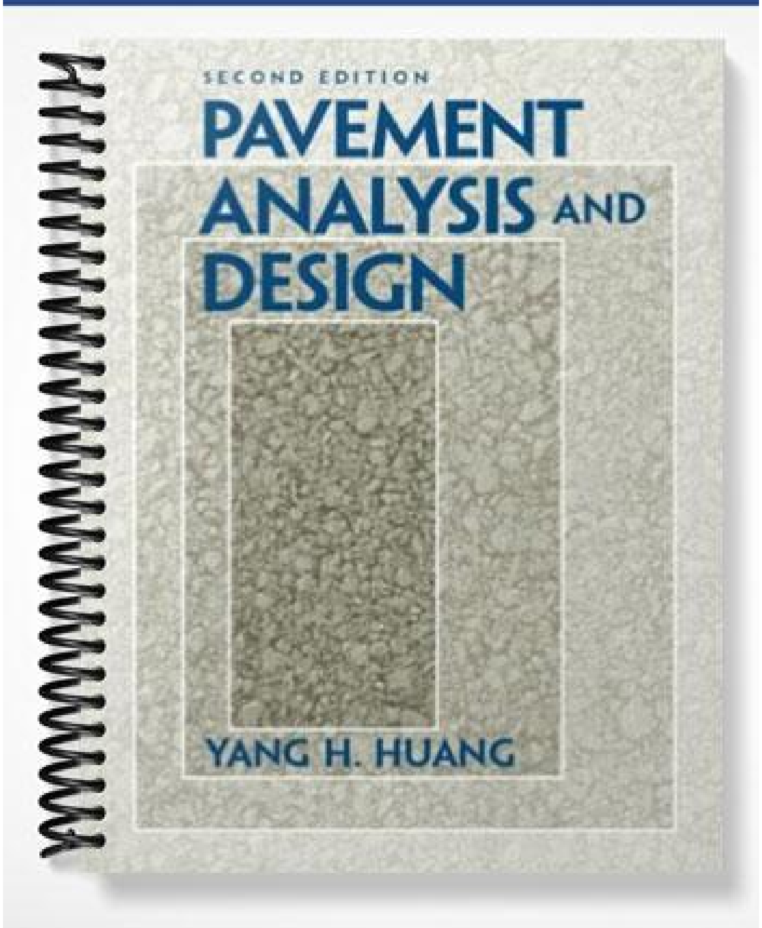
SOLUTIONS MANUAL



SOLUTIONS MANUAL

PAVEMENT ANALYSIS AND DESIGN

SECOND EDITION

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PEARSON
Prentice Hall

Pearson Education, Inc.
Upper Saddle River, New Jersey 07458

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Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, NJ 07458

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-184244-7

Pearson Education Ltd., *London*
Pearson Education Australia Pty. Ltd., *Sydney*
Pearson Education Singapore, Pte. Ltd.
Pearson Education North Asia Ltd., *Hong Kong*
Pearson Education Canada, Inc., *Toronto*
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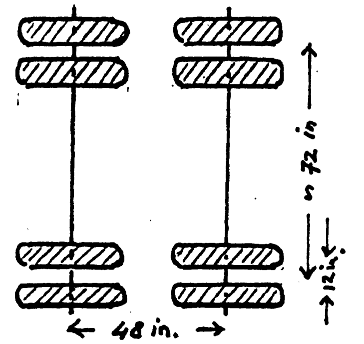
Chapter 1
Introduction

1-1. The wheel configuration for a dual-tandem axle is as follows :



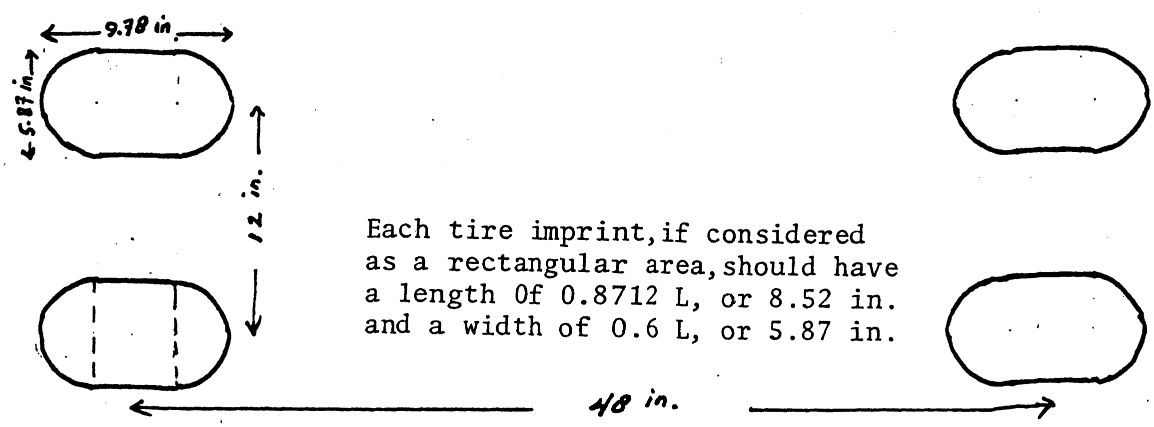
The 40 Kip load is applied over 8 tires. Thus, each tire bears 5000 Lbs (22.2 kN) load with 100 Psi (690 kPa) tire pressure. The contact area of each tire, Ac= Load of each tire/tire pressure = 5000/100 = 50 $in.^2$ (8.2×10^4 mm^2). The dimension of the contact area is :

From Eq.1.7. (Lecture Text) :

$$L = \sqrt{Ac/0.5227} = \sqrt{50/0.5227}$$
$$= 9.78 \text{ in. } (248 \text{ mm}).$$

$$\text{width} = 0.6\ L = 5.87 \text{ in } (149 \text{ mm.})$$

The most realistic contact area consisting a rectangle and two semi-circles as shown in following figure :



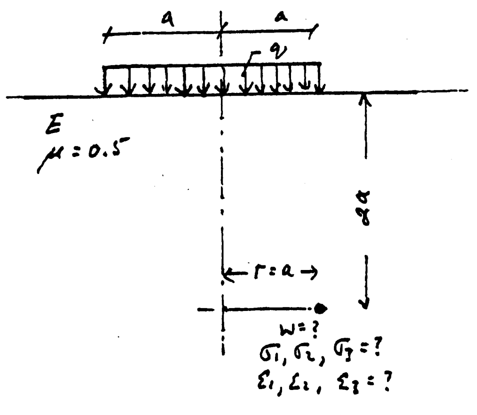
Each tire imprint, if considered as a rectangular area, should have a length Of 0.8712 L, or 8.52 in. and a width of 0.6 L, or 5.87 in.

