MATERIALS FOR CIVIL AND CONSTRUCTION ENGINEERS

3rd Edition

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Solution Manual

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FOREWORD

This solution manual includes the solutions to numerical problems at the end of various chapters of the book. It does not include answers to word questions, but the appropriate sections in the book are referenced. The procedures used in the solutions are taken from the corresponding chapters and sections of the text. Each step in the solution is taken to the lowest detail level consistent with the level of the text, with a clear progression between steps. Each problem solution is self-contained, with a minimum of dependence on other solutions. The final answer of each problem is printed in bold.

The instructors are advised not to spread the solutions electronically among students in order not to limit the instructor's choice to assign problems in future semesters.

CHAPTER 1. MATERIALS ENGINEERING CONCEPTS

1.2. Strength at rupture = **45 ksi**
Toughness = (45 x 0.003) / 2 = **0.0675 ksi**

1.3. $A = 0.36\ in^2$
$\sigma = 138.8889$ ksi
$\varepsilon_A = 0.0035$ in/in
$\varepsilon_L = -0.016667$ in/in
E = 39682 ksi
ν = 0.21

1.4. $A = 201.06\ mm^2$
$\sigma = 0.945$ GPa
$\varepsilon_A = 0.002698$ m/m
$\varepsilon_L = -0.000625$ m/m
E = 350.3 **GPa**
ν = 0.23

1.5. $A = \pi d^2/4 = 28.27\ in^2$
$\sigma = P / A = -150{,}000 / 28.27\ in^2 = -5.31$ ksi
$E = \sigma / \varepsilon = 8000$ ksi
$\varepsilon_A = \sigma / E = -5.31$ ksi / 8000 ksi = -0.0006631 in/in
$\Delta L = \varepsilon_A L_o$ = -0006631 in/in (12 in) = -0.00796 in
$L_f = \Delta L + L_o$ = 12 in – 0.00796 in = **11.992 in**
$\nu = -\varepsilon_L / \varepsilon_A = 0.35$
$\varepsilon_L = \Delta d / d_o = -\nu\ \varepsilon_A$ = -0.35 (-0.0006631 in/in) = 0.000232 in/in
$\Delta d = \varepsilon_L d_o$ = 0.000232 (6 in) = 0.00139 in
$d_f = \Delta d + d_o$ = 6 in + 0.00139 in = **6.00139 in**

1.6. $A = \pi d^2/4 = 0.196\ in^2$
$\sigma = P / A = 2{,}000 / 0.196\ in^2 = 10.18$ ksi (Less than the yield strength. Within the elastic region)
$E = \sigma / \varepsilon = 10{,}000$ ksi
$\varepsilon_A = \sigma / E = 10.18$ ksi / 10,000 ksi = 0.0010186 in/in
$\Delta L = \varepsilon_A L_o$ = 0.0010186 in/in (12 in) = 0.0122 in
$L_f = \Delta L + L_o$ = 12 in + 0.0122 in = **12.0122 in**
$\nu = -\varepsilon_L / \varepsilon_A = 0.33$
$\varepsilon_L = \Delta d / d_o = -\nu\ \varepsilon_A$ = -0.33 (0.0010186 in/in) = -0.000336 in/in
$\Delta d = \varepsilon_L d_o$ = -0.000336 (0.5 in) = -0.000168 in
$d_f = \Delta d + d_o$ = 0.5 in - 0.000168 in = 0**.49998 in**

1.7. L_x =30 mm, L_y = 60 mm, L_z = 90 mm
$\sigma_x = \sigma_y = \sigma_z = \sigma$ = 100 MPa
E = 70 GPa
ν = 0.333

$\varepsilon_x = [\sigma_x - \nu(\sigma_y + \sigma_z)]/E$
$\varepsilon_x = [100 \times 10^6 - 0.333(100 \times 10^6 + 100 \times 10^6)] / 70 \times 10^9 = 4.77 \times 10^{-4} = \varepsilon_y = \varepsilon_z = \varepsilon$
$\Delta L_x = \varepsilon \times L_x = 4.77 \times 10^{-4} \times 30 = 0.01431$ mm
$\Delta L_y = \varepsilon \times L_y = 4.77 \times 10^{-4} \times 60 = 0.02862$ mm
$\Delta L_z = \varepsilon \times L_z = 4.77 \times 10^{-4} \times 90 =$ **0.04293 mm**
ΔV = New volume - Original volume = $[(L_x - \Delta L_x)(L_y - \Delta L_y)(L_z - \Delta L_z)] - L_x L_y L_z$
= (30 - 0.01431) (60 - 0.02862) (90 - 0.04293)] - (30 x 60 x 90) = 161768 - 162000
= **-232 mm^3**

1.8. L_x =4 in, L_y = 4 in, L_z = 4 in
$\sigma_x = \sigma_y = \sigma_z = \sigma$ = 15,000 psi
E = 1000 ksi
ν = 0.49

$\varepsilon_x = [\sigma_x - \nu(\sigma_y + \sigma_z)]/E$
$\varepsilon_x = [15 - 0.49(15 + 15)] / 1000 = 0.0003 = \varepsilon_y = \varepsilon_z = \varepsilon$
$\Delta L_x = \varepsilon \times L_x = 0.0003 \times 15 = 0.0045$ in
$\Delta L_y = \varepsilon \times L_y = 0.0003 \times 15 = 0.0045$ in
$\Delta L_z = \varepsilon \times L_z = 0.0003 \times 15 = 0.0045$ in
ΔV = New volume - Original volume = $[(L_x - \Delta L_x)(L_y - \Delta L_y)(L_z - \Delta L_z)] - L_x L_y L_z$
= (15 - 0.0045) (15 - 0.0045) (15 - 0.0045)] - (15 x 15 x 15) = 3371.963 - 3375
= **-3.037 in^3**

1.9. $\varepsilon = 0.3 \times 10^{-16} \sigma^3$
At σ = 50,000 psi, $\varepsilon = 0.3 \times 10^{-16}(50{,}000)^3 = 3.75 \times 10^{-3}$ in./in.
Secant Modulus = $\dfrac{\Delta\sigma}{\Delta\varepsilon} = \dfrac{50{,}000}{3.75x10^{-3}}$ = **1.33 x 10^7 psi**
$\dfrac{d\varepsilon}{d\sigma} = 0.9 \times 10^{-16} \sigma^2$
At σ = 50,000 psi, $\dfrac{d\varepsilon}{d\sigma} = 0.9 \times 10^{-16}(50{,}000)^2 = 2.25 \times 10^{-7}$ in.^{2}/lb
Tangent modulus = $\dfrac{d\sigma}{d\varepsilon} = \dfrac{1}{2.25x10^{-7}}$ = **4.44x10^6 psi**

1.11. $\varepsilon_{lateral} = \dfrac{-3.25x10^{-4}}{1}$ = -3.25 x 10^{-4} in./in.

$\varepsilon_{axial} = \dfrac{2x10^{-3}}{2}$ = 1 x 10^{-3} in./in.

$\nu = -\dfrac{\varepsilon_{lateral}}{\varepsilon_{axial}} = -\dfrac{-3.25x10^{-4}}{1x10^{-3}}$ = **0.325**

1.12. $\varepsilon_{lateral}$ = 0.05 / 50 = 0.001 in./in.

ε_{axial} = ν x $\varepsilon_{lateral}$ = 0.33 x 0.001 = 0.00303 in.

$\Delta d = \varepsilon_{axial}$ x d_0= - 0.00825 in. (Contraction)

1.13. L = 380 mm
D = 10 mm
P = 24.5 kN
$\sigma = P/A = P/\pi\, r^2$
σ = 24,500 N/ π (5 mm)^2= 312,000 N/mm^2 = 312 MPa

$\delta = \dfrac{PL}{AE} = \dfrac{24{,}500 lb x 380 mm}{\pi(5mm)^2 E(kPa)} = \dfrac{118{,}539}{E(MPa)}$ mm

Material	Elastic Modulus (MPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Stress (MPa)	δ (mm)
Copper	110,000	248	289	312	1.078
Al. alloy	70,000	255	420	312	1.693
Steel	207,000	448	551	312	0.573
Brass alloy	101,000	345	420	312	1.174

The problem requires the following two conditions:
a) No plastic deformation $\Rightarrow$ Stress < Yield Strength
b) Increase in length, δ < 0.9 mm
The only material that satisfies both conditions is **steel**.

1.14. a. E = σ / ε = 40,000 / 0.004 = **10 x 10^6 psi**
b. Tangent modulus at a stress of 45,000 psi is the slope of the tangent at that stress = **4.7 x 10^6 psi**
c. Yield stress using an offset of 0.002 strain = **49,000 psi**
d. Maximum working stress = Failure stress / Factor of safety = 49,000 / 1.5 = **32,670 psi**

1.15.a. Modulus of elasticity within the linear portion = **20,000 ksi.**

b. Yield stress at an offset strain of 0.002 in./in. ≈ **70.0 ksi**

c. Yield stress at an extension strain of 0.005 in/in. ≈ **69.5 ksi**

d. Secant modulus at a stress of 62 ksi. ≈ **18,000 ksi**

e. Tangent modulus at a stress of 65 ksi. ≈ **6,000 ksi**

1.16. a. Modulus of resilience = the area under the elastic portion of the stress strain curve = ½(50 x 0.0025) ≈ **0.0625 ksi**

b. Toughness = the area under the stress strain curve (using the trapezoidal integration technique) ≈ **0.69 ksi**

c. σ = 40 ksi , this stress is within the elastic range, therefore, E = **20,000 ksi**

ε_{axial} = 40/20,000 = 0.002 in./in.

$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{axial}} = -\frac{-0.00057}{0.002} = \mathbf{0.285}$$

d. The permanent strain at 70 ksi = **0.0018 in./in.**

1.17.

	Material A	Material B
a. Proportional limit	**51 ksi**	**40 ksi**
b. Yield stress at an offset strain of 0.002 in./in.	**63 ksi**	**52 ksi**
c. Ultimate strength	**132 ksi**	**73 ksi**
d. Modulus of resilience	**0.065 ksi**	**0.07 ksi**
e. Toughness	**8.2 ksi**	**7.5 ksi**
f.	Material B is more ductile as it undergoes more deformation before failure	

1.18. Assume that the stress is within the linear elastic range.

$$\sigma = \varepsilon.E = \frac{\delta.E}{l} = \frac{0.3x16{,}000}{10} = 480 \text{ ksi}$$

Thus $\sigma > \sigma_{yield}$

Therefore, the applied stress is not within the linear elastic region and it is not possible to compute the magnitude of the load that is necessary to produce the change in length based on the given information.

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1.19. Assume that the stress is within the linear elastic range.

$$\sigma = \varepsilon . E = \frac{\delta . E}{l} = \frac{7.6 x 105{,}000}{250} = 3{,}192 \text{ MPa}$$

Thus $\sigma > \sigma_{yield}$

Therefore, the applied stress is not within the linear elastic region and it is not possible to compute the magnitude of the load that is necessary to produce the change in length based on the given information.

1.20. At σ = 60,000 psi, ε = σ / E = 60,000 / (30 x 10^6) = 0.002 in./in.

a. For a strain of 0.001 in./in.:

σ = ε E = 0.001 x 30 x 10^6 = **30,000 psi (**for both i and ii)

b. For a strain of 0.004 in./in.:

_σ = **60,000 psi** (for i)

σ = 60,000 + 2 x 10^6 (0.004 - 0.002) = **64,000 psi (**for ii)

1.21. a. Slope of the elastic portion = 600/0.003 = 2x10^5 MPa

Slope of the plastic portion = (800-600)/(0.07-0.003) = 2,985 MPa

Strain at 650 MPa = 0.003 + (650-600)/2,985 = 0.0198 m/m

Permanent strain at 650 MPa = 0.0198 – 650/(2x10^5) = **0.0165 m/m**

b. Percent increase in yield strength = = 100(650-600)/600 = **8.3%**

c. The strain at 625 MPa = 625/(2x10^5) = **0.003125 m/m**

This strain is elastic.

1.22. See Sections 1.2.3, 1.2.4 and 1.2.5.

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1.23. The stresses and strains can be calculated as follows:

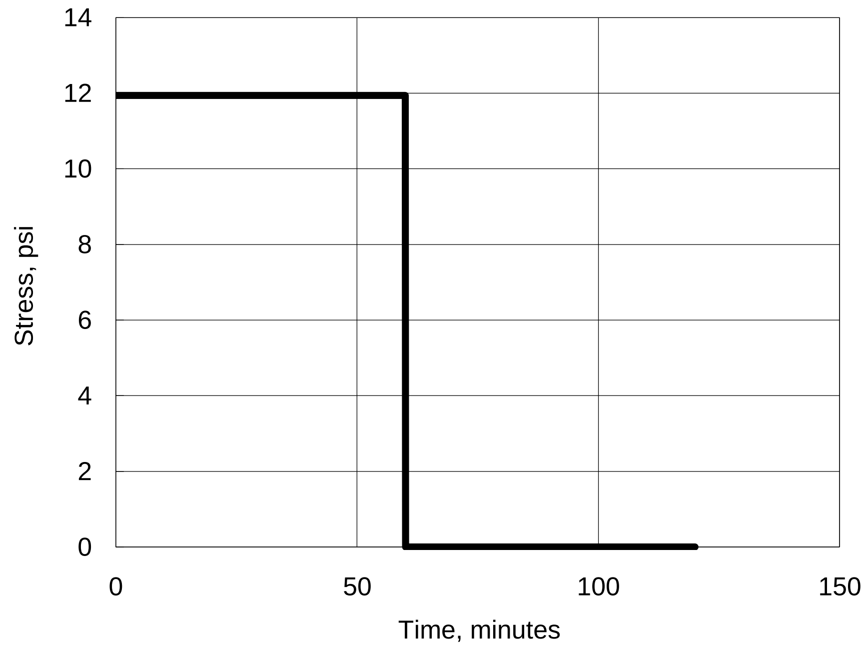
$\sigma = P/A_o = 150 / (\pi \text{ x } 2^2) = 11.94$ psi

$\varepsilon = (H_o\text{-}H)/H_o = (6\text{-}H)/6$

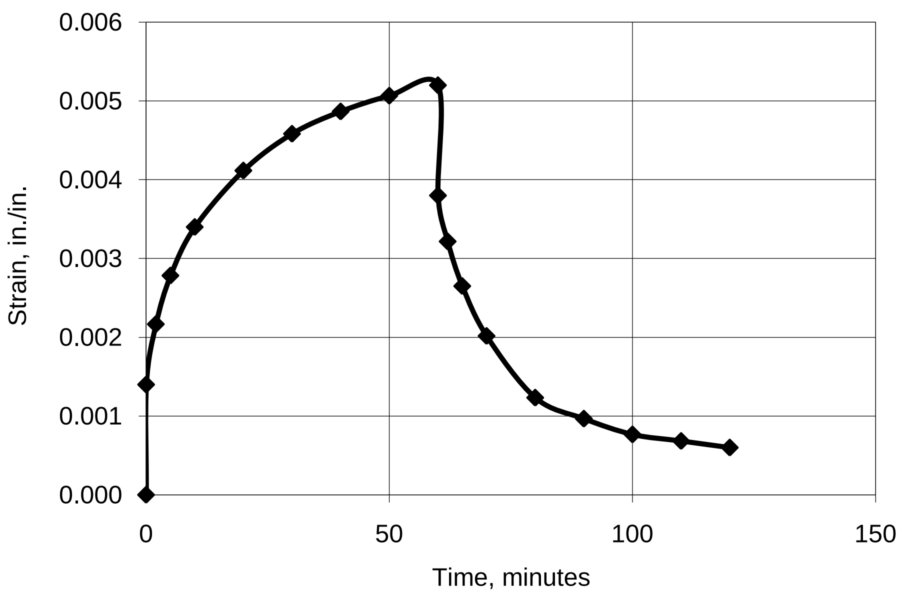
The stresses and strains are shown in the following table:

Time (min.)	H (in.)	Strain (in./in.)	Stress (psi)
0	6	0.00000	11.9366
0.01	5.9916	0.00140	11.9366
2	5.987	0.00217	11.9366
5	5.9833	0.00278	11.9366
10	5.9796	0.00340	11.9366
20	5.9753	0.00412	11.9366
30	5.9725	0.00458	11.9366
40	5.9708	0.00487	11.9366
50	5.9696	0.00507	11.9366
60	5.9688	0.00520	11.9366
60.01	5.9772	0.00380	0.0000
62	5.9807	0.00322	0.0000
65	5.9841	0.00265	0.0000
70	5.9879	0.00202	0.0000
80	5.9926	0.00123	0.0000
90	5.9942	0.00097	0.0000
100	5.9954	0.00077	0.0000
110	5.9959	0.00068	0.0000
120	5.9964	0.00060	0.0000

a. Stress versus time plot for the asphalt concrete sample



Strain versus time plot for the asphalt concrete sample



b. Elastic strain = **0.0014 in./in.**

c. The permanent strain at the end of the experiment = **0.0006 in./in.**

d. The phenomenon of the change of specimen height during static loading is called **creep** while the phenomenon of the change of specimen height during unloading called is called **recovery.**

1.24. See Figure 1.12(a).

1.25 See Section 1.2.7.

1.27. a. For P = 5 kN

Stress = P / A = 5000 / (π x 5^2) = 63.7 N/mm^2 = 63.7 MPa

Stress / Strength = 63.7 / 290 = 0.22

From Figure 1.16, an **unlimited number** of repetitions can be applied without fatigue failure.

b. For P = 11 kN

Stress = P / A = 11000 / (π x 5^2) = 140.1 N/mm^2 = 140.1 MPa

Stress / Strength = 140.1 / 290 = 0.48

From Figure 1.16, N $\approx$**700**

1.28 See Section 1.2.8.

1.29.

Material	Specific Gravity
Steel	7.9
Aluminum	2.7
Aggregates	2.6 - 2.7
Concrete	2.4
Asphalt cement	1 - 1.1

1.30 See Section 1.3.2.

1.31. $\delta L = \alpha_L \, x \, \delta T \, x \, L$ = 12.5E-06 x (115-15) x 200/1000 = 0.00025 m = 250 microns

Rod length = L + δL = 200,000+ 250 = **200,250 microns**

Compute change in diameter linear method

$\delta d = \alpha_d \, x \, \delta T \, x \, d$ = 12.5E-06 x (115-15) x 20 = 0.025 mm

Final d = **20.025 mm**

Compute change in diameter volume method

$\delta V = \alpha_V \, x \, \delta T \, x \, V$ = (3 x 12.5E-06) x (115-15) x π (10/1000)^2 x 200/1000 = 2.3562 x 10^{11} m^3

Rod final volume = $V + \delta V = \pi r^2 L + \delta V$= 6.28319 x 10^{13} + 2.3562 x 10^{11} = 6.31 x 10^{13} m^3

Final d = **20.025 mm**

There is no stress acting on the rod because the rod is free to move.

1.32. Since the rod is snugly fitted against two immovable nonconducting walls, the length of the rod will not change, **L = 200 mm**

From problem 1.25, δL = 0.00025 m
$\varepsilon = \delta L$ / L = 0.00025 / 0.2 = 0.00125 m/m
$\sigma = \varepsilon$ E = 0.00125 x 207,000 = **258.75 MPa**
The stress induced in the bar will be compression.

1.33. a. The change in length can be calculated using Equation 1.9 as follows:
$\delta L = \alpha_L \; x \; \delta T \; x \; L$ = 1.1E-5 x (5 - 40) x 4 = **-0.00154 m**

b. The tension load needed to return the length to the original value of 4 meters can be calculated as follows:
$\varepsilon = \delta L$ / L = -0.00154/ 4 = -0.000358 m/m
$\sigma = \varepsilon$ E = -0.000358 x 200,000 = -77 MPa
P = σ x A = -77 x (100 x 50) = -385,000 N = **-385 kN (tension)**

c. Longitudinal strain under this load = **0.000358 m/m**

1.34. If the bar was fixed at one end and free at the other end, the bar would have contracted and no stresses would have developed. In that case, the change in length can be calculated using Equation 1.9 as follows.
$\delta L = \alpha_L \; x \; \delta T \; x \; L$ = 0.000005 x (0 - 100) x 50 = -0.025 in.
$\varepsilon = \delta L$ / L = 0.025 / 50 = 0.0005 in./in.

Since the bar is fixed at both ends, the length of the bar will not change. Therefore, a tensile stress will develop in the bar as follows.
$\sigma = \varepsilon$ E = -0.0005 x 5,000,000 = -2,500 psi

Thus, the tensile strength should be larger than **2,500 psi** in order to prevent cracking.

1.36 See Section 1.7.

1.37 See Section 1.7.1

1.38. H_o: $\mu \geq 32.4$ MPa
H_1: $\mu < 32.4$ MPa
$\alpha = 0.05$
$T_o = \dfrac{\bar{x} - \mu}{(\sigma / \sqrt{n})} = -3$
Degree of freedom = ν = n - 1 = 15
From the statistical t-distribution table, $T_{\alpha, \upsilon} = T_{0.05, 15} = -1.753$
$T_o < T_{\alpha, \upsilon}$
Therefore, **reject** the hypothesis. The contractor's claim is not valid.

