Assignment # 1

Ch # 1

Submitted By:

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2018 - MS - CEH - 11

Submitted To : Dr. Zia - ur - Rehman

Submitted On : 16 - Sep - 2019

Q = 1.1

Data:

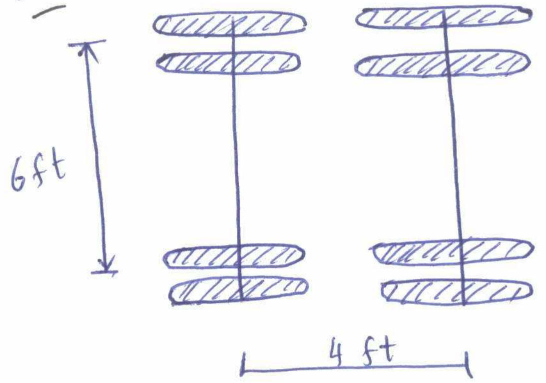
Dual Tandem Axle

Load = 40,000 lb = 40 Kip

Tire pressure = 100psi

If contact areas are rectangle, dimension of rectangular area = ?

Sol: The wheel configuration for a dual-tandem axle is as follows.



The 40,000 lbs load is applied over 8 tires.

Thus, each tire bears $\frac{40,000}{8} = 5000$ lbs load with 100psi tire pressure.

The contact area of each tire is

$$A_c = \frac{\text{Load of each tire}}{\text{tire pressure}} = \frac{5000}{100} = 50 \text{ in}^2$$

The dimension of contact area is $\Rightarrow$ $\boxed{A = 0.5227L^2}$

Most realistic $L = \sqrt{\frac{A_c}{0.5227}} = \sqrt{\frac{50}{0.5227}} = \underline{9.78 \text{ inch}}$

Width $= 0.6L = 0.6 \times 9.78 = \underline{5.87 \text{ in}}$

The most realistic contact area consisting a rectangle and 2 semicircles as shown in following figure:

Each tire imprint, if considered as a rectangular area, should have a length of 0.8712 L, $= 0.8712 \times 9.78 = 8.52$ inch and a width of 0.6 L, $= 0.6 \times 9.78 = 5.87$ inch

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Q = 1.2

Data:

Mean Monthly temperatures

Sept	= 50°F	Dec	= −3°F
Oct	= 32°F	Jan	= 14°F
Nov	= 24°F	Feb	= 16°F
		March	= 22°F
		April	= 25°F
		May	= 40°F

Freezing Index = ?

Sol:

$$
\begin{aligned}
\text{Freezing Index} &= (32-24)\times 30 \\
&+ (32+3)\times 31 \\
&+ (32-14)\times 31 \\
&+ (32-16)\times 28 \\
&+ (32-22)\times 31 \\
&+ (32-25)\times 30 \\
\hline
&\quad 2851 \text{ degreedays}
\end{aligned}
$$

Yes, this value is likely to be different because the last few days in Oct and first few days in May may have mean daily temp. lower than 32°F, so the degree days for these 2 months may not be zero.

Q=1.3

Limiting shear failure method is used to determine the thickness of pavements so that shear failures will not occur.
With ever increasing speed and volume of traffic, pavements should be designed for riding comfort rather than for barely preventing shear failures.

Q=1.4

The mechanistic-empirical method of design is based on the mechanics of materials that relates input, such as a wheel load, to an output or pavement response, such as stress or strain.
Dependence on observed performance is necessary because theory alone has not proven sufficient to design pavements realistically.

Q=1.5

Seal coat is a thin asphalt surface treatment used to waterproof the surface or to provide skid resistance where the aggregates in the surface course could be polished by traffic and become slippery.

Q=1.6

Tack coat is used to ensure a bond b/w the surface being paved and the overlying course. Tack coats are also used to bond the asphalt layer to a PCC base or an old asphalt pavement.
A prime coat is an application of low viscosity cutback asphalt to an absorbent surface, such as an untreated granular base on which an asphalt layer will be placed.

Its purpose is to bind the granular base to asphalt base.

Q=1.7

Flexible pavements are layered systems with better materials on top where the intensity of stress is high and inferior materials at bottom where intensity is low. The basic purpose of layered system is to protect the subgrade material from stresses and deflections.

Q=1.8

Surface course is the top surface of an asphalt pavement sometimes called wearing course. It is constructed of dense HMA. It must be tough to resist distortion due to loading and to provide smooth and skid resistant riding surface.

The binder course sometimes called asphalt base course is asphalt layer below the surface course.

There are 2 reasons that a binder course is used in addition to surface course.

i) HMA is too thick to be compacted in one layer, so it must be placed in 2 layers.

ii) Binder course consists of larger aggregates with less asphalt, so it is sometimes economical to replace some part of surface course with that of binder course.

Q=1.9

Q=1.10

Although permanent deformation are not considered in rigid pavement design, the resilient deformation under repeated wheel loads will cause pumping of slabs.

Q=1.11

Rigid pavements are constructed of PCC. They are placed in the form of slabs jointed together through dowel bars. Pumping occurs mostly under the leading slab when the trailing slab rebounds which creates a vaccum and sucks the fine material from underneath the leading slab. Pumping usually does not occur in flexible pavements because they are not constructed in the form of slabs.

Q=1.12

Silt is more susceptible because it has high capillary as well as high permeability. On the other hand clay also has a very high capillary but its permeability is so low that very little water can be attracted from W/T to form ice lenses during freezing period.

Prob 1.13

The increase in vol. of 9% when water becomes frozen is not the real cause of frost heave. Frost heave is caused by the formation and continuous expansion of ice lenses, which occurs due to freezing of water in larger voids where the temp. is below normal freezing temp. and the smaller voids remain unfrozen and act as conduits to deliver water to larger voids. This results in increment of amount of water in freezing zones. The amount of heave is at least as much as combined lens thickness.

Prob 1.14

JPCP

→ All plain concrete pavements should be constructed with closely spaced contraction joints.

→ Depending on type of aggregate, climate and prior experience, joint spacing b/w 15 and 30 ft has been used.

→ Dowels or aggregate interlocks may be used for load transfer across the joints.

JRCP

→ Steel reinforcement is in the form of wire mesh or deformed bars does not increase the structural capacity.

→ Reinforcement allows the use of longer joint spacing.

→ Joint spacing varies from (30 – 100 ft) but 40 ft is more economical.

Prob 1.15

CRCP

→ Due to elimination of joints the thickness of CRCP reduced by 1-2 inch (70-80%) of conventional pavements.

→ Advantage of CRCP is the elimination of transverse joints.

→ The formation of transverse cracks at relatively close intervals is the characteristics of CRCP which are held tightly by reinforcement.

Prob 1.16

Advantages	Disadvantages
1) Concrete is weak in tension but strong in compression.	1) It is very difficult to repair the services beneath the slab.
2) The pre application of a compressive stress to the concrete greatly reduces the tensile stress caused by traffic and thus decrease the thickness of concrete required.	2) It requires supervision of experts for construction.
3) They have less probability of cracking and fewer transverse joints and therefore results in less maintenance and longer pavement life.	3) It possess certain constructional difficulties at bends and curves.

Q = 1.17

Fatigue cracking of cement treated bases, instability rutting, top down cracking, shrinkage cracking, reflective cracking and thermal fatigue cracking have been identified as the most common distresses affecting the service life of composite pavement.

It can be prevented by using asphalt mixes with less aging susceptibility, gradations more resilient to fractures along with avoiding high air to void ratios.

Q = 1.18

This type of pavement is more costly to construct because of grading operations required at the thickened edge.

Q = 1.19

Maryland Road test	AASHO Road test
1) Pumping occurred on plastic clay soils but not on granular subgrades with low % of silt and clay.	1) Pumping of subbase material, including the coarser fractions, was major factor causing failures of sections with subbase.
2) With exception of corner case of loading for pumping soils, the stress and deflection resulting at vehicle speed of 40mph averaged approx. 20% less than those at creep speed.	2) Corner deflections of a 40 ft reinforced panel usually exceeded those of a 15 ft non reinforced panel, if all other conditions were the same.

Q = 1.22

The contact pressure is smaller than the tire pressure for high pressure, tires because the wall of tires is in tension. However, in pavement design, the contact pressure is generally assumed to be equal to tire pressure.

Q = 23

Method used for design of rigid pavements is based on finite element procedure, and rectangular area is assumed with

$$L = 0.8712\,L$$

$$W = 0.6L \quad \text{and} \quad A = 0.5227\,L^2.$$

Method used for design of flexible pavement is based on layered theory. Areas menthioned for rigid pavement are not axisymmetric and cannot be used for layered theory.

Q = 24

Pumping phenomenon occurs frequently in highway pavements more than airport pavement because the no. of load repitition in airport pavement is usually smaller than that on highway pavements.

Q=25

The design of highway pavement is based on moving loads with the loading duration as an input for viscoelastic behaviours and the resilient modulus under repeated loads for elastic behaviours. The design of airport pavements is based on moving loads in the interiors of runways but stationary loads at end of runways. As a result thicker pavements are used at runway end than in the interior.

Q=1.26

The design principles used for highway pavements can be equally applied to airport pavements with only few exceptions, such as the consideration of aircraft wandering on the no. of load repetitions and the use of stationary loads at the end of runways.

Q=1.27

Major difference is the distribution of wheel loads to layered system. On highway pavements, wheel loads are applied over small areas and the magnitude of loads on each area is a constant independent of stiffness of layered system.

Q-1.28

→ Full depth asphalt pavements are constructed by placing one or more layers of HMA directly on subgrade or improved subgrade. This concepth was conceived by Asphalt institude in 1960.

→ The use of full depth asphalt is popular for highway pavements, is ineffective for railroad track beds. It is more economical to place HMA under the ballast rather than over ballast.

