ASSIGNMENT

Pavement Analysis and Design

CH # 11

SUBMITTED TO: Dr. ZIA UR Rehman

SUBMITTED BY:
Usman Iftikhar
2018-MS-CEH-11

SUBMITTED ON:
2-12-2019

Prob 11.1

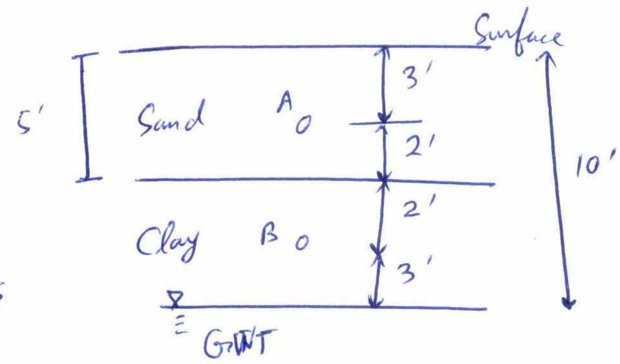
Data:

Determine moisture content of subgrade at A and B.

α = Compressibility factor

$\gamma = 120 pcf$

$\gamma = 100 pcf$
C.F = 0.5



Sol:

At point A

Overburden pressure

$$P = 3 \times 120 = 360 \; psf =$$

$$ft \times \frac{lb}{ft^3} = \frac{lb}{ft^2}$$

As $S = -z\gamma_w - \alpha P$

Soil Suction $= -7 \times 62.4 - 0(360) = 436.8 \; psf$

$$= \frac{436.8}{12^2} = -3.033 \; psi$$

From figure P11.1

For $S = 3.033 \; psi \Rightarrow w \approx 10\%$ for sand

At point B

Overburden Pressure $\Rightarrow P = 5 \times 120 + 2 \times 100 = 800 psf$

$$S = -z\gamma_w - \alpha P$$

$$= -3 \times 62.4 - 0.5 \times 800$$

$$= -587.2 \; psf$$

$$= -4.08 \; psi$$

From fig. P11.1

For $S = 4.08 \; psi \Rightarrow w \approx 20\%$

Prob 11.2

Data: Based on fig 11.4, 11.5, estimate coefficients of permanent deformation in Ohio state model as indicated by a, b, m in eq 11.16

eq 11.16

$$\epsilon_p = a(\epsilon)^b (N)^{1-m}$$

$$= a\left(\frac{M_R}{\sigma_d}\right)^b (N)^{1-m}$$

Let $A = a\left(\frac{M_R}{\sigma_d}\right)^{-b}$

$$\log A = \log a - b \log\left(\frac{M_R}{\sigma_d}\right)$$

From fig 11.5

when $A = 0.0002 = 2\times10^{-4}$ $\Rightarrow$ $\frac{M_R}{\sigma_d} = 10^4$

when $A = 6\times10^{-4}$ $\Rightarrow$ $\frac{M_R}{\sigma_d} = 3\times10^3$

Now

$\log(2\times10^{-4}) = \log a - b\log(10^4)$ and $\log(6\times10^{-4}) = \log a - b\log(3\times10^3)$

$-3.69897 = \log a - 4b$ $\qquad$ $-3.22185 = \log a - 3.47712\,b$

By solving eq

$4b - 3.69897 = \log a$

$\text{antilog}(4b - 3.69897) = a$

$-3.22185 = 4b - 3.69897 - 3.47712\,b$

$\boxed{b = 0.9125}$

$a = \text{antilog}(4\times0.9125 - 3.69897)$

$\boxed{a = 0.8937}$

From fig 11.4

m is the slope of $\frac{\epsilon_p}{N}$ vs N graph.

Hence

$$m = \frac{\log(2\times10^{-5}) - \log(2\times10^{-6})}{\log(200) - \log 5000} = -0.72 = 0.72$$

Hence eq becomes

$$\epsilon_p = 0.8937(\epsilon)^{0.9125}(N)^{0.28}$$

Prob 11.3

Data:

Fatigue equation for asphalt pavement $= N_f = 5 \times 10^{-6} (\epsilon_t)^{-3}$ eq 11.9

Thermal cycles = 5000

Max tensile strain = 0.0005 in/in

Coefficient of variation of N_f, $C(N_f) = 0.8$

% area cracked that is due to thermal fatigue cracking = ?

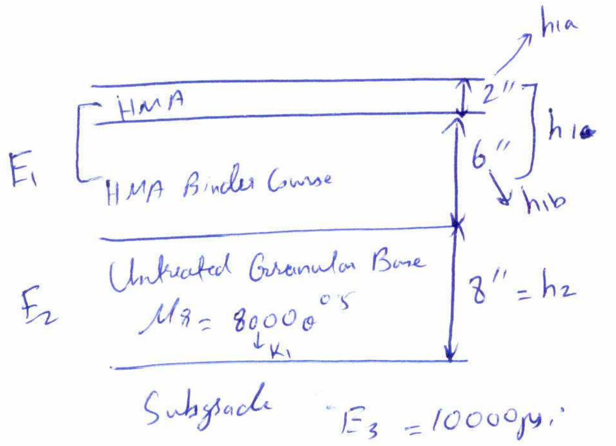
Sol:

$$N_f = 5 \times 10^{-6} (\epsilon_t)^{-3}$$

$$= 5 \times 10^{-6} (0.0005)^{-3} = 40000$$

Prob 11.4

Data:



λ = HMA $\Rightarrow$ 2.5×10^6 poise at 70°F

V_b = Bitumen volume = 11%

P_{200} = Fine content = 5% (Passing No 200)

f = 8 Hz

V_a = Air void content for surface course = 4%

V_a = " " " Binder course = 7%

a) Temperatures for surface and binder courses = ? $M_a = T = 68$°F (Mean monthly air T)

b) Dynamic modulus for surface and binder courses using eq 7.27 = ?

c) Modulus of untreated base using eq 3.28, 3.29 = ?