1.39. H_o: $\mu \geq 5{,}000$ psi

H_1: $\mu < 5{,}000$ psi

$\alpha = 0.05$

$$T_o = \frac{\bar{x} - \mu}{(\sigma / \sqrt{n})} = -2.236$$

Degree of freedom = ν = n - 1 = 19

From the statistical t-distribution table, $T_{\alpha,\upsilon} = T_{0.05,\,19} = -1.729$

$T_o < T_{\alpha,\upsilon}$

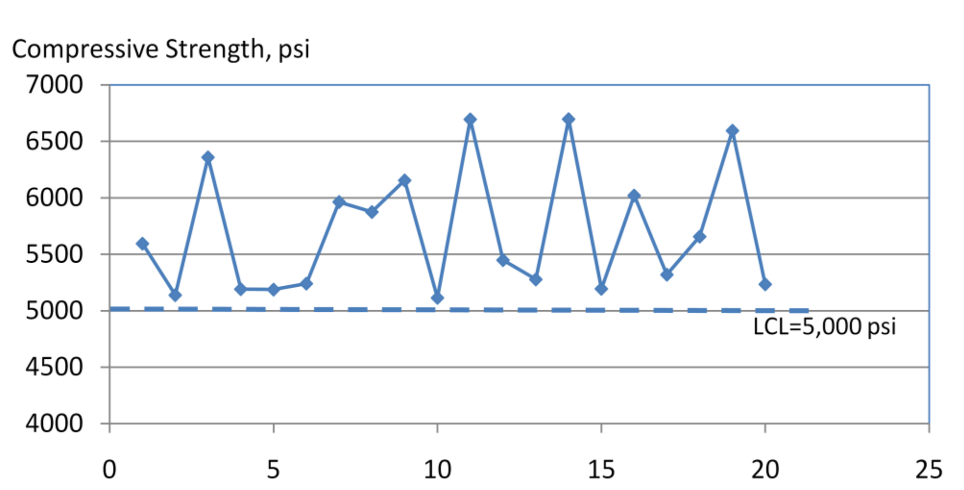
Therefore, **reject** the hypothesis. The contractor's claim is not valid.

1.40. $$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{\sum_{i=1}^{20} x_i}{20} = \frac{113{,}965}{20} = 5{,}698.25\,psi$$

$$s = \left(\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1} \right)^{1/2} = \left(\frac{\sum_{i=1}^{20} (x_i - 5698.25)^2}{20-1} \right)^{1/2} = 571.35\,psi$$

$$\text{Coefficient of Variation} = 100\left(\frac{s}{\bar{x}}\right) = 100\left(\frac{571.35}{5698.25}\right) = 10.03\%$$

b. The control chart is shown below.



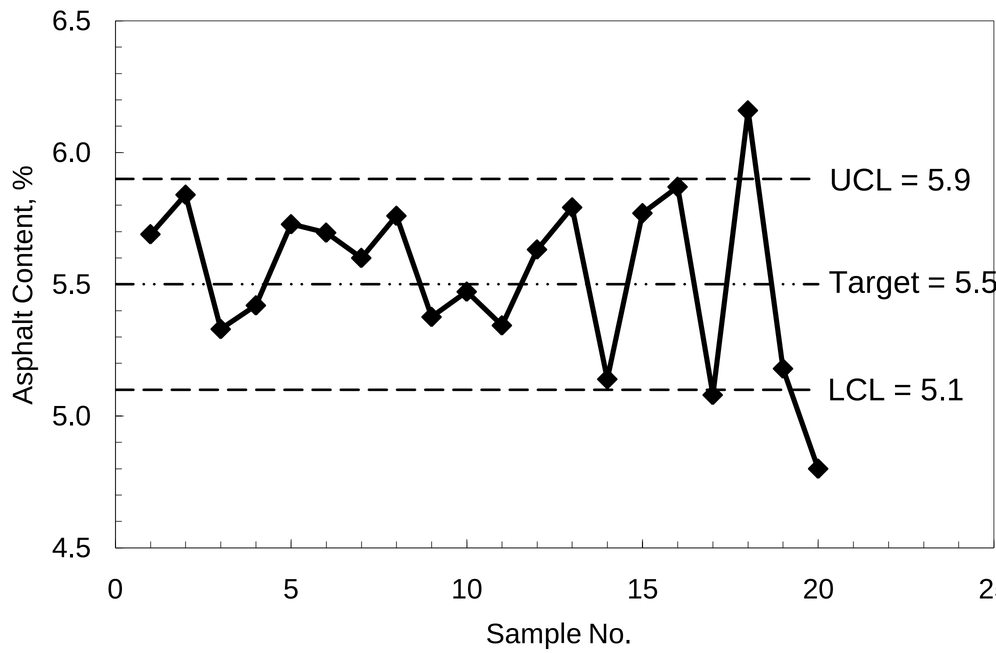
The target value is any value above the specification limit of 5,000 psi. The plant production is meeting the specification requirement.

1.41. a. $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{\sum_{i=1}^{20} x_i}{20} = \frac{110.7}{20} = \mathbf{5.5\ \%}$

$$s = \left(\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1} \right)^{1/2} = \left(\frac{\sum_{i=1}^{20} (x_i - 5.5)^2}{20-1} \right)^{1/2} = \mathbf{0.33\ \%}$$

$$C = 100\left(\frac{s}{\bar{x}}\right) = 100\left(\frac{0.33}{5.5}\right) = \mathbf{6\ \%}$$

b. The control chart is shown below.



The control chart shows that most of the samples have asphalt content within the specification limits. Only few samples are outside the limits. The plot shows no specific trend, but large variability especially in the last several samples.

1.42 See Section 1.8.2.

1.43 See Section 1.8.

1.44. a. No information is given about accuracy.

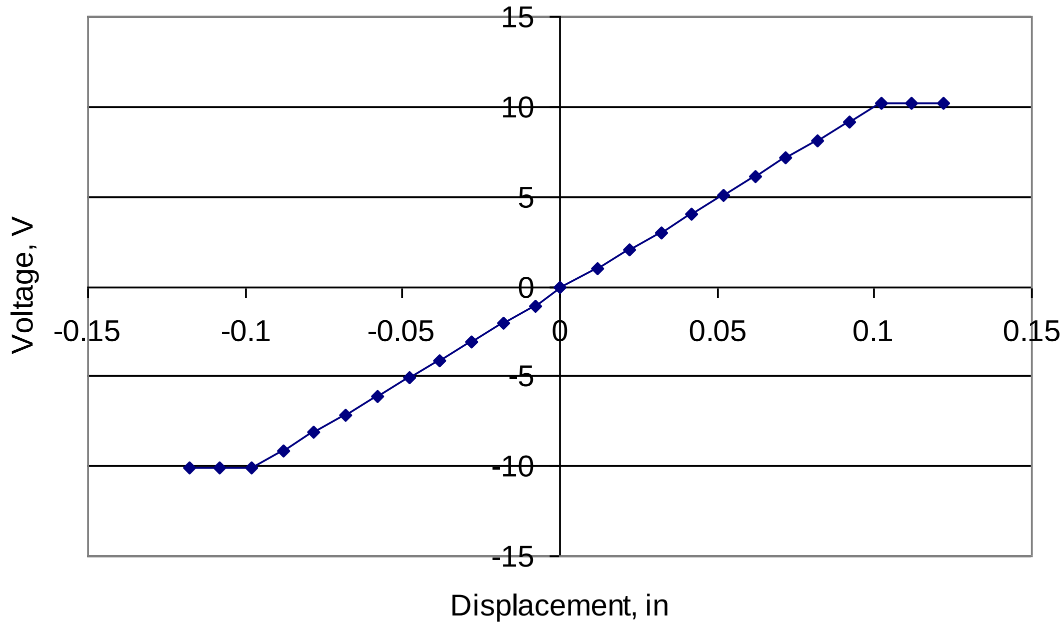
b. Sensitivity == **0.001 in.**

c. Range = 0 – 1 inch

d. Accuracy can be improved by calibration.

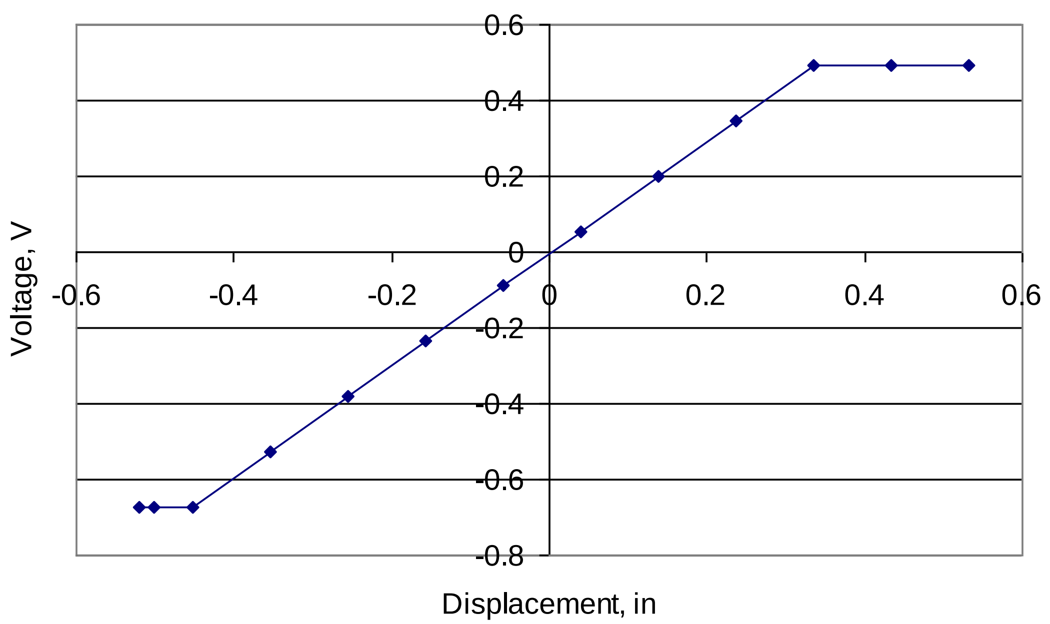
1.45. a. 0.001 in.
b. 100 psi
c. 100 MPa
d. 0.1 ge. 10 psi
f. 0.1 %
g. 0.1 %
h. 0.001
i. 100 miles
j. 10^{-6} mm

1.46 The voltage is plotted versus displacement is shown below.



From the figure:
Linear range = ± 0.1 in.
Calibration factor = 101.2 Volts/in.

1.47 The voltage is plotted versus displacement is shown below.



From the figure:
Linear range = ± 0.3 in.
Calibration factor = 1.47 Volts/in.

CHAPTER 2. NATURE OF MATERIALS

2.1. See Section 2.2.1.

2.2. See Section 2.1.

2.3. See Section 2.1.1.

2.4. See Section 2.1.1.

2.5. See Section 2.1.2.

2.6. See Section 2.2.1.

2.7. See Section 2.1.2.

2.8. See Section 2.2.1.

2.9. See Section 2.2.1.

2.10. For the face-center cubic crystal structure, number of equivalent whole atoms in each unit cell = 4
By inspection the diagonal of the face of a FCC unit cell = 4r
Using Pythagorean theory:
$(4r)^2 = a^2 + a^2$
$16r^2 = 2a^2$
$8r^2 = a^2$
$a = 2\sqrt{2}r$

2.11. a. Number of equivalent whole atoms in each unit cell in the BCC lattice structure = **2**

b. Volume of the sphere = $(4/3)\,\pi\, r^3$
Volume of atoms in the unit cell = $2 \times (4/3)\,\pi\, r^3 = (8/3)\,\pi\, r^3$
By inspection, the diagonal of the cube of a BCC unit cell
$= 4r = \sqrt{a^2 + a^2 + a^2} = a\sqrt{3}$
a = Length of each side of the unit cell = $\frac{4r}{\sqrt{3}}$

c. Volume of the unit cell = $\left[\frac{4r}{\sqrt{3}}\right]^3$

$$APF = \frac{volume\ of\ atoms\ in\ the\ unit\ cell}{total\ unit\ volume\ of\ the\ cell} = \frac{(8/3)\pi . r^3}{(4r/\sqrt{3})^3} = \mathbf{0.68}$$

2.12. For the BCC lattice structure: $a = \dfrac{4r}{\sqrt{3}}$

Volume of the unit cell of iron = $\left[\dfrac{4r}{\sqrt{3}}\right]^3 = \left[\dfrac{4x0.124x10^{-9}}{\sqrt{3}}\right]^3$ = **2.349 x 10^{-29} m^3**

2.13. For the FCC lattice structure: $a = 2\sqrt{2}r$

Volume of unit cell of aluminum = $(2\sqrt{2}r)^3 = (2\sqrt{2}x0.143)^3$ =0.06616725 nm^3 = **6.6167x10^{-29} m^3**

2.14. From Table 2.3, copper has an FCC lattice structure and r of 0.1278 nm

Volume of the unit cell of copper = $(2\sqrt{2}r)^3 = (2\sqrt{2}x0.1278)^3$ = **0.04723 nm^3 = 4.723 x10^{-29} m^3**

2.15. For the BCC lattice structure: $a = \dfrac{4r}{\sqrt{3}}$

Volume of the unit cell of iron = $\left[\dfrac{4r}{\sqrt{3}}\right]^3 = \left[\dfrac{4x0.124x10^{-9}}{\sqrt{3}}\right]^3$ = 2.349 x 10^{-29} m^3

Density = $\rho = \dfrac{nA}{V_C N_A}$

n = Number of equivalent atoms in the unit cell = 2

A = Atomic mass of the element = 55.9 g/mole

N_A= Avogadro's number = 6.023 x 10^{23}

$\rho = \dfrac{2x55.9}{2.349x10^{-29}x6.023x10^{23}}$ = 7.9 x 10^6 g/m^3 = **7.9 Mg/m^3**

2.16. For the FCC lattice structure: $a = 2\sqrt{2}r$

Volume of unit cell of aluminum = $(2\sqrt{2}r)^3 = (2\sqrt{2}x0.143)^3$ =0.06616725 nm^3 = 6.6167x10^{-29} m^3

Density = $\rho = \dfrac{nA}{V_C N_A}$

For FCC lattice structure, n = 4

A = Atomic mass of the element = 26.98 g/mole

N_A= Avogadro's number = 6.023 x 10^{23}

$\rho = \dfrac{4x26.98}{6.6167x10^{-29}x6.023x10^{23}}$ = 2.708 x 10^6 g/m^3 = **2.708 Mg/m^3**

2.17. $\rho = \dfrac{nA}{V_C N_A}$

For FCC lattice structure, n = 4

$V_c = \dfrac{4x63.55}{8.89x10^6x6.023x10^{23}}$ = 4.747 x 10^{-29} m^3

APF = 0.74 = $\dfrac{4x(4/3)\pi.r^3}{4.747x10^{-29}}$

r^3 = 0.2097 x 10^{-29} m^3 r =0.128 x 10^{-9} m = **0.128 nm**

2.18. a. $\rho = \dfrac{nA}{V_C N_A}$

For FCC lattice structure, n = 4

$V_c = \dfrac{4x40.08}{1.55x10^6 x6.023x10^{23}} = 1.717 \text{ x } 10^{-28} \text{ m}^3$

b. $\text{APF} = 0.74 = \dfrac{4x(4/3)\pi .r^3}{1.717x10^{-28}}$

$r^3 = 0.7587 \text{ x } 10^{-29} \text{ m}^3$

$r = 0.196 \text{ x } 10^{-9}$ m = **0.196 nm**

2.19. See Section 2.2.2.

2.20. See Section 2.2.2.

2.21. See Section 2.2.2.

2.22. See Figure 2.14**.**

2.23. See Section 2.2.5.

2.24. m_t = 100 g

P_B = 65 %

P_{lB} = 30 %

P_{sB} = 80 %

From Equations 2.4 and 2.5,

$m_l + m_s = 100$

$30\, m_l + 80\, m_s = 65 \text{ x } 100$

Solving the two equations simultaneously, we get:

m_l = mass of the alloy which is in the liquid phase = **30 g**

m_s = mass of the alloy which is in the solid phase = **70 g**

2.25. m_t = 100 g

P_B = 45 %

P_{lB} = 17 %

P_{sB} = 65 %

From Equations 2.4 and 2.5,

$m_l + m_s = 100$

$17\, m_l + 65\, m_s = 45 \text{ x } 100$

Solving the two equations simultaneously, we get:

m_l = mass of the alloy which is in the liquid phase = **41.67 g**

m_s = mass of the alloy which is in the solid phase = **58.39 g**

2.26. m_t = 100 g
P_B = 60 %
P_{lB} = 25 %
P_{sB} = 70 %
From Equations 2.4 and 2.5,
$m_l + m_s = 100$
$25\ m_l + 70\ m_s = 60 \times 100$
Solving the two equations simultaneously, we get:
m_l = mass of the alloy which is in the liquid phase = **22.22 g**
m_s = mass of the alloy which is in the solid phase = **77.78 g**

2.27. m_t = 100 g
P_B = 40 %
P_{lB} = 20 %
P_{sB} = 50 %
From Equations 2.4 and 2.5,
$m_l + m_s = 100$
$40\ m_l + 50\ m_s = 40 \times 100$
Solving the two equations simultaneously, we get:
m_l = mass of the alloy which is in the liquid phase = **33.33 g**
m_s = mass of the alloy which is in the solid phase = **66.67 g**

2.28. a. Spreading salt reduces the melting temperature of ice. For example, at a salt composition of 5%, ice starts to melt at -21^{o}C. When temperature increases more ice will melt. At a temperature of -5^{o}C, all ice will melt.

b. **-21^{o}C**

c. **-21^{o}C**

2.29. See Section 2.3**.**

2.30. See Section 2**.3.**

2.31. See Section 2.4**.**

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CHAPTER 3. STEEL

3.1 See Section 3.1.

3.2 See Section 3.2.

3.3 See Section 3.2.

3.4 See Section 3.2.

3.5. At a temperature just higher than 727°C all the austenite will have a carbon content of 0.77% and will transform to pearlite. The ferrite will remain as primary ferrite. The proportions can be determined from using the lever rule.

$$\text{Primary}\,\alpha:\ 0.022\%\,\text{C, Percent primary}\,\alpha = \left[\frac{0.77-0.10}{0.77-0.022}\right]\times 100 = 89.6\%$$

$$\text{Percent pearlite} = \left[\frac{0.25-0.022}{0.77-0.022}\right] = 10.4\%$$

At a temperature just below 727°C the phases are ferrite and iron carbide. The ferrite will have 0.022% carbon.

$$\text{Percent ferrite, }\alpha:\ (0.022\%\ C) = \left[\frac{6.67-0.25}{6.67-0.022}\right]\times 100 = 98.8\%$$

$$\text{Percent pearlite} = \left[\frac{0.25-0.022}{6.67-0.022}\right] = 1.2\%$$

3.6. See Section 3.3.

3.7. See Section 3.4.

3.8. See Section 3.4.

3.9. A wide-flange shape that is nominally 36 in. deep and weighs 182 lb/ft

3.10. See Section 3.5.3.

3.11. See Section 3.6.

3.12. See Section 3.6.

3.13. Cold forming will almost double the yield strength to 66 ksi.

3.14. See Section 3.7.

3.15. See Section 3.5.3**.**

3.16. See Section 3.9.

3.17. See Section 3.9.

3.18. See Figures 3.17 and 3.18.

3.19. See Figure 3.17**.**

3.20. a. $A = 1.0 \times 0.25 = 0.25$ in.^{2}
$P_y = 12,500$ lb
$P_f = 17,500$ lb
$\sigma_y = 12,500 / 0.25 =$ **50,000 psi**
$\sigma_f = 17,500 / 0.25 =$ **70,000 psi**

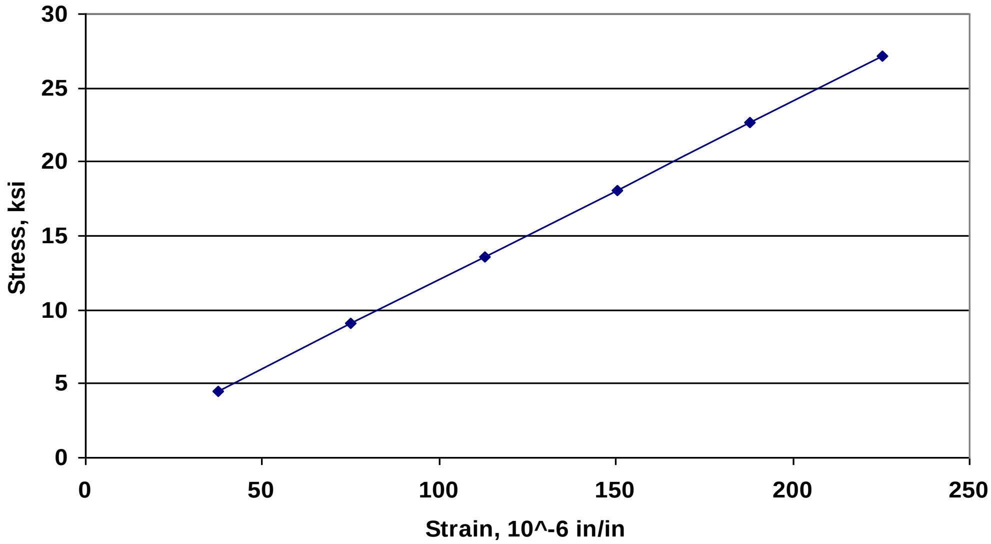
b. Assume $E = 30 \times 10^6$ psi
$\varepsilon = 0.6\ \sigma_y / E = 0.6 \times 50 \times 10^3 / (30 \times 10^6) = 0.001$ in./in.
$\Delta L = 2 \times 0.001 =$ **0.002 in.**