FEATURES OF TYRES

Size example : 225/ 55 R 17 97 W

Here

225 ⇒ tyre width in (mm) e.g 225mm

55 ⇒ aspect ratio or height of sidewall expressed as % of tread width.

e.g. sidewall height is 55% of tread width.

Lower the figure, lower the side wall height.

R ⇒ Internal construction of tyre.

R indicates radial tyre construction.

17 ⇒ This is inside diameter of tyre in inches.

e.g: the diameter of tyre i.e rim height is 17 inches

97 ⇒ This is the load index.

It indicates max. load the tyre can carry.

e.g. we have to refer look up table in our case for index of 97 → max load weight = 730k

: e
: tyre

W ⇒ This is speed rating. The max. speed at which it has been certified that a tyre can carry load safely. It can be Q, R, S, T, H, V, Y, W

For our case W ⇒ 270 km/h.

Assignment # 2

(Pavement Analysis and Design)

Submitted By:

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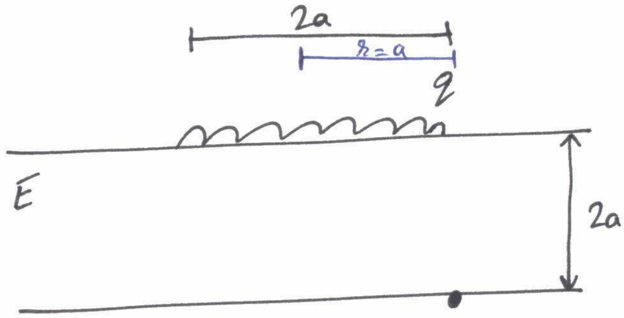
Submitted On:

30 Sep 2019

Prob = 2.1



$\nu = 0.5$

$w = ?$

3 principal stresses = ?

3 " strains = ?

point 2a below the surface under the edge r = a of loaded area.

In terms of q, a, E

Sol:

$z = 2a$

As $\dfrac{r}{a} = \dfrac{a}{a} = 1$ and $\dfrac{z}{a} = \dfrac{2a}{a} = 2$

From fig 2.2

$$\frac{\sigma_z}{q} \times 100 = 18$$

$$\sigma_z = \frac{18q}{100} \qquad \sigma_z = 0.18q$$

From fig 2.3

$$\frac{\sigma_r}{q} \times 100 = 5.7$$

$$\sigma_r = 0.057q$$

From fig 2.4

$$\frac{\sigma_t}{q} \times 100 = 1.1$$

$$\sigma_t = 0.011q$$

From fig 2.5

$$\frac{\tau_{rz}}{q} \times 100 = 7$$

$$\tau_{rz} = 0.07q$$

Principal Stresses

$$\sigma_1, \sigma_3 = \frac{\sigma_z + \sigma_r}{2} \pm \sqrt{\tau_{rz}^2 + \left(\frac{\sigma_z - \sigma_r}{2}\right)^2}$$

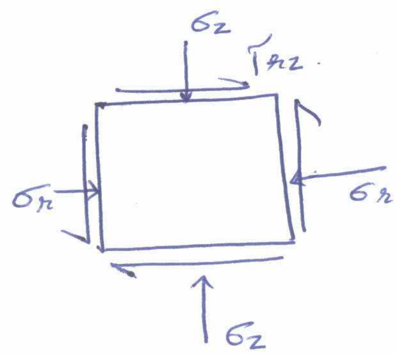
$$\sigma_1, \sigma_3 = \frac{0.18q + 0.057q}{2} \pm \sqrt{(0.07q)^2 + \left(\frac{0.18q - 0.057q}{2}\right)^2}$$

$$\sigma_1 = 0.2111q$$

$$\sigma_3 = 0.0253q$$

$$\sigma_2 = \sigma_t = 0.011q$$

$\because$ There is no shear stress in z-t plane therefore $\sigma_t = \sigma_2$



(Z - r plane)

Principal Strains:

$$\Rightarrow \varepsilon_1 = \frac{1}{E}\left[\sigma_1 - \nu(\sigma_2 + \sigma_3)\right]$$

$$= \frac{1}{E}\left[0.2117q - 0.5(0.011q + 0.0253q)\right]$$

$$= \frac{1}{E}\left[0.2117q - 0.01815q\right]$$

$$\varepsilon_1 = \frac{0.1936q}{E} \quad \text{Ans}$$

$$\Rightarrow \varepsilon_2 = \frac{1}{E}\left[\sigma_2 - \nu(\sigma_1 + \sigma_3)\right]$$

$$= \frac{1}{E}\left[0.011q - 0.5(0.2117q + 0.0253q)\right]$$

$$= -0.1075\frac{q}{E} \quad \text{Ans}$$

$$\Rightarrow \varepsilon_3 = \frac{1}{E}\left[\sigma_3 - \nu(\sigma_1 + \sigma_2)\right]$$

$$= \frac{1}{E}\left[0.0253q - 0.5(0.2117q + 0.011q)\right]$$

$$= -0.08605\frac{q}{E} \quad \text{Ans}$$

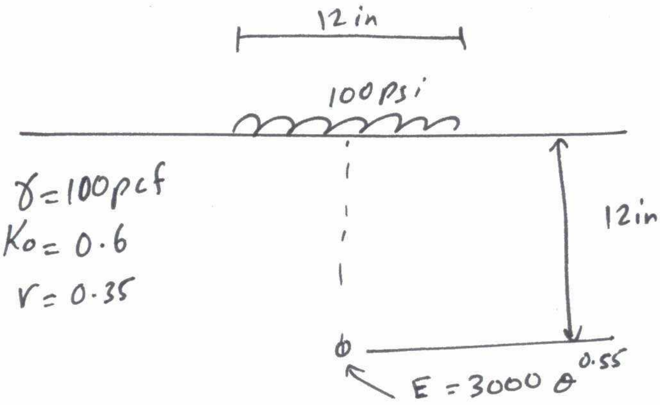
Vertical displacement:

From fig 2.6

$$\underbrace{\frac{r}{a} = 1 \qquad \frac{z}{a} = 2}_{F = 0.57}$$

$$w = \frac{qaF}{E} = \frac{0.57qa}{E} \quad \text{Ans}$$

Prob 2.2



$\gamma = 100pcf$
$K_o = 0.6$
$\nu = 0.35$

Determine max. surface displacement

Sol: $z = 12in$, $a = 6in$

From eq 2.2

$$\sigma_z = q\left[1 - \frac{z^3}{(a^2+z^2)^{1.5}}\right] = 100\left[1 - \frac{12^3}{(6^2+12^2)^{1.5}}\right] = 28.446 psi$$

From eq 2.3

$$\sigma_r = \frac{q}{2}\left[1 + 2\nu - \frac{2(1+\nu)z}{\sqrt{a^2+z^2}} + \frac{z^3}{(a^2+z^2)^{1.5}}\right]$$

$$= \frac{100}{2}\left[1 + 2\times0.35 - \frac{2(1+0.35)12}{\sqrt{6^2+12^2}} + \frac{12^3}{(6^2+12^2)^{1.5}}\right] = 0.0294 psi$$

$$\theta = \sigma_z + \sigma_r + \sigma_t + \gamma z(1+2K_o)$$

$$= 28.446 + 0.0294 + 0.0294 + \frac{100}{12^3} \times 12(1+2\times0.6)$$

$$\theta = 30.03 \ psi$$

$$E = 3000 \times (30.03)^{0.55} = 19488.42 psi$$

Using eq 2.8 when $z = 0$ (for max. surface deflection)

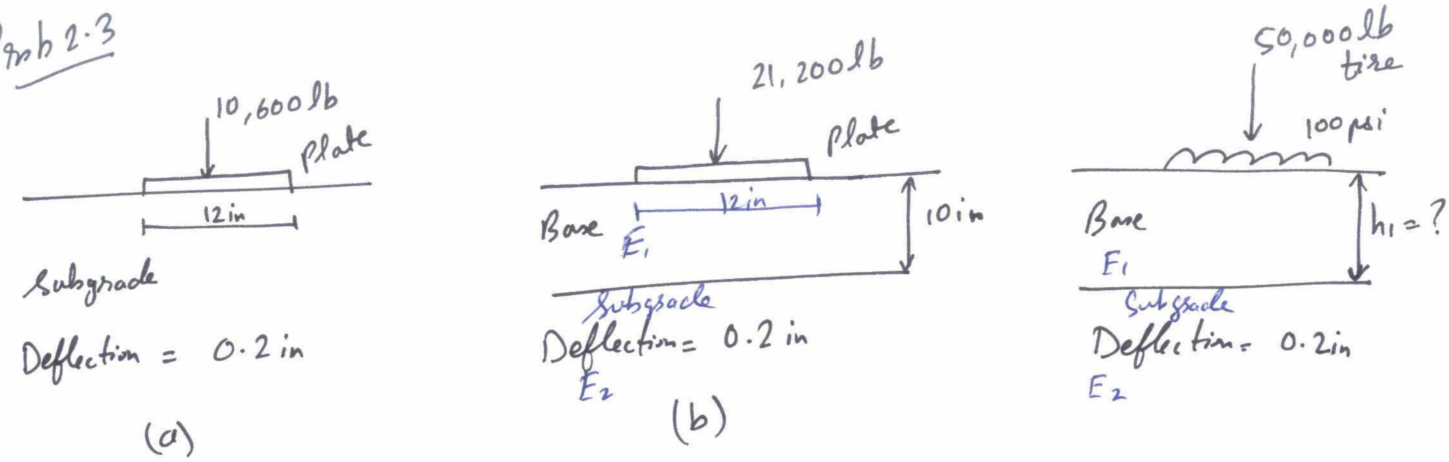
$$w_o = \frac{2(1-\nu^2)qa}{E} = \frac{2(1+0.35^2)(100)(6)}{19488.42} = 0.054 \ in$$

