k (pci) = 945

Corrected for Loss of Support: k (pci) Fig. 12.21 = 480

3.2 Portland Cement Concrete (PCC)

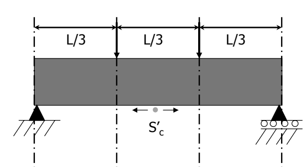
Elastic Modulus of Concrete (E_c):

- Correlated with compressive strength

$$E_c = 57{,}000\sqrt{f_c^{'}}$$

Modulus of Rupture (S'_c):

- Third-point loading @ 28 days



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3.3 Pavement Structure Characteristics

Drainage Coefficient (C_d):

- Quality of drainage & percent time exposed to moisture (Table 12.20)

Quality of drainage		Percentage of time pavement structure is exposed to moisture levels approaching saturation			
Rating	Water removed within	Less than 1%	1–5%	5–25%	Greater than 25%
Excellent	2 hours	1.25–1.20	1.20–1.15	1.15–1.10	1.10
Good	1 day	1.20–1.15	1.15–1.10	1.10–1.00	1.00
Fair	1 week	1.15–1.10	1.10–1.00	1.00–0.90	0.90
Poor	1 month	1.10–1.00	1.00–0.90	0.90–0.80	0.80
Very poor	Never drain	1.00–0.90	0.90–0.80	0.80–0.70	0.70

Load Transfer Coefficient (J):

- Ability to transfer loads across joints and cracks (Table 12.19)
- Lower J → better performance/less conservative

Type of shoulder	Asphalt		Tied PCC	
Load transfer devices	Yes	No	Yes	No
JPCP and JRCP	3.2	3.8–4.4	2.5–3.1	3.6–4.2
CRCP	2.9–3.2	N/A	2.3–2.9	N/A

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4. Thickness Design

4.1 Input Variables

- Modulus of Subgrade Reaction, k_{eff} =70 pci
- Traffic, W_{18} =5 million
- Design Reliability, R =95%
- Overall Standard Deviation, S_0 =0.30
- ΔPSI =1.7
- Elastic Modulus, E_c =5,000,000 psi
- Modulus of Rupture, S'_c =650 psi
- Load Transfer Coefficient, J =3.3
- Drainage Coefficient, C_d =1.0

Use Nomograph (Figures 12.17a&b) or solve equation

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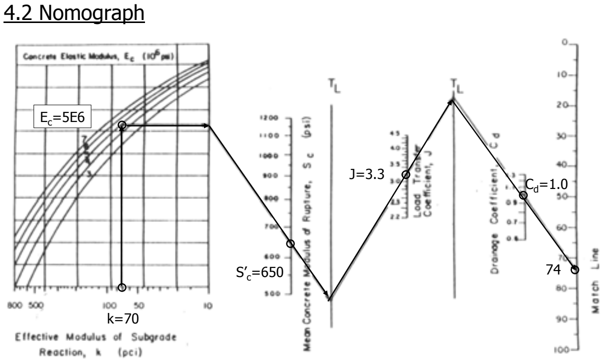
4.2 Nomograph



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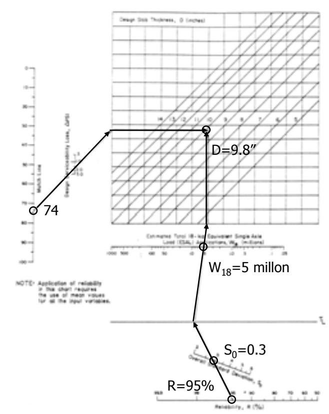
4.2 Nomograph

Use D=10″



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4.3 Equation

$W_{18} := 5000000 \quad Z_R := -1.645 \quad S_0 := 0.3 \quad \Delta PSI := 1.7 \quad k := 70$

$S_c := 650 \quad J := 3.3 \quad C_d := 1.0 \quad p_t := 2.8 \quad E_c := 5000000$

$D := 4.5$

Given

$$\log(W_{18}) = (Z_R \cdot S_0) + 7.35 \cdot \log(D+1) - 0.06 + \frac{\log\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1 + \frac{1.624 \cdot 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 \cdot p_t) \cdot \log\left[\frac{S_c \cdot C_d \cdot (D^{0.75} - 1.132)}{215.63 \cdot J \cdot \left[D^{0.75} - \frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right]}\right]$$

Find(D) = 9.9

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5. Other Design Features

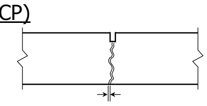
5.1 Slab Length

What does this (length) depend on?