3.21. a. $A = \pi\ (10/8/2)^2 = 1.227$ in.^{2}
$P_y = 41,600$ lb
$P_f = 48,300$ lb
$\sigma_y = 41,600 / 1.227 =$ **33,904 psi**
$\sigma_f = 48,300 / 1.227 =$ **39,364 psi**

b. Assume $E = 29 \times 10^6$ psi
$\varepsilon = 0.7\ \sigma_y / E = 0.7 \times 33,904 / (29 \times 10^6) = 0.0008$ in./in.
$\Delta L = 2 \times 0.0008 =$ **0.0016 in.**

3.22. $\sigma = P / [\pi (0.375)^2]$

$\varepsilon = \Delta L / 3$



From the graph, E = slope = 1.204×10^8 psi

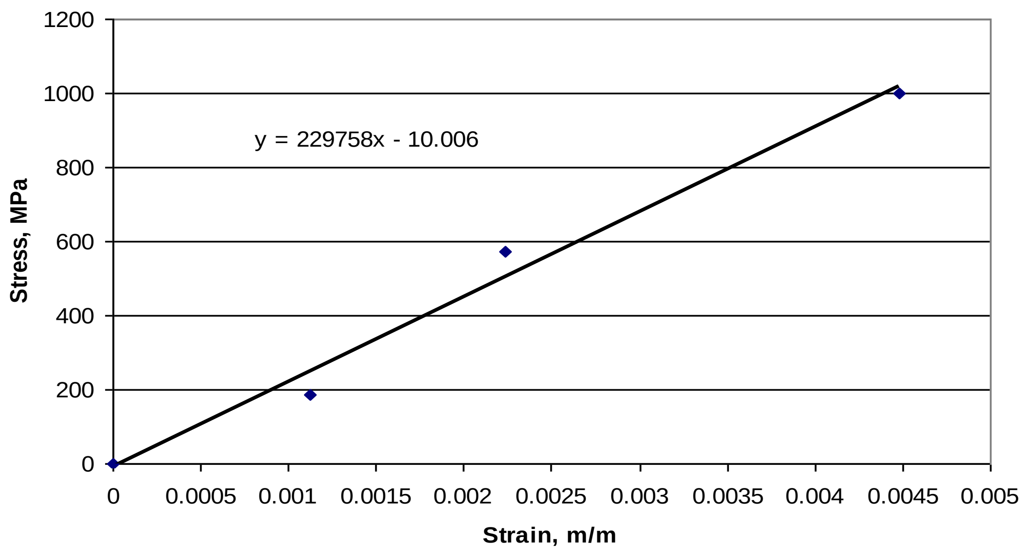
P = 8,225 lb

$\sigma = 8{,}225 / [\pi (0.375)^2] = 1.861 \times 10^4$ psi

$\Delta L = (\sigma \cdot L) / E =$ **4.64×10^{-4} in.**

3.23. $\sigma = P / [\pi (9.5)^2]$

$\varepsilon = \Delta L / 75$



From the graph, E = slope = 230 GPa

P = 600 KN

$\sigma = 600 / [\pi (9.5)^2] = 528.8$ MPa

$\Delta L = (\sigma \cdot L) / E =$ **0.172 mm.**

3.24. a. $E = \sigma / \varepsilon$ = 500 MPa / 0.002 = 250,000 MPa = **250 GPa**

b. The proportional limit is at a stress of **600 MPa** and a strain of **0.0025 m/m**

c. Yield strength at 0.002 strain offset = **650 MPa**

d. Tensile strength = **680 MPa**

e. ΔL = 0.38 mm
$\varepsilon = \Delta L/L$ =0.38 / 250 = 0.00152 m/m
$\sigma = E\,\varepsilon = (250 \times 10^9) \times (0.00152)$ = 380 MPa
From the graph, the applied stress is below the proportional limit.
$A = \pi\,(15)^2 / 4 = 176.7\ mm^2 = 176.7 \times 10^{-6}\ m^2$
$\sigma = P / A$
$380{,}000{,}000 = P / (176.7 \times 10^{-6})$
$P = 6.715 \times 10^4$ N = **67.15 kN**

f. **No deformation** because the applied stress is below the proportional limit (and therefore below the elastic limit).

g. **Yes**, because the applied stress is much below the yield strength.

3.25. $\sigma = \frac{102000}{\pi(0.025)^2 / 4}$ = 2.0779×10^8 Pa

$= \frac{}{L} = \frac{0.1}{100}$ = 0.001

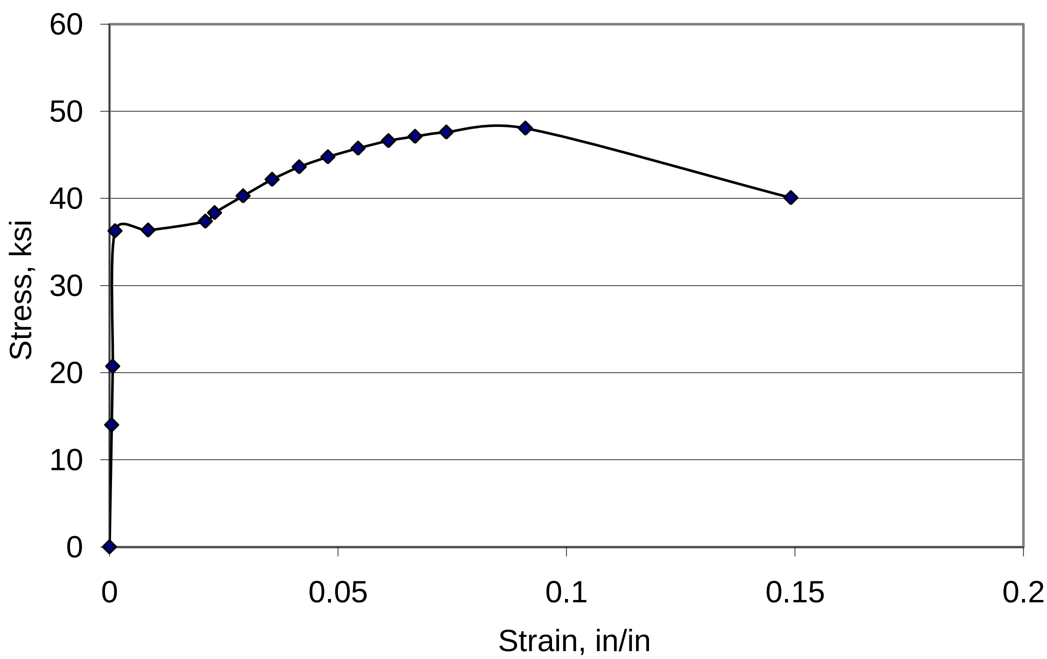
$E = \frac{}{} = \frac{2.0779x10^8}{0.001}$ = 2.0779×10^{11} Pa = 207.79 GPa

$\varepsilon_{laleral} = (d_{final} - d_{original}) / d_{original}$ = (24.99325 - 25) / 25 = -2.7×10^{-4} in./in.

$\nu = -\varepsilon_{lateral} / \varepsilon_{axial} = 2.7 \times 10^{-4} / 0.001$ = **0.27**

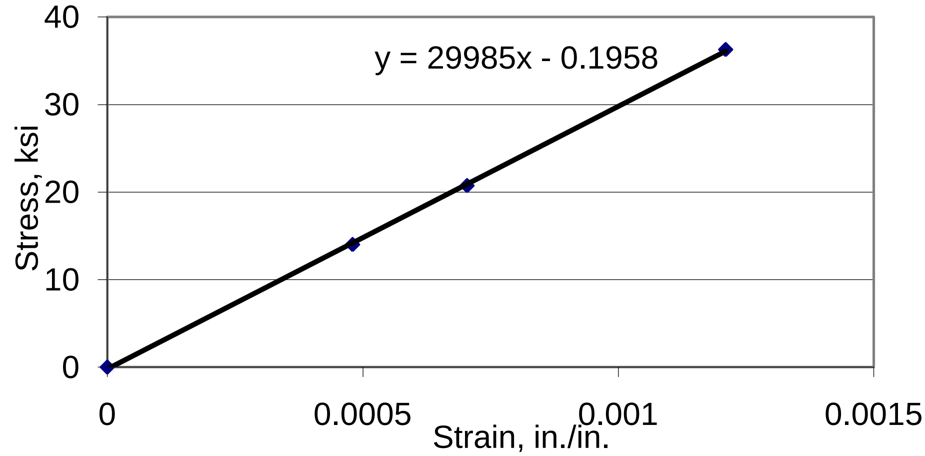
3.26. a. Stress = Load / Area
Strain = Displacement / Gage Length

Stress (ksi)	Strain (in/in)	Stress (ksi)	Strain (in/in)
0	0	43.617	0.04150
14.000	0.00048	44.766	0.04778
20.729	0.00070	45.756	0.05439
36.271	0.00121	46.617	0.06103
36.361	0.00846	47.113	0.06686
37.378	0.02098	47.607	0.07370
38.349	0.02299	48.057	0.09099
40.283	0.02923	40.078	0.14907
42.177	0.03558		



Stress-Strain Relation

b.



Stress-Strain Relation of the Linear Range

Modulus of elasticity = **29,985 ksi**

c. The proportional limit is at a stress of **36.27** ksi and a strain of **0.0012** in./in.

d. Yield stress = **36.50 ksi**

e. Ultimate strength = **48.20 ksi**

f. ε_l = change in diameter / diameter = (0.5 - 0.499905) / 0.5 = 0.00019 in./in.
at P = 4.07 kips, the displacement = 0.00141 in
ε_a = change in length / length = 0.00141 / 2 = 0.000705 in./in.
$\nu = -\varepsilon_l / \varepsilon_a$ = 0.00019 / 0.000705 = **0.27**

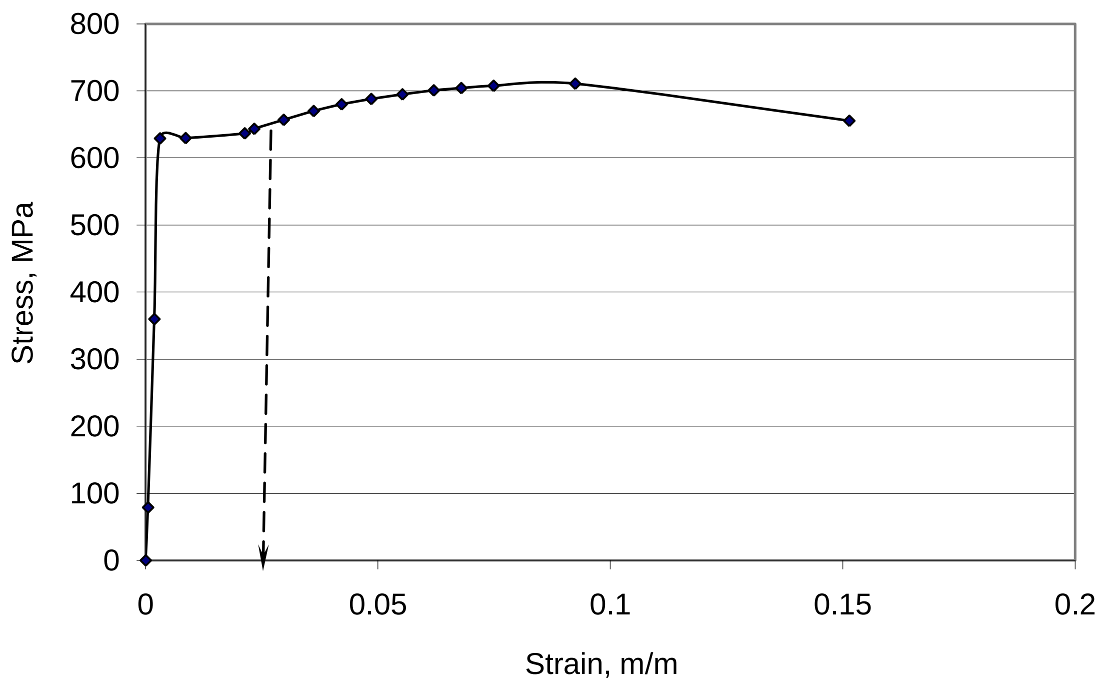
g. Cross sectional are at failure = $\pi\ (0.416012)^2 / 4 = 0.136\ in^2$
True stress = 7.87 / 0.136 = **57.868 ksi**
The true stress at failure (57.868 ksi) is **larger** than the engineering stress (40.078 ksi) since the cross sectional area at the neck is smaller than the original cross section.

h. The true strain at failure is **larger** than the engineering strain at failure since the increase in length at the vicinity of the neck is much larger than the increase in length outside of the neck. The specimen experiences the largest deformation (contraction of the cross-sectional area and increase in length) at the regions closest to the neck due to the nonuniform distribution of the deformation. The large increase in length at the neck increases the true strain to a large extent for the following reason. The definition of true strain utilizes a ratio of the change in length in an infinitesimal gauge length. By decreasing the gauge length toward an infinitesimal size and increasing the length due to localization in the neck, the numerator of an expression is increased while the denominator stays small resulting in a significant increase in the ratio of the two numbers. Note that when calculating the true strain, a small gauge length should be used at the neck since the properties of the material (such as the cross section) at the neck represent the true material properties.

3.27. a. Stress = Load / Area
Strain = Displacement / Gage Length

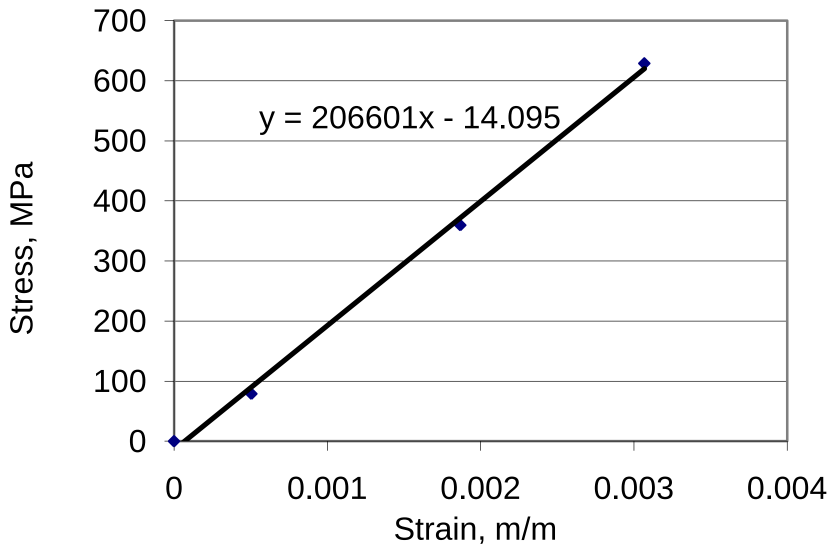
Stress (MPa)	Strain (m/m)	Stress (MPa)	Strain (m/m)
0	0	679.91	0.0422
78.97	0.0005	687.88	0.0485
359.78	0.0019	694.75	0.0553
629.11	0.0031	700.72	0.0620
629.58	0.0086	704.16	0.0679
636.63	0.0213	707.59	0.0749
643.37	0.0234	710.71	0.0924
656.78	0.0297	655.36	0.1515
669.92	0.0362		

The stress-strain relationship is shown below.



Stress-strain relation

b. The linear portion of the stress-strain relationship is shown below.



Stress-strain relation of the linear range

Modulus of elasticity = **206,601 MPa**

c. The proportional limit is at a stress of **629** MPa and a strain of **0.003** m/m

d. Yield stress = **634 MPa**

e. Ultimate strength = **712 MPa**

f. Stress = Load / Area = 1000 x 155 / (37.5 x 6.25) = 661.33 MPa
By drawing a line parallel to the linear portion on the stress-strain diagram at a stress of 661.33 MPa, the permanent strain = 0.026 m/m.
The permanent deformation = ε x L = 0.026 x 203 = **5.278 mm**

g. **No**, because the applied stress would result in permanent deformation in the structure.

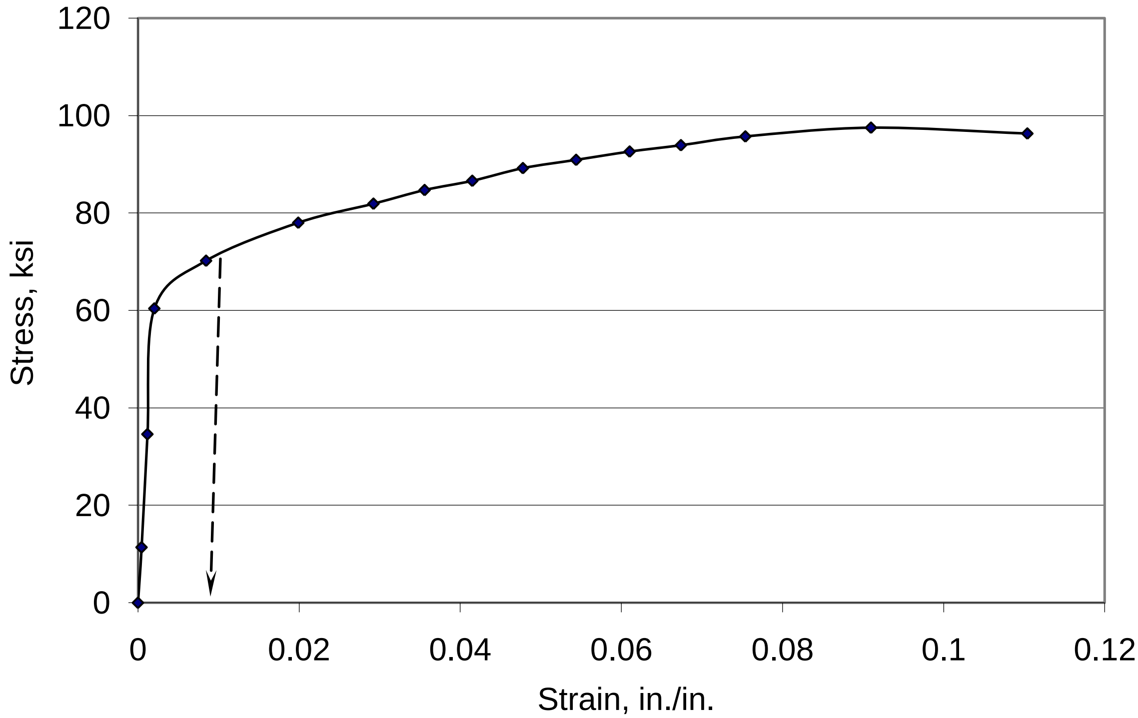
3.28. Easiest solution is to "google" the shape 350S125-27. The area is 0.173 in^2

a. Max. force = 0.173 x 33000=5710 lb. This is conservative since yield strength will increase by strain hardening.
b. No, in compression buckling would control for a thin member.

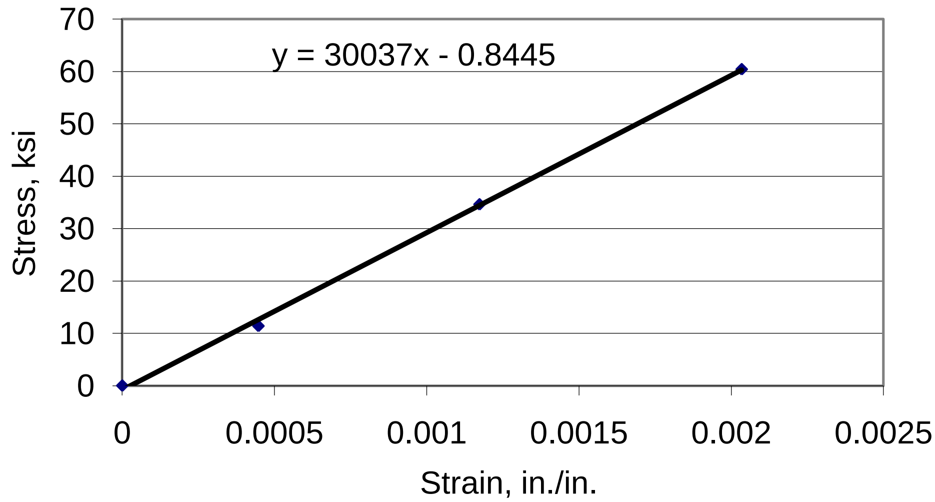
3.29. a. Stress = Load / Area
Strain = Displacement / Gage Length

Stress (ksi)	Strain (in/in)	Stress (ksi)	Strain (in/in)
0	0	86.600	0.04150
11.385	0.00045	89.200	0.04778
34.600	0.00117	90.900	0.05439
60.392	0.00203	92.600	0.06103
70.200	0.00846	93.900	0.06740
78.000	0.01990	95.700	0.07540
81.900	0.02923	97.500	0.09099
84.700	0.03558	96.300	0.11040

The stress-strain relationship is shown below.



b. The linear portion of the stress-strain relationship is shown below.