From eq 3.27 $M_p = M_a\left(1+\frac{1}{z+4}\right) - \frac{34}{z+4} + 6$ z = depth below surface in inches

Sol:

Surface

a) $M_p = 68\left(1+\frac{1}{0.67+4}\right) - \frac{34}{0.67+4} + 6 = 81.3$°F

Binder

$M_p = 68\left(1+\frac{1}{4+4}\right) - \frac{34}{4+4} + 6 = 78.3$°F

AI Formulas Pg 307 (Dynamic Modulus)

b) Using eq 7.27f

$\beta_5 = 1.3 + 0.49825 \log f$

$= 1.3 + 0.49825 \log 8 = 1.75$

eq 7.27e

$\beta_4 = 0.483\, V_b$

$= 0.483 \times 11 = 5.313$

eq 7.27d

$\beta_3 = 0.553833 + 0.028829\left(P_{200}\, f^{-0.1703}\right) - 0.03476\, V_a$ (P_{200} → 5, f → 8, V_a = 4 Surface, = 7 Binder)

$+ 0.070377\, \lambda + 0.931757\, f^{0.02774}$ (λ → 2.5, f → 8) $= 1.5714$ (Surface)

$\beta_3 = 1.46714$ (Binder)

eq 7.27c

$\beta_2 = \beta_4^{0.5}\, T^{\beta_5}$

(Surface) $\beta_2 = 5.313^{0.5} \times 81.3^{1.75} = 5073.74$

(Binder) $\beta_2 = 5.313^{0.5} \times 78.3^{1.75} = 4750.65$

eq. 7.27b

$\beta_1 = \beta_3 + 0.000005\beta_2 - 0.00189\beta_2 f^{-1.1}$

Surface

$\beta_1 = 1.5714 + 5\times10^{-6}\times5073.74 - 0.00189\times5073.74\times8^{-1.1}$

$= 0.62315$

Binder

$\beta_1 = 1.46714 + 5\times10^{-6}\times4750.65 - 0.00189\times4750.65\times8^{-1.1}$

$= 0.57927$

~~for~~ eq 7.27a

Surface

$|E^*| = 100000\times10^{\beta_1}$

$E_{1a} = 10^5\times10^{0.62315} \approx 4.2\times10^5$ psi

Binder

$E_{1b} = |E^*| = 10^5\times10^{0.57927} \approx 3.8\times10^5$ psi

c) Using eq 3.29

$$E_1 = \left[\frac{h_{1a}(E_{1a})^{\frac{1}{3}} + h_{1b}(E_{1b})^{\frac{1}{3}}}{h_{1a}+h_{1b}}\right]^3$$

$$= \left[\frac{2\times(4.2\times10^5)^{\frac{1}{3}} + 6\times(3.8\times10^5)^{\frac{1}{3}}}{2+6}\right]^3 = 3.897\times10^5 \text{ psi}$$

$\approx 3.9\times10^5$ psi

Using eq 3.28

$E_2 = 10.447\, h_1^{-0.471}\, h_2^{-0.041}\, E_1^{-0.139}\, E_3^{0.287}\, K_1^{0.868}$

$= 10.447\times 8^{0.471}\; 8^{-0.042}\; (3.9\times10^5)^{-0.139}\times10000^{0.287}\times8000^{0.868}$

$E_2 = 20627$ psi

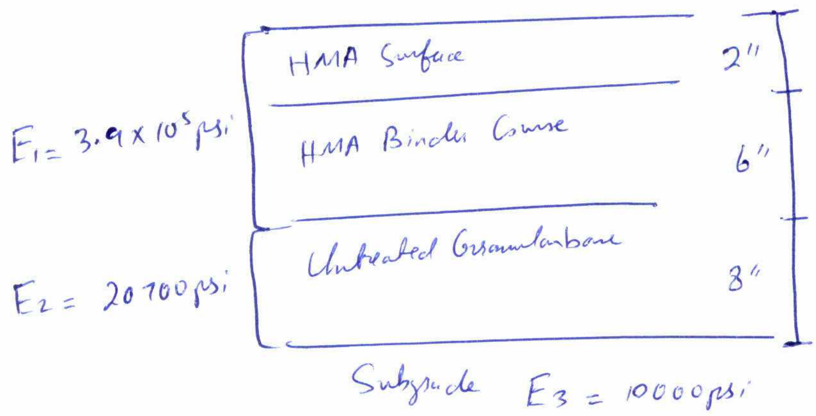
≈ 20700 psi

Prob 11.7

Data from properties in 11.4, find SN of pavement.

Assuming m for base = 1

Sol:



As

$$SN = a_1 D_1 + a_2 D_2 m_2$$

$$= 0.41 \times 8 + 0.0977 \times 8 \times 1$$

$$SN = 4.06$$

a_1

For $E = 3.9 \times 10^5$ psi

$a_1 = 0.41$ (fig 11.27)

a_2 eq 11.44

$$a_2 = 0.249 \log E_2 - 0.977$$

$$= 0.249 \log (20700) - 0.977$$

$$= 0.0977$$

Note: This problem is not solved according to solution and answer in book.

Prob 11.5

Data:

Six lane (3 lanes in each direction)

Rural Interstate Highway

ADT = 1885 per day (2 axle, 4 tire, pickup trucks)

$r = 4\%$

Untreated granular base = 8"

$M_R = 10,000$ psi

a) Table 6.9, 6.10, find ESAL for 20 years

b) Determine HMA by AI method

c) If HMA is replaced by asphalt mix type I, find HMA and emulsified asphalt required.

Sol:

a) $T = 100\%$

Truck factor = 0.52 (Table 6.10) $L = 0.8$ (Table 6.16)

$G_Y = 29.78$ (Table 6.13)

$$ESAL = (ADT)_0 \, T \, T_f \times G_Y \, D \, L \, 365$$

$$= 1885 \times 1 \times 0.52 \times 29.78 \times 0.5 \times 0.8 \times 365 = 4.26 \times 10^6$$

b) From fig 11.17, with 8" untreated granular base

For

ESAL = 4.26×10^6
and M_R = 10,000 psi } HMA thickness = 10"

c) Using fig 11.11

To find substitution Ratio.