5.1.1 Jointed Plain Concrete Pavement (JPCP)

- Governed by joint opening

$$\delta = C \cdot L(\alpha_t \cdot \Delta T + \varepsilon)$$



Where:
δ = Joint opening
α_t = Coefficient of thermal contraction
ε = Drying shrinkage coefficient
L = Slab length
C = adjustment factor for subgrade friction

Remember (?):
If δ≥ 0.05″ then USE dowels

For NO dowels, determine L for δ=0.05″

$$L = \frac{\Delta L}{C(\alpha_t \times \Delta T + \varepsilon)} = \frac{0.05}{0.65(5.5\times10^{-6}\times60+1.0\times10^{-4})} = 179"$$

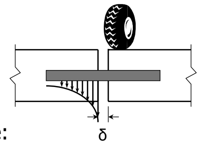
$L \cong 15 ft$

IF SLAB > 15 ft → USE DOWELS

5.1.2 Jointed Reinforced Concrete Pavement (JRPC)

- Always doweled

Remember (?):
$\delta \leq$ 0.25" to LIMIT bearing stress



Use same typical values from before:

$$L = \frac{\Delta L}{C(\alpha_t \times \Delta T + \varepsilon)} = \frac{0.25}{0.65(5.5\times10^{-6}\times60+1.0\times10^{-4})} = 894$$

$L \cong 75ft$

Lengths typically between 30'-100'

⚠ Guideline

≈40' slab length has been found to be OPTIMAL for JRCP

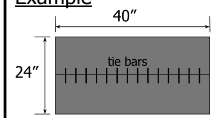
5.1.3 JRCP Reinforcement

If (when) concrete cracks, steel picks up stress

$$A_s = \frac{f_a \gamma_c L h}{2 f_s}$$

Where:
A_s = Area of required steel per unit width
f_s = Allowable stress in steel
f_a = Average friction coefficient between slab and foundation

Example



γ_c = 0.0868 pci
h = 10 in
f_a = 1.5
f_s = 43,000

Longitudinal:

$$A_s = \frac{0.0868\times480\times10\times1.5}{2\times43000} = 0.00727\cdot\frac{in^2}{in}$$

$$A_s = 0.0872\cdot\frac{in^2}{ft}$$

Transverse:

$$A_s = 0.0523\cdot\frac{in^2}{ft}$$

Table 4.3 select welded wire fabric

5.1.3 JRCP Reinforcement (cont)

TABLE 4.3 WEIGHTS AND DIMENSIONS OF WELDED WIRE FABRIC

Wire size no.		Diameter	Weight	Cross-sectional area (in.²/ft) center-to-center spacing (in.)						
Smooth	Deformed	(in.)	lb/ft	2	3	4	6	8	10	12
W31	D31	0.628	1.054	1.86	1.24	.93	.62	.465	.372	.31
W30	D30	0.618	1.020	1.80	1.20	.90	.60	.45	.36	.30
W28	D28	0.597	.952	1.68	1.12	.84	.56	.42	.336	.28
W26	D26	0.575	.934	1.56	1.04	.78	.52	.39	.312	.26
W24	D24	0.553	.816	1.44	.96	.72	.48	.36	.288	.24
W22	D22	0.529	.748	1.32	.88	.66	.44	.33	.264	.22
W20	D20	0.504	.680	1.20	.80	.60	.40	.30	.24	.20
W18	D18	0.478	.612	1.08	.72	.54	.36	.27	.216	.18
W16	D16	0.451	.544	.96	.64	.48	.32	.24	.192	.16
W14	D14	0.422	.476	.84	.56	.42	.28	.21	.168	.14
W12	D12	0.390	.408	.72	.48	.36	.24	.18	.144	.12
W11	D11	0.374	.374	.66	.44	.33	.22	.165	.132	.11
W10.5		0.366	.357	.63	.42	.315	.21	.157	.126	.105
W10	D10	0.356	.340	.60	.40	.30	.20	.15	.12	.10
W9.5		0.348	.323	.57	.38	.285	.19	.142	.114	.095
W9	D9	0.338	.306	.54	.36	.27	.18	.135	.108	.09
W8.5		0.329	.289	.51	.34	.255	.17	.127	.102	.085
W8	D8	0.319	.272	.48	.32	.24	.16	.12	.096	.08
W7.5		0.309	.255	.45	.30	.225	.15	.112	.09	.075
W7	D7	0.298	.238	.42	.28	.21	.14	.105	.084	.07
W6.5		0.288	.221	.39	.26	.195	.13	.097	.078	.065
W6	D6	0.276	.204	.36	.24	.18	.12	.09	.072	.06
W5.5		0.264	.187	.33	.22	.165	.11	.082	.066	.055
W5	D5	0.252	.170	.30	.20	.15	.10	.075	.06	.05
W4.5		0.240	.153	.27	.18	.135	.09	.067	.054	.045
W4	D4	0.225	.136	.24	.16	.12	.08	.06	.048	.04