Stress-strain relation of the linear range

Modulus of elasticity = **30,037 ksi**

c. The proportional limit is at a stress of **60.4** ksi and a strain of **0.0021** in./in.

d. Yield stress = **66.5 ksi (using the offset method)**

e. Ultimate strength = **97.5 ksi**

f. Stress = Load / Area = 88,000/(1.22718x1000) = 71.71 ksi

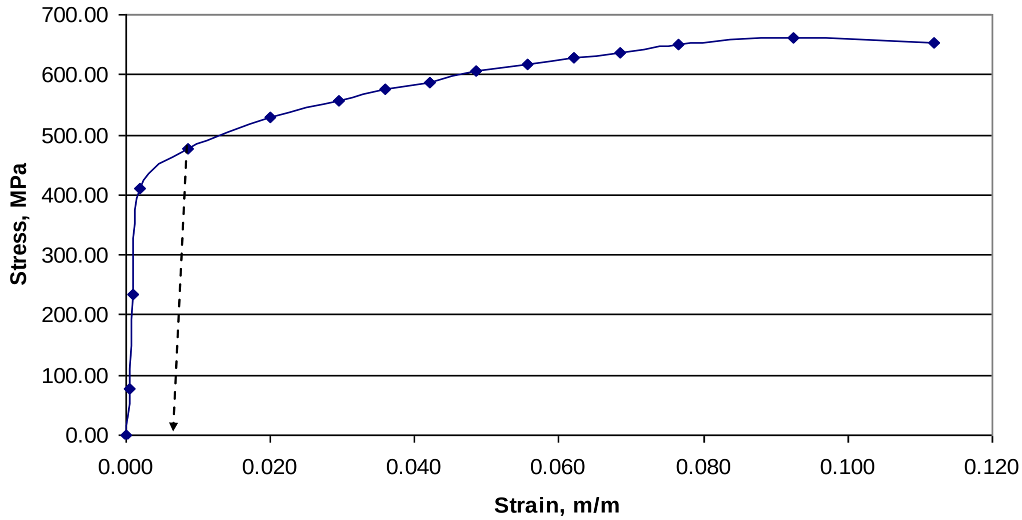
By drawing a line parallel to the linear portion on the stress-strain diagram at a stress of 71.71 ksi, the permanent strain = 0.008 in./in.

The permanent change in length = ε x L = 0.008 x 8 = **0.064 in.**

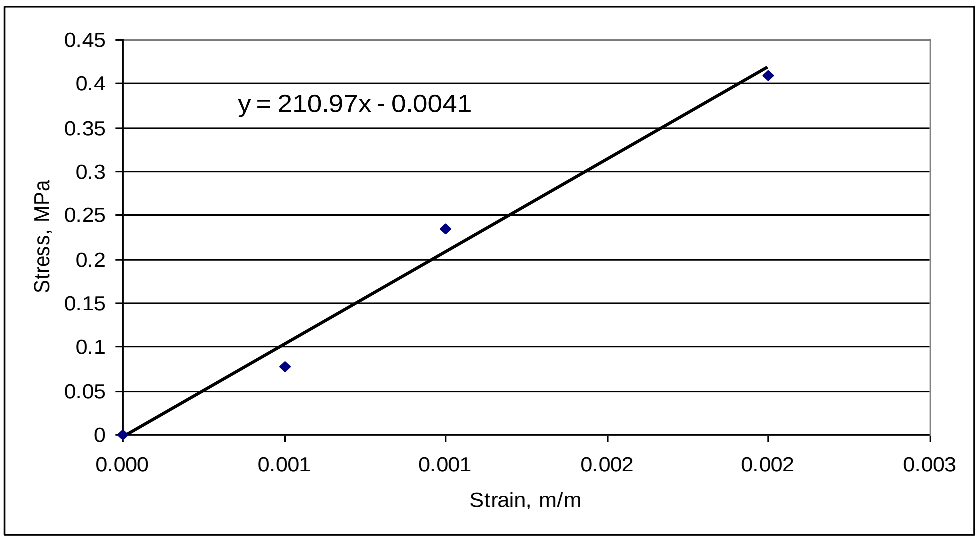
3.30. a. Stress = Load / Area
Strain = Displacement / Gage Length

Stress (MPa)	Strain (m/m)	Stress (MPa)	Strain (m/m)
0.00	0.000	587.77	0.042
77.31	0.001	605.42	0.049
234.78	0.001	616.97	0.056
409.91	0.002	628.53	0.062
476.53	0.009	637.36	0.069
529.47	0.020	649.54	0.077
555.95	0.030	661.72	0.093
574.84	0.036	653.64	0.112

The stress-strain relationship is shown below.



b. The linear portion of the stress-strain relationship is shown below.



Stress-strain relation of the linear range

Modulus of elasticity = **210 GPa**

c. The proportional limit is at a stress of **409** Mpa and a strain of **0.002** m/m

d. Yield stress = **480 MPa (using the offset method)**

e. Ultimate strength = **660 MPa**

f. Stress = Load / Area = 390/(π*16^2) = 485 MPa

By drawing a line parallel to the linear portion on the stress-strain diagram at a stress of 485 MPa , the permanent strain = 0.009 m/m

The permanent change in length = ε x L = 0.009 x 200 = **1.8 mm.**

3.31. a. $A = \pi\ (6^2 - 5^2) / 4 = 8.6429\ in^2$
$\sigma = P / A = 50{,}000 / 8.6429 = 5.785$ ksi
$\varepsilon = \sigma / E = 5.785 / 30000 = 0.000193$ in./in.
$\delta = \varepsilon L = 0.000193 \times 4 \times 12 =$ **0.00926 in.**

b. $\varepsilon_{lateral} = -\nu \cdot \varepsilon_{axial} = 0.27 \times 0.000193 = 0.00005211$ in./in.
$\varepsilon_{lateral} = (d_{outer,\ final} - d_{outer,\ inital}) / d_{outer,\ inital}$
$0.00005211 = (d_{outer,\ final} - 6) / 6$
$d_{outer,\ final} = 6.0031266$ in
$\Delta\ d_{outer} = 6.0031266 - 6 =$ **0.0031266 in.**

c. $\varepsilon_{lateral} = (d_{inner,\ final} - d_{inner,\ inital}) / d_{inner,\ inital}$
$0.0000503 = (d_{inner,\ final} - 0.18) / 0.18$
$d_{inner,\ final} = 0.18000905$ m = 180.00905 mm
Final wall thickness = $(d_{outer,\ final} - d_{inner,\ final}) / 2$ = (200.01005 - 180.00905) / 2 = 10.0005 mm
Increase in wall thickness = **0.0005 mm**

3.32. a. $A = \pi (0.20^2 - 0.18^2) / 4 = 0.005969\ m^2$

$\sigma = P / A = 200 \times 10^3 / 0.005969 = 33506304$ Pa = 0.033506 GPa

$\varepsilon = \sigma / E = 0.033506 / 200 = 0.0001675$ m/m

$\delta = \varepsilon L = 0.0001675 \times 1000 =$ **0.1675 mm**

b. $\varepsilon_{lateral} = -\nu \cdot \varepsilon_{axial} = 0.3 \times 0.0001675 = 0.0000503$ m/m

$\varepsilon_{lateral} = (d_{outer, final} - d_{outer, inital}) / d_{outer, inital}$

$0.0000503 = (d_{outer, final} - 0.2) / 0.2$

$d_{outer, final} = 0.20001005$ m = 200.01005 mm

$\Delta d_{outer} = 200.01005 - 200 =$ **0.01005 mm**

c. $\varepsilon_{lateral} = (d_{inner, final} - d_{inner, inital}) / d_{inner, inital}$

$0.0000503 = (d_{inner, final} - 0.18) / 0.18$

$d_{inner, final} = 0.18000905$ m = 180.00905 mm

Final wall thickness = $(d_{outer, final} - d_{inner, final}) / 2 = (200.01005 - 180.00905) / 2 = 10.0005$ mm

Increase in wall thickness = **0.0005 mm**

3.33. d = 12 mm

G = 80 GPa

$\theta = 90^o \times \pi / 180 = \pi/2$

$\tau_{max} = 300$ MPa

Equation 3.3, $G = \tau_{max} / \gamma$

Equation 3.2, $\gamma = \theta r / L$

$G = \tau_{max} L / \theta r$

$L = G \theta r / \tau_{max} = 80 \times 10^3 \times (\pi/2) \times 0.006 / 300 =$ **2.513 m**

3.34. d = ½ in.

$G = 11.6 \times 10^6$ psi

$\theta = 60^o \times \pi / 180 = \pi/3$

$\tau_{max} = 45 \times 10^3$ psi

Equation 3.3, $G = \tau_{max} / \gamma$

Equation 3.2, $\gamma = \theta r / L$

$G = \tau_{max} L / \theta r$

$L = G \theta r / \tau_{max} = 11.6 \times 10^6 \times (\pi/3) \times 0.25 / 45*10^3 =$ **67.45 in.**

3.35. a. Using S.I Units

$G = \tau / \gamma = 135 / 0.0049 =$ **27551 GPa**

b. Using U.S. Customary Units

$G = \tau / \gamma = 19.6 / 0.0049 =$ **4000 ksi**

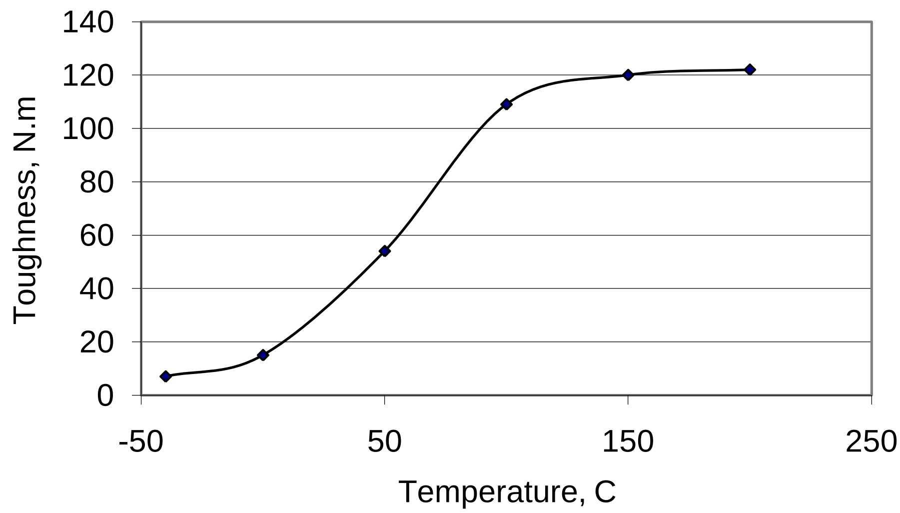
3.36. $\sigma = P/A$

$\varepsilon = \Delta L / L$

Observation No.	P (lb)	ΔL (in.)	σ (psi)	ε (in./in.)	u_i (psi)
0	0	0	0	0	N/A
1	1420	0.0005	5680	0.000125	0.36
2	2850	0.001	11400	0.00025	1.07
3	4270	0.0015	17080	0.000375	1.78
4	5690	0.002	22760	0.0005	2.49
5	7110	0.0025	28440	0.000625	3.20
6	7500	0.003	30000	0.00075	3.65
7	7500	0.0035	30000	0.000875	3.75
8	7560	0.004	30240	0.001	3.77
9	8250	0.0045	33000	0.001125	3.95
10	8300	0.005	33200	0.00125	4.14
11	8450	0.01	33800	0.0025	41.88
12	8490	0.015	33960	0.00375	42.35
13	8620	0.02	34480	0.005	42.78
14	8820	0.025	35280	0.00625	43.60
15	9050	0.03	36200	0.0075	44.68
16	9220	0.035	36880	0.00875	45.68
17	9540	0.04	38160	0.01	46.90
18	9650	0.045	38600	0.01125	47.98
19	10,060	0.05	40240	0.0125	49.28
20	11,870	0.1	47480	0.025	548.25
21	12,830	0.15	51320	0.0375	617.50
22	13,360	0.2	53440	0.05	654.75
23	13,670	0.25	54680	0.0625	675.75
24	13,850	0.3	55400	0.075	688.00
25	13,920	0.35	55680	0.0875	694.25
26	13,960	0.4	55840	0.1	697.00
27	13,800	0.5	55200	0.125	1,388.00
28	13,600	0.55	54400	0.1375	685.00
29	13,150	0.6	52600	0.15	668.75
30	12,510	0.65	50040	0.1625	641.50
31	11,690	0.7	46760	0.175	605.00
				u_t =	**8,997.00**

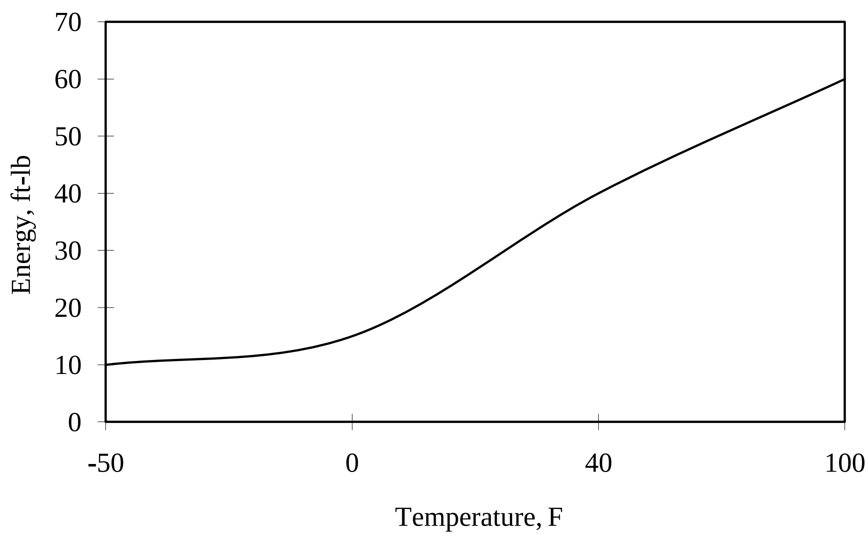
Material toughness = **8,997.00 psi**

3.37. The toughness versus temperature relation is shown below.



Temperature transition zone between ductile and brittle behavior = **0 – 120°C**

3.38.



From the graph the energy corresponding to 30°F is 32 ft.lb. Therefore, the steel member has **adequate Chary V-notch fracture toughness**.

3.39. See Section 3.10.

3.40. See Section 3.10**.**

3.41. See Section 3.11**.**

3.42. See Section 3.11**.**

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CHAPTER 4. ALUMINUM

4.1. See the introduction section of Chapter 4**.**

4.2.

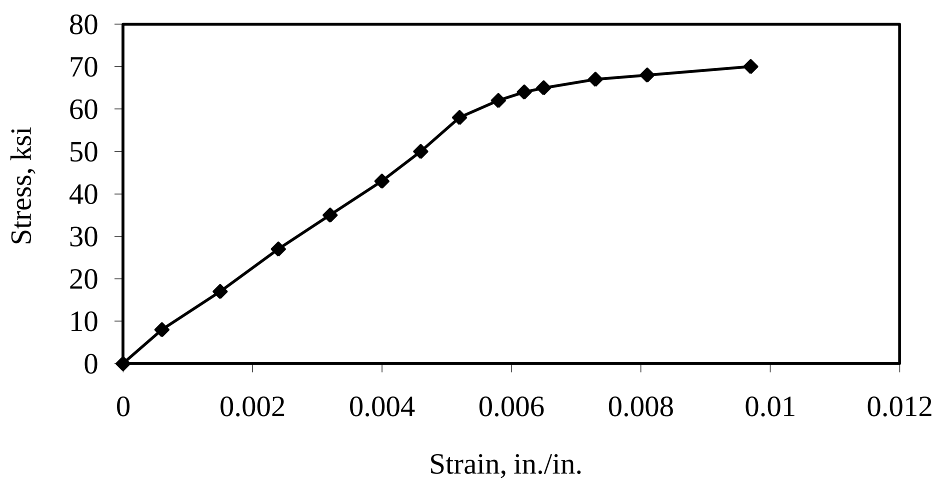
	A36 Steel*	7178 T76 Aluminum**
Yield Strength	36 ksi	73 ksi
Ultimate Strength	58-80 ksi	83 ksi
Modulus of Elasticity	29,000 ksi	10,500 ksi

*See Table 3.2 and 1.1
** See Tables 4.5 and 1.1

The material property that controls the deflection is the modulus of elasticity. The modulus of aluminum is lower. Therefore, the aluminum section must be larger.

The material property that controls the tension is the yield strength. The yield s of the steel is lower. Therefore, steel would require a larger cross section.

4.3. a. The stress-strain relationship is shown below.



b. Modulus of elasticity = $\mathbf{11.15 \times 10^6}$ **psi**

c. The proportional limit is at a stress of **58 ksi** and a strain of **0.004 in./in.**

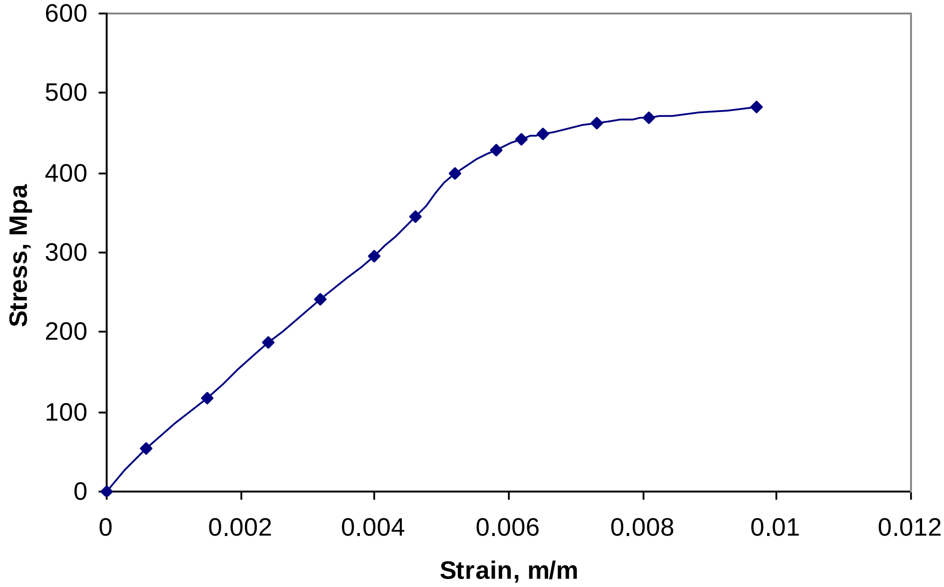
d. $A = \pi (0.28)^2 = 0.2463$ in.^{2}
$P = 58 \times 10^3 \times 0.2463 =$ **14,285 lb**

e. Yield strength = $\mathbf{68 \times 10^3}$ **psi**

f. Tensile strength = $\mathbf{70 \times 10^3}$ **psi**

g. Elongation at failure = $9.7 \times 10^{-3} \times 100 =$ **0.97%**

4.4. a. The stress-strain relationship is shown below.



b. Modulus of elasticity = **73.8 MPa**

c. The proportional limit is at a stress of **380 MPa** and a strain of **5.2 m/m.**

d. A = π $(7)^2$ = 153.86 mm.^{2}
P = 380 x 10^3 x 153.86 = **58,467 kN**

e. Yield strength = **400 MPa**

f. Tensile strength = **482.7 MPa**

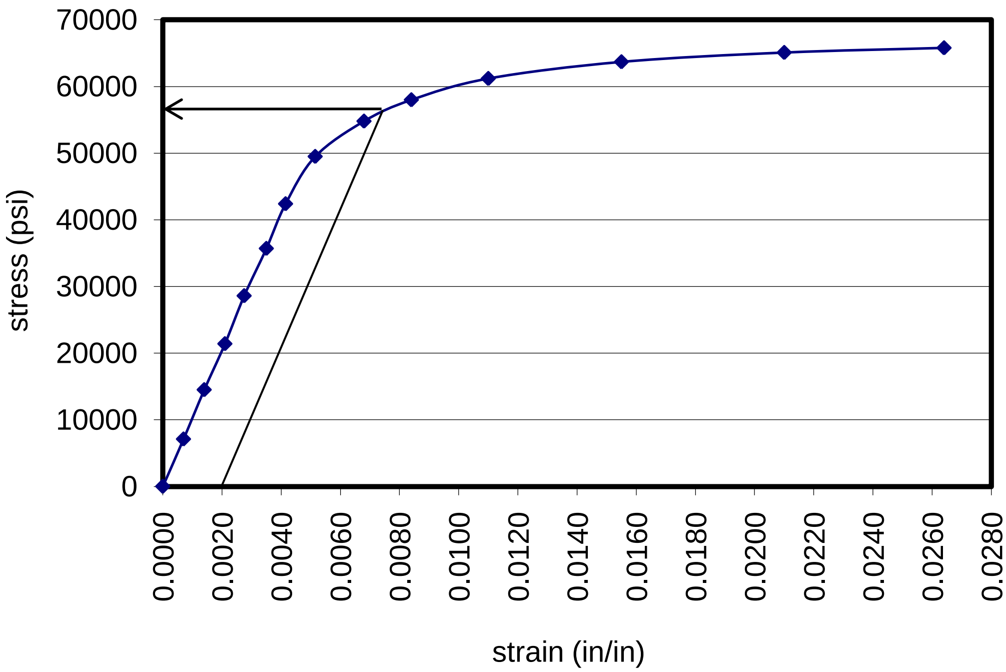
g. Elongation at failure = 9.7 x 10^{-3} x 100 = **0.97%**