1-2. Freezing Index = (32 - 24) x 30 +(32 + 3) x 31 + (32 - 14) x 31 + (32 - 16) x 28 + (32 - 22) x 31 + (32 -25) x 30 = 2851 degree days.

Yes, this value is likely to be different because the last few days in October and the first few days in May may have mean daily temperatures lower than $32^{o}F$, so the degree days for these two months may not be zero.

Chapter 2
Stresses and Strains in Flexible Pavements

2-1.



Solution:

$r/a = 1$; $z/a = 2$

From Fig. 2.2:

$(\sigma_z/q)100\% = 18$

$\sigma_z = 0.18\,q$

From Fig 2.3:

$(\sigma_r/q)\times 100\% = 4.05$

$\sigma_r = 0.0405\,q$

From Fig 2.4:

$(\sigma_t/q)\,100\,\% = 1.1$

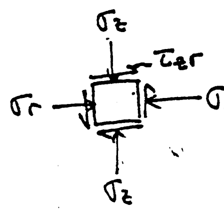
$\sigma_t = 0.011\,q$

From Fig. 2.5: $\left(\frac{\tau_{rz}}{q}\right)100\% = 8.0$

$\therefore\ \tau_{rz} = 0.08\,q$.

The principal stresses can be calculated by following formula:

General form: $\sigma_1, \sigma_2 = \frac{\sigma_x+\sigma_y}{2} \pm \sqrt{\tau_{xy}^2 + \left(\frac{\sigma_x-\sigma_y}{2}\right)^2}$



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

$= \frac{0.18\,q + 0.0405\,q}{2} \pm \sqrt{0.08q^2 + \left(\frac{0.18\,q - 0.0405\,q}{2}\right)^2}$

$\underline{\sigma_1 = 0.22\,q}$ ✓ & $\underline{\sigma_3 = 0.0041\,q}$. ✓

(z - r plane).

There is no shear stress in z - t plane, therefore

$\underline{\sigma_t = \sigma_2 = 0.011\,q}$ is principal stress. ✓

Vertical displacement:

From Fig. 2.6, for $\frac{r}{a} = 1$ & $z/a = 2 \rightarrow F = 0.57$

$\therefore\ w = \frac{qa}{E} \times F = \underline{0.57\,\frac{qa}{E}}$ ✓

Strains:

$\varepsilon_1 = \frac{1}{E}\left(\sigma_1 - \mu\,(\sigma_2 + \sigma_3)\right]$

$= \frac{q}{E}\left[0.22 - 0.5(0.0041 + 0.011)\right]$

$\underline{\varepsilon_1 = 0.212\,q/E}$ ✓

$$\varepsilon_2 = \frac{1}{E}[(\sigma_2 - \mu(\sigma_1 + \sigma_3)]$$
$$= \frac{q}{E}[(0.011 - 0.5(0.22 + 0.0041)]$$
$$\underline{\varepsilon_2 = -0.101\ q/E}\ ✓$$

$$\varepsilon_3 = \frac{1}{E}[(\sigma_3 - \mu(\sigma_1 + \sigma_2)]$$
$$= q/E\,[0.0041 - 0.5(0.22 + 0.011)]$$
$$\underline{\varepsilon_3 = -0.1114\ q/E}\ ✓$$

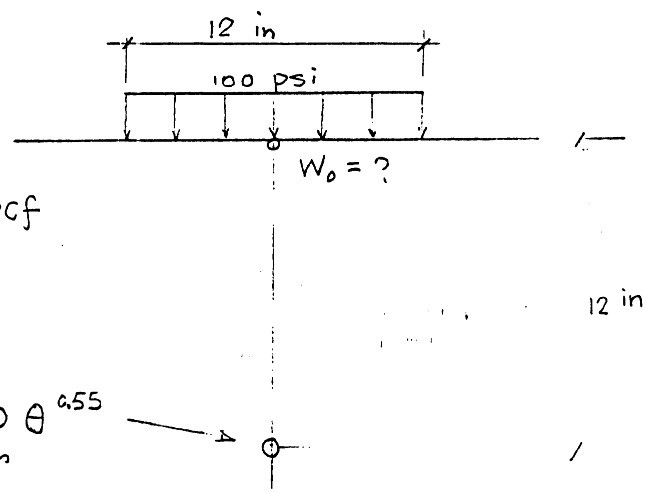
$\therefore\ \sigma_1 = 0.22\,q,\ \sigma_2 = 0.011\,q,\ \sigma_3 = 0.0041\,q$

$\varepsilon_1 = 0.212\ q/E;\ \varepsilon_2 = -0.101\ q/E;\ \varepsilon_3 = -0.1114\ q/E$

$w = 0.57\ \frac{qa}{E}$ ✓

2-2.