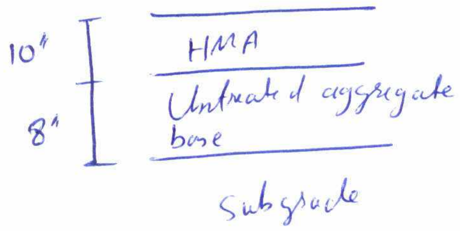
i) From fig 11.11 $\Rightarrow$ Full depth HMA = 11.5 in

ii) From fig 11.12 $\Rightarrow$ Combined thickness of HMA and emulsified I asphalt mix = 12 in

Assume a min. HMA thickness = 2 in

3) Substitution Ratio $= \dfrac{12 - 2}{11.5 - 2} = 1.053$

4) Thickness of HMA over 8" untreated aggregate base = 10"



5) From table 11.12 min thickness of HMA over type I mix = 2"

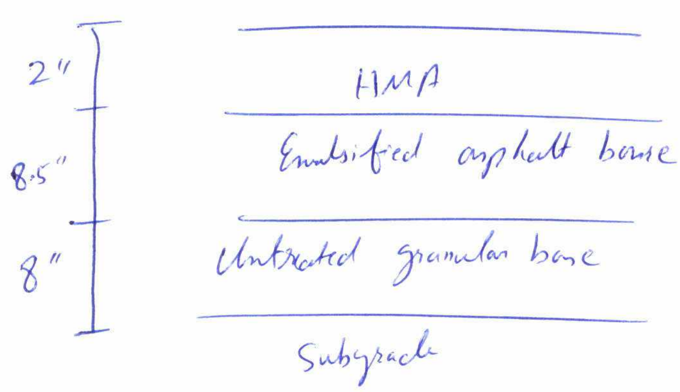
Total HMA = 10"

HMA thickness = 2"

Thickness of HMA that must be replaced by emulsified asphalt base = 10 − 2 = 8"

5) Thickness of emulsified asphalt base = 8 × 1.053 = 8.424 ≈ 8.5"

Final design



Prob 11.6

Data:

Full depth asphalt pavement

3 stage construction

$M_R = 5000$ psi

$Y = 30$ years

		Dr. at end of each stage
3 stages	= 5 years	0.5
	= 10 years	0.75
	= 15 years	1

1st year traffic on design lane = 30,000 equivalent to 18 Kip single axle load applications.

$r = 3.5\%$

HMA thickness = ? (each stage by AI method)

Sol:

For 1st stage $Y = 5$ years $\Rightarrow$ $G_Y = \dfrac{(1+0.035)^5 - 1}{0.035} = 5.36$

For 2nd stage $Y = 15$ years $\Rightarrow$ $G_Y = \dfrac{(1+0.035)^{15} - 1}{0.035} = 19.296$

For 3rd stage $Y = 30$ years $\Rightarrow$ $G_Y = \dfrac{(1+0.035)^{30} - 1}{0.035} = 51.623$

1st stage

Actual ESAL = $n_1 = 30{,}000 \times 5.36 = 160800$

Allowable ESAL = eq 11.25 $\Rightarrow$ $N_1 = \dfrac{n_1}{D_R} = \dfrac{160800}{0.5} = 321600$ ≈ [illegible]

From fig 11.11 For $N_1 = 3.22 \times 10^5$ $\Rightarrow$ $h_1 \approx 8.5$ in

2nd stage

Actual ESAL = $n_2 = 30{,}000(19.296 - 5.36) = 418080$

Allowable ESAL = $N_2 = \dfrac{418080}{0.75 - 0.5} = 1.67 \times 10^6$

From fig 11.11 For $N_2 = 1.67 \times 10^6$ $\Rightarrow$ $h_2 \approx 10.5$ in Use 11 in

Overlay = $11 - 8.5 = 2.5$ in

3rd stage:

Actual ESAL = n_3 = 30,000 (51.623 − 19.296) = 970620

Allowable ESAL = N_3 = $\frac{970620}{1-0.75}$ = 3.88×10^6

From fig 11.11 ⇒ for $N_3 = 3.88 \times 10^6$ ⇒ $h_3 = 12.5$ in

Overlay = 12.5 − 11
= 1.5"

Final Result

	HMA thickness
1st stage =	8.5"
2nd stage =	2.5"
3rd stage =	1.5"

Prob 11.8

Data:

Mean annual air temp. = 45°F = MAAT

Normal Modulus = 22500 psi

Effective roadbed soil resilient Modulus for monthly model shown in table 11.10 = ?

Sol:

Table 11.10

Month	M_R (psi)	Relative Damage (U_f) = $1.18 \times 10^{8} M_R^{-2.32}$ ($\times 10^{-3}$)
Jan	29400	5.07
Feb	36300	3.11
March	43100	2.09
April	50000	1.48
May	15800	21.43
June	17100	17.84
July	18500	14.86
August	19800	12.69
Sept.	21200	10.83
Oct.	22500	9.44
Nov.	22500	9.44
Dec.	22500	9.44

$$\Sigma u_f = 117.72 \times 10^{-3}$$

$$\text{Avg. } \bar{U}_f = \frac{\Sigma u_f}{12} = \frac{117.72 \times 10^{-3}}{12} = 9.81 \times 10^{-3}$$

Effective roadbed soil M_R =

$$\bar{U}_f = 1.18 \times 10^{8} M_R^{-2.32}$$

$$9.81 \times 10^{-3} = 1.18 \times 10^{8} (M_R)^{-2.32}$$

$$M_R = 22127 \text{ psi}$$

Prob 11.9

Data:

Full depth asphalt pavement = 12 in

Effective Road bed M_R = 10,000 psi

Layer coefficient of hot mix asphalt = $a_1 = 0.44$

drop in PSI = 4.2 → 2.5 (P_t)

S_o = 0.5

W_{18} = ESAL = 3×10^7

R = ? (By AASHTO eq)

Check result by AASHTO chart

Sol:

⇒ $\Delta PSI = 4.2 - 2.5 = 1.7$

⇒ For full depth asphalt $SN = a_1 D_1$
$= 0.44 \times 12 = 5.28$

⇒ From eq 11.34

$$\log W_{t18} = 9.36 \log(SN+1) - 0.2 + \frac{\log\left[\frac{(4.2-P_t)}{4.2-1.5}\right]}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log M_R - 8.07$$

$$\log W_{t18} = 9.36 \log(5.28+1) - 0.2 + \frac{\log\left[\frac{4.2-2.5}{4.2-1.5}\right]}{0.4 + \frac{1094}{(5.28+1)^{5.19}}} + 2.32 \log(10{,}000) - 8.07$$

$$W_{t18} = 114.67 \times 10^6$$

⇒ From eq 11.36

$$Z_R = \frac{\log W_{18} - \log W_{t18}}{S_o} = \frac{\log 3\times 10^7 - \log 114.67\times 10^6}{0.5}$$

$$Z_R = -1.165$$

⇒ From table 11.15

	Z_R	R%
when	−1.037	85
and when	−1.282	90
Hence By interpolation	−1.165	**87.6%**

$$y = 85 + \frac{(1.165 - 1.037) \times (90 - 85)}{1.282 - 1.037}$$

OR

From eq 11.37

$$\log(3\times10^7) = Z_R \times 0.5 + 9.36\log(5.28+1) - 0.2 + \frac{\log\left[\frac{1.7}{4.2-1.5}\right]}{0.4 + \frac{1094}{(5.28+1)^{5.19}}} + 2.32\log 10{,}000 - 8.07$$

$Z_R = -1.165$

Prob 11.10

Data:

Interstate highway Pavement
- HMA Surface course
- Cement Treated Base Course
- Sand gravel sub base

$W_{18} = ESAL = 1.2\times10^6$

Drainage Quality = Fair (Water can be removed from sub base in a week)

Pavement exposed to moisture levels approaching saturation = 25%

Effective Road bed soil M_R = 5500 psi

M_R (Subbase) = 15000 psi

Unconfined compressive strength of cement treated base at 7 days = 500 psi (See fig 7.15c)

M_R (HMA) = 4.3×10^5 psi

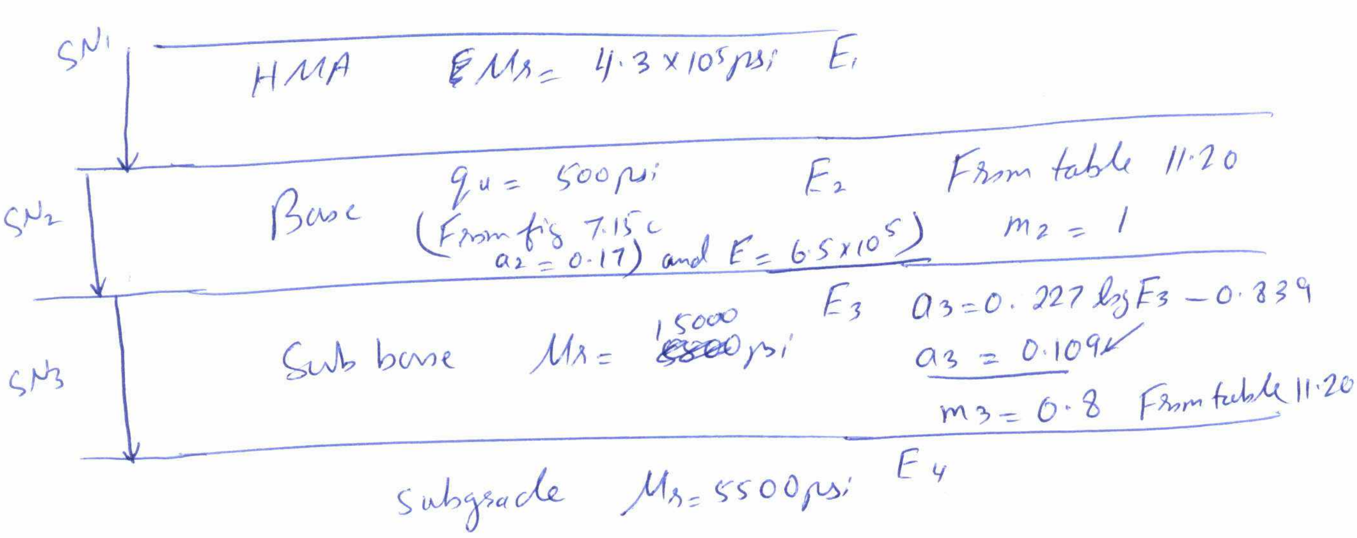
Assume thickness of HMA = minimum

Determine thickness of surface, base, sub base courses?

Sol:

~~HMA~~

~~$M_R = 4.3\times10^5$ psi~~
~~From figure 11.27~~ ⇒ $a_1 \approx 0.44$



1) HMA thickness D_1

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

with $M_R = E_2 = 6.5 \times 10^5$ psi find SN

and $a_1 \Rightarrow$ From fig 11.27

For $M_R = 4.3 \times 10^5$ $a_1 \approx 0.44$

Can see from Pg 794 and Pg 516 Same Results

with $E = 6.5 \times 10^5$ psi

from fig 11.25 Max. value of $M_R = 40{,}000$ psi hence AASHTO Method is unapplicable.

Let take min thickness of HMA = $\boxed{D_1 = 3''}$ (Table 11.21)

2) Base thickness D_2

$D_2 = \frac{SN_2 - a_1 D_1}{a_2 m_2}$

with $M_R = E_3 = 15000$ psi

~~From eq 11.35~~ ~~SN_2~~

$SN_2 \leq (a_1 D_1 + a_2 D_2 m_2)$

From eq 11.37

with $R = 50\%$ $Z_R = 0$ (Assume) and $\Delta PSI = 2$

$$\log(1.2 \times 10^6) = 9.36 \log(SN+1) - 0.2 + \frac{\log\left[\frac{2}{4.2 - 1.5}\right]}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log(15000) - 8.07$$

$SN_2 = 2.2$

$D_2 = \frac{2.2 - 0.44 \times 3}{0.17 \times 1}$

$= 5.18 \approx 5.2$

But Assume $\boxed{D_2 = 6 \text{ in}}$ Because Min thickness of aggregate base From table 11.21 = 6"

3) Sub base thickness D_3

$D_3 = \frac{SN_3 - a_1 D_1 - a_2 D_2 m_2}{a_3 m_3}$

with $M_R = E_4 = 5500$ psi

From eq 11.37 with $R = 50\%$, $Z_R = 0$, $\Delta PSI = 2$

$SN_3 = 3.2$

$D_3 = \frac{3.2 - 0.44 \times 3 - 0.17 \times 6 \times 1}{0.109 \times 0.8}$

$D_3 = 9.86$ in

$\boxed{D_3 = 10 \text{ in}}$

Prob 11.11

Data:

ESAL = 5×10^6

Encroaching traffic = 2.5%

Parking traffic = 0.02%

M_R (Subgrade) = 8000 psi

Full depth construction for both main and shoulders pavements.