Using eq 2.6 at $z = 12in$

$$w = \frac{(1+0.35) \times 100 \times 6}{19543.7} \times \left(\frac{6}{\sqrt{6^2+12^2}} + \frac{1-2\times0.35}{6} \times \left(\sqrt{6^2+12^2} - 12\right)\right)$$

$= 0.02147$

Prob 2.3



$\nu = 0.5$

a) Avg. Pressure on plate

$$q = \frac{P}{A} = \frac{10,600}{\pi (6)^2} = 93.72 \text{ psi}$$

As from eq 2.10

$$w_0 = \frac{\pi (1-\nu^2) q a}{2E} \Rightarrow \frac{\pi (1-0.5^2) 93.72 \times 6}{2 \times E} = 0.2$$

$$\boxed{E_2 = 3312.3 \text{ psi}} \quad \text{Subgrade}$$

b) Avg. pressure on plate

$$q = \frac{P}{A} = \frac{21,200}{\pi \times 6^2} = 187.45 \text{ psi}$$

$h_1 = 10$ in $\qquad E_2 = 3312.3$ psi

$w_0 = 0.2$ in

$a = 6$

From eq 2.15

$$w_0 = \frac{1.18 q a F_2}{E_2}$$

$$0.2 = \frac{1.18 \times 187.45 \times 6 \times F_2}{3312.3}$$

$$F_2 = 0.5$$

From fig 2.17

$$\left.\begin{aligned} \frac{h_1}{a} &= \frac{10}{6} = 1.67 \\ F_2 &= 0.5 \end{aligned}\right\} \frac{E_1}{E_2} = 4$$

$$E_1 = 4 E_2$$
$$= 4 \times 3312.3$$
$$\boxed{E_1 = 13249.2 \text{ psi}}$$

$$\sigma = \frac{P}{A}$$

c) $$A_c = \frac{P}{q} = \frac{50000}{100} = 500 \text{ in}^2$$

$$A = \pi r^2$$

$$r = a = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{500}{\pi}} = 12.62 \text{ in}$$

$E_1 = 13249.2$ psi

$E_2 = 3312.3$ psi

$w = 0.2$ in

As from eq 2.14

$$w_o = \frac{1.5 q a F_2}{E_2}$$

$$0.2 = \frac{1.5 \times 100 \times 12.62 \times F_2}{3312.3}$$

$$F_2 = 0.35$$

From fig 2.17

$$\left.\begin{aligned} \frac{E_1}{E_2} &= \frac{13249.2}{3312.3} = 4 \\ F_2 &= 0.35 \end{aligned}\right\} \quad \frac{h_1}{a} = 5.5$$

$$h_1 = 5.5\,a$$

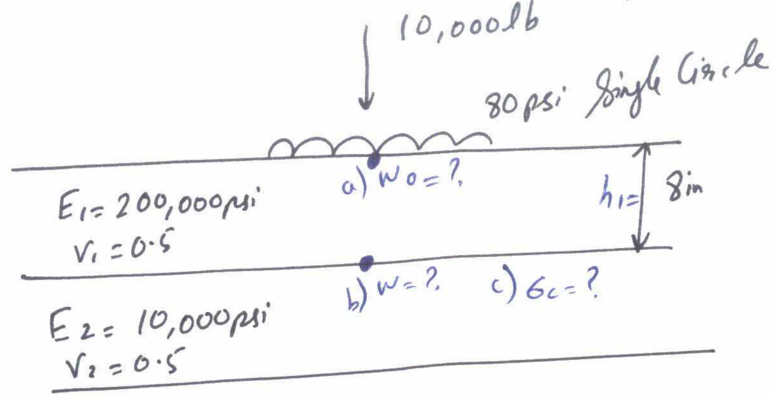
$$= 5.5 \times 12.62$$

$$h_1 = 69.41$$

$$\boxed{h_1 \simeq 70 \text{ in}}$$

Prob 2.4

Elastic
2 layer System



a) Max. surface deflection = ?
b) Interface deflection = ?
c) Interface stresses = ?

Sol:

a) As $\sigma = \dfrac{P}{A}$

$$A = \frac{P}{q} = \frac{10{,}000}{80} = 125 \text{ in}^2$$

$$\pi r^2 = 125 \text{ in}^2$$

$$r = a = \sqrt{\frac{125}{\pi}} = 6.31 \text{ in}$$

As from eq 2.14

$$w_0 = \frac{1.5\, q\, a\, F_2}{E_2}$$

$$= \frac{1.5 \times 80 \times 6.31 \times 0.33}{10{,}000}$$

$$\boxed{w_0 = 0.025 \text{ in}}$$

From fig 2.17

$$\left.\begin{aligned} \frac{h_1}{a} &= \frac{8}{6.31} = 1.27 \\ \frac{E_1}{E_2} &= \frac{200{,}000}{10{,}000} = 20 \end{aligned}\right\} F_2 = 0.33$$

b) As from eq 2.16

$$w = \frac{q a F}{E_2}$$

$$w = \frac{80 \times 6.31 \times 0.483}{10{,}000}$$

$$\boxed{w = 0.0244 \text{ in}}$$

For 'F'

$$\frac{E_1}{E_2} = 20 \qquad \frac{h_1}{a} = \frac{8}{6.31} = 1.27$$

$$\frac{r}{a} = 0$$

For $\dfrac{E_1}{E_2} = 10 \Rightarrow F = 0.595$

For $\dfrac{E_1}{E_2} = 25 \Rightarrow F = 0.425$

By Interpolation

For $\dfrac{E_1}{E_2} = 20 \Rightarrow \boxed{F = 0.483}$

c) Using fig 2.15

$$\frac{a}{h_1} = \frac{6.31}{8} = 0.789$$

$$\frac{E_1}{E_2} = 20$$

For $\frac{E_1}{E_2} = 10 \Rightarrow \frac{\sigma_c}{q} = 0.21$

For $\frac{E_1}{E_2} = 25 \Rightarrow \frac{\sigma_c}{q} = 0.125$

By linear interpolation

For $\frac{E_1}{E_2} = 20 \Rightarrow \frac{\sigma_c}{q} = 0.153$

$$\sigma_c = 0.153\, q$$

$$\sigma_c = 0.153 \times 80 = \boxed{12.24\,psi}$$

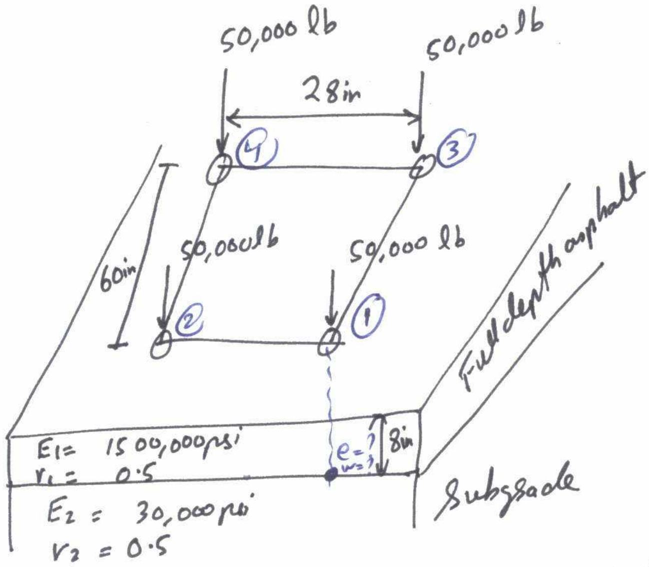
Prob 2.5

Dual tandem wheel

$q = 100\,psi$

$S_d = 28\,in$

$S_t = 60\,in$



Full depth asphalt pavement.

a) Max. tensile strain at bottom of asphalt layer under center of one wheel (e) = ? (Critical tensile strain)

b) Vertical deflection on surface of subgrade under center of one wheel = ? (w)

Sol:

$$\sigma = \frac{P}{A}$$

$$A = \frac{P}{q} = \frac{50{,}000}{100} = 500\ in^2$$

$$a = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{500}{\pi}} = 12.62\ in$$

$S_d = 28\ in$

$S_t = 60\ in$

$$\frac{E_1}{E_2} = \frac{1500\,000}{30\,000} = 50$$

The charts are available for $S_d = 24\ in$

for $S_d = 28\ in$, a, h, S_t must be modified.

$$\text{Modified } S_t' = \frac{24 S_t}{S_d} = \frac{24 \times 60}{28} = \underline{51.43}\ in$$

$$\text{Modified } a' = \frac{24 a}{S_d} = \frac{24 \times 12.62}{28} = 10.82\ in$$

$$\text{Modified } h' = \frac{24 h_1}{S_d} = \frac{24 \times 8}{28} = 6.86\ in$$

When $S_t = 48\ in$, $a' = 10.82\ in$, $h_1' = 6.86\ in$

From fig 2.26

$C_1 = 1.08$ $\quad$ $C_2 = 1.135$

$$C = C_1 + 0.2(a' - 3)(C_2 - C_1)$$

$$= 1.08 + 0.2(10.83 - 3)(1.135 - 1.08) = 1.166$$

When $S_t = 72\ in$, $a' = 10.82\ in$, $h_1' = 6.86\ in$

From fig 2.27

$C_1 = 1.12$ $\quad$ $C_2 = 1.3$

$$C = C_1 + 0.2(a' - 3)(C_2 - C_1)$$

$$= 1.12 + 0.2(10.83 - 3)(1.3 - 1.12) = 1.4$$

For

$S_t = 48 in$ $\quad C = 1.166$

$S_t = 72 in$ $\quad C = 1.4$

By linear Interpolation

$S_t = 51.43 in$ $\quad C = 1.2$

Strain factor (F_e) for single wheel

From fig 2.21

$$\left.\begin{aligned} \frac{E_1}{E_2} &= 50 \\ \frac{8}{12.62} = \frac{h_1}{a} &= \frac{h_1'}{a'} = \frac{6.86}{10.82} = 0.64 \end{aligned}\right\} F_e = 2.5$$