4.5. See Table 4.5.

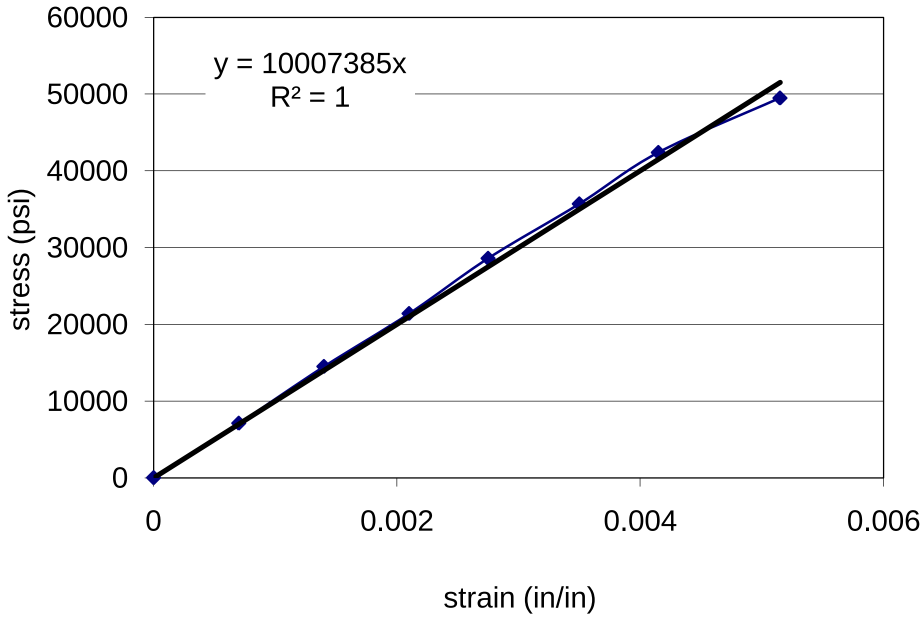
4.6. Stress = Load / Area
Strain = Displacement / Gage Length

Load (lb)	ΔL (in.)	σ (ksi)	ε (in./in.)
0	0	0	0
2000	0.0014	7100	0.0007
4100	0.0028	14500	0.0014
6050	0.0042	21400	0.0021
8080	0.0055	28600	0.00275
10100	0.007	35700	0.0035
12000	0.0083	42400	0.00415
14000	0.0103	49500	0.00515
15,500	0.0136	54800	0.0068
16,400	0.0168	58000	0.0084
17,300	0.022	61200	0.011
18,000	0.031	63700	0.0155
18,400	0.042	65100	0.021
18,600	0.0528	65800	0.0264
18,800	fracture	66500	

a. The stress-strain relationship is shown below.



b. The linear portion of the stress-strain relationship is shown below.



c. The proportional limit is at a stress of **50,000 psi**.

d. Yield stress at an offset strain of 0.002 in/in = **58,000 psi**

e. Tangent modulus at a stress of 60 ksi = **1,053,000 psi**
f. Secant modulus at a stress of 60 ksi = **6,316,000 psi**

4.7. a. Stress = Load / Area
Strain = Displacement / Gage Length

Stress (MPa)	Strain (m/m)	Stress (MPa)	Strain (m/m)
0	0	428.36	0.0297
41.71	0.0005	451.89	0.0438
179.46	0.0023	483.47	0.0678
319.71	0.0044	508.88	0.0966
371.09	0.0081	522.07	0.1192
391.62	0.0141	532.70	0.1477
405.67	0.0196	527.82	0.1609
418.16	0.0249		

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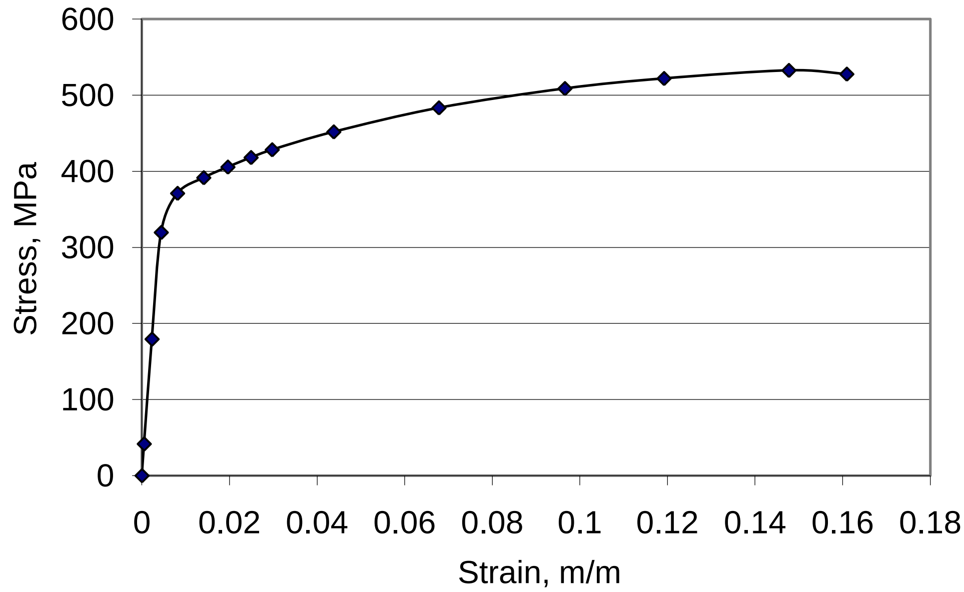
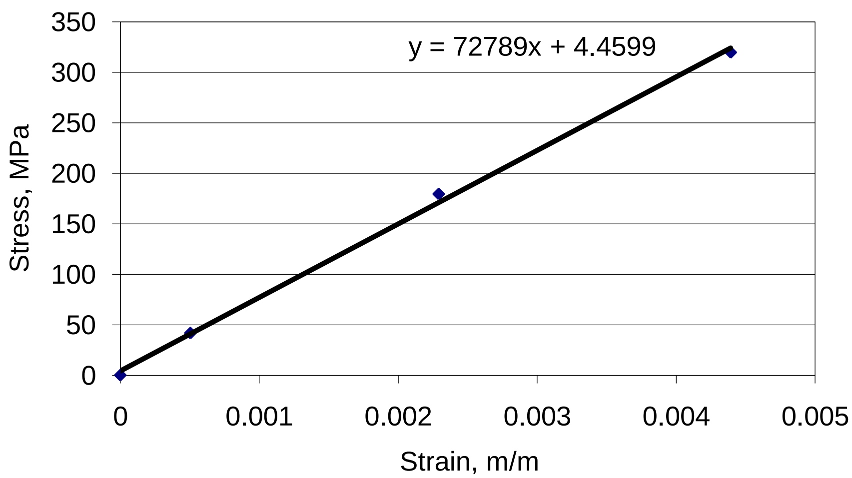
The stress-strain relationship is shown below.



Stress-Strain Relation

b. The linear portion of the stress-strain relationship is shown below.



Stress-strain relation of the linear range

Modulus of elasticity = **72,789 MPa**

c. The proportional limit is at a stress of **319** MPa and a strain of **0.0043** m/m

d. Yield stress at an offset strain of 0.002 in./in. = **360 MPa**

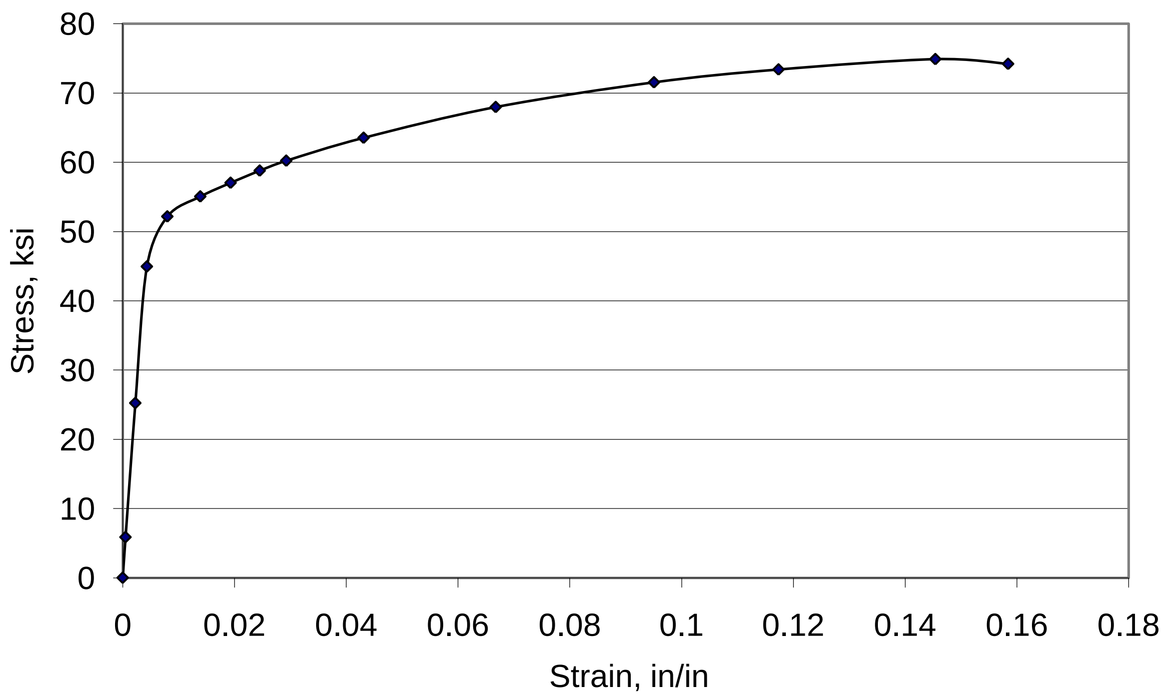
e. Tangent modulus at a stress of 450 MPa = **1,715 MPa**

f. Secant modulus at a stress of 450 MPa = **10,500 MPa**

4.8. a. Stress = Load / Area
Strain = Displacement / Gage Length

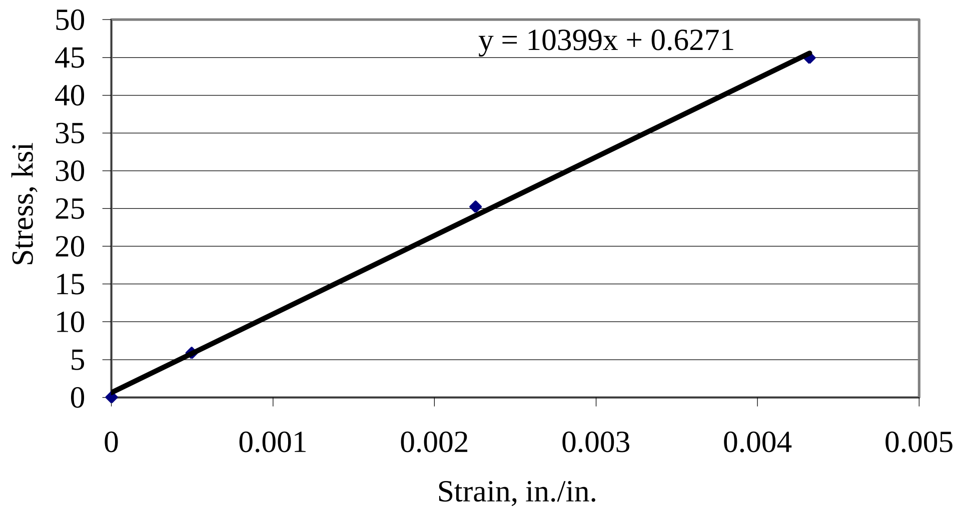
Stress (ksi)	Strain (in/in)	Stress (ksi)	Strain (in/in)
0	0	60.234	0.02926
5.865	0.00050	63.541	0.04310
25.234	0.00225	67.983	0.06674
44.955	0.00432	71.555	0.09506
52.181	0.00799	73.410	0.11734
55.067	0.01388	74.905	0.14539
57.043	0.01930	74.219	0.15841
58.799	0.02451		

The stress-strain relationship is shown below.



Stress-strain diagram

b. The linear portion of the stress-strain relationship is shown below.



Stress-strain relation of the linear range

Modulus of elasticity = **10,399 ksi**

c. The proportional limit is at a stress of **45,000 psi** and a strain of **0.0043 in./in.**

d. Yield stress at an offset strain of 0.002 in./in. = **60,000 psi**

e. Initial tangent modulus = **11,730,000 psi**

f. Stress = $\dfrac{3200}{\pi x 0.25 x 0.25/4}$ = 65,190 psi

From the stress-strain diagram, the permanent strain = 0.045 in./in.
Permanent change in gage length = 0.045 x 1 = **0.045 in.**

g. $\varepsilon_{lateral} = \dfrac{-(0.25-0.249814)}{0.25}$ = - 0.000744 in./in.

$\varepsilon_{axial} = \dfrac{1239/(\pi x 0.25 x 0.25/4)}{10399000}$ = 0.002427 in./in.

$\nu = -\dfrac{\varepsilon_{lateral}}{\varepsilon_{axial}} = -\dfrac{-0.000744}{0.002427}$ = **0.307**

4.9. a. $\sigma = 4000 / (\pi \times 0.004^2) = 79.5774 \times 10^6$ Pa = 79.5774 MPa
$\varepsilon_{axial} = \sigma / E = 79.5774 / (69 \times 10^3)$ = **0.001153 m/m**
$\varepsilon_{lateral} = -\nu\, \varepsilon_{axial}$ = - 0.33 x 0.001153 = - 0.000381 m/m

b. $\varepsilon_{lateral} = (d_f - d_o) / d_o$
$d_f = d_o \times (1+\varepsilon_{lateral})$ = 8 x (1 - 0.000381) = **7.99695 mm**

4.10. a. $\sigma = -50000 / (\pi \times 3^2) = -1768.4 \times 10^3$ lb/in^2 = -1.768 ksi

$\varepsilon_{axial} = \sigma / E = -1.768 / 11 \times 10^3$ = **-0.000161 in./in.**
$\varepsilon_{lateral} = - \nu\, \varepsilon_{axial} = - 0.33 \times 0.000161 = 0.000053$ in./in.

b. $\varepsilon_{lateral} = (d_f - d_o) / d_o$
$d_f = d_o \times (1+\varepsilon_{lateral}) = 3 \times (1 + 0.000053)$ = **3.000159 in.**

c. $\Delta L = L \times \varepsilon_{axial} = 6 \times (-0.000161) = -0.000966$ in.
Final height = 6 - 0.000966 = **5.999034 in.**

4.11. For the tensile stress
$\sigma = 2000 / (\pi \times 0.5^2/4) = 10{,}185.9$ psi

Since σ_y = 21000 psi, it is clear that the applied stress is well below the yield stress and as a result the deformation is elastic.

$\varepsilon_{axial} = \sigma / E = 10{,}185.9 / (10 \times 10^6) = 0.0010186$ in./in.
$\varepsilon_{lateral} = - \nu\, \varepsilon_{axial} = - 0.33 \times 0.0010186 = - 0.000336$ in.
$\varepsilon_{lateral} = (d_f - d_o) / d_o$
$d_f = d_o \times (1+\varepsilon_{lateral}) = 0.5 \times (1 - 0.000336)$ = **0.4998 in.**

For the compressive stress
$\varepsilon_{lateral} = + 0.000336$
$d_f = 0.5 \times (1 + 0.000336)$ = **0.50017 in**

4.12. $$\varepsilon = \frac{\sigma}{70{,}000}\left[1+\frac{3}{7}\left(\frac{\sigma}{270}\right)^9\right] = \frac{1}{70{,}000}\left[\sigma+\frac{3}{7}\left(\frac{\sigma^{10}}{(270)^9}\right)\right]$$

$\sigma = [20{,}000/ (\pi \times 0.01^2 / 4)] \times 10^{-6} = 254.65$ Mpa

$\varepsilon_{total} = 0.0045585$ m/m

$$\frac{d\varepsilon}{d\sigma} = \frac{1}{70{,}000}\left[1+\frac{30}{7}\left(\frac{\sigma}{270}\right)^9\right]$$

At $\sigma = 0$

$$\frac{d\varepsilon}{d\sigma} = \frac{1}{70{,}000}$$

$$\frac{d\sigma}{d\varepsilon} = 70{,}000 \text{ = Initial tangent modulus}$$

$\varepsilon_{recoverable} = 254.65 / 70{,}000 = 0.0036379$ m/m

$\varepsilon_{permanent} = \varepsilon_{total} - \varepsilon_{recoverable} = 0.0045585 - 0.0036379 = 0.0009206$ m/m

Permanent deformation = $\varepsilon_{lateral}$. L = **1.841 mm**

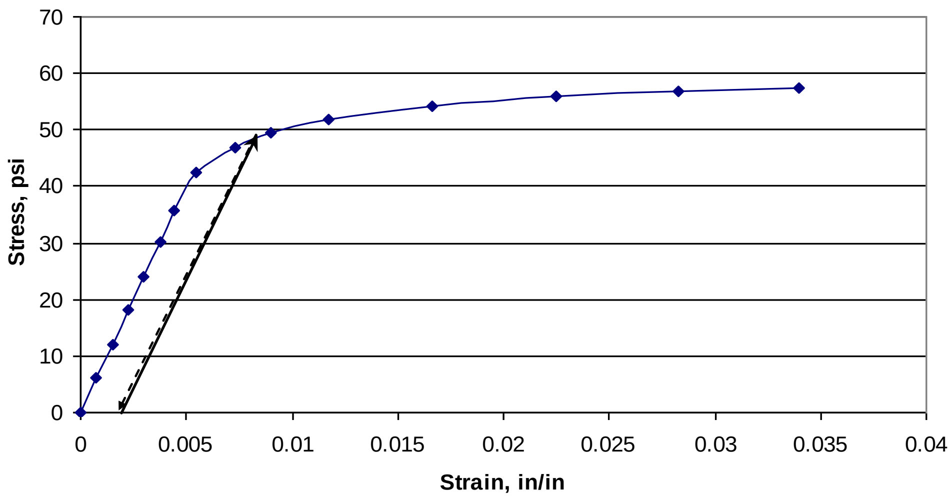
4.13.

Observation	*P* (lb)	ΔL	σ (psi)	ε	u_i (psi)
0.00	0	0.0000	0.00	0.00000	N/A
1.00	1181	0.0015	6014.78	0.00075	2.25554
2.00	2369	0.0030	12065.22	0.00150	6.78000
3.00	3550	0.0045	18080.00	0.00225	11.30446
4.00	4738	0.0059	24130.44	0.00295	14.77365
5.00	5932	0.0075	30211.43	0.00375	21.73675
6.00	7008	0.0089	35691.45	0.00445	23.06601
7.00	8336	0.0110	42454.90	0.00550	41.02683
8.00	9183	0.0146	46768.63	0.00730	80.30118
9.00	9698	0.0180	49391.51	0.00900	81.73612
10.00	10196	0.0235	51927.80	0.01175	139.31405
11.00	10661	0.0332	54296.03	0.01660	257.59278
12.00	10960	0.0449	55818.82	0.02245	322.08593
13.00	11159	0.0565	56832.32	0.02825	326.68831
14.00	11292	0.0679	57509.68	0.03395	325.87471
				$u_t =$	**1654.5363**

Material toughness = **1,655 psi**

4.14

Observation	*P* (lb)	ΔL	σ (psi)	ε
0.00	0	0.0000	0.00	0.00000
1.00	1181	0.0015	6014.78	0.00075
2.00	2369	0.0030	12065.22	0.00150
3.00	3550	0.0045	18080.00	0.00225
4.00	4738	0.0059	24130.44	0.00295
5.00	5932	0.0075	30211.43	0.00375
6.00	7008	0.0089	35691.45	0.00445
7.00	8336	0.0110	42454.90	0.00550
8.00	9183	0.0146	46768.63	0.00730
9.00	9698	0.0180	49391.51	0.00900
10.00	10196	0.0235	51927.80	0.01175
11.00	10661	0.0332	54296.03	0.01660
12.00	10960	0.0449	55818.82	0.02245
13.00	11159	0.0565	56832.32	0.02825
14.00	11292	0.0679	57509.68	0.03395



a. E = **8,020 ksi**

b. Proportional limit = **43 ksi**

c. The yield strength at a strain offset of 0.002 = **49 ksi**

d. The tensile strength = **57.5 ksi**

e. ε_{axial} = 0.016/2 = 0.008 in./in.
From graph (or by interpolation from table), σ = 48,000 psi
P = σ x A = 9,425 lb

f. Drawing a line parallel to the original part of the curve shows that the final (plastic) strain is about 0.0018 in./in.
Final Deformation = 0.0018 x 2 = **0.0036 in.**

g. No, since it is too close to the yield strength. Using a factor of safety, the applied stress must be much less than the yield strength.