Given:



$\gamma = 100$ pcf

$K_o = 0.6$

$\nu = 0.35$

$a = 6$ in

$E = 3000\,\theta^{0.55}$

$z = 12$ in

Boussinesq's stress distribution is valid

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

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

$$\sigma_r = \sigma_t = \frac{q}{2}\left[1 + 2\nu - \frac{2(1+\nu)z}{(a^2+z^2)^{1/2}} + \frac{z^3}{(a^2+z^2)^{3/2}}\right]$$
$$= \frac{100}{2}\left[1 + 2*0.35 - \frac{2(1+0.35)*12}{(6^2+12^2)^{1/2}} + \frac{12^3}{(6^2+12^2)^{3/2}}\right]$$
$$= 0.0294 \text{ psi}$$

$$\Theta = 28.446 + 2 * 0.0294 + \frac{100}{12^3} * 12 * (1 + 2 * 0.6)$$

$$= 30.03 \text{ psi}$$

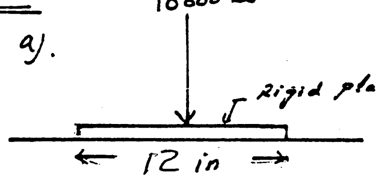
$$E = 3000\, \Theta^{0.55} = 19489.34 \text{ psi}$$

$$W_0 = \frac{(1+\nu) q a}{E} 2(1-\nu) = \frac{2(1-\nu^2) q a}{E}$$

$$= \frac{2(1-0.35^2)\, 100 * 6}{19489.34} = \underline{0.054} \text{ in}$$ ✓ #

2-3 :

a).



Subgrade $E_2 = ?$

Rigid plate deflects 0.2 in.

The average pressure on the plate : ✓

$$q = \frac{P}{A} = \frac{10600}{\frac{1}{4}\pi\, 12^2} = 93.7 \text{ psi}.$$

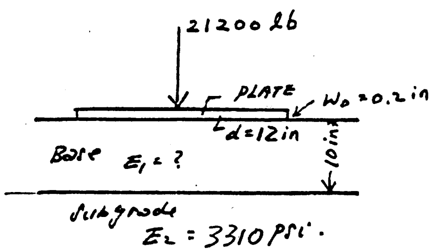
deflection of plate can be calculated by:

$$W_0 = \frac{\pi(1-\mu^2) q a}{2E_2} \qquad W_0 = 0.2 \text{ in}; \ a = 6 \text{ in}; \ \mu = 0.5.$$

$$E_2 = \frac{\pi(1-\mu^2) q a}{2 W_0} = \frac{\pi(1-0.5^2) \times 93.7 \times 6}{2 \times 0.2}$$

$$E_2 = \underline{3310 \text{ psi}}. \ ✓$$

b).



$$q = \frac{P}{\frac{1}{4}\pi d^2} = \frac{21200}{\frac{1}{4}\pi\, 12^2} = \underline{187.5 \text{ psi}}.$$

$h_1 = 10$ in. $\quad W_0 = 0.2$ in.

$a = 6$ in

Two-layer system → Burmister :

$$h_1/a = \frac{10}{6} = 1.67$$

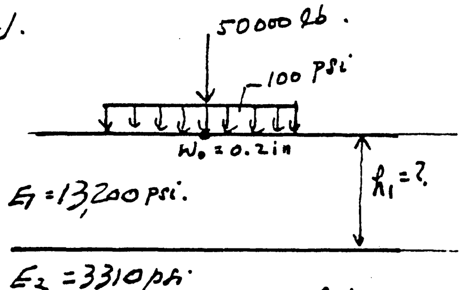
for Rigid plate : $$W_0 = \frac{1.178\, q \cdot a}{E_2} F_2$$

$$F_2 = \frac{W_0 E_2}{1.178\, q \cdot a} = \frac{0.2 \times 3310}{1.178 \times 187.5 \times 6} = 0.5$$

for $h_1/a = 1.67$; $F_2 = 0.5$, from Fig. 2.17, E_1/E_2 can be determined

$$E_1/E_2 = 4 \rightarrow E_1 = 13{,}200 \text{ psi}$$ ✓

e/.



$h_1/a = ?$

$$A_c = \frac{P}{\sigma} = \frac{50000}{100} = 500 \text{ in}^2.$$

$$a = 12.6 \text{ in}$$

surface deflection

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

$$F_2 = \frac{W_o E_2}{1.5\, q a} = \frac{0.2 \times 3310}{1.5 \times 100 \times 12.6}$$

$$F_2 = 0.35$$

From Fig. 2.17, for $F_2 = 0.35$ and $E_1/E_2 = 4$

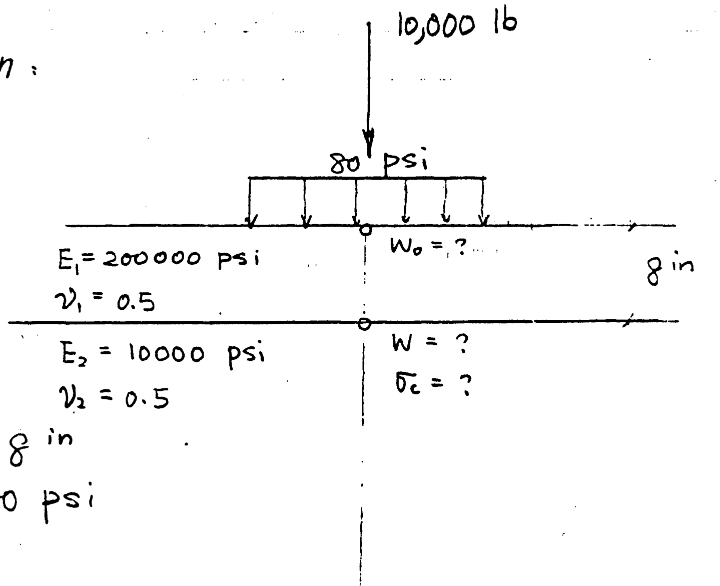
$$\frac{h_1}{a} = 5.5$$

$$h_1 = 5.5\, a = 5.5 \times 12.6 = \underline{70 \text{ in.}}$$

$\therefore$ $E_2 = 3310$ psi ; $E_1 = 13{,}200$ psi ; $h_1 = 70$ in. ✓

2-4.