Strain factor due to dual tandem wheels $= C \times F_e$

$= 1.2 \times 2.5 = 3$

From eq 2.17

Critical tensile strain

$$e = \frac{q F_e}{E_1}$$

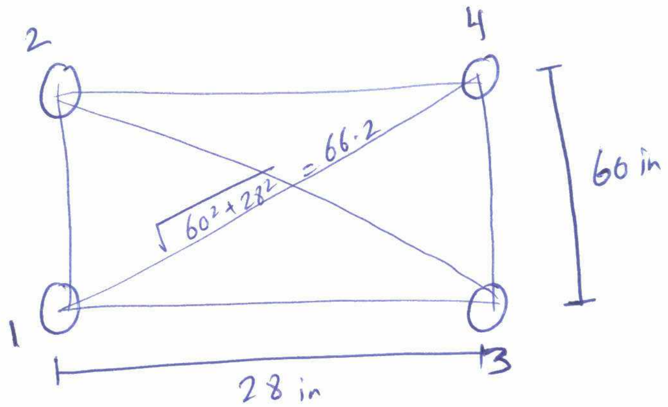
$$e = \frac{100 \times 3}{1500{,}000} = 2 \times 10^{-4}$$

$$\boxed{e = 2 \times 10^{-4}}$$

b) Vertical deflection on surface of subgrade under the center of one wheel

Say wheel # 1

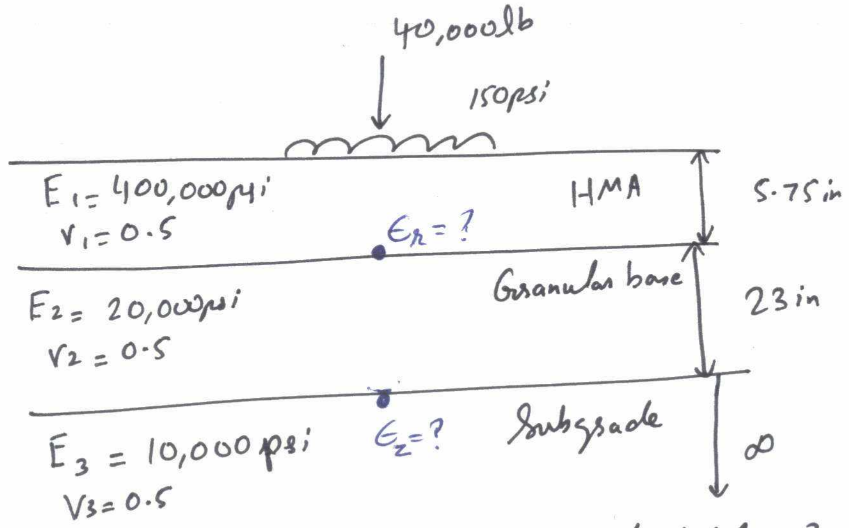
	Loading 1	Loading 2	Loading 3	Loading 4
$\frac{E_1}{E_2}$	50	50	50	50
$\frac{h_1}{a}$	0.635	0.635	0.635	0.635
a (in)	12.6	12.6	12.6	12.6
r (in)	0	60	28	66.2
$\frac{r}{a}$	0	4.76	2.22	5.25
F (fig 2.19)	0.62	0.2	0.37	0.15



$$F_{total} = 0.62 + 0.2 + 0.37 + 0.15$$
$$= 1.34$$

$$w = \frac{q a F}{E_2} = \frac{100 \times 12.6 \times 1.34}{30000} = 0.0563 \text{ in}$$

Prob 2.6



a) Max. horizontal tensile strain at bottom of HMA = ?
b) Max. vertical compressive strain on top of subgrade under wheel = ?

Sol:

$$\sigma = \frac{P}{A}$$

$$A = \frac{P}{q} = \frac{40{,}000}{150} = 266.67 \text{ in}^2$$

$$a = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{266.67}{\pi}} = 9.21 \text{ in}$$

$$K_1 = \frac{E_1}{E_2} = \frac{400{,}000}{20{,}000} = 20 \qquad A = \frac{a}{h_2} = \frac{9.21}{23} = 0.4$$

$$K_2 = \frac{E_2}{E_3} = \frac{20{,}000}{10{,}000} = 2 \qquad H = \frac{h_1}{h_2} = \frac{5.75}{23} = 0.25$$

a) Using table 2.3

$ZZ1 = 0.37832$

$ZZ2 = 0.07933$

$ZZ1 - RR1 = 3.86779$

$ZZ2 - RR2 = 0.14159$

Max. horizontal tensile strain (From eq 2.20b or 2.25)

$$\epsilon_r = \frac{q}{E}\left(\frac{RR1 - ZZ1}{2}\right)$$

$$= \frac{150}{400{,}000}\left(\frac{-3.86779}{2}\right)$$

$$\epsilon_r = -7.25 \times 10^{-4} \quad \text{(Tension)}$$

b) Vertical compressive strain $\epsilon_z = ?$

$$\epsilon_{z2} = \frac{1}{E}(\sigma_z - \sigma_r)$$

From eq 2.24d

$$\sigma_{z2} - \sigma_{r2} = q\,(ZZ_2 - RR2)$$

$$= 150 \times 0.14159 = 21.23 \text{ psi}$$

From eq 2.23b

$$\sigma_{z2} - \sigma_{r2}' = \frac{\sigma_{z2} - \sigma_{r2}}{K_2}$$

$$\sigma_{z2} - \sigma_{r2}' = \frac{21.23}{2} = 10.615$$

$$\epsilon_z = \frac{1}{E_3}\left[\sigma_{z2} - \sigma_{r2}'\right]$$

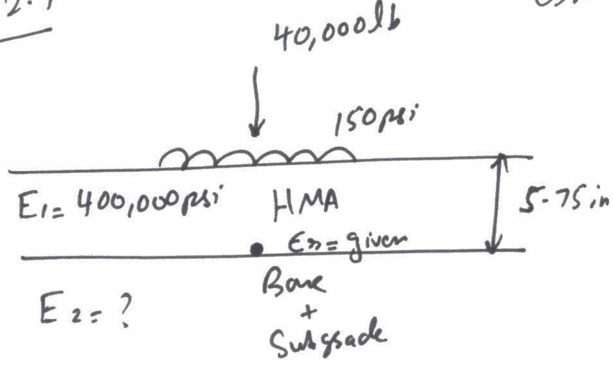
$$= \frac{10.615}{10{,}000} = 0.001062$$

$$= 1.062 \times 10^{-3}$$

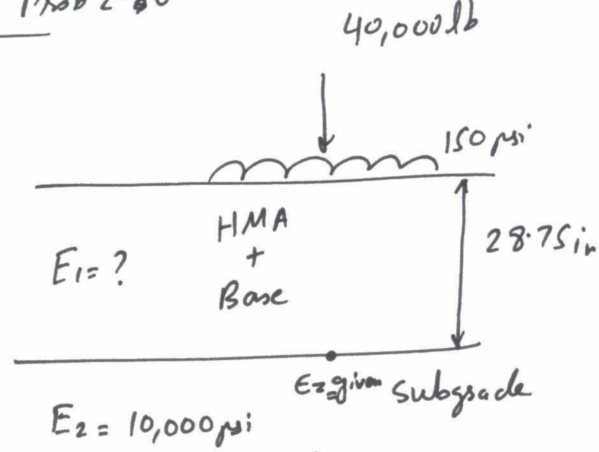
Vertical strain

Prob 2.7

Continue Prob 2.6



(a)



(b)

$$\left.\begin{aligned} \epsilon_r &= -0.000725 \\ \epsilon_z &= 1.06 \times 10^{-3} \end{aligned}\right\} \text{Problem} = 2.6 \text{ (Critical tensile strain)}$$

$a = 9.21$ in

Sol:

a) As from eq 2.17

$$e = \frac{q F_e}{E_1}$$

From fig 2.21

$$\left.\begin{aligned} F_e &= \frac{e E_1}{q} = \frac{0.000725 \times 400,000}{150} = 1.933 \\ \text{and} \quad \frac{h_1}{a} &= \frac{5.75}{9.21} = 0.624 \end{aligned}\right\} \frac{E_1}{E_2} = 20$$

$$\frac{E_1}{E_2} = 20$$

$$E_2 = \frac{400000}{20} = 20000 \text{ psi}$$

b) $\epsilon_z = 1.06 \times 10^{-3}$

As from eq 2.21

$$\epsilon_z = -2\,\epsilon_r$$

$$\epsilon_r = -\frac{\epsilon_z}{2} = -\frac{1.06 \times 10^{-3}}{2}$$

$$\epsilon_r = -5.3 \times 10^{-4}$$

And

$$\frac{h_1}{a} = \frac{28.75}{9.21} = 3.12$$

and

$$F_e = \frac{e E_1}{q} = \frac{5.3 \times 10^{-4} \times 35000}{150} = 0.124$$

By trial and error it was found that $E_1 = 35000$ psi because when $E_1 = 35000$ psi $F_e = 0.124$ and with $\frac{h_1}{a} = 3.12$ from fig 2.21

$$\frac{E_1}{E_2} = 3.5$$

$$E_1 = 3.5 \times 10{,}000 = 35000 \text{ psi}$$

Data for all problems:

$E_c = 4\times10^6$ psi $K_d = 1.5\times10^6$ pci

$\nu_c = 0.15$ $\alpha = 5\times10^{-6}$ in/in/°F

$E_s = 29\times10^6$ psi $f_a = 1.5$

$\nu_s = 0.3$

Prob 4.1

Data:

Curling stresses = ?