4.15. See Section 4.5.

CHAPTER 5. AGGREGATES

5.1. See Section 5.2**.**

5.2. See Section 5.5.

5.3. See Section 5.5.

5.5. See Section 5.5.1.

5.6. See Section 5.5.4**.**

5.7. Sample A: Total moisture content = [(521.0 – 491.6) / 491.6] x 100 = **5.98%**
Free moisture content = 5.98 – 2.5 = **3.48%**

Sample B: Total moisture content = [(522.4 – 491.7) / 491.7] x 100 = **6.24%**
Free moisture content = 6.24 – 2.4 = **3.84%**

Sample C: Total moisture content = [(523.4 – 492.1) / 492.1] x 100 = **6.36%**
Free moisture content = 6.36 – 2.3 = **4.06%**

5.8. Total moisture content == [(297.2 – 281.5) / 281.5] x 100 = 5.58 %
Free moisture content = **3.08 %**

5.9. a. Bulk dry specific gravity = 5216/(5227-3295) = **2.6998**
b. Apparent specific gravity = 5216/(5216-3295) = **2.715**
c. Moisture content of stockpile aggregate =100 x (5298-5216)/ 5216 =**1.57%**
d. Absorption = 100 x (5227-5216)/5216= **0.21%**

5.10. Volume = 2000 x 48 x 0.5 = 48,000 ft^3
Required density = 0.95 x 119.7 = 113.7 lb/ ft^3
Dry weight = 48,000 x 113.7 = 5,458,320 lb
Wet weight = 3,086,200 x 1.031 = 5,627,527 lb = **2,552.6 tons**

5.11. The bulk dry specific gravity considers the total particle volume, whereas the dry-rodded unit weight considers the volume of the container.

Percent volume of particles = $\frac{88.0}{2.701x62.4} = 52.2\%$

Percent voids = 100 – 52.2 = **47.8%**

5.12. The bulk dry specific gravity considers the total particle volume, whereas the dry-rodded unit weight considers the volume of the container.

Percent volume of particles = $\frac{72.5}{2.639x62.4} = 44.0\%$

Percent voids = 100 – 44.0 = **56.0%**

5.13. a. Dry-rodded unit weight for trial 1 = (69.6 – 20.3)/0.5 = 98.6 lb/ft^3

Dry-rodded unit weight for trial 2 = (68.2 – 20.3)/0.5 = 95.8 lb/ft^3

Dry-rodded unit weight for trial 3 = (71.6 – 20.3)/0.5 = 102.6 lb/ft^3

Average dry-rodded unit weight = 99.0 lb/ft^3

b. Percent volume of particles = 98.6/(2.620 x 62.3) x 100 = 60.4 %
Percent voids for trial 1 = 100 – 60.4 = 39.6%

Percent volume of particles = 95.8/(2.620 x 62.3) x 100 = 58.7 %
Percent voids for trial 2 = 100 – 58.7 = 41.3%

Percent volume of particles = 102.6/(2.620 x 62.3) x 100 = 62.9 %
Percent voids for trial 3 = 100 – 62.9 = 37.1%

5.14. See Section 5.5**.**

5.15. Bulk dry specific gravity = 495.5/(623+500-938.2) = **2.681**
Bulk SSD specific gravity = 500/(623+500-938.2) = **2.706**
Apparent specific gravity = 495.5/(623+495.5-938.2) = **2.748**
Absorption = 100 x (500-495.5)/ 495.5 = **0.91%**

5.16.

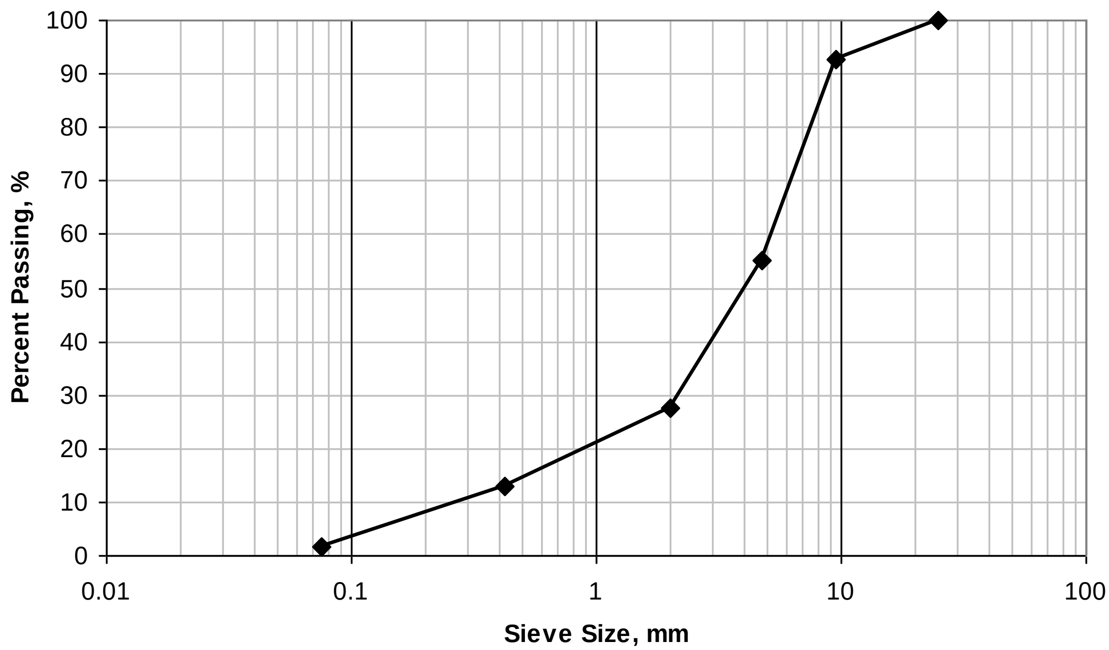
Size No.	Maximum sieve size	Nominal maximum sieve size
357	63 mm (2.5 in.)	50 mm (2 in.)
57	37.5 mm (1.5 in.)	25 mm (1 in.)
8	12.5 mm (0.5 in.)	9.5 mm (3/8 in.)

5.17.

Sieve	Amount Retained (g)	Percent Retained	Cumulative Percent Retained	Percent Passing
25 mm	0	0	0	100
9.5 mm	47.1	7.3	7.3	93
4.75 mm	239.4	37.4	44.8	55
2.00 mm	176.5	27.6	72.4	28
0.425 mm	92.7	14.5	86.9	13
0.075 mm	73.5	11.5	98.4	1.5
Pan	9.6	1.5	100	0.0
Total	638.8			

Note that the values of the percent passing are rounded off to the nearest 1%, except the percent passing the 0.075 mm sieve is rounded off to the nearest 0.1%.

Semi-log gradation chart:

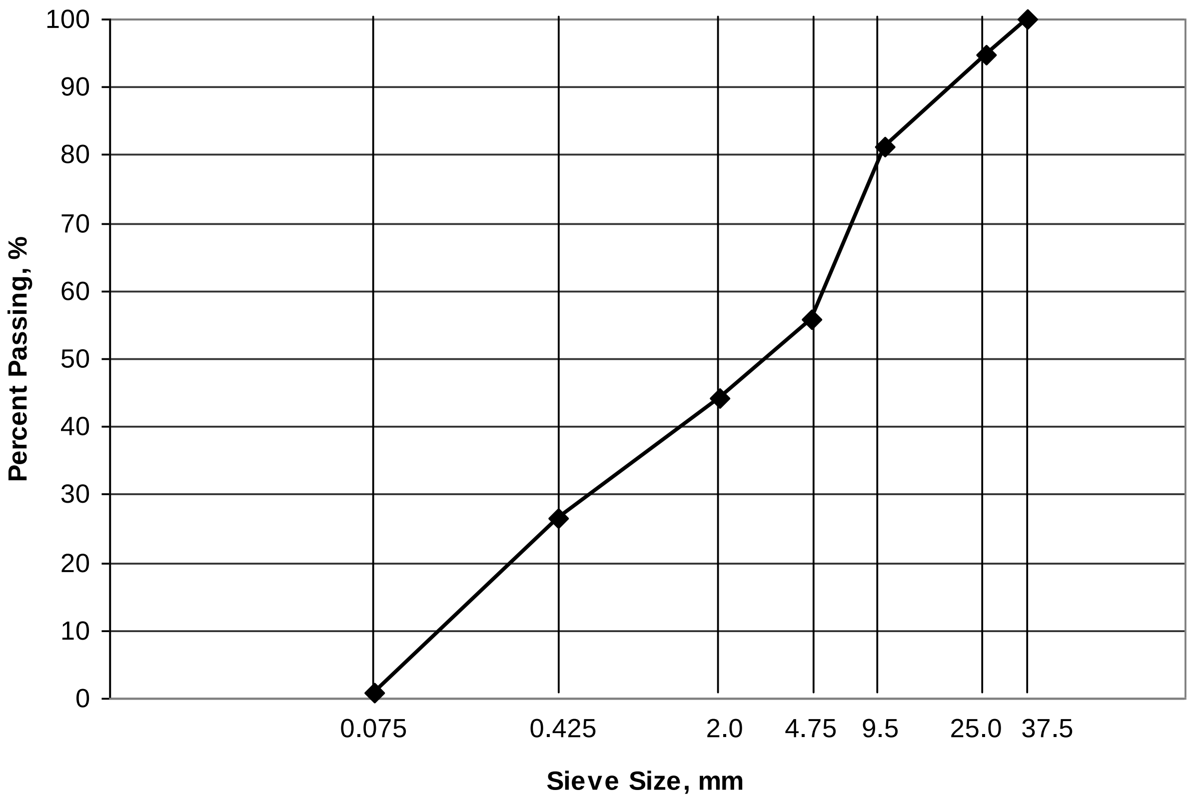


The Maximum Size = **25 mm**
The Nominal Maximum Size = **9.5**

5.18.

.Sieve size	Amount Retained, g	Cumulative Amount Retained, g	Cumulative Percent Retained	Percent Passing
Plus 37.5 mm	0.0	0.0	0.0	100
37.5 mm to 25 mm	315.0	5.4	5.4	95
25 mm to 19 mm	782.0	13.3	18.7	81
19 mm to 9.5 mm	1493.0	25.5	44.2	56
9.5 mm to 4.75 mm	677.0	11.6	55.8	44
4.75 mm to 0.60 mm	1046.0	17.8	73.6	26
0.60 mm to 0.075 mm	1502.0	25.6	99.2	0.8
Pan	45.0	0.8	100.0	0.0
Total	5860.0			

The 0.45 power gradation chart:



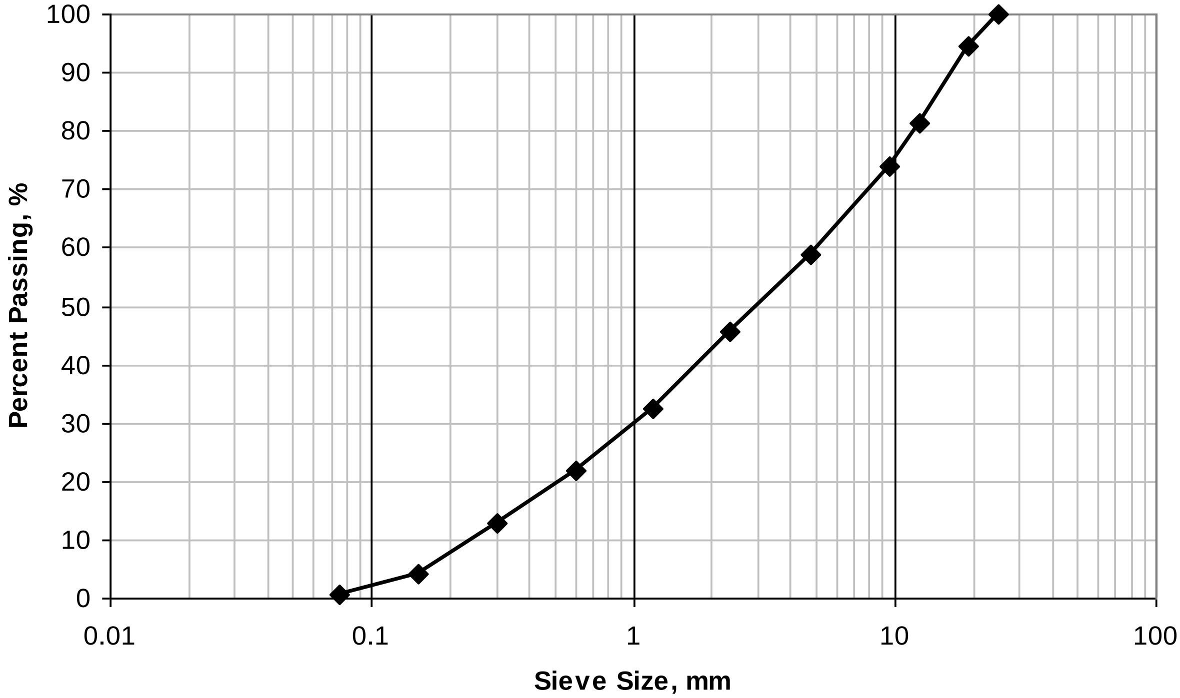
Note: In order to plot the 0.45 power gradation chart the horizontal axis represents the sieve size raised to 0.45, $(d_i)^{0.45}$. The vertical axis represents the percent passing calculated using Equation 5.16. The values on the x-axis are then deleted and the text box feature is used to label the x-axis with the actual sieve values. In addition, the drawing tool is used to add vertical lines between the axis and the data points. The following table is used to plot the 0.45 gradation chart:

$(d_i)^{0.45}$	$P_i = 100(d_i/D)^{0.45}$
5.11	100
4.26	95
2.75	81
2.02	56
1.37	44
0.68	26
0.31	0.8

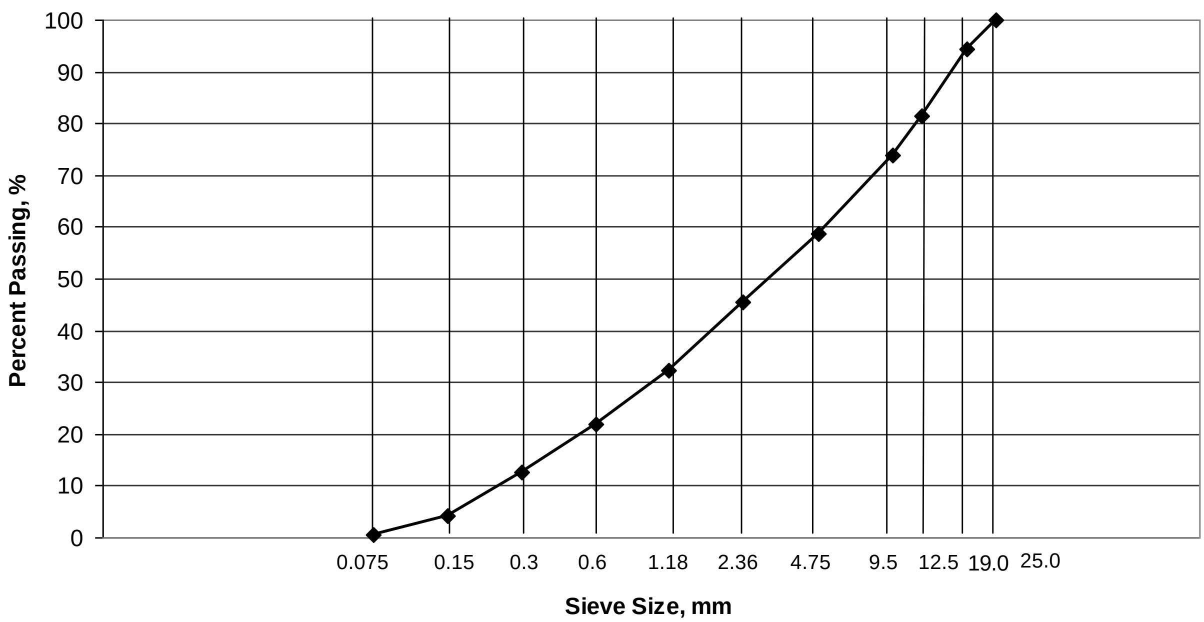
5.19.

Sieve Size, mm	Amount Retained, g	Cumulative Amount Retained, g	Cumulative Percent Retained	Percent Passing
25	0.0	0.0	0.0	100
19	376.7	5.5	5.5	94
12.5	888.4	13.0	18.6	81
9.5	506.2	7.4	26.0	74
4.75	1038.4	15.3	41.3	59
2.36	900.1	13.2	54.5	46
1.18	891.5	13.1	67.6	32
0.6	712.6	10.5	78.0	22
0.3	625.2	9.2	87.2	13
0.15	581.5	8.5	95.8	4
0.075	242.9	3.6	99.3	0.7
Pan	44.9	0.7	100.0	0.0
Total	6808.4			

Semi-log gradation chart



b. 0.45 gradation chart



5.20.

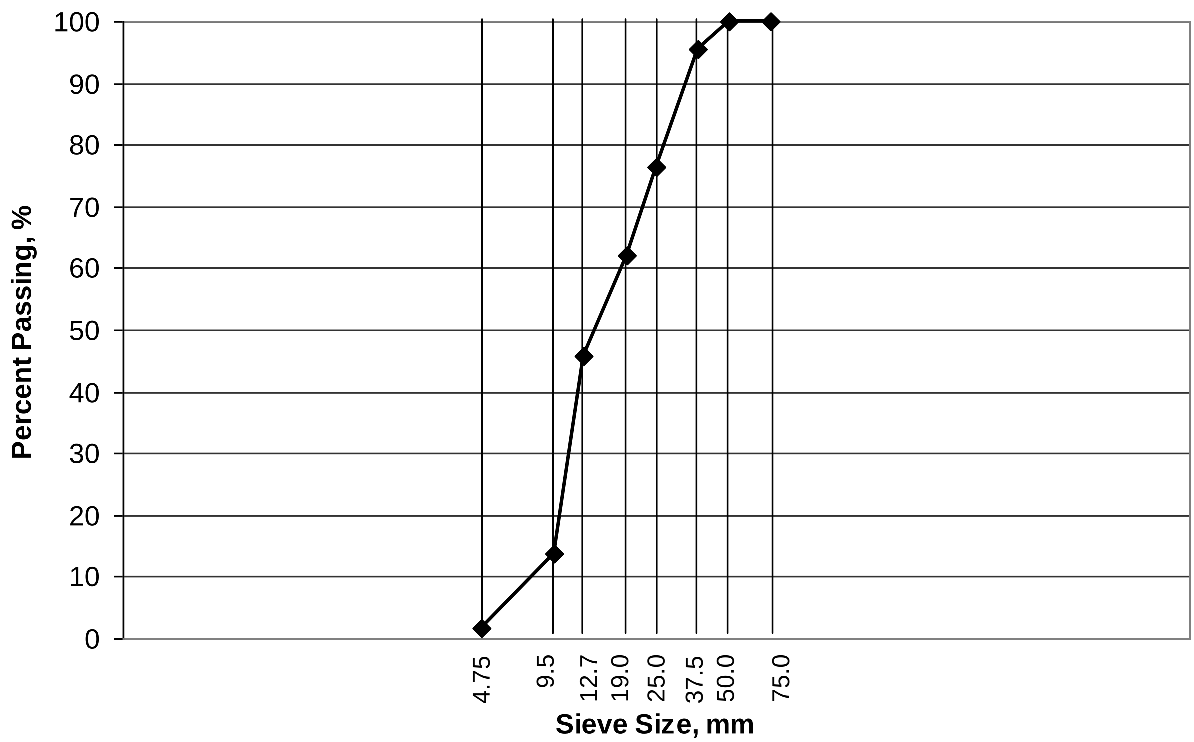
Sieve	Sieve size (in.)	Amount Retained (lb)	Percent Retained	Cumulative Percent Retained	Percent Passing
3 in.	3	0.0	0.0	0.0	100
2 in.	2	0.0	0.0	0.0	100
1-1/2 in.	1.5	3.7	4.4	4.4	96
1 in.	1	15.9	19.1	23.6	76
3/4 in.	0.75	12.0	14.4	38.0	62
1/2 in.	0.5	13.5	16.2	54.2	46
3/8 in.	0.375	26.7	32.1	86.3	14
No. 4	0.187	10.1	12.1	98.4	1.6
Pan		1.3	1.6	100.0	0.0
	Total	83.2			

b. The maximum size is **2 in.**

c. The nominal maximum size is **1-1/2 in.**

d. Semi-log gradation chart

e. 0.45 power gradation chart.