Given :



$h_1 = 8$ in

$q = 80$ psi

$$\frac{10000}{\pi a^2} = 80$$

$$a = \sqrt{\frac{10000}{\pi * 80}} = 6.31 \text{ in}$$

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

($E_1/E_2 = 20$, $h_1/a = 1.268$)

$F_2 = 0.33$ (Fig 2.17)

$$= \frac{1.5 * 80 * 6.31}{10000} * 0.33$$

$$= \underline{0.025} \text{ in}$$ ✓

$W = \frac{q a}{E} \cdot F$ ($E_1/E_2 = 20$, $h_1/a = 1.268$, $r/a = 0$)

$= \frac{80 * 6.31}{10000} * 0.483$

Interpolate (Fig 2.19): $E_1/E_2 = 10$, $F = 0.595$; $E_1/E_2 = 25$, $F = 0.425$; $E_1/E_2 = 20$, $F = 0.483$

$= \underline{0.0244}$ in ✓

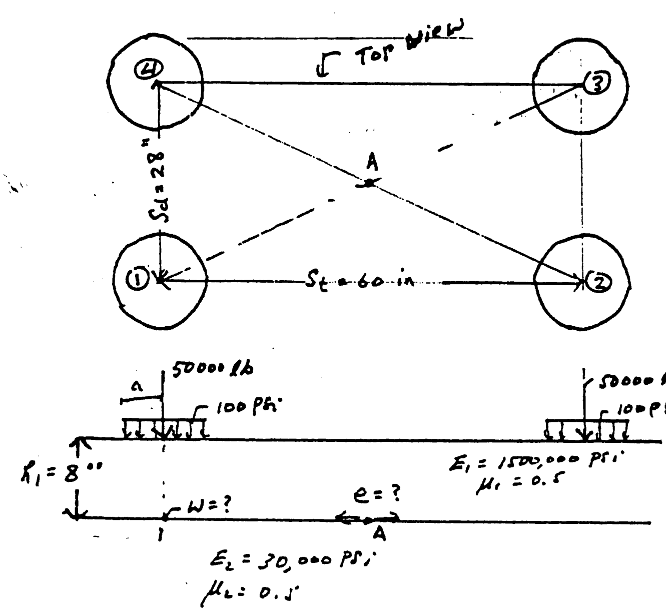
$\sigma_c/q = 0.153$

Interpolate (Fig 2.15): $E_1/E_2 = 10$, $\sigma_c/q = 0.21$; $E_1/E_2 = 25$, $\sigma_c/q = 0.125$; $E_1/E_2 = 20$, $\sigma_c/q = 0.153$; $a/h = 0.789$

$\sigma_c = 0.153\, q = \underline{12.24}$ psi # ✓

Note. The linear interpolation is used to get the coefficient value between 2 chart given values. The nonlinear interpolation has been also tried and no big differecen was shown
say linear interpolation $\sigma_c/q = 0.153$ use 2 points.
Nolinear interpolation $\sigma_c/q = 0.15$ use 3 points

2-5:



Contact area $A = \frac{P}{q} = \frac{50000}{100}$
$A = 500\ in^2$.
$a = 12.6$ in.
$Sd = 28$ in
$St = 60$ in.

$E_1/E_2 = 50$

Since design charts are based on $Sd = 24$ in, thus, for $Sd = 28$ in
a, h, St' must be modified:

$St' = St\,\frac{24}{28} = 60 \times \frac{24}{28} = 51.4$ in.

$a' = \frac{24}{28} a = 10.8$ in" ; $h' = \frac{24}{28} h = 6.86$ in.

Determination Conversion factor C, using Figs. 2.26 and 2.27

- For $S_t = 48$ in ; $E_1/E_2 = 50$; $h' = 6.86$

$C_2 = 1.135$ & $C_1 = 1.08$

$$C = C_1 + 0.2\,(a' - 3) \times (C_2 - C_1) = 1.166$$

- For $S_t = 72$ in ; $E_1/E_2 = 50$; $h' = 6.86$

$C_2 = 1.3$; $C_1 = 1.12$

$$C = 1.12 + 0.2\,(10.8 - 3)(1.3 - 1.12) = 1.4.$$

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

$S_t' = 57.4$ in $\rightarrow$ $C = ?$ $\rightarrow$ Linear interpolation

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

$$C \text{ for } S_t' = 57.4 \text{ in} = 1.4 - \left(\frac{1.4 - 1.166}{72 - 48}\right)(72 - 51.4)$$

$$= \underline{\underline{1.2}}.$$

Strain Factor (F_e):

From Fig. 2.21 for $\frac{h'}{a'}$ or $\frac{h}{a} = 0.64$ and $E_1/E_2 = 50$, $F_e = 2.5$

Modified $F_e = F_e' = C \times F_e = 1.2 \times 2.5 = 3.0$.

Critical tensile strain : $e = \frac{q}{E_1} F_e'$

$$= \frac{100}{150000} \times 3$$

$\underline{\underline{e = 2.0 \times 10^{-4}}}$ (below point A).

b). Vertical deflection on surface of subgrade under the center of one wheel (say, point 1).

using Fig. 2.17

deflection factor F can be determined.

	LOADING ① (x)	LOADING ②	LOADING ③	LOADING ④
E_1/E_2	50	50	50	50
h_1/a	0.635	0.635	0.635	0.635
a (in)	12.6	12.6	12.6	12.6
r (in)	0 (x)	60	66.2	28
r/a	0	4.76	5.25	2.22
F	0.62	0.20	0.15	0.37

(x). See: wheele configuration.