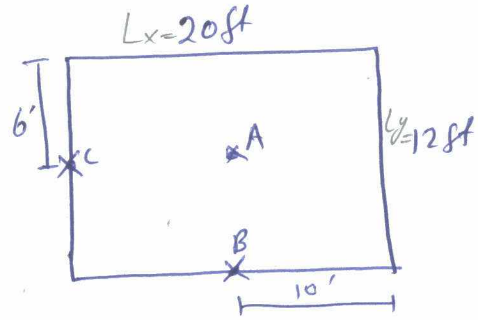
$h = 8$ in

Temperature gradient = 3°F per inch of slab

a) Interior and at edge of infinite slab

b) At A, B, C in finite slab

$K_s = 50$ pci



Sol:

From eq 4.10

$$l = \left[\frac{Eh^3}{12(1-\nu^2)k}\right]^{0.25} = \left[\frac{4\times10^6\times8^3}{12(1-0.15^2)\,50}\right]^{0.25} = 43.23 \text{ in}$$

a) Interior curling stress (At center of slab) (Eq 4.9a)

From fig 4.4

When $L = \infty$

$C_x = C_y \approx 1$

As

In x-direction $\sigma_x = \dfrac{E\alpha_t\,\Delta t}{2(1-\nu^2)}(C_x+\nu C_y)$

$$= \frac{E\alpha_t\,\Delta t}{2(1-\nu^2)}(1+\nu) = \frac{E\alpha_t\,\Delta t}{2(1-\nu)} = \frac{4\times10^6\times5\times10^{-6}\times24}{2(1-0.15)}$$

$\Delta t = 3\times8 = 24$°F

Hence $\sigma_x = 282.35$ psi

Edge stresses in infinite slab.

(eq 4.11) In x-direction $\sigma_x = \dfrac{C_x E\alpha_t\,\Delta t}{2} = \dfrac{1\times4\times10^6\times5\times10^{-6}\times24}{2}$

$= 240$ psi

Stresses are calculated only in x-direction, because they are max. in x direction.

b) From figure 4.4

$$\frac{L_x}{l} = \frac{20\times12}{43.23} = 5.55 \Rightarrow C_x = 0.85$$

$$\frac{L_y}{l} = \frac{12\times12}{43.23} = 3.33 \Rightarrow C_y = 0.25$$

At point A,B,C of finite slab

From eq 4.9a

Center of slab

$$\sigma_{xA} = \frac{E\alpha_t \Delta t}{2(1-\nu^2)}(C_x + \nu C_y)$$

$$= \frac{4\times10^6 \times 5\times10^{-6}\times 24}{2(1-0.15^2)}(0.85 + 0.15\times 0.25) = 218 \text{ psi}$$

From eq 4.11

Edge of slab

$$\sigma_{xB} = \frac{C_x E \alpha_t \Delta t}{2}$$

$$= \frac{0.85\times 4\times10^6 \times 5\times10^{-6}\times 24}{2} = 204 \text{ psi}$$

Edge of slab

From eq 4.11

$$\sigma_{yc} = \frac{C_y E\alpha_t \Delta t}{2}$$

$$= \frac{0.25\times 4\times10^6 \times 5\times10^{-6}\times 24}{2}$$

$$= 60 \text{ psi}$$

Prob 4.2 Same as Example 4.5

Data:

$h = 10$ in

$K_s = 200$ pci

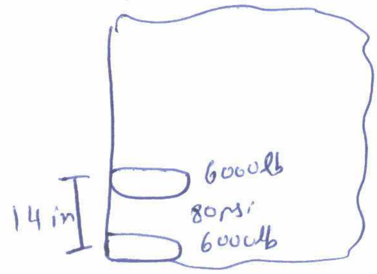
$P =$ Dual wheel load $= 12000$ lb

$S_d = 14$ in

Applied at corner of slab

$q = 80$ psi

Max. stress in concrete by Westergaard Method = ?



Sol:

$P_d =$ Load on single tire $= \frac{12000}{2} = 6000$ lb

As from eq 4.31

$$a = \sqrt{\frac{0.8521 P_d}{q\pi} + \frac{S_d}{\pi}\left(\frac{P_d}{0.5227 q}\right)^{0.5}}$$

$$= \sqrt{\frac{0.8521 \times 6000}{80\pi} + \frac{14}{\pi}\left(\frac{6000}{0.5227 \times 80}\right)^{0.5}}$$

$a = 8.59$ in

From eq 4.10

$$l = \left[\frac{Eh^3}{12(1-\nu^2)k}\right]^{0.25}$$

$$= \left[\frac{4 \times 10^6 \times 10^3}{12(1-0.15^2)\ 200}\right]^{0.25} = 36.14 \text{ in}$$

From eq 4.13

$$\sigma_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

$$= \frac{3 \times 12000}{10^2}\left[1 - \left(\frac{8.59\sqrt{2}}{36.14}\right)^{0.6}\right] = 172.84 \text{ psi}$$

Prob 4.3

Same as Prob 4.2 but load is applied in interior of infinite slab:

Sol:

$1.724h = 1.724 \times 10 = 17.24$ in

Hence From eq 4.19 b ; As $a = 8.59 < 17.24$

$$b = \sqrt{1.6a^2 + h^2} - 0.675h$$

$$= \sqrt{1.6 \times 8.59^2 + 10^2} - 0.675 \times 10 = 8.02 \text{ in}$$

From eq 4.18

$$\sigma_i = \frac{3(1+\nu)P}{2\pi h^2}\left(\ln\frac{l}{b} + 0.6159\right)$$

$$= \frac{3(1+0.15)12000}{2\pi \times 10^2}\left(\ln\left(\frac{36.14}{8.02}\right) + 0.6159\right)$$

$$= 139.8 \text{ psi}$$

Prob 4.4 Same as Prob 4.2, except load is applied on slab edge.

From eq 4.26

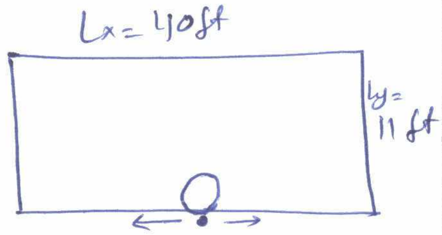
$$\sigma_{e\,circle} = \frac{0.803P}{h^2}\left[4\log\left(\frac{l}{a}\right) + 0.666\left(\frac{a}{l}\right) - 0.034\right]$$

$$\sigma_{e\,circle} = \frac{0.803 \times 12000}{10^2}\left[4\log\frac{36.14}{8.59} + 0.666\left(\frac{8.59}{36.14}\right) - 0.034\right]$$

$$\sigma_{e\,circle} = 252.5 \text{ psi}$$

Prob 4.8

Data:



$L = 40\,ft$

$W = 11\,ft$

$h = 9\,in$

$K_s = 200\,pci$

Single wheel load = 9000 lb on edge

$q = 100\,psi$

a) Curling stress during night when temp. differential is 1.5°F per inch of slab

b) Loading stress due to 9000 lb wheel load.

c) Combined stress at edge beneath load due to (a) and (b).

$\sigma = \frac{P}{A}$

$\pi \cdot \frac{a^2}{2} = \frac{P}{q}$

$a = r = \sqrt{\frac{P}{q\pi}} = \sqrt{\frac{9000}{100\pi}} = 5.35\,in$

Sol:

a) From eq 4.10

$$l = \left[\frac{Eh^3}{12(1-\nu^2)K}\right]^{0.25}$$

$$= \left[\frac{4\times10^6 \times 9^3}{12(1-0.15^2)(200)}\right]^{0.25} = 33.39\ in$$

As from fig 4.4

$$\frac{L_x}{l} = \frac{40\times12}{33.39} = 14.38 \Rightarrow C_x = 1.05$$

$$\frac{L_y}{l} = \frac{11\times12}{33.39} = 3.95 \Rightarrow C_y = 0.5$$

$$\Delta t = 1.5\times 9 = 13.5\ °F$$

From eq 4.11 Curling stress at edge

$$\sigma = \frac{C E \alpha_t \Delta t}{2}$$

$$= \frac{1.05\times 4\times10^6 \times 5\times10^{-6} \times 13.5}{2}$$

$$= 141.75\ psi \quad \text{———} \ (1)$$

b) Loading Stress

From eq 4.26

$$\sigma_{e\,circle} = \frac{0.803P}{h^2}\left[4\log\left(\frac{l}{a}\right) + 0.666\left(\frac{a}{l}\right) - 0.034\right]$$

$$= \frac{0.803 \times 9000}{9^2}\left[4\log\left(\frac{33.39}{5.35}\right) + 0.666\left(\frac{5.35}{33.39}\right) - 0.034\right]$$

$$\sigma_e = 290.31 \text{ psi} \quad \text{———} \; 2$$

c) Combined Stress at edge beneath the load due to 1 and 2

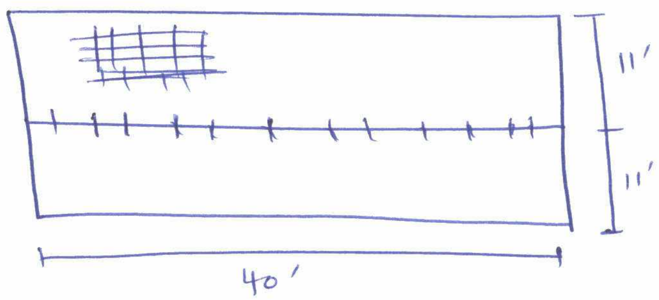
$$\sigma = 290.31 - 141.75 = 148.56 \text{ psi}$$

Prob 4.9

Data: Continue Prob 4.8

a) Design welded wire fabric
b) and tie bars.