By AI method

Find thickness of mainline and shoulder pavement = ?

Sol:

Thickness for Main line:

From figure 11.11

For ESAL = 5×10^6 and M_R = 8000 } Full HMA thickness = 12 inch

Thickness of shoulder pavement:

Now $ESAL = 5 \times 10^6 \left[\frac{2.5}{100} + \frac{0.02}{100} \right] = 126000$

$= 1.26 \times 10^5$

and $M_R = 8000$

From figure 11.11

Thickness for full depth HMA = 6.2 in

≈ 6.5 in

Prob 11.12

Data:

ESAL = 5×10^6

P_e = 2.5% (% encroaching)

P_P = 0.02% (% parking)

ΔPSI = 1.7

M_R = 5000 psi

R = 50%

Determine SN for mainline and ?
SN " shoulder pavement ?

Sol:

Using eq 11.37 — For mainline SN

For R = 50%
$Z_R = 0$

$$\log(5\times10^6) = 9.36\log(SN+1) - 0.2 + \frac{\log\left[\frac{1.7}{4.2-1.5}\right]}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\log 5000 - 8.07$$

SN = 4.22 = 4.2

For Shoulder

$$W_{18} = 5\times10^6\left(\frac{2.5}{100} + \frac{0.02}{100}\right) = 126000$$

Using eq 11.37

$$\log(126000) = 9.36\log(SN+1) - 0.2 + \frac{\log\left[\frac{1.7}{4.2-1.5}\right]}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\log 5000 - 8.07$$

SN = 2.31

= 2.4

Assignment #

Pavement Analysis And Design

Ch # 12

Submitted By:

2018-MS-CEH-11

Submitted On:

Prob 12.1

Data:

h = thickness of concrete pavement = 10 in (No concrete shoulders)

Placed on untreated subbase having K = 150 pci

Allowable corner deflection = ? (By PCA erosion method)

n = ESAL = 2 million.

Sol:

No concrete shoulder

⇒ From eq 12.9

$$\% \text{ erosion damage} = 100 \sum \frac{C_2 n_i}{N}$$

If damage is 100% then

$$100 = 100 \frac{C_2 n_i}{N}$$

$$N = C_2 n$$

$C_2 = 0.06$ for pavements without concrete shoulders

$$N = 0.06 \times (2 \times 10^6)$$
$$N = 120000$$

⇒ From eq 12.7 $C_1 = 1$ (for untreated bases)

$$\log N = 14.524 - 6.777 (C_1 P - 9)^{0.103}$$

$$\log (120000) = 14.524 - 6.777 (1 \times P - 9)^{0.103}$$

$$P = 34.0942$$

⇒ From eq 12.8

$$P = 268.7 \frac{p^2}{h K^{0.73}}$$

$$34.0942 = 268.7 \times \frac{p^2}{10 \times 150^{0.73}}$$

$$p = 7.014 \text{ psi}$$

⇒ As

$$K = \frac{p}{w}$$

$$150 = \frac{7.014}{w}$$

$$\boxed{w = 0.04676 \text{ in}}$$

with presence of shoulder, deflection decreases.

Prob 12.2

Concrete shoulder

$C_2 = 0.94$ (pavement with shoulders)

$$N = 0.94 \times (2 \times 10^6)$$
$$N = 1.88 \times 10^6$$

$$C_1 = 1$$

$$\log (1.88 \times 10^6) = 14.524 - 6.777 (P - 9)^{0.103}$$

$$P = 15.7485$$

$$15.7485 = 268.7 \times \frac{p^2}{10 \times 150^{0.73}}$$

$$p = 4.767 \text{ psi}$$

$$150 = \frac{4.767}{w}$$

$$\boxed{w = 0.0318 \text{ in}}$$

Prob 12.3

Data:

thickness = D = ?

2 lane highway by PCA method

Doweled joints = ✓

No concrete shoulders = x

K = 200 pci

Modulus of rupture of concrete = 650 psi

LSF = 1.1

Y = 20 years

ADT = 2500 (35% trucks)

Truck weight distribution data:

Single axle: Axle load (G)	(G) No. of axles per 1000 trucks	Expected Repititions: Axles in design Period	Tandem axle: Axle load (G)	(G) No. of axles per 1000 trucks	Axles in design Period
16	130.9	$\frac{130.9 \times 3193750}{1000} = 418062$	24	80.2	256139
18	110.8	353868	28	34.4	109865
20	65.4	208871	32	24	76650
22	15.6	49823	36	17.2	54933
24	2.3	7346	40	16.8	53655
26	1.9	6068	44	10.5	33534
28	0.9	2874	48	9.6	30660

Sol:

Total no. of trucks during design period on design lane

$= ADT \times T \times D \times Y \times 365$

$= 2500 \times 0.35 \times 0.5 \times 20 \times 365$

$= 3193750$

Trial thickness = 8 in

Subgrade K = 200 pci

MR = 650 psi

LSF = 1.1

Design period = 20 years

Doweled joints = ✓

Concrete shoulder = x

	Single Axle	Tandem Axle
8) Equivalent Stress (Table 12.6)	= 242	11) = 208
9) Stress ratio factor	= 0.372	12) = 0.32
10) Erosion factor (Table 12.8)	= 2.8	13) = 2.93

$$\text{Axles in design period} = \frac{\text{No. of axles per 1000 trucks} \times \text{Total no. of trucks}}{1000}$$

$$\text{Stress ratio factor} = \frac{\text{Equivalent Stress}}{MR}$$

Axle load Kips (Descending order)	Multiplied by LSF % x 1.1	Expected repetitions	Fatigue Analysis: Allowable Repetitions Fig 12.12	Fatigue %	Erosion Analysis: Allowable Repetitions Fig 12.13	Damage %
Single axle						
28	30.8	2874	19000	15.1	900,000	0.3
26	28.6	6068	45000	13.5	1,400,000	0.4
24	26.4	7346	160,000	4.6	2,100,000	0.4
22	24.2	49823	800000	6.2	3,500,000	1.4
20	22	208871	—	—	7,200,000	2.9
18	19.8	353868	—	—	16,000,000	2.2
16	17.6	418062	—	—	40,000,000	1
Tandem Axle			Fig 12.12		Fig 12.13	
48	52.8	30660	10000000	0.3	950,000	3.2
44	48.4	33534	—		1,600,000	2.1
40	44	53655	—		2,600,000	2.1
36	39.6	54933	—		5,600,000	1
32	35.2	76650	—		12,000,000	0.6
28	30.8	104865	—		40,000,000	0.3
24	26.4	256139	—			
			Total	39.7		17.9