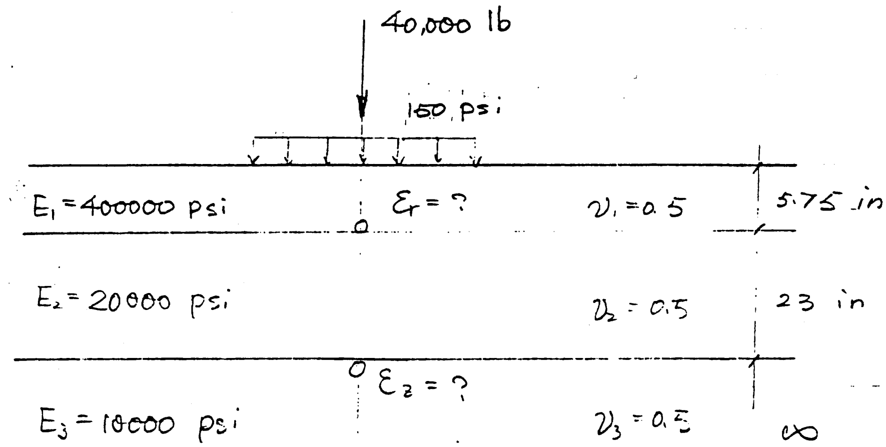
$F_{total} = 1.34$

$$W = \frac{q \cdot a}{E_2} F = \frac{100 \times 12.6}{30\,000} \times 1.34 = \underline{0.0563 \text{ in.}}$$

Answer: $e = 2.0 \times 10^{-4}$; $W = 0.0563$ in.

2-6

Given.



$$a = \sqrt{\frac{40000}{\pi \cdot 150}} = 5.21 \text{ in}$$

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

$$= \frac{-150}{400000} * 2$$

$$= \underline{-0.00075} \quad (\text{tension})$$

$K_1 = \frac{E_1}{E_2} = 20$

$K_2 = \frac{E_2}{E_3} = 2$

$A = \frac{a}{h_2} = \frac{9.21}{23} = 0.4$

$H = \frac{h_1}{h_2} = \frac{5.75}{23} = 0.25$

$\frac{RR1 - ZZ1}{2} = 2$ (Fig 2.31c)

If use Table 2.3

$ZZ1 - RR1 = 3.86779$

$$\varepsilon_r = \frac{q}{E_1}\frac{(RR1 - ZZ1)}{2}$$

$$= -\frac{150}{400000} \cdot \frac{3.86779}{2}$$

$$= -0.000725 \quad \text{(tension)}$$

No big difference between Using Table from using Figures.

when $\nu = 0.5$.

Table 2.3

$(ZZ2 - RR2) = 0.14159$

$$\sigma_{z2} - \sigma_{r2} = q\,(ZZ2 - RR2)$$

$$= 150 * 0.14159 = 21.23$$

$$\sigma_{z2} - \sigma_{r2}' = (\sigma_{z2} - \sigma_{r2})/k_2$$

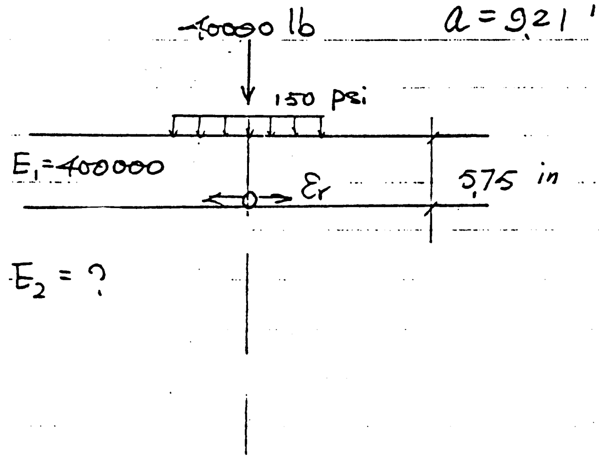
$$= 21.23/2 = 10.61 \text{ psi}$$

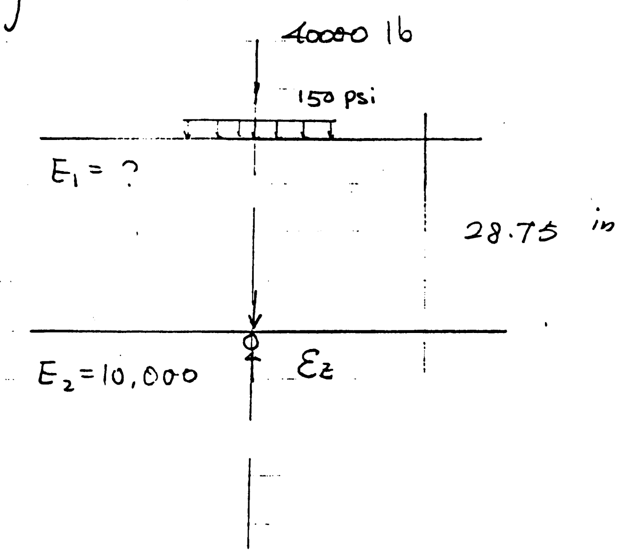
$$\varepsilon_z = \frac{\sigma_{z2} - \sigma_{r2}'}{E_2} = \frac{10.61}{10000} = \underline{0.001062} \quad \checkmark \; \#$$

2-7.