$h = 9''$
$K = 200$ pci



Sol:

a) From eq 4.37 (Longitudinal Steel)

$\gamma_c = 150$ pcf
$f_s = 43000$ psi for cold drawn wire smooth

$$A_s = \frac{\gamma_c h L f_a}{2 f_s} = \frac{150 \times 9 \times 40 \times 12 \times 1.5}{12^3 \times 2 \times 43000} = 6.541 \times 10^{-3} \text{ in}^2/\text{in}$$

$$= 0.0785 \text{ in}^2/\text{ft}$$

From eq 4.37 (Transverse steel)

$$A_s = \frac{150 \times 9 \times 22 \times 12 \times 1.5}{12^3 \times 2 \times 43000} = 3.597 \times 10^{-3} \text{ in}^2/\text{in}$$

$$= 0.0432 \text{ in}^2/\text{ft}$$

Use $6 \times 12 - W4.5 \times W4.5$ wire mesh

↓ 0.09   ↓ 0.045 in²/ft

b) Tie bars

$f_s = 27000$ psi for Billet Steel

$L' = 11'$

From eq 4.38

$$A_s = \frac{\gamma_c h L' f_a}{f_s} = \frac{150 \times 9 \times (11 \times 12) \times 1.5}{12^3 \times 27000} = 5.73 \times 10^{-3}\ in^2/in$$

If # 4 bars is used from table 4.2

$A_b = 0.2\ in^2$

$D_b = 0.5 in$

$$\text{Bar spacing} = \frac{A_b}{A_s} = \frac{0.2}{5.73 \times 10^{-3}} = 34.9\ in$$

Design selected

$D_b = 0.5$ in

Length = 22.3in ≈ 2ft

Spacing = 34.9in ≈ 3ft

As From eq 4.40

$$t = \frac{1}{2}\left(\frac{f_s d}{\mu}\right)$$

$$= \frac{1}{2}\left(\frac{27000 \times 0.5}{350}\right)$$

$= 19.3$ in

$t = 19.3 + 3 = 22.3$ in

Prob 4.11

Data $B = 12\,ft$

$h = 10\,in$

$K_s = 300\,pci$

Axle load = 24 000 lb

S_d = 6 ft applied at joint

Edge distance of wheel = 6"

Max. Bearing stress b/w dowel and concrete

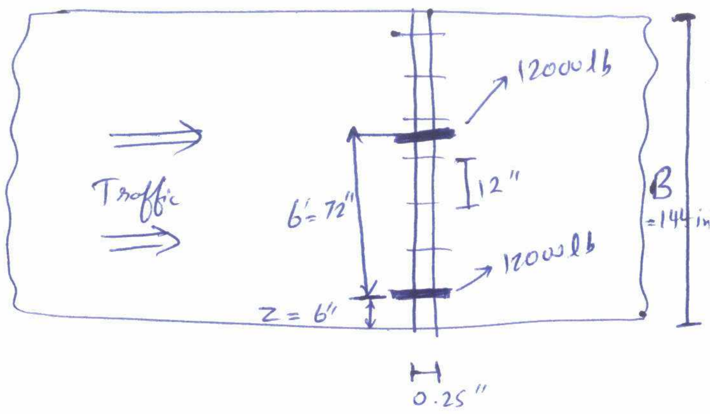
Load transfer = 100%

Z = Joint opening = 0.25 in

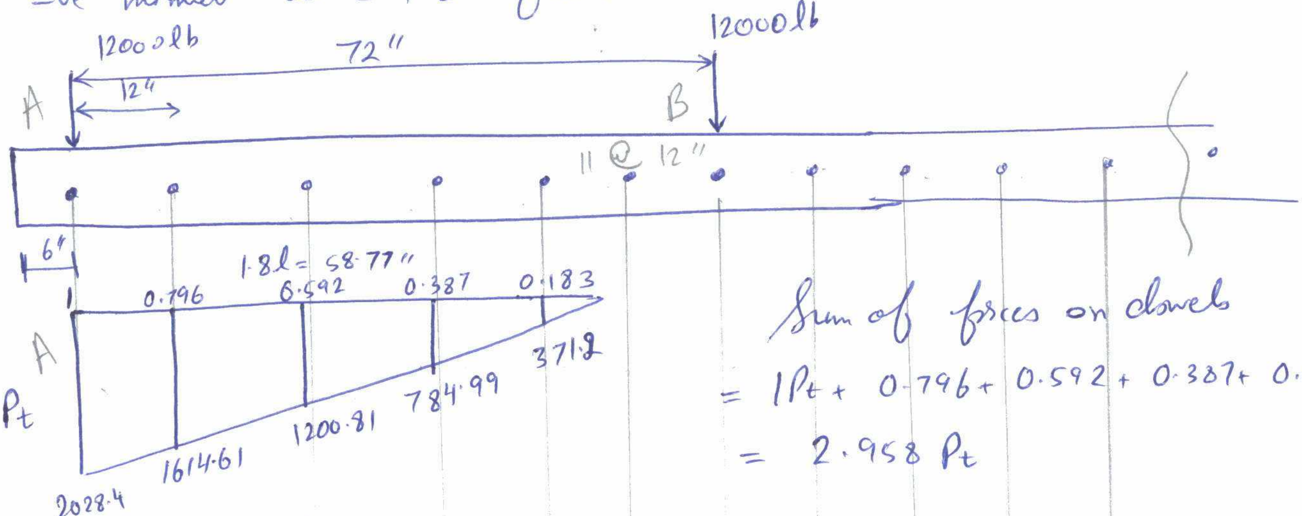
Dowel bar dia = 1"

Spacing of dowels = 12"

Max. −ve moment at = $1.8\,l$ from load.



Sol:



Sum of forces on dowels

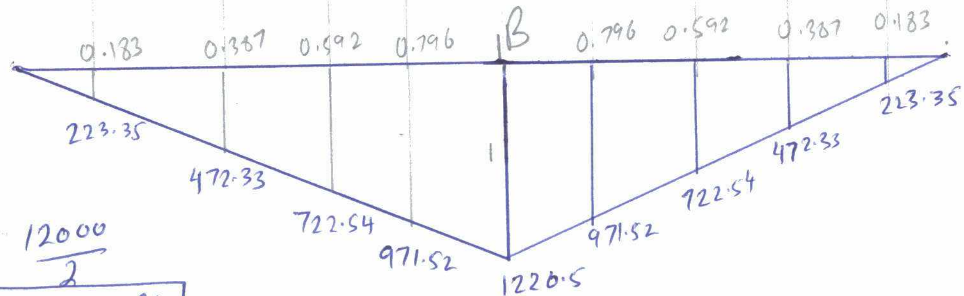
$= 1P_t + 0.796 + 0.592 + 0.387 + 0.183$

$= 2.958\,P_t$

As $2.958\,P_t = \frac{W}{2} = \frac{12000}{2}$

$$\boxed{P_t = 2028.4\,lb}$$

From eq



Sum of forces on all dowels $= 4.916\,P_t$

$4.916\,P_t = \frac{12000}{2}$

$$\boxed{P_t = 1220.5\,lb}$$

The max. stress is at dowel near edge, so don't need to consider interior load.

From eq 4.10

$$l = \left[\frac{Eh^3}{12(1-\nu^2)K}\right]^{0.25} = \left[\frac{4\times10^6\times10^3}{12(1-0.15^2)\,300}\right]^{0.25} = 32.65 \text{ in}$$

$$1.8\,l = 1.8\times32.65 = 58.77 \text{ in}$$

No. of dowels under influence $= \dfrac{58.77}{12} = 5$

From eq 4.43

$$\beta = \sqrt[4]{\frac{Kd}{4E_dI_d}} \quad \text{and} \quad I_d = \frac{\pi d^4}{64}$$

$$= \frac{\pi\,1^4}{64} = 0.0491 \text{ in}^4$$

$$\beta = \sqrt[4]{\frac{1.5\times10^6\times1}{4\times29\times10^6\times0.0491}}$$

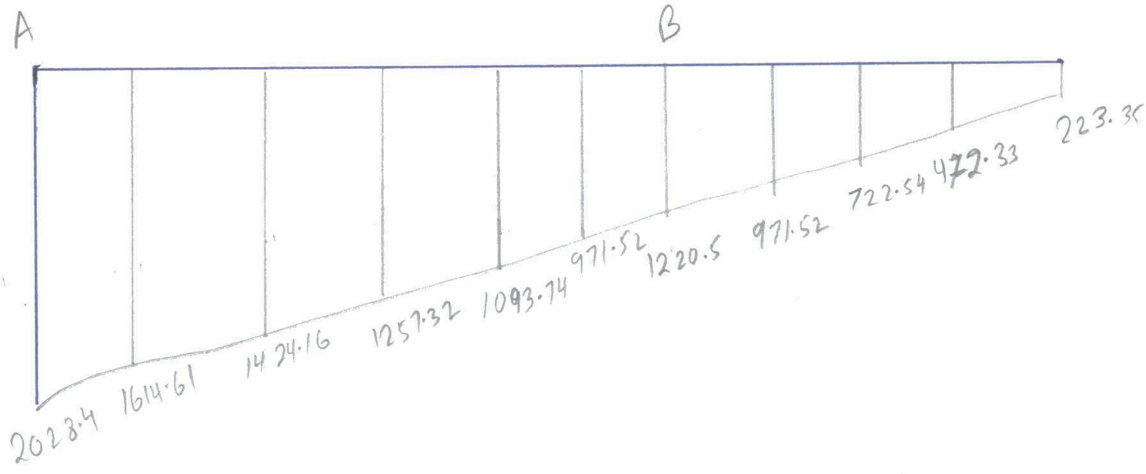
$$= 0.7164$$

From eq 4.45 Max. bearing stress b/w concrete and dowel.