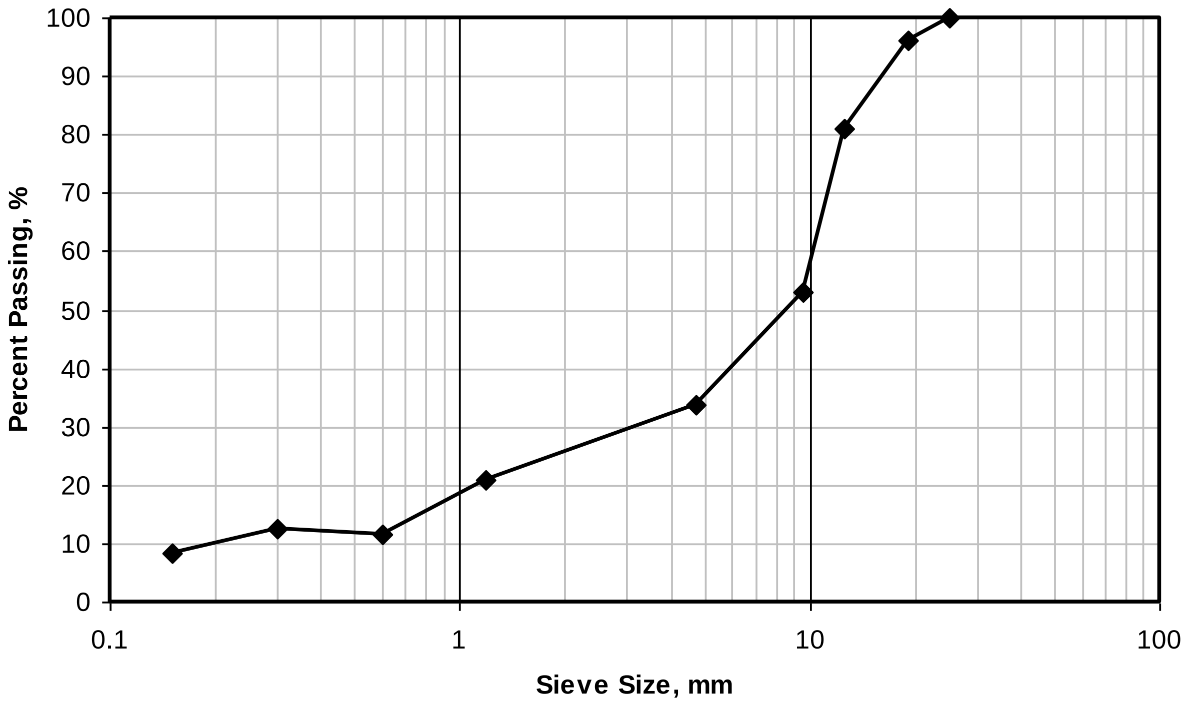
f. The closest size number according to ASTM C33, Table 5.5, is **467**. This coarse aggregate meets the gradation of Size No. **467.**

5.21. See Figure 5.15.

5.22. From Equation 5.17, $P_i = 0.15 A_i + 0.25 B_i + 0.60 C_i$

	Percent Passing								
Size, mm	25	19	12.5	9.5	4.75	1.18	0.60	0.30	0.15
Agg. A	100	100	100	77	70	42	34	28	20
Agg. B	100	85	62	43	24	13	7	0	0
Agg. C	100	100	84	51	29	19	8	14	9
Blend	100	96	81	53	34	21	12	13	8

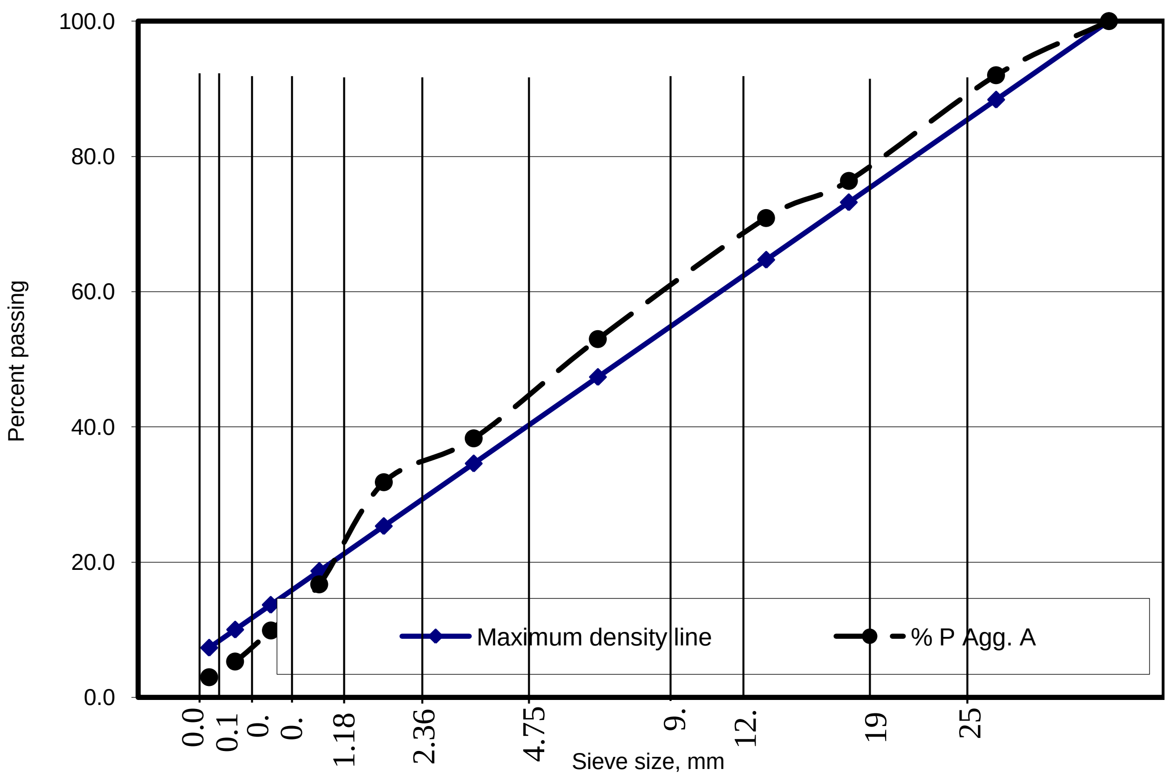
The grain size distribution of the blend is shown below



5.23. The maximum size of aggregate A is **25.0 mm.**
The maximum size of aggregate B is **19.0 mm.**

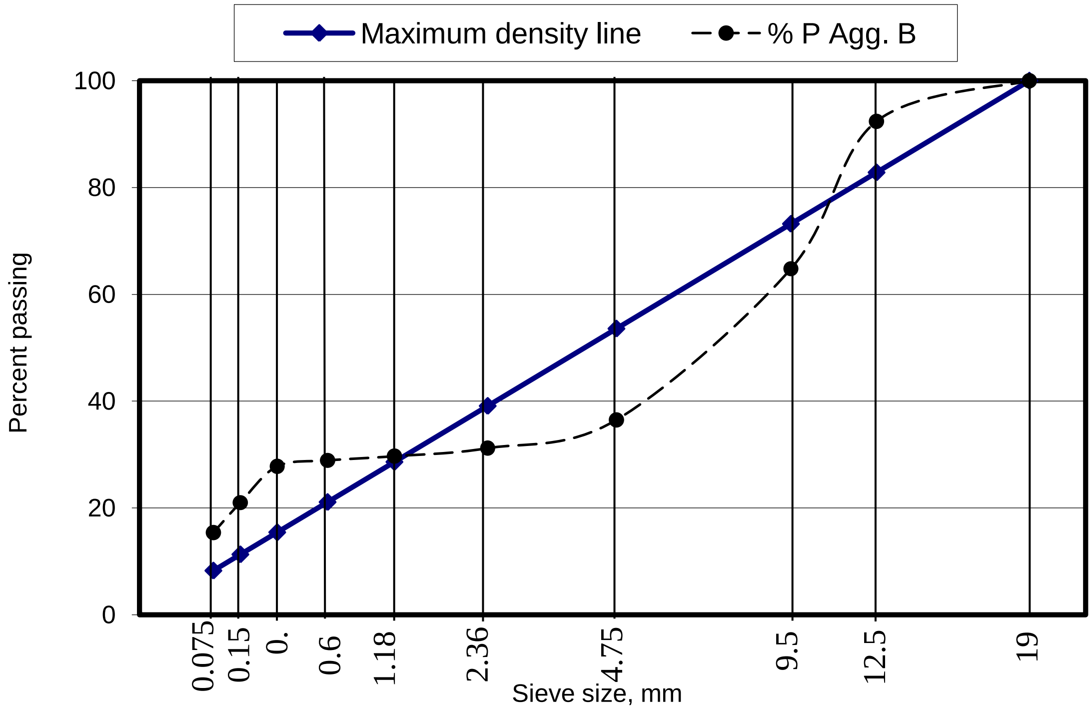
Sieve Size, mm	% Passing Aggr. A	% Passing Aggr. B	$(d_i)^{0.45}$	$P_{Ai}= (d_i/D)^{0.45}$	$P_{Bi} = (di/D)^{0.45}$
25	100	100	4.257	100	
19	92	100	3.762	88	100
12.50	76	92	3.116	73	83
9.50	71	65	2.754	65	73
4.75	53	37	2.016	47	54
2.36	38	31	1.472	35	39
1.18	32	30	1.077	25	29
0.600	17	29	0.795	19	21
0.300	10	28	0.582	14	15
0.150	5	21	0.426	10	11
0.075	3.0	15.4	0.312	7	8

0.45 Gradation chart for aggregate A:



The figure above shows that the gradation curve of aggregate A is almost a straight line very close to the maximum density line. Therefore, aggregate A is **well graded**.

0.45 Gradation chart for aggregate B:



The figure above shows that the gradation curve of aggregate B is deviated from the straight line (maximum density line). Therefore, aggregate B is **not well graded**.

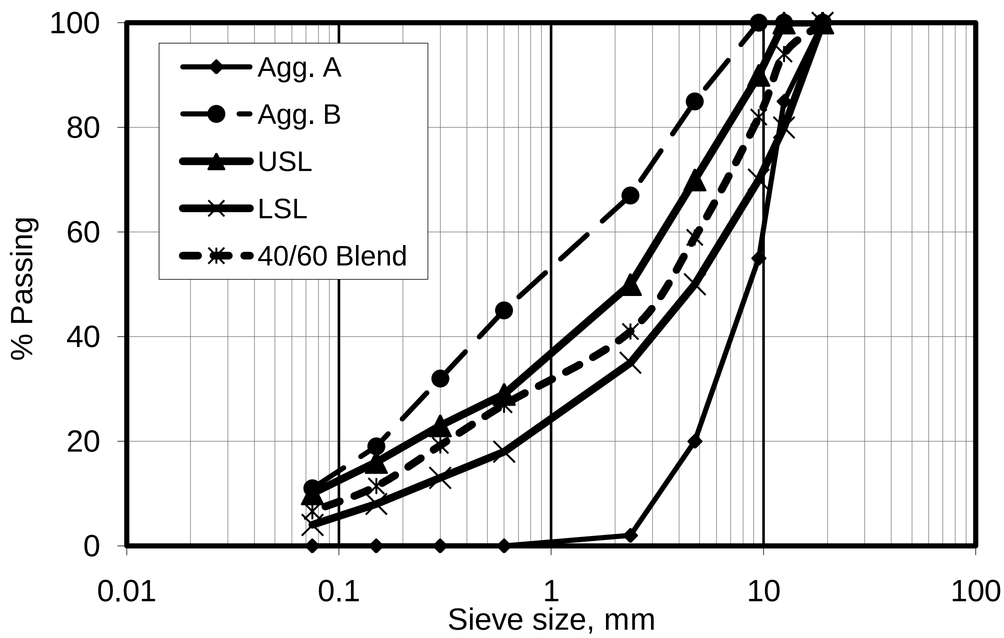
5.24. $P_i = 0.35\ A_i + 0.40\ B_i + 0.25\ C_i$ (Equation 5.17)

Sieve Size (mm)	% Passing Agg. A	% Passing Agg. B	% Passing Agg. C	**% Passing Blended Agg.**
9.5	85	50	40	**60**
4.75	70	35	30	**46**
0.6	35	20	5	**22**
0.3	25	13	1	**14**
0.15	17	7	0	**9**

5.25. Using Equation 5.17, $P_i = a\,A_i + b\,B_i$, the following table can be developed by trial and error:

Size (mm)	19	12.5	9.5	4.75	2.36	0.60	0.30	0.15	0.075
Specs.	100	80-100	70-90	50-70	35-50	18-29	13-23	8-16	4-10
Target Gradation	100	90	80	60	42.5	23.5	18	12	7
Agg. A	100	85	55	20	2	0	0	0	0
Agg. B	100	100	100	85	67	45	32	19	11
50/50	100	93	78	53	35	23	16	10	6
45/55	100	93	80	56	38	25	18	10	6
40/60	100	94	82	59	41	27	19	11	7

The best combination is obtained by blending 40 % of material A and 60 % of material B.



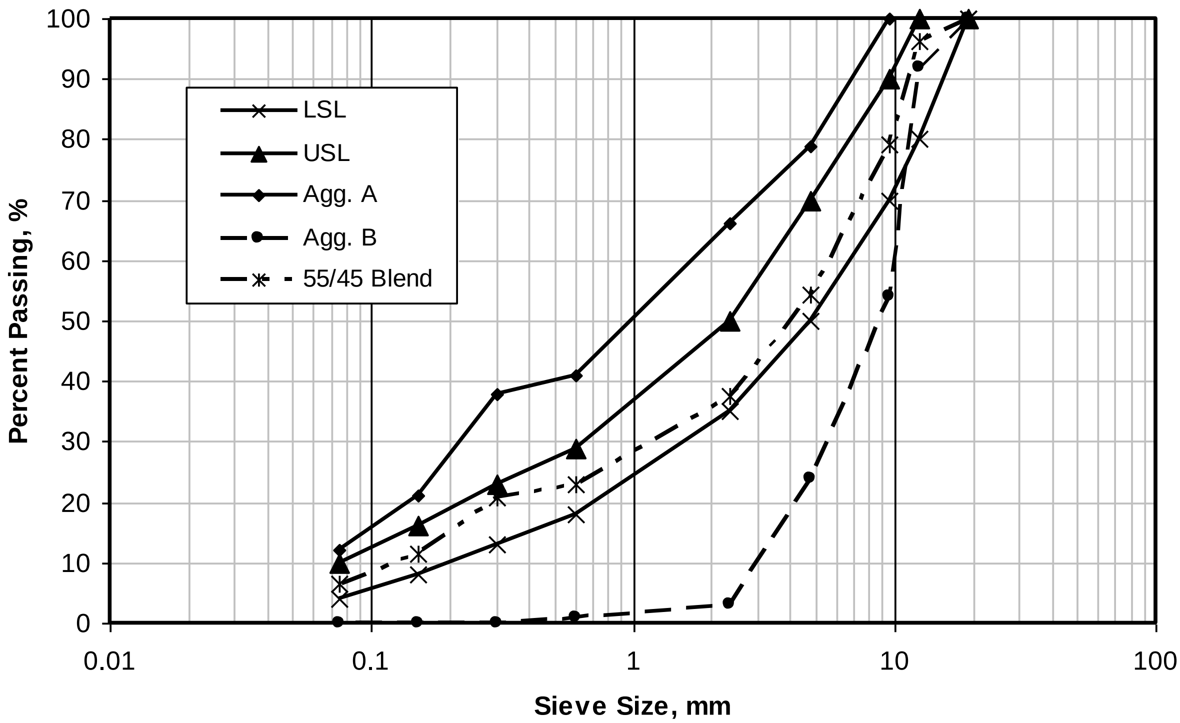
5.26. a. Bulk specific gravity of the mixture = $\dfrac{1}{\dfrac{0.5}{2.814}+\dfrac{0.5}{2.441}}$ **= 2.614**

b. Absorption of the mixture = 0.5 x 0.4 + 0.5 x 5.2 = **2.8 %**

5.27. Using Equation 5.17, $P_i = a\,A_i + b\,B_i$, the following table can be developed by trial and error:

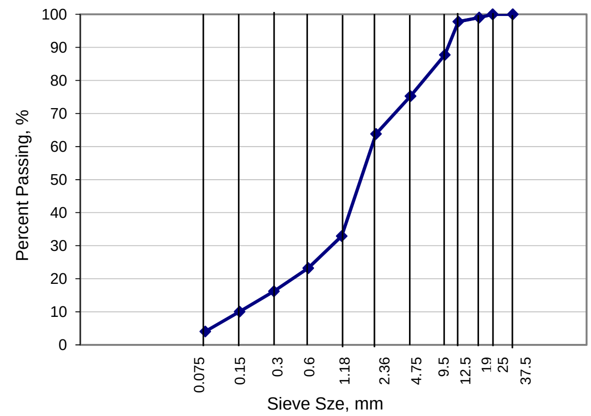
Size (mm)	19	12.5	9.5	4.75	2.36	0.60	0.30	0.15	0.075
Specs.	100	80–100	70–90	50–70	35–50	18–29	13–23	8–16	4–10
Target Gradation	100	90	80	60	42.5	23.5	18	12	7
Agg. A	100	100	100	79	66	41	38	21	12
Agg. B	100	92	54	24	3	1	0	0	0
50/50	100	96	77	52	35	21	19	11	6
45/55	100	96	75	49	31	19	17	9	5
40/60	100	96	79	54	38	23	21	12	7

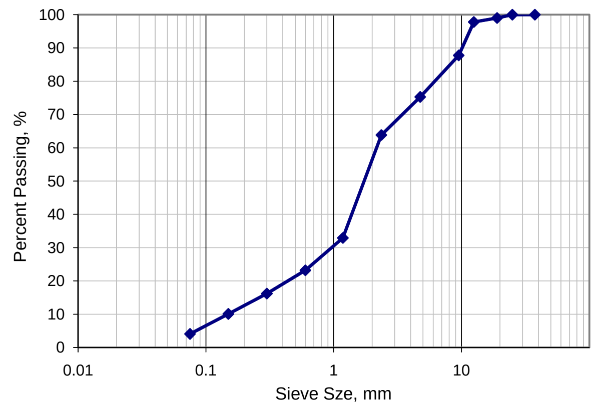
The best combination is obtained by blending 55 % of material A and 45 % of material B.



5.28.

Input data		Aggregate				
output data		A	B	C	D	Blend
Blend Percent		20%	15%	25%	40%	
Sieve Size (mm)	Sieve Size ^0.45 (mm)	Percent Passing				
37.5	5.11	100	100	100	100	100
25	4.26	100	100	100	100	100
19	3.76	95	100	100	100	99
12.5	3.12	89	100	100	100	98
9.5	2.75	50	85	100	100	88
4.75	2.02	10	55	100	100	75
2.36	1.47	2	15	88	98	64
1.18	1.08	2	5	55	45	33
0.6	0.79	2	3	35	34	23
0.3	0.58	2	2	22	25	16
0.15	0.43	2	2	15	14	10
0.075	0.31	2	1	6	5	4.1





5.29. a. Bulk specific gravity of the mixture = $\dfrac{1}{\dfrac{0.5}{2.491}+\dfrac{0.5}{2.773}}$ = **2.624**

b. Absorption of the mixture = 0.5 x 0.8 + 0.5 x 4.6 = **2.7 %**

5.30. Assume decimal fraction of fine aggregate by weight is x
(1-x)/2 * 0.5 + (1-x)/2 * 1.5 + 11.5 x = 4
x = 0.29 , **approximately 30%**

5.31. See Section 5.5.8**.**

5.32. The sieves used to calculate the fineness modulus are 19, 12.5, 9.5, 4.75, 2.36, 1.18, 0.6, 0.3, and 0.15.

Sieve, mm	Percent Passing	Cumulative Percent Retained
25	100	0
19	92	8
12.50	76	24
9.50	71	29
4.75	53	47
2.36	38	62
1.18	32	68
0.600	17	83
0.300	10	90
0.150	5	95
Total		506

Fineness modulus = 506 / 100 = **5.06**
No, it is not within the typical range (2.3 – 3.1) indicating it is coarse aggregate.

5.33. The sieves used to calculate the fineness modulus are 9.5, 4.75, 2.36, 1.18, 0.6, 0.3, and 0.15. The percent passing the 1.18 mm sieve is estimated by proportions.