Given, $\varepsilon_r = -0.000725$, $\varepsilon_z = 0.001062$ } from 2-6

$a = 9.21$ in ✓





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

$$F_e = \frac{\varepsilon_r \cdot E_1}{q} = \frac{0.000725 \times 400000}{150} = 1.933 \quad \checkmark$$

$h_1/a = 0.624$ ✓

$E_1/E_2 \doteq 20$ from Fig. 2.17

$$E_2 = E_1/20 = 400000/20 = \underline{20000} \text{ psi.} \quad \checkmark$$

$\varepsilon_z = 0.00106$, from Eq. 2.21, $\varepsilon_r = 0.5\,\varepsilon_z = 0.00053$

By trial and error, it was found $E_1 = 35{,}000$ psi

because when $E_1 = 35{,}000$ psi $\quad F_e = \dfrac{0.00053 \times 35000}{150} = 0.124$

and with $\dfrac{h_1}{a} = \dfrac{28.75}{9.21} = 3.12$, from Fig. 2.21

$\dfrac{E_1}{E_2} = 3.5 \quad$ or $\quad E_1 = 3.5 \times 10{,}000 = \underline{35{,}000 \text{ psi}}$

2-8. For the Maxwell model $D(t) = \dfrac{1}{E_0}\left(1 + \dfrac{t}{T_0}\right)$

$$W_0 = \frac{2(1-\nu^2)\,q\,a}{E} = \frac{2 \times 0.91 \times 80 \times 6}{10{,}000}\left(1 + \frac{t}{10}\right)$$

$$= 0.0874\,(1 + 0.1t)$$

(a) For triangular loading

$$L(t) = \frac{2t}{d} + 1 \qquad \text{for} \quad -\frac{d}{2} < t \le 0$$

$\dfrac{dL}{dt} = \dfrac{2}{d}$ Since the first term of W_0 is constant independent of t, so Boltzmann's superposition principle need only be applied to the second term

$$W_0 = 0.0874 + 0.0874 \times \frac{2}{10}\int_{-5}^{0} 0.1\,t\,dt$$

$$= 0.0874 + 0.00175\,\frac{t^2}{2}\Big|_{-5}^{0} = \underline{0.109} \text{ in.}$$

(b) For haversine loading, from Eqs 2.57 and 2.58

$$W_0 = 0.0874 + 0.0874\left(\frac{\pi}{10}\right) \times 0.1 \int_{-5}^{0} \sin\left(\frac{2\pi t}{10}\right) t\,dt$$

$$= 0.0874 - 0.00275\left[\frac{1}{(0.2\pi)^2}\sin(0.2\pi t) - \frac{t}{0.2\pi}\cos(0.2\pi t)\right]_{-5}^{0}$$

$$= 0.0874 + 0.00275\left(\frac{5}{0.2\pi}\right) = \underline{0.109} \text{ in.}$$

Chapter 3
KENLAYER Computer Program

```
1   (1) NPROB
Problem 3.1
2   0   1   1   (3) MATL NDAMA NPY NLG
0.001   (4) DEL
2   1   80   1   0   (5) NL NZ ICL NSTD NUNIT
12    (6) TH
0.35    0.35    (7) PR
0    (8) ZC
1   (9) NBOND
3000    3000    (11) E
0    (13) LOAD
6    100    (14) CR CP
1    (16) NR
0    (17) RC
2   2   (25) NOLAY ITENOL
1    0    2    0    (26) LAYNO NCLAY
12    12    (27) ZCNOL
0   0   0   0   0.01   (28) RCNOL XCNOL YCNOL SLD DELNOL
1    (29) RELAX
145    0    (30) GAM
0.55   0.6   (31) K2 K0
0.55   0.6   (31) K2 K0
0    3000    (33) PHI K1
0    3000    (33) PHI K1
```

answer: 0.05339 in.

```
1   (1) NPROB
PROBLEM 3.2
1   0   1   1   (3) MATL NDAMA NPY NLG
0.001   (4) DEL
2   2   80   5   0   (5) NL NZ ICL NSTD NUNIT
8    (6) TH
0.5    0.5    (7) PR
0    8    (8) ZC
1   (9) NBOND
200000    10000    (11) E
0    (13) LOAD
6.308    80    (14) CR CP
1    (16) NR
0    (17) R
```

answer: 0.02512 in.
0.02347 in.
11.394 psi

```
1   (1) NPROB
PROBLEM 3.3
1   0   1   1   (3) MATL NDAMA NPY NLG
0.001   (4) DEL
2   1   80   9   0   (5) NL NZ ICL NSTD NUNIT
8    (6) TH
0.5    0.5    (7) PR
8    (8) ZC
1   (9) NBOND
1500000    30000    (11) E
2    (13) LOAD
12.616    100    (14) CR CP
1    (19) NPT
60    28    0    0    (20) XW YW XPT
```

answer: -2.065E-04
0.05709 in.

```
1  (1) NPROB
PROBLEM 3.4
1  0  1  1   (3) MATL NDAMA NPY NLG
0.001   (4) DEL
3  2  80  9  0   (5) NL NZ ICL NSTD NUNIT
5.75   23   (6) TH
0.5   0.5   0.5   (7) PR
5.75   28.7501   (8) ZC
1  (9) NBOND
400000   20000   10000   (11) E
0   (13) LOAD
9.213   150   (14) CR CP
1   (16) NR
0   (17) RC
```

Answer:
-7.259 E-04
1.065 E-03

```
2  (1) NPROB
PROBLEM 3.5(a)
2  0  1  1  (3) MATL NDAMA NPY NLG
0.001  (4) DEL
4  2  80  9  0  (5) NL NZ ICL NSTD NUNIT
8   2   2   (6) TH
0.45   0.3   0.3   0.4   (7) PR
8   12.0001   (8) ZC
1  (9) NBOND
500000   30000   15000   5000   (11) E
0   (13) LOAD
4.5   75   (14) CR CP
1   (16) NR
0   (17) RC
3  15  (25) NOLAY ITENOL
2   0   3   0   4   1   (26) LAYNO NCLAY
9   11   13   (27) ZCNOL
0  0  0  0  0.01  (28) RCNOL XCNOL YCNOL SLD DELNOL
0.5   (29) RELAX
145   135   135   130   (30) GAM
0.5  0.6  (31) K2 K0
0.5  0.6  (31) K2 K0
6.2  1110  178  0.8  (31) K2 K3 K4 K0
0   10000   (33) PHI K1
0   10000   (33) PHI K1
1827   7682   3020   (33) EMIN EMAX K1
```