$$\sigma_b = \frac{KP_t(2+\beta z)}{4\beta^3E_dI_d}$$

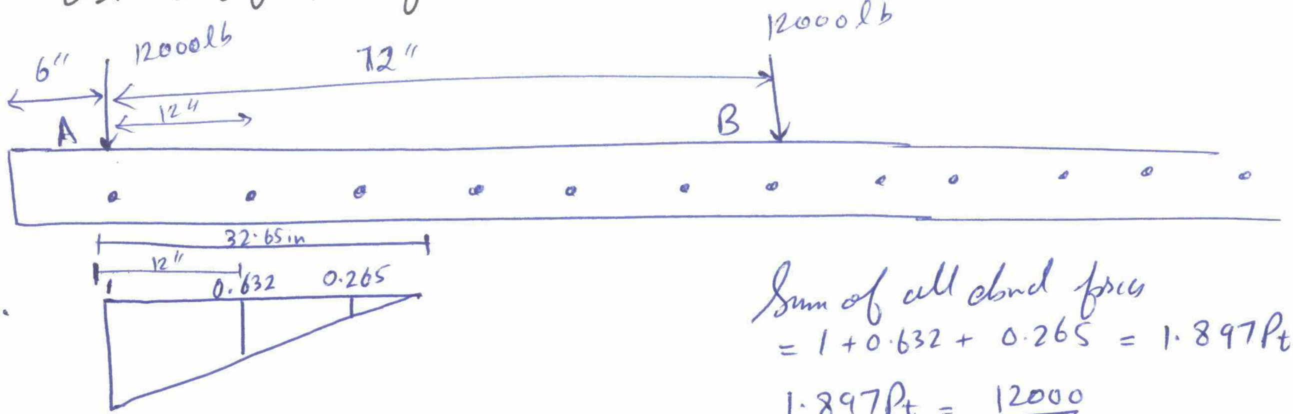
$$\sigma_b = \frac{1.5\times10^6\times2028.4\,(2+0.7164\times0.25)}{4\times0.7164^3\times29\times10^6\times0.0491} = 3166 \text{ psi}$$

Ans



Prob 4.12

Data: Same as Prob. 4.11, Assume max. +-ve moment occurs at distance of 1l from load.



Sum of all dowel forces $= 1 + 0.632 + 0.265 = 1.897 P_t$

$1.897 P_t = \frac{12000}{2}$

$\boxed{P_t = 3162.9 \text{ lb}}$

Since loading spacing = 72 in > l = 32.65 in, only load near the pavement edge to be considered. The right wheel has no effect on max. force P_t on the dowel near the pavement edge. (Same conclusion for Prob 4.11)

From prob 4.11

$\beta = 0.7164$

$I_d = 0.0491 \text{ in}^4$

$\boxed{l = 32.65 \text{ in}}$

∴ No. of dowels under influence $= \frac{32.65}{12} = 3$

Max. bearing stress b/w concrete and dowel bar,

From eq 4.45

$$\sigma_b = \frac{K P_t (2 + \beta z)}{4 \beta^3 E_d I_d}$$

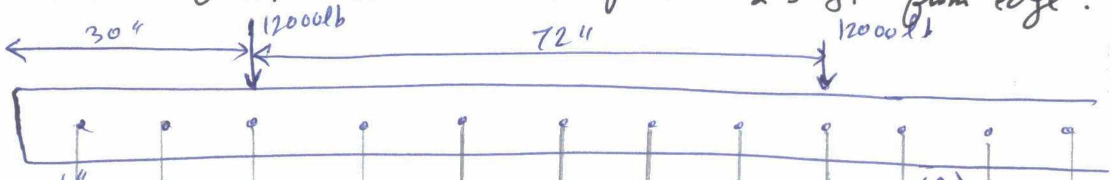
$$= \frac{1.5 \times 10^6 \times 3162.9 (2 + 0.7164 \times 0.25)}{4 \times 0.7164^3 \times 29 \times 10^6 \times 0.0491} = 4936.8 \text{ psi}$$

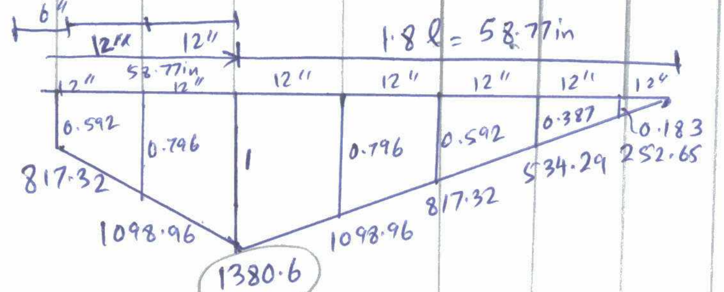
Prob 4.13

no. of dowels = 12

Same as Prob 4.11

Except each of 12,000 lb wheels is placed 2.5 ft $= 30''$ from edge.





(A)

Sum of all dowel forces

$= 0.592 + 0.796 + 1 + 0.796 + 0.592 + 0.387 + 0.183$

$= 4.346 P_t$

$4.346 P_t = \frac{12000}{2}$

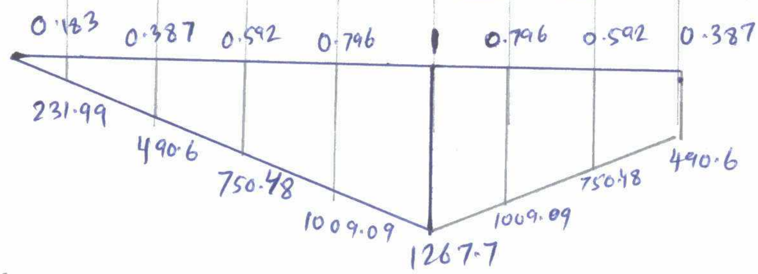
$\boxed{P_t = 1380.6 \text{ lb}}$

(B)

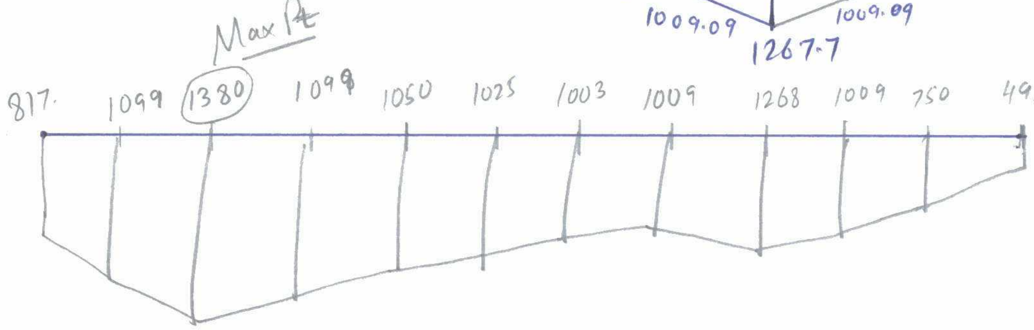
Sum of all dowel forces $= 4.733 P_t$

$4.733 P_t = \frac{12000}{2}$

$\boxed{P_t = 1267.7 \text{ lb}}$



Combined



From Prob 4.11

$l = 32.65$ in $\qquad 1.8\,l = 58.77$ in

No. of dowels under influence $= \frac{58.77}{12} = 5$

$\beta = 0.7164$

$I_d = 0.0491$

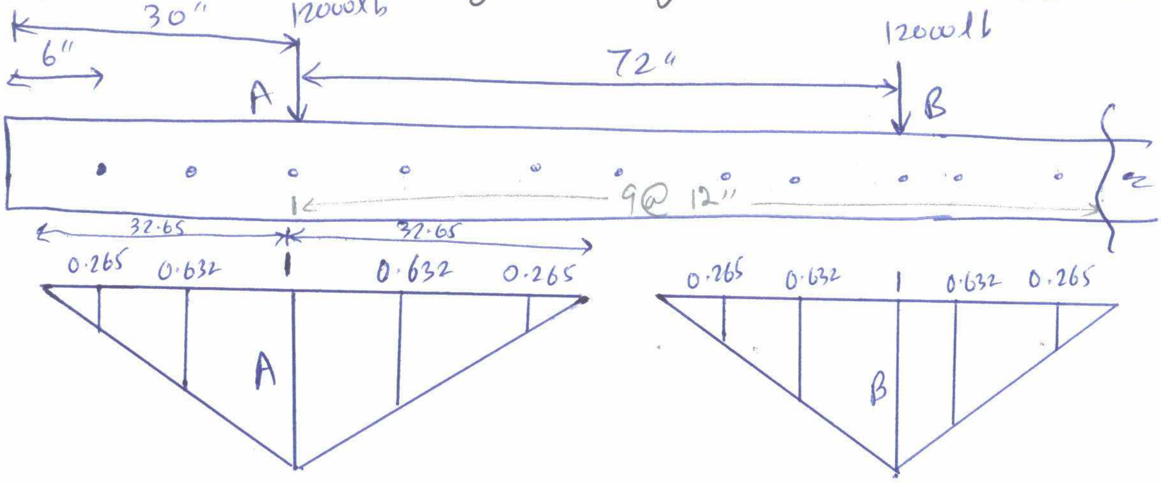
Max. bearing stress b/w concrete and dowel bar

$$\sigma_b = \frac{K P_t (2 + \beta z)}{4 \beta^3 E_d I_d}$$

$$= \frac{1.5 \times 10^6 \times 1380.6\,(2 + 0.7164 \times 0.25)}{4 \times 0.7164^3 \times 29 \times 10^6 \times 0.0491} = 2155 \text{ psi}$$

Prob 4·14

Same as 4·13 by assuming max. −ve moment at 1 l



Sum of all dowel forces

$= 0.265 + 0.632 + 1 + 0.632 + 0.265$

$= 2.794 P_t$

$$2.794 P_t = \frac{12000}{2}$$

$$\boxed{P_t = 2147.5 \text{ lb}}$$

As

From Prob 4·11

$l = 32.65$ in

No. of dowel bars under influence $= \frac{32.65}{12} = 3$

$\beta = 0.7164$

$I_d = 0.0491 \text{ in}^4$

From eq 4·45

Max. bearing stress b/w concrete and dowel bar

$$\sigma_b = \frac{K P_t (2 + \beta z)}{4\beta^3 E_d I_d}$$

$$\sigma_b = \frac{1.5 \times 10^6 \times 2147.5 \times (2 + 0.7164 \times 0.25)}{4 \times 0.7164^3 \times 29 \times 10^6 \times 0.0491}$$

$= 3352$ psi

Prob 6.1

Data:

Dual tires

$S_d = 34$ in

Total load $= 45000$ lb

$q = 100$ psi

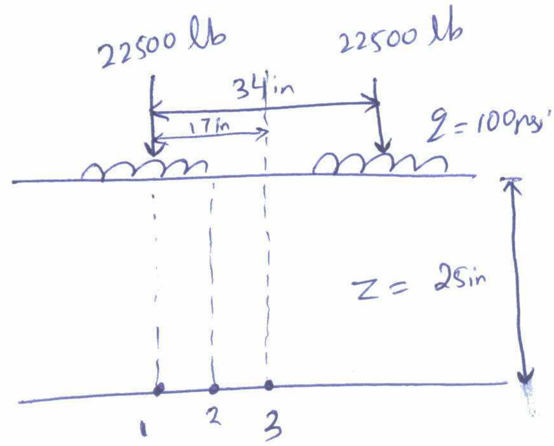
ESWL = ?