Both are < 100 hence <u>OK</u>

$$\text{Fatigue \%} = \frac{\text{Expected Repititions}}{\text{Allowable Repetition}} \times 100$$

Damage % →

Problem 12.4								
ADTT=				3460		Dowel joints	Yes	
Design period=Y=				20		Concrete shoulders	Yes	
Total no. of trucks during design period on design lane=				25258000		K=	150	pci
Trial thickness=				8.5		MR=	650	psi
			Single axle	**Tandem axle**		LSF=	1.2	
Equivalent stress		Table 12.7	191	166				
Stress ratio factor=			0.29	0.26				
Erosion factor=		Table 12.10	2.315	2.450				
					Fatigue analysis		**Damage analysis**	
Axle load	**Axles per 1000 trucks**	**Adjusted axles per 1000 trucks**	**Axles in design period (Expected repetitions)**	**Axle load *LSF**	**Allowable repetitions**	**Fatigue**	**Allowable repetitions**	**Damage**
Kip				**kips**	**Fig.**	%	Fig.	%
				Single axle				
30	0.45		11366	36	110000	10.3	680000	1.7
28	0.85		21469	33.6	300000	7.2	1200000	1.8
26	1.78		44959	31.2	1750000	2.6	2000000	2.2
24	5.21		131594	28.8			5000000	2.6
22	7.85		198275	26.4			15000000	1.3
20	16.33		412463	24				
18	25.15		635239	21.6				
16	31.82		803710	19.2				
14	47.73		1205564	16.8				
12	182.02		4597461	14.4				
				Tandem axle				
52	1.19		30057	62.4			680000	4.4
48	2.91		73501	57.6			1300000	5.7
44	8.01		202317	52.8			3000000	6.7
40	21.31		538248	48			8000000	6.7
36	56.25		1420763	43.2				
32	103.63		2617487	38.4				
28	121.22		3061775	33.6				
24	72.54		1832215	28.8				
20	85.94		2170673	24				
16	99.34		2509130	19.2				
					Total=	20.1		33.2

Problem 12.5								
ADTT=				3460		Dowel joints	Yes	
Design period=Y=				20		Concrete shoulders	no	
Total no. of trucks during design period on design lane=				25258000				
Trial thickness=				9.5		K=	150	pci
			Single axle	**Tandem axle**		MR=	650	psi
Equivalent stress	Table 12.6		200	183		LSF=	1.2	
Stress ratio factor=			0.31	0.28				
Erosion factor=	Table 12.8		2.590	2.775				
					Fatigue analysis		**Damage analysis**	
Axle load	**Axles per 1000 trucks**	**Adjusted axles per 1000 trucks**	**Axles in design period (Expected repetitions)**	**Axle load *LSF**	**Allowable repetitions**	**Fatigue**	**Allowable repetitions**	**Damage**
Kip				**kips**	**Fig.**	%	**Fig.**	%
				Single axle				
30	0.45		11366	36	40000	28.4	1400000	0.8
28	0.85		21469	33.6	120000	17.9	2000000	1.1
26	1.78		44959	31.2	400000	11.2	3400000	1.3
24	5.21		131594	28.8	3000000	4.4	5800000	2.3
22	7.85		198275	26.4			10000000	2.0
20	16.33		412463	24			21000000	2.0
18	25.15		635239	21.6			60000000	1.1
16	31.82		803710	19.2				
14	47.73		1205564	16.8				
12	182.02		4597461	14.4				
				Tandem axle				
52	1.19		30057	62.4	4000000	0.8	900000	3.3
48	2.91		73501	57.6			1400000	5.3
44	8.01		202317	52.8			2100000	9.6
40	21.31		538248	48			4000000	13.5
36	56.25		1420763	43.2			8000000	17.8
32	103.63		2617487	38.4			20000000	13.1
28	121.22		3061775	33.6			80000000	3.8
24	72.54		1832215	28.8				
20	85.94		2170673	24				
16	99.34		2509130	19.2				
					Total=	62.7		76.8

Prob 12.6

Data:

$W_{18} = 5\times10^6[1.04^y - 1]$

$\Delta PSI_{FH} = 0.08(y)^{0.6}$

Performance Period = ?

$R = 90\%$

$S_o = 0.4$

$K = 100 pci$

$D = 8 in$

$\Delta PSI = 4.5 - 2.5 = 2$
$= P_o - p_t$

$S_c = 600 psi$

$C_d = 1.05$

$J = 3.2$

$E_c = 5\times10^6$

Sol:

From table 11.15

For $R = 90\%$ $\Rightarrow$ $Z_R = -1.282$

Using eq 12.21

$$\log W_{18} = -1.282\times0.4 + 7.35\log(8+1) - 0.06 + \frac{\log\left[\frac{\Delta PSI}{3}\right]}{1+\frac{1.624\times10^7}{(8+1)^{8.46}}}$$

$$+ (4.22 - 0.32\times2.5)\log\left\{\frac{600\times1.05(8^{0.75}-1.132)}{215.63\times3.2\left[8^{0.75}-\frac{18.42}{\left(\frac{5\times10^6}{100}\right)^{0.25}}\right]}\right\}$$

$$\log W_{18} = 6.441 + \log\left[\frac{\Delta PSI}{3}\right]\times0.879 - 0.094$$

$$\log W_{18} = 6.347 + 0.879\log\left[\frac{\Delta PSI}{3}\right]$$

Now by trial and error

Assume $y = 8.5$ years

$W_{18} = 5\times10^6[1.04^{8.5}-1] = 1.98\times10^6$

$\Delta PSI_{FH} = 0.08(8.5)^{0.6} = 0.289$

$\Delta PSI = 2 - 0.289 = 1.711$

$\log W_{18} = 6.347 + 0.879\log\left(\frac{1.711}{3}\right)$

$W_{18} = 1.36\times10^6$

Now

$1.36\times10^6 = 5\times10^6[1.04^y - 1]$

$y = 6.13$ years

Try again

Assume $y = 6.2$ years

$W_{18} = 5\times10^6[1.04^{6.2}-1] = 1.38\times10^6$

$\Delta PSI_{FH} = 0.08(6.2)^{0.6} = 0.239$

$\Delta PSI = 2 - 0.239 = 1.761$

$\log W_{18} = 6.347 + 0.879\log\left(\frac{1.761}{3}\right)$

$W_{18} = 1.39\times10^6$

Now

$1.39\times10^6 = 5\times10^6[1.04^y - 1]$

$y = 6.25$ years

Satisfactory Performance Period = 6.2 years

Prob 12.7

Data:

PCC	$E_c = 4\times10^6$ psi	8"
Granular Subbase $E_{SB} = 30000$ psi		8" = D_{SB}
$M_R = 5000$ psi		

D = 8"

$S_c = 650$ psi

J = 3.2

ΔPSI = 4.5 − 2 = 2.5

Poor drainage (5% of time near saturation)

Performance traffic by eq 12.21 = ? (without Reliability)

check result by AASHTO Chart.

Sol:

Using figure 12.18

For D_{SB} = 8", M_R = 5000 psi, E_{SB} = 30,000 psi } Composite modulus of subgrade reaction = K ≈ 350 pci

From table 12.20

For Poor drainage (5%) $C_d = 0.9$

Using eq 12.21

$$\log W_{18} = 7.35\log(8+1) - 0.06 + \frac{\log\left[\frac{2.5}{3}\right]}{1+\frac{1.624\times10^7}{(8+1)^{8.46}}} + (4.22-0.32\times2)\log\left[\frac{650\times0.9\,(8^{0.75}-1.132)}{215.63\times3.2\times\left[8^{0.75}-\frac{18.42}{\left(\frac{4\times10^6}{350}\right)^{0.25}}\right]}\right]$$

$W_{18} = 8597448$

$\approx 8.6\times10^6$

By assuming R = 50%, drawing a line along the scale of overall standard deviation, from AASHTO chart $W_{18} = 8.5\times10^6$

Prob 12.8

$D = 8.5$ in

Effective modulus of subgrade reaction = ?

$K = \frac{M_R}{19.4}$

$U = (D^{0.75} - 0.39 K^{0.25})^{3.42}$

Month	M_R (psi)	$K = \frac{M_R}{19.4}$ (pci)	
Jan	15900	819.6	37.8
Feb	27300	1407.2	25.9
March	38700	1994.8	19.2
April	50000	2577.3	14.81
May	900	46.4	110.7
June	1620	83.5	96.06
July	2340	120.6	86.6
August	3060	157.7	79.6
Sep	3780	194.8	74.1
Oct.	4500	232	69.5
Nov.	4500	232	69.5
Dec	4500	232	69.5
		Avg $\bar{u}$ =	62.8

$\bar{u} = (D^{0.75} - 0.39 K^{0.25})^{3.42}$

$62.8 = (8.5^{0.75} - 0.39 K^{0.25})^{3.42}$

$K_{eff} = 300$ pci

Prob 12.9

Data:

Same as prob 12.8

eq 5.7 $K = 0.95\left(\frac{E_f}{E}\right)^{\frac{1}{3}}\left(\frac{E_f}{(1-\nu_f^2)h}\right)$ Effective modulus of subgrade reaction = ?

$E = E_c = 4\,000000\,psi = 4\times10^6\,psi$

$\nu_c = 0.15$

$\nu_f = \nu_s = 0.45$

$h = D = 8.5\,in$

Sol:

Month	$M_R = E_f$ psi	K (eq 5.7)	$u = (D^{0.75} - 0.39K^{0.25})^{3.42}$
Jan	15900	353	58.6
Feb	27300	725.7	40.6
March	38700	1155.7	30.0
April	50000	1626.2	23
May	900	7.7	150.1
June	1620	16.8	134.1
July	2340	27.4	123.2
Aug	3060	39.2	114.8
Sep	3780	52	107.9
Oct	4500	65.6	102.2
Nov	4500	65.6	102.2
Dec	4500	65.6	102.2
		Avg $\bar{u}$	73.7

$$\bar{u} = (D^{0.75} - 0.39K_{eff}^{0.25})^{3.42}$$

$$K_{eff} = 196\,pci$$

Prob 12.10

Data:

CRCP
Coarse aggregate = Limestone
ESAL = 10^7
$K = 75$ pci
$E_c = 4 \times 10^6$ psi

$S_c = 650$ psi
$C_d = 1.05$
$J = 2.9$
$R = 95\%$
$S_o = 0.3$

$\Delta PSI = 2$
$DT_D = 60°F$
Wheel load = 18000 lb
$P_t = 4.5 - \Delta PSI = 2.5$

a) ⇒ Determine thickness of concrete
b) ⇒ No. of No 5 bars per 12ft lane required.

Sol:

Using eq 12.21 For $R = 95\%$ ⇒ $Z_R = -1.645$

$$\log(1\times10^7) = -1.645\times0.3 + 7.35\log(D+1) - 0.06 + \frac{\log\left[\frac{2}{3}\right]}{1+\frac{1.624\times10^7}{(D+1)^{8.46}}} + (4.22 - 0.32\times2.5)\log\left[\frac{650\times1.05\,(D^{0.75}-1.132)}{215.63\times2.9\left[D^{0.75}-\frac{18.42}{\left(\frac{4\times10^6}{75}\right)^{0.25}}\right]}\right]$$

$$7 = -0.4935 + 7.35\log(D+1) - 0.06 + \frac{(-0.1761)}{1+\frac{1.624\times10^7}{(D+1)^{8.46}}} + 3.42\log\left[\frac{682.5\,(D^{0.75}-1.132)}{625.327\left[D^{0.75}-1.212\right]}\right]$$

$D = 9.7$ in

Use $D = 9.5$ in

⇒ b) As $D = 9.5$ in, Wheel load = 18000 lb, $K = 75$ pci } From fig 12.22

Wheel load tensile stress $= \sigma_w = 235$ psi

The min amount of steel P_{min} must satisfy the following 3 criteria

1) $\bar{x} < 8$ ft
2) $CW < 0.04$ in
3) $\sigma < 62000$ psi

α_s = Steel thermal coefficient $= 5\times10^{-6}/°F$ (Pg 584)

$f_t = 0.86$

$S_c = 559$

$\phi = \frac{5}{8}$ in $= 0.625$ in $Z = 0.00036$ (Table 12.2)

From eq 12.33 based on $\bar{x} = 8$ ft

$$P_{min} = \frac{1.062\left(1+\frac{559}{1000}\right)^{1.457}\left(1+\frac{5\times10^{-6}}{2\times3.8\times10^{-6}}\right)^{0.23}\left(1+0.625\right)^{0.476}}{(8)^{0.217}\left(1+\frac{235}{1000}\right)^{1.13}\left(1+1000\times0.00036\right)^{0.389}} - 1$$

$= 0.29\%$.