answer:
-1.019 E-04
2.845 E-04

```
PROBLEM 3.5(b)
2  0  1  1  (3) MATL NDAMA NPY NLG
0.001  (4) DEL
3  2  80  9  0  (5) NL NZ ICL NSTD NUNIT
8   4   (6) TH
0.45   0.3   0.4   (7) PR
8   12.0001   (8) ZC
1  (9) NBOND
500000   20000   5000   (11) E
0   (13) LOAD
4.5   75   (14) CR CP
1   (16) NR
0   (17) RC
2  15  (25) NOLAY ITENOL
2   0   3   1   (26) LAYNO NCLAY
9   13   (27) ZCNOL
0  0  0  0  0.01  (28) RCNOL XCNOL YCNOL SLD DELNOL
0.5   (29) RELAX
145   135   130   (30) GAM
0.5  0.6  (31) K2 K0
6.2  1110  178  0.8  (31) K2 K3 K4 K0
10000   10000   (33) PHI K1
1827   7682   3020   (33) EMIN EMAX K1
```

answer:
-1.040 E-04
2.853 E-04

```
1  (1) NPROB
PROBLEM 3.6
2  1  1  1   (3)  MATL NDAMA NPY NLG
0.001   (4)  DEL
3  0  80  9  0   (5)  NL NZ ICL NSTD NUNIT
4   8    (6)  TH
0.4    0.3    0.45    (7)  PR
1  (9) NBOND
400000    10000    10000    (11)  E
1   (13)  LOAD
4.5   75   (14)  CR CP
3   (19)  NPT
0   13.5   0   0   0   4.5   0   6.75   (20)  XW YW XPT
1  15  (25)  NOLAY ITENOL
2   0   (26)  LAYNO NCLAY
6   (27)  ZCNOL
0  0  0  0  0.01   (28)  RCNOL XCNOL YCNOL SLD DELNOL
0.5   (29)  RELAX
145 135   0   (30)  GAM
0.5  0.6  (31)  K2 K0
8000 8000  (33)  PHI K1
1  1  (46)  NLBT NLTC
1   (47)  LNBT
3   (48)  LNTC
36500   (49)  TNLR
0.0796   3.291   0.854   (50)  FT1 FT2 FT3
1.365E-09   4.477   (51)  FT4 FT5
```

answer: 5.49 years

```
1  (1) NPROB
PROBLEM 3.7
2  1  1  1   (3)  MATL NDAMA NPY NLG
0.001   (4)  DEL
6  0  80  9  0   (5)  NL NZ ICL NSTD NUNIT
4   2   2   2   2   (6)  TH
0.4   0.3   0.3   0.3   0.3   0.45   (7)  PR
1  (9) NBOND
400000   50000   40000   30000   20000   10000   (11)  E
1   (13)  LOAD
4.5   75   (14)  CR CP
3   (19)  NPT
0   13.5   0   0   0   4.5   0   6.75   (20)  XW YW XPT
4  15  (25)  NOLAY ITENOL
2   0   3   0   4   0   5   0   (26)  LAYNO NCLAY
5   7   9   11   (27)  ZCNOL
0  0  0  0  0.01   (28)  RCNOL XCNOL YCNOL SLD DELNOL
0.5   (29)  RELAX
145   135   135   135   135   130   (30)  GAM
0.5  0.6  (31)  K2 K0
0.5  0.6  (31)  K2 K0
0.5  0.6  (31)  K2 K0
0.5  0.6  (31)  K2 K0
0   8000  (33)  PHI K1
0   8000  (33)  PHI K1
0   8000  (33)  PHI K1
0   8000  (33)  PHI K1
1  1  (46)  NLBT NLTC
1  (47)  LNBT
6   (48)  LNTC
36500   (49)  TNLR
.0796  3.291  .854   (50)  FT1 FT2 FT3
1.365E-09   4.477   (51)  FT4 FT5
```

answer: 5.08 years

```
1  (1) NPROB
PROBLEM 3.8
2  0  1  1  (3) MATL NDAMA NPY NLG
0.001  (4) DEL
3  1  80  9  0  (5) NL NZ ICL NSTD NUNIT
4   8   (6) TH
0.4   0.3   0.45   (7) PR
6   (8) ZC
1  (9) NBOND
400000 8000  10000  (11) E
1   (13) LOAD
4.5   75   (14) CR CP
1   (19) NPT
0   13.5   0   6.75   (20) XW YW XPT
1  15  (25) NOLAY ITENOL
2   0   (26) LAYNO NCLAY
6   (27) ZCNOL
0  0  0  0  0.01  (28) RCNOL XCNOL YCNOL SLD DELNOL
0.5   (29) RELAX
145   135   0   (30) GAM
0.5  0.6  (31) K2 K0
8000   8000   (33) PHI K1
```

answer: 2.956E+04 psi
14.003 psi
1.113 psi
-3.083 psi

```
1  (1) NPROB
PROBLEM 3.9
3  0  1  1  (3) MATL NDAMA NPY NLG
0.001  (4) DEL
2  1  80  1  0  (5) NL NZ ICL NSTD NUNIT
8   (6) TH
0.5   0.5   (7) PR
0   (8) ZC
1  (9) NBOND
0   10000   (11) E
0   (13) LOAD
6   75   (14) CR CP
1   (16) NR
0   (17) RC
0  (36) DUR
1  1   (37) NVL LNV
6  (38) NTYME
0   0.01   0.1   1   10   100   (39) TYME
0.113   70   (41) BETA TEMPREF
0.000002  2.37E-06   3.81E-06   4.38E-06   4.57E-06   0.0000046   (42) CREEP
70   (44) TEMP
```