Longitudinal:

$$A_s = 0.0872\cdot\frac{in^2}{ft}$$

Transverse:

$$A_s = 0.0523\cdot\frac{in^2}{ft}$$

Select:
6x12 – W4.5 x W5.5

5. Design Example

Given the following information:

Roadbed soil M_R:
- 20,000 psi (December – January)
- 8,000 psi (February – March)
- 15,000 psi (April – November)

Subbase Information:
- Loss of Support =0.5
- Friction factor =1.5
- Thickness =6 inches
- Elastic Modulus =100,000 psi

Design Factors:
- Design Reliability, R =90%
- Overall Standard Deviation, S_0 =0.40
- ΔPSI =1.5
- Traffic =37.9 million ESAL
- Drainage coefficient =1.0
- Shoulders =10-ft wide PCC
- Temperature drop =55 °F

5. Design Example (cont)

PCC:
- Elastic Modulus, E_c = 4,500,000 psi
- Modulus of Rupture, S'_c = 725 psi
- Limestone rock
- Indirect Tensile Strength = 500 psi

Design a JPCP (w/o dowels) and a JRCP (35-ft, w/ dowels). For each pavement determine the slab thickness, joint spacing (for the JCPC), and reinforcement (mesh designation for the JRCP)

5.1 Effective modulus of subgrade reaction

Next page

5.2 JPCP Design

5.2.1 Slab Length for no Dowels (δ<0.05")

$$\delta = C \cdot L(\alpha_t \cdot \Delta T + \varepsilon) \qquad L = \frac{\delta}{C(\alpha_t \Delta T + \varepsilon)}$$

δ = 0.05
$\alpha_t = 3.8 \times 10^{-6}$ /°F (Table 12.23, Limestone)
ε = 0.00045 (Table 12.22, Indirect Tensile Strength = 500 psi)
C = 0.65 (Cement Treated)

$$L = \frac{\delta}{C(\alpha_t \times \Delta T + \varepsilon)} = \frac{0.05}{0.65(3.8\times10^{-6}\times55+4.5\times10^{-4})} = 116.7"$$

$L \cong 9.7ft$

Use SLAB LENGTH= 9 ft

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5.2.2 Slab Thickness

Declare the variables:

$W_{18} := 37900000$ $E_c := 4500000$ $\Delta PSI := 1.5$ $k := 480$ $S_c := 725$

$C_d := 1.0$ $p_t := 3$ $Z_R := -1.282$ $S_0 := 0.4$

$J := 3.9$ Table 12.19, No Dowels

Give an initial estimate:

$D := 4.5$

Solver iteration:

Given

$$\log(W_{18}) = (Z_R \cdot S_0) + 7.35 \cdot \log(D+1) - 0.06 + \frac{\log\left(\frac{\Delta PSI}{4.5 - 1.5}\right)}{1 + \frac{1.624 \cdot 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 \cdot p_t) \cdot \log\left[\frac{S_c \cdot C_d \cdot (D^{0.75} - 1.132)}{215.63 \cdot J \cdot \left[D^{0.75} - \frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right]}\right]$$

$\text{Find}(D) = 13.195$

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5.3 JRCP Design

5.3.1 Slab Thickness

Declare the variables:

$W_{18} := 37900000$ $E_c := 4500000$ $\Delta PSI := 1.5$ $k := 480$ $S_c := 725$

$C_d := 1.0$ $p_t := 3.0$ $Z_R := -1.282$ $S_0 := 0.4$

$J := 2.8$ (Table 12.19, With Dowels)

Give an initial estimate:

$D := 4.5$

Solver iteration:

Given

$$\log(W_{18}) = (Z_R \cdot S_0) + 7.35 \cdot \log(D+1) - 0.06 + \frac{\log\left(\frac{\Delta PSI}{4.5 - 1.5}\right)}{1 + \frac{1.624 \cdot 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 \cdot p_t) \cdot \log\left[\frac{S_c \cdot C_d \cdot (D^{0.75} - 1.132)}{215.63 \cdot J \cdot \left[D^{0.75} - \frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right]}\right]$$

$\text{Find}(D) = 11.11$

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5.3.2 Reinforcement

Longitudinal:

$$A_s = \frac{(0.0868)(11)(35 \times 12)(1.5)}{2 \times 43000} = 0.0070 \cdot \frac{in^2}{in} \qquad A_s = 0.0839 \cdot \frac{in^2}{ft}$$

Transverse: **12'(lane)+12'(lane)+10'(shoulder)**

$$A_s = \frac{(0.0868)(11)(34 \times 12)(1.5)}{2 \times 43000} = 0.0068 \cdot \frac{in^2}{in} \qquad A_s = 0.0816 \cdot \frac{in^2}{ft}$$

Fabric: 6 x 12 – W4.5 x W8.5