$h = 25$ in

a) Boyd and Foster Method

b) Foster and Ahlvin method

c) Huang's chart



Sol:

a) Vertical Stress Criteria

As From eq 6.1

$$\log(ESWL) = \log P_d + \frac{0.301 \log\left(\frac{2z}{d}\right)}{\log\left(\frac{4S_d}{d}\right)}$$

d = clear spacing b/w tires

$= 34 - 2 \times 8.46 = 17.08$ in

$$\log(ESWL) = \log 22500 + \frac{0.301 \log\left(\frac{2 \times 25}{17.08}\right)}{\log\left(\frac{4 \times 34}{17.08}\right)}$$

$$a = \sqrt{\frac{P}{\pi q}} = \sqrt{\frac{22500}{\pi \times 100}}$$

$a = 8.46$ in

ESWL = anti log (4.508)

= 32211.6 lb

b) Vertical deflection Criteria

Using Fig 2.6 for deflection factors $\Rightarrow \frac{Z}{a} = \frac{25}{8.46} = 2.96 \approx 3$

Deflection factors Under dual wheels for a homogeneous half space

Point #	Left Wheel $\frac{r}{a}$	F_s Fig 2.6	Right Wheel $\frac{r}{a}$	F_s	F_d Sum
1	$0/8.46 = 0$	$\boxed{0.47}$	$34/8.46 = 4.02$	0.21	0.68
2	$8.5/8.46 = 1$	0.42	$25.5/8.46 = 3.01$	0.27	0.69
3	$17/8.46 = 2$	0.35	$17/8.46 = 2$	0.35	$\boxed{0.7}$

Using eq 6.6

$$ESWL = \frac{F_d}{F_s} P_d = \frac{0.7 \times 22500}{0.47} = 33510 \text{ lb}$$

c) Equal Interface deflection criteria

Using fig 6.4

1) $a' = \frac{48a}{S} = \frac{48 \times 8.46}{34} = 11.94$ and $\frac{E_1}{E_2} = 1$

$h_1' = \frac{48 h_1}{S} = \frac{48 \times 25}{34} = 35.3$

2) $L_1 = 1.38$

$L_2 = 1.33$

3) $L = L_1 - 0.1 \times (a' - 6)(L_1 - L_2)$

$= 1.38 - 0.1 (11.94 - 6)(1.38 - 1.33) = 1.35$

From eq 6.7b

$ESWL = \frac{2P_d}{L} = \frac{2 \times 22500}{1.35} = 33333$ lb

Prob 6.2

Data:

Dual wheel

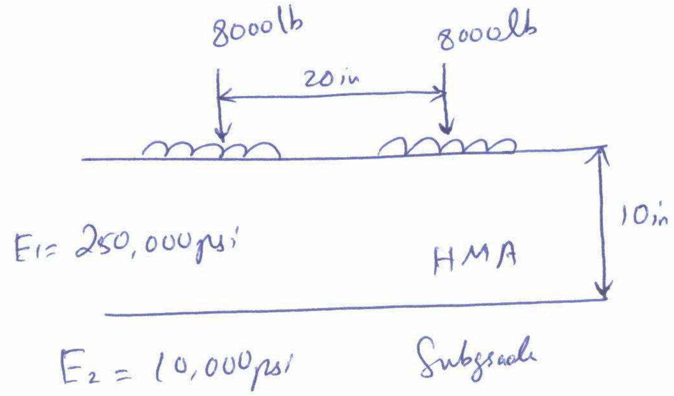
$P_d = 8000\ lb$

$S_d = 20\ in$

$h = 10\ in$

$E_1 = 250{,}000\ psi$

$\nu = 0.5$



Dual wheel radius = Equivalent single wheel radius = 6 in

ESWL = ? a) Equal Interface deflection
b) Equal tensile strain at bottom of asphalt layer.

Sol:

a) Using fig 6.4

1) $a' = \frac{48a}{S} = \frac{48 \times 6}{20} = 14.4$

$h_1' = \frac{48h_1}{S} = \frac{48 \times 10}{20} = 24$

2) $\frac{E_1}{E_2} = \frac{250{,}000}{10{,}000} = 25$

$L_1 = 1.18$

$L_2 = 1.13$

3) $L = L_1 - 0.1(a' - 6) \times (L_1 - L_2)$

$= 1.18 - 0.1(14.4 - 6)(1.18 - 1.13) = 1.138$

Using eq 6.7b

$ESWL = \frac{2P_d}{L} = \frac{2 \times 8000}{1.138} = 14060\ lb$

b)

From eq 2.18a, b

$a' = \frac{24a}{S_d} = \frac{24 \times 6}{20} = 7.2$

$h_1' = \frac{24 h_1}{S_d} = \frac{24 \times 10}{20} = 12$

From figure 2.23

$\frac{E_1}{E_2} = 25 \implies C_1 = 1.3$

$C_2 = 1.43$

From eq 2.19

$C = C_1 + 0.2(a' - 3) \times (C_2 - C_1)$

$= 1.3 + 0.2(7.2 - 3)(1.43 - 1.3) = 1.4092$

From eq 6.14

$ESWL = P_s = C P_d$

$= 1.4092 \times 8000$

$= 11273.6$ lb

Prob 6.3

Data:

Single axle loads

ESAL = ?

$y = 20$ years

a) AI's equivalent axle load factors

b) EALF from eq 6.23

Given Axle load (Kip) (L_x)	Given Number per day N	Table 6.4 F_i (EALF) T_f	From eq 6.23 $EALF = \left(\frac{L_x}{18}\right)^4$ T_f	AI ~~F_d~~ $T_f N$	Eq 6.23 $T_f N$
12	200	0.189	0.198	37.8	39.6
14	117.4	0.36	0.366	42.264	42.968
16	84.5	0.623	0.624	52.644	52.728
18	61.4	1	1	61.4	61.4
20	47.2	1.51	1.524	71.272	71.933
22	21.4	2.18	2.232	46.652	47.765
24	12.9	3.03	3.160	39.087	40.764
26	6.1	4.09	4.353	24.949	26.553
28	2.9	5.39	5.856	15.631	16.982
30	1.2	6.97	7.716	8.364	9.259
32	0.7	8.88	9.989	6.216	6.992
34	0.3	11.18	12.73	3.354	3.819
				$\Sigma = 409.636$	420.763

Since no data is given about r, L, D, Hence using G Y DL = 20

For $r = 0$
$Y = 20 \rightarrow GY = 20$

By AI method $ESAL = \Sigma T_f N \times (GY \times DL)\, 365$

$= 409.636 \times 20 \times 365$

$= 2.99$ Million

By eq 6.23

$ESAL = 420.763 \times 20 \times 365$

$= 3.07$ Million

Prob 6.4

Based on eq 6.25 discuss effect of P_t on EALF

For rigid pavements

terminal serviceability of new pavement $P_t = 4.5$

" " " failed " $= P_t = 1.5$

Let $D = 9$ in

L_x = Single axle load = 18 Kip

$L_2 = 1$

when $P_t = 1.5$	when $P_t = 2.5$	when $P_t = 2$
$\Rightarrow G_t = \log\left(\frac{4.5-1.5}{4.5-1.5}\right) = 0$	$G_t = -0.176$	$G_t = -0.079$
$\Rightarrow \beta_x = 1 + \frac{3.63(18+1)^{5.2}}{(9+1)^{8.46}(1)^{3.52}} = 1.06$	$\beta_x = 1.056$	$\beta_x = 1.056$
$\Rightarrow \beta_{18} = 1 + \frac{3.63(18+1)^{5.2}}{(9+1)^{8.46}(1)^{3.52}} = 1.06$	$\beta_{18} = 1.06$	$\beta_{18} = 1.06$
$\Rightarrow \log\frac{W_{tx}}{W_{t18}} = 4.62\log(18+1) - 4.62\log(18+1) + 3.28\log(1) + \frac{0}{1.06} - \frac{0}{1.06}$	$\frac{W_{tx}}{W_{t18}} = 1$	$\frac{W_{tx}}{W_{t18}} =$
$\frac{W_{tx}}{W_{t18}} = 1$		
EALF = 1	EALF = 1	

Prob 6.5

Derive

$$G_r y = \frac{(1+r)^y - 1}{r}$$

and indicate the assumptions on which equation is obtained

Hint $\quad G_r y = \int_0^y (1+r)^n$

$$= \left. \frac{(1+r)^n}{\ln(1+r)} \right|_0^y$$

$$\ln(1+r) = r - \frac{1}{2} r^2 + \ldots$$

when r is much smaller than 1, the 2nd and all higher order terms can be neglected or

$$\ln(1+r) = r$$

So,

$$G_r y = \frac{(1+r)^y}{r} - \frac{1}{r}$$

$$= \frac{(1+r)^y - 1}{r}$$

Assumption is $\quad r \lll 1$