answer: 0.01561 in., 0.01657 in.,
0.01957 in., 0.02056 in.,
0.02087 in., 0.02092 in.

```
1  (1) NPROB
PROBLEM 3.10
3  1  1  1  (3) MATL NDAMA NPY NLG
0.001  (4) DEL
2  0  80  9  0  (5) NL NZ ICL NSTD NUNIT
8   (6) TH
0.5   0.5   (7) PR
1  (9) NBOND
0   10000   (11) E
0   (13) LOAD
6   75   (14) CR CP
1   (16) NR
0   (17) RC
0.1  (36) DUR
1  1   (37) NVL LNV
11  (38) NTYME
0.001   0.003   0.01   0.03   0.1   0.3   1   3   10   30   100   (39) TYME
```

answer: 21.09 years

0.113 70 (41) BETA TEMPREF
2.04E-06 2.12E-06 2.37E-06 2.92E-06 3.81E-06 4.19E-06 4.38E-06
4.49E-06 4.57E-06 0.0000046 0.0000046 (42) CREEP
70 (44) TEMP
1 1 (46) NLBT NLTC
1 (47) LNBT
2 (48) LNTC
100000 (49) TNLR
0.0796 3.291 0.854 (50) FT1 FT2 FT3
1.365E-09 4.477 (51) FT4 FT5

1 (1) NPROB
PROBLEM 3.11
1 1 1 1 (3) MATL NDAMA NPY NLG
0.001 (4) DEL
3 0 80 9 0 (5) NL NZ ICL NSTD NUNIT
6 8 (6) TH
0.4 0.35 0.45 (7) PR
1 (9) NBOND
740000 23000 11000 (11) E
2 (13) LOAD
4.52 70 (14) CR CP
3 (19) NPT
48 13.5 0 0 0 3.375 0 6.75 (20) XW YW XPT
1 1 (46) NLBT NLTC
1 (47) LNBT
3 (48) LNTC
200000 (49) TNLR
0.0796 3.291 0.854 (50) FT1 FT2 FT3
1.365E-09 4.477 (51) FT4 FT5

NDAMA should be 2 to get the following: Damage ratio due to max. tensile strain = 0.04357 and that due to differential strain = 0.008804

answer: 19.09 years

3 (1) NPROB
Problem 3-12(a)
2 1 1 1 (3) MATL NDAMA NPY NLG
0.001 (4) DEL
7 2 80 9 0 (5) NL NZ ICL NSTD NUNIT
2 2 2 2 2 2 (6) TH
0.35 0.35 0.35 0.35 0.35 0.35 0.45 (7) PR
1 (9) NBOND
120000 100000 80000 68000 40000 20000 5000 (11) E
0 (13) LOAD
6 100 (14) CR CP
1 (16) NR
0 (17) RC
7 15 (25) NOLAY ITENOL
1 0 2 0 3 0 4 0 5 0 6 0 7 1 (26) LAYNO NCLAY
1 3 5 7 9 11 13 (27) ZCNOL
0 0 0 0 0.01 (28) RCNOL XCNOL YCNOL SLD DELNOL
0.5 (29) RELAX
135 135 135 135 135 135 115 (30) GAM
0.5 0.6 (31) K2 K0
0.5 0.6 (31) K2 K0
0.5 0.6 (31) K2 K0
0.5 0.6 (31) K2 K0
0.5 0.6 (31) K2 K0
0.5 0.6 (31) K2 K0
6.2 1110 178 0.8 (31) K2 K3 K4 K0
0 10000 (33) PHI K1
0 10000 (33) PHI K1
0 10000 (33) PHI K1
0 10000 (33) PHI K1
0 10000 (33) PHI K1

```
0   10000   (33) PHI K1
1827   7682   3020   (33) EMIN EMAX K1
0  1  (46) NLBT NLTC
7   (48) LNTC
1000   (49) TNLR
1.365E-09   4.477   (51) FT4 FT5
```

answer: 1.89 years

```
Problem 3-12(b)
2  2  1  1  (3) MATL NDAMA NPY NLG
0.001  (4) DEL
2  2  80  9  0  (5) NL NZ ICL NSTD NUNIT
12   (6) TH
0.35   0.45   (7) PR
1  (9) NBOND
10000   3020   (11) E
0   (13) LOAD
6   100   (14) CR CP
1   (16) NR
0   (17) RC
2  15  (25) NOLAY ITENOL
1   0   2   1   (26) LAYNO NCLAY
4   13   (27) ZCNOL
0  0  0  0  0.01  (28) RCNOL XCNOL YCNOL SLD DELNOL
0.5   (29) RELAX
135   115   (30) GAM
0.5  0.6  (31) K2 K0
6.2  1110  178  0.8  (31) K2 K3 K4 K0
10000   10000   (33) PHI K1
1827   7682   3020   (33) EMIN EMAX K1
0  1  (46) NLBT NLTC
2   (48) LNTC
1000   (49) TNLR
1.365E-09   4.477   (51) FT4 FT5
```

answer: 24.22 years

```
Problem 3-12(c)
2  2  1  1  (3) MATL NDAMA NPY NLG
0.001  (4) DEL
2  2  80  9  0  (5) NL NZ ICL NSTD NUNIT
12   (6) TH
0.35   0.45   (7) PR
1  (9) NBOND
10000   3020   (11) E
0   (13) LOAD
6   100   (14) CR CP
1   (16) NR
0   (17) RC
2  15  (25) NOLAY ITENOL
1   0   2   1   (26) LAYNO NCLAY
6   13   (27) ZCNOL
0  0  0  0  0.01  (28) RCNOL XCNOL YCNOL SLD DELNOL
0.5   (29) RELAX
135   115   (30) GAM
0.5  0.6  (31) K2 K0
6.2  1110  178  0.8  (31) K2 K3 K4 K0
40   10000   (33) PHI K1
1827   7682   3020   (33) EMIN EMAX K1
0  1  (46) NLBT NLTC
2   (48) LNTC
1000   (49) TNLR
1.365E-09   4.477   (51) FT4 FT5
```

answer: 7.75 years