From fig 12.34 (based on CW = 0.04 in)

$$P_{min} = \frac{0.358\left(1+\frac{559}{1000}\right)^{1.435}\left(1+0.625\right)^{0.484}}{(0.04)^{0.22}\left(1+\frac{235}{1000}\right)^{1.079}} - 1$$

$= 0.38\%$.

From fig 12.35 (Based on $\sigma_s = 62000$ psi, $DT_D = 60°F$)

$$P_{min} = \frac{50.834\left(1+\frac{60}{100}\right)^{0.155}\left(1+\frac{559}{1000}\right)^{1.493}}{(62000)^{0.365}\left(1+\frac{235}{1000}\right)^{1.146}\left(1+1000\times0.00036\right)^{0.180}} - 1$$

$= 0.4\%$.

Use $P_{min} = 0.4\%$.

Max. amount of steel P_{max} should be based on a crack spacing not less than 3.5 ft

From eq 12.33 (Based on $\bar{x} = 3.5$ ft)

$$P_{max} = \frac{1.062(1.559)^{1.435}(1.658)^{0.25}(1.625)^{0.476}}{(3.5)^{0.217}(1.235)^{1.13}(1.36)^{0.389}} - 1$$

$= 0.53\%$.

$$N_{min} = \frac{0.01273\times0.4\times12\times12\times9.5}{0.625^2} = 17.8$$

Use a min. of 18 bars per 12 ft lane

$$N_{max} = \frac{0.01273 \times 0.53 \times 12 \times 12 \times 9.5}{(0.625)^2} = 23.6$$

Use a max. of 24 bars per 12 ft lane.

Problem 12.11								
Thickness of outer pavement edge is to be determined								
ADTT=				3460		Dowel joints	Yes	
Design period=Y=				20		Concrete shoulders	no	
Total no. of trucks during design period on design lane=				25258000		K=	150	pci
Trial thickness=				8.5		MR=	650	psi
			Single axle	Tandem axle		LSF=	1.2	
Equivalent stress		Table 12.6	234	208				
Stress ratio factor=			0.36	0.32				
Erosion factor=		Table 12.8	2.730	2.895				
					Fatigue analysis		Damage analysis	
Axle load	Axles per 1000 trucks	Adjusted axles per 1000 trucks	Axles in design period (Expected repetitions)	Axle load *LSF	Allowable repetitions	Fatigue	Allowable repetitions	Damage
Kip				kips	Fig.	%	Fig.	%
Single axle								
30	0.45		227	36	2400	9.5	610000	0.0
28	0.85		429	33.6	8000	5.4	850000	0.1
26	1.78		899	31.2	23000	3.9	1400000	0.1
24	5.21		2632	28.8	52000	5.1	2100000	0.1
22	7.85		3966	26.4	300000	1.3	2400000	0.2
20	16.33		8249	24	4000000	0.2	7000000	0.1
18	25.15		12705	21.6			14000000	0.1
16	31.82		16074	19.2			39000000	0.0
14	47.73		24111	16.8				
12	182.02		91949	14.4				
Tandem axle								
52	1.19		601	62.4	190000	0.3	430000	0.1
48	2.91		1470	57.6	800000	0.2	630000	0.2
44	8.01		4046	52.8	10000000	0.0	1000000	0.4
40	21.31		10765	48			1900000	0.6
36	56.25		28415	43.2			3800000	0.7
32	103.63		52350	38.4			8000000	0.7
28	121.22		61235	33.6			20000000	0.3
24	72.54		36644	28.8			100000000	0.0
20	85.94		43413	24				
16	99.34		50183	19.2				
					Total=	25.9		3.8

Problem 12.12								
Thickness of inner shoulder edge is to be determined								
ADTT=				3460		Dowel joints	Yes	
Design period=Y=				20		Concrete shoulders	Yes	
Total no. of trucks during design period on design lane=				25258000		K=	150	pci
Trial thickness=				7		MR=	650	psi
			Single axle	Tandem axle		LSF=	1.2	
Equivalent stress		Table 12.7	248	210				
Stress ratio factor=			0.38	0.32				
Erosion factor=		Table 12.10	2.540	2.620				
					Fatigue analysis		Damage analysis	
Axle load	**Axles per 1000 trucks**	**Adjusted axles per 1000 trucks**	**Axles in design period (Expected repetitions)**	**Axle load *LSF**	**Allowable repetitions**	**Fatigue**	**Allowable repetitions**	**Damage**
Kip				**kips**	**Fig.**	**%**	**Fig.**	**%**
Single axle								
30	0.45		227	36	730	31.1	150000	0.2
28	0.85		429	33.6	2600	16.5	220000	0.2
26	1.78		899	31.2	7800	11.5	320000	0.3
24	5.21		2632	28.8	30000	8.8	520000	0.5
22	7.85		3966	26.4	100000	4.0	1000000	0.4
20	16.33		8249	24	600000	1.4	2500000	0.3
18	25.15		12705	21.6			7000000	0.2
16	31.82		16074	19.2				
14	47.73		24111	16.8				
12	182.02		91949	14.4				
Tandem axle								
52	1.19		601	62.4	140000	0.4	180000	0.3
48	2.91		1470	57.6	700000	0.2	280000	0.5
44	8.01		4046	52.8			500000	0.8
40	21.31		10765	48			1000000	1.1
36	56.25		28415	43.2			2000000	1.4
32	103.63		52350	38.4			10000000	0.5
28	121.22		61235	33.6				
24	72.54		36644	28.8				
20	85.94		43413	24				
16	99.34		50183	19.2				
					Total=	73.9		6.7