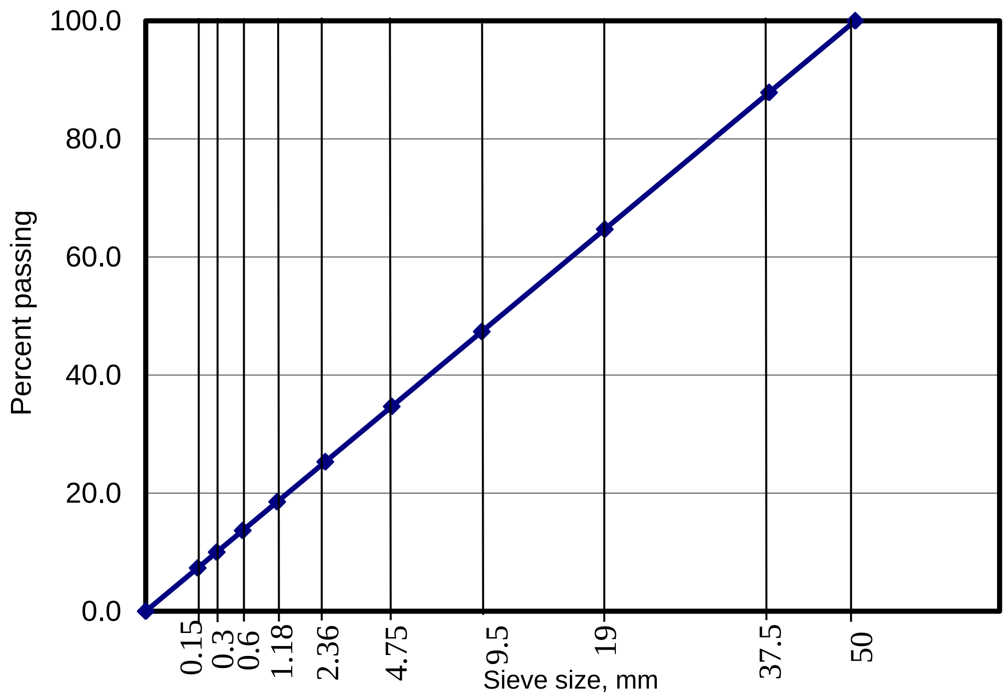
Sieve, mm	Percent Passing	Cumulative Percent Retained
9.5	100	0
4.75	85	15
2.36	67	33
1.18	56	44
0.6	45	55
0.3	32	68
0.15	19	81
Total		296

Fineness modulus = 296 / 100 = **2.96**
It is within the typical range of 2.3 – 3.1.

5.34.

Sieve, mm	% Passing for Sand	% Passing for Gravel	40% Passing for Sand	60% Passing for Gravel	% Passing for Blend
50	100	100	40	60	100
37.5	100	97.5	40	58.5	99
19	100	52.5	40	31.5	72
9.5	100	20	40	12	52
4.75	97.5	2.5	39	1.5	41
2.36	90	0	36	0	36
1.18	67.5	0	27	0	27
0.6	42.5	0	17	0	17
0.3	20	0	8	0	8
0.15	6	0	2.4	0	2

0.45 gradation chart



The gradation curve of the blend is slightly deviated from a straight line. Therefore, the blend is **almost well graded**.

5.35. See Table 5.3**.**

5.36. Since sand is not considered in coarse aggregate angularity, use Equation 5.18b,

$$X = \frac{(x_1P_1p_1 + x_2P_2p_2 + \ldots + x_nP_np_n)}{(P_1p_1 + P_2p_2 + \ldots + P_np_n)} = \frac{(100)(55)(90) + (87)(25)(90)}{(55)(90) + (25)(90)} = \mathbf{96}$$

From Equation 5.19,

$$\text{Bulk specific gravity of the blend} = \frac{1}{\dfrac{0.55}{2.631} + \dfrac{0.25}{2.711} + \dfrac{0.20}{2.614}} = \mathbf{2.647}$$

From Equation 5.19,

$$\text{Apparent specific gravity of the blend} = \frac{1}{\dfrac{0.55}{2.732} + \dfrac{0.25}{2.765} + \dfrac{0.20}{2.712}} = \mathbf{2.736}$$

5.37. Since sand is not considered in coarse aggregate angularity, use Equation 5.18b,

$$X = \frac{(x_1P_1p_1 + x_2P_2p_2 + \ldots + x_nP_np_n)}{(P_1p_1 + P_2p_2 + \ldots + P_np_n)} = \frac{(73)(25)(90) + (95)(60)(90)}{(25)(90) + (60)(90)} = \mathbf{89}$$

From Equation 5.19,

$$\text{Bulk specific gravity of the blend} = \frac{1}{\dfrac{0.25}{2.774} + \dfrac{0.60}{2.390} + \dfrac{0.15}{2.552}} = \mathbf{2.500}$$

From Equation 5.19,

$$\text{Apparent specific gravity of the blend} = \frac{1}{\dfrac{0.25}{2.810} + \dfrac{0.60}{2.427} + \dfrac{0.15}{2.684}} = \mathbf{2.551}$$

5.38. Bulk specific gravity for blended aggregate 1 = $\dfrac{1}{\dfrac{0.45}{2.702} + \dfrac{0.35}{2.331} + \dfrac{0.20}{2.609}}$ **= 2.542**

Bulk specific gravity for blended aggregate 2 = $\dfrac{1}{\dfrac{0.55}{2.702} + \dfrac{0.20}{2.331} + \dfrac{0.25}{2.609}}$ **= 2.596**

Bulk specific gravity for blended aggregate 3 = $\dfrac{1}{\dfrac{0.50}{2.702} + \dfrac{0.30}{2.331} + \dfrac{0.20}{2.609}}$ **= 2.561**

5.39. See Section 5.5.10.

5.40. See Section 5.5.9.

CHAPTER 6. PORTLAND CEMENT, MIXING WATER AND ADMIXTURES

6.1. See Section 6.1**.**

6.2. See Section 6.1**.**

6.3. See Section 6.3**.**

6.4. See Section 6.5**.**

6.5. See Section 6.5.

6.6. See Table 6.1**.**

6.7. See Section 6.5**.**

6.8. See Section 6.6**.**

6.9. See Section 6.7.1**.**

6.10. See Section 6.7**.**

6.11. See Section 6.7.1**.**

6.12. See Section 6.10.1**.**

6.13. a. (d)

b. 0.4 - 0.5

c. 0.22 – 0.25

d. Most of the water is needed for workability.

e. Extremely low w/c ratio (0.25) for high strength and a super plasticizer for an acceptable slump. Extreme care in choosing aggregate size, shape and gradation.
Curing is optimized and carefully controlled.

6.14. See Section 6.8.

6.15. See Figure 6.8.

6.16. The two batches are expected to have about the same compressive strength since they have the same w/c ratio.

6.17. See Section 6.9.1.

6.18. See Section 6.12.

6.19. See Section 6.9.

6.20. a. Average strength using non-potable water = 15,294 / (2 x 2) = 3,824 psi
Average strength using potable water = 17,186 / (2 x 2) = 4,296 psi
Percent difference = (4,296 – 3,824) / 4,296 = 11.00% < 10%
Therefore, **do not accept the water.**

b. The set time measured by the Vicat test should not change significantly.

6.21. Average strength of mortar cubes with non-potable average = 15,267 / (2 x 2) =3,817 psi
Average strength of mortar cubes with potable average = 17,667 / (2 x 2) = 4,417 psi
Ratio = 3,817/4,417 = 0.879 = 86.4%
Since the average strength of the cubes made with non-potable water is less than 90% of the strength of the cubes made with potable water, I would not accept the questionable water according to ASTM standards.

6.22. Average failure load of mortar cubes with non-potable average = 6,909 kg.
Average failure load of mortar cubes with potable average = 7,512 kg.
Ratio = 6,909 / 7,512 = 0.879 = 92.0%
Since the average strength of the cubes made with non-potable water is higher than 90% of the strength of the cubes made with potable water, I would accept the questionable water according to ASTM standards.

6.23. See Section 6.10.2**.**

6.24. See Section 6.11**.**

6.25. See Section 6.11.1**.**

6.26. See Section 6.11.1**.**

6.27. See Section 6.11.2**.**

6.28. See Section 6.11.2**.**

6.29.

Cement (lb)	Water (lb)	Admixture	What will happen?	
			Workability	Ultimate Compressive Strength
25	15	None	Increase	Decrease
28	11	None	Approx. same	Increase
25	11	Water reducer	Increase	Approx. same
25	8	Water reducer	Approx. same	Increase
25	11	Superplasticizer	Increase	Approx. same
25	11	Air entrainer	Increase	Decrease
25	11	Accelerator	Approx. same	Approx. same

6.30. a. Water/cement ratio for case 1 = 350/700 =**0.50**
Water/cement ratio for case 2 = 280/700 =**0.40**
Water/cement ratio for case 3 = 315/630 =**0.50**
b. Add water reducer and decrease the amount of water (Case 2)
c. Add water reducer (Case 1)
d. Add water reducer and decrease both the amount of cement and water to maintain the same water to cement ratio (Case 3)

6.31. a. Water/cement ratio for case 1 = 465/850 =**0.55**
Water/cement ratio for case 2 = 370/850 =**0.44**
Water/cement ratio for case 3 = 419/765 =**0.55**
b. Add water reducer and decrease the amount of water (Case 2)
c. Add water reducer (Case 1)
d. Add water reducer and decrease both the amount of cement and water to maintain the same water to cement ratio (Case 3)

6.32. a. **Hydration-control admixture (stabilizer)**
b. **Retarder**
c. **Air Entrainer**
d. **Water reducer**
e. **Retarder or hydration-control admixture**
f. **Accelerator**

6.33. See Section 6.12**.**

6.34. $H_o : \mu_1 < \mu_2$ (One-tail test)

$H_1 : \mu_1 \geq \mu_2$

x_1 = average strength without admixture = 24.78 MPa

s_1 = 0.74 MPa

x_2 = average strength with admixture = 25.54 MPa

s_2 = 1.03 MPa

$\alpha = 0.05$

$$T_o* = \frac{24.78 - 25.54}{\sqrt{\frac{0.74^2}{10} + \frac{1.03^2}{10}}} = -1.895$$

Assume that $\sigma_1 \neq \sigma_2$

From the statistical t-distribution table, $T_{\alpha, \nu} = 1.734$

$$\nu = \frac{(\frac{0.74^2}{10} + \frac{1.03^2}{10})^2}{\frac{(0.74^2/10)^2}{10+1} + \frac{(1.03^2/10)^2}{10+1}} - 2 \approx 18$$

($T_{\alpha, \nu} = 1.734$) > ($T_o^* = -1.895$)

We reject H_o. Therefore, **the admixture does not increase the strength**.

6.35. H_o : $\mu_1 = \mu_2$ (2-tail test)

H_1 : $\mu_1 \neq \mu_2$

x_1 = average strength without admixture = 3607.5 psi

s_1 = 118.533 psi

x_2 = average strength with admixture = 3567.375 psi

s_2 = 103.652 psi

$\alpha = 0.1$

Assume that $\sigma_1 \neq \sigma_2$

$$\nu = \frac{\left(\frac{118.533^2}{8} + \frac{103.652^2}{8}\right)^2}{\frac{(118.533^2/8)^2}{8+1} + \frac{(103.652^2/8)^2}{8+1}} - 2 \approx 16$$

$$T_o* = \frac{3607.5 - 3567.375}{\sqrt{\frac{118.533^2}{8} + \frac{103.652^2}{8}}} = 0.721$$

From the statistical t-distribution table, $T_{\alpha/2, \nu} = \pm 1.746$

$-1.746 < T_o* = 0.721 < 1.746$

Therefore we cannot reject H_o . Therefore, there is no significant difference between the means. This means that **the admixture does not significantly increase the strength**.

CHAPTER 7. PORTLAND CEMENT CONCRETE

7.1. a. $f'_{cr} = f'_c + 1400 = 5500 + 1400 =$ **6,900 psi**

b. Need to interpolate modification factor

$$F = 1.08 - \left(\frac{1.08 - 1.03}{25 - 20}\right)(22 - 20) = 1.06$$

Multiply standard deviation by the modification factor

s' = (s) (F) = 500 (1.06) = 530 psi

Determine maximum from Equations 7.1 and 7.2

f'_{cr} = 5500 + 1.34 (530) = 6210 psi

f'_{cr} = 5500 + 2.33 (530) - 500 = 6235 psi

Use f'_{cr} = **6240 psi**

c. Determine maximum from Equations 7.1 and 7.2

f'_{cr} = 5500 + 1.34 (400) = 6036 psi

f'_{cr} = 5500 + 2.33 (400) - 500 = 5932 psi

Use f'_{cr} = **6040 psi**

d. Determine maximum from Equations 7.1 and 7.2

f'_{cr} = 5500 + 1.34 (600) = 6304 psi

f'_{cr} = 5500 + 2.33 (600) - 500 = 6389 psi

Use f'_{cr} = **6390 psi**

7.2. a. $f'_{cr} = f'_c + 1.34\,s$ = 24.1 MPa + 1.34 (3.8 MPa) = 29.2 MPa

$f'_{cr} = f'_c + 2.33\,s$ – 3.45 MPa = 24.1 MPa + 2.33 (3.8 MPa) – 3.45 MPa = **29.5 MPa**

b. $E_c = 4731\sqrt{f'_c} = 4731\sqrt{29.5\text{ MPa}}$ = **25696 MPa**

7.3. $f'_{cr} = f'_c + 1.34\,s$ = 3000 psi + 1.34 (350 psi) = **3469 psi**

$E_c = 57000\sqrt{f'_c} = 57000\sqrt{3469\text{ psi}}$ = **3.4 x 10^6 psi**

7.4. 1/5 minimum clear distance = (1/5) x 10 = 2 in.

3/4 minimum clear space between steel bars = (3/4) x (6-0.75) = 3.9375 in.

3/4 minimum clear space between steel bars and form = (3/4) x (4) = 3 in.

Therefore, the maximum size coarse aggregate **should not be more than 2 in.**

7.5. Assume the nominal maximum size of coarse aggregate is 1 in.
Table 7.5 Coarse aggregate factor = = 0.71 yd^3/yd^3
Weight of coarse aggregate = 0.71 x 1700 = **1207 lb/yd^3**

Changing the w/c ratio does not affect the quantity of coarse aggregate because it depends only on its maximum size and the fineness modulus of the fine aggregate.

7.6. a. Required compressive strength = $f'_c + 1.34s$ = 4000 + 1.34 x (1.08 x 200) = 4289.44 psi
= $f'_c + 2.33s - 500$ = 4000 + 2.33 x (1.08 x 200) – 500 = 4003.28 psi
Therefore, the required compressive strength = 4289.44 psi

b. w/c ratio, according to Figure 7.2 and Table 7.1, w/c = 0.48 (air Entrained)

c. Coarse Aggregate Requirements
2 in. < (1/3) (12 in.) slab thickness
Aggregate size OK for dimensions
(Table 7.5) 1.5 in. nominal max. size coarse aggregate and 2.6 FM of fine aggregate
Coarse aggregate factor = 0.73
Oven dry weight of coarse aggregate = (0.73) (125 pcf) = **91.25 pcf**

d. The quantity of coarse aggregate will remain the same because it is not affected by the w/c ratio.

7.7. W_{water} = 0.45 x 565 = 254 lb/yd^3

$\gamma_w = 62.4 \text{ lb/ft}^3 (3 \text{ ft / yd})^3 = 1684.8 \text{ lb/yd}^3$

Step 9

V_{cement} = 565/3.15 (1684.8) = 0.106 yd^3
V_{water} = 254/1684.8 = 0.151 yd^3
V_{gravel} = 1963/2.7 (1684.8) = 0.432 yd^3
V_{air} = 4% = 0.04 yd^3
Subtotal = 0.729 yd^3

V_{sand} = 1 – 0.729 = 0.271 yd^3
m_{sand} = 2.5(1684.8)(0.271) = 1141 lb/yd^3

Step 10

mix water = 254 – 1963(0.016-0.024) – 1141(0.048-0.015)
= 254 + 15.7 - 37.65
= **232.0 lb/yd^3**
moist gravel = 1963(1.016)= **1994.4 lb/yd^3**
moist sand = 1141(1.048)= **1195.8 lb/yd^3**
cement = **565.0 lb/yd^3**

Summary

Batch ingredients required for 1 yd^3 concrete mix	
Water	232 lb
Cement	565 lb
Fine Aggregate	1195.8 lb
Coarse Aggregate	1994.4 lb

7.8. 1. Required strength = 27.6 MPa
S = 2.1 MPa
$f_{cr} = f_c + 1.34\ S = 30.4$ MPa
$f_{cr} = f_c + 2.33\ S - 3.45 = 29.0$ MPa
$f_{cr} = 30.4$ MPa

2. Water-Cement Ratio
Strength requirement (Table 7.1):

$$\text{Water-Cement ratio} = 0.48 - \left(\frac{30.4 - 27.6}{34.5 - 27.6}\right)(0.48 - 0.40) = 0.45$$

Mild exposure requirements – use air entrainer

3. Coarse aggregate requirements
Minimum dimension = 150 mm
Minimum space between rebar = 40 mm
Minimum cover over rebar = 40 mm
Coarse aggregate: 19 mm nominal maximum size, river gravel (rounded). Maximum size is 25 mm.
25 mm < 1/5 x 150 mm
25 mm < 3/4 x 40 mm
25 mm < 3/4 x 40 mm
Fineness modulus = 2.47
Table 7.5 Coarse aggregate factor = 0.65 m^3/m^3
Oven dry weight of coarse aggregate = 1761 x 0.65 = 1145 kg/m^3

4. Air Content
Only air entrainer is allowed
Table 7.6 for mild exposure, air content = 3.5 %

5. Workability Requirements
Table 7.7, slump range = 25 to 100 mm
Use 25 to 50 mm for the following calculations

6. Water Content
Table 7.8, water content = 168 kg/m^3
Reduction in water content because of aggregate shape = 27 kg/m^3
Required water content = 168 – 27 = 141 kg/m^3

7. Cement content
   Cement content = Water content / Water-cement ratio
   Cement content = 141 / 0.45 = 313 kg/m^3
   Table 7.9, minimum cement content = 320 kg/m^3
   Cement content = **320 kg/m^3**

8. Admixture
   3.5 % air content
   Admixture = 6.3 x 3.5 x (320/100) = **71 ml/m^3**

9. Fine Aggregate Requirements
   Water volume = 141 / (1 x 1000) = 0.141 m^3/m^3
   Cement volume = 320 / (3.15 x 1000) = 0.102 m^3/m^3
   Air volume = 0.035 m^3/m^3
   Coarse aggregate volume = 1145 / (2.55 x 1000) = 0.449 m^3/m^3
   Subtotal volume = 0.727 m^3/m^3
   Fine aggregate volume = 1- 0.727 = 0.273 m^3/m^3
   Fine aggregate weight = 2.66 x 0.273 x 1000 = 726 kg/m^3

10. Moisture Corrections
   Coarse aggregate in dry condition = 1145 kg/m^3
   Increase by 2.5 %
   Coarse aggregate = 1145 x 1.025 = **1174 kg/m^3**
   Fine aggregate in dry condition = 726 kg/m^3
   Increase by 2.0 %
   Fine aggregate = 769 x 1.020 = **741 kg/m^3**
   Water = 141 - 1145 (0.025 – 0.003) – 726 (0.02 – 0.005) = **105 kg/m^3**

Summary

Batch ingredients required for 1 m^3 PCC	
Water	105 kg
Cement	320 kg
Fine Aggregate	741 kg
Coarse Aggregate	1174 kg
Admixture	71 ml

7.9. 1. Required Strength

f_c' =3000 psi

s = 250 (enough samples so no correction is needed)

f_{cr}' = f'_c + 1.34 s = 3000 +1.34 (250) = 3,335 psi

f_{cr}' = f'_c + 2.33 s - 500 = 3000 + 2.33 (250) - 500 = 3,083 psi

f_{cr}' **= 3,335 psi**

2. Water-cement ratio
   Strength requirement (Table 7.1), Water-cement ratio = 0.55 by interpolation
   Exposure requirement, freeze and thaw and deicing chemicals (Table 7.3), maximum water-cement ratio = 0.45
   Water-cement ratio **= 0.45**

3. Coarse Aggregate Requirements
   Nominal maximum size = 2 in. Therefore, maximum size = 3 in.
   3 in. < (1/3) (12 in.) slab thickness
   Aggregate size OK for dimensions
   (Table 7.5) 2 in. nominal maximum size coarse aggregate and 2.68 FM of fine aggregate
   Coarse aggregate factor = 0.75
   Oven dry weight of coarse aggregate = (120) (0.75) (27ft^3/yd^3) = 2430 lb/yd^3
   Coarse aggregate = 2430 lb/yd^3

4. Air Content
   (Table 7.6) Severe exposure, Target air content = 5.0%
   Job range = 4 to 7 % base
   Design on 6%

5. Workability
   (Table 7.7), slump range = 1 to 3 in.
   Use 2 in.

6. Water Content
   (Table 7.8) 2 in. nominal maximum size aggregate with air entrainment and 2 in. slump, Water = 240 lb/yd^3 for angular aggregates
   Required water = 240 lb/yd^3

7. Cement Content
   Water-cement ratio = 0.45, water = 240 lb/yd^3
   Cement = 240 / 0.45 = 533 lb/yd^3
   Increase for the minimum criterion of 564 lb/yd^3 for exposure
   Cement = 564 lb/yd^3

8. Admixture

6% air, cement = 564 lb/yd^3

Admixture = (0.15) (6) (564/100) = 5.1 fl oz/yd^3

Admixture = 5.1 fl oz/yd^3

9. Fine Aggregate Requirements

Find fine aggregate content - Use the absolute volume method

Water volume = 240 / 62.4 = 3.846 ft^3/yd^3

Cement volume = 564 / (3.15 x 62.4) = 2.869 ft^3/yd^3

Air volume = 0.06 x 27 = 1.620 ft^3/yd^3

Coarse aggregate volume = 2430 / (2.573 x 62.4) = 15.135 ft^3/yd^3

Subtotal volume = 23.470 ft^3/yd^3

Fine aggregate volume = 27 – 23.470 = 3.530 ft^3/yd^3

Fine aggregate weight = (3.530) (2.540) (62.4) = 559 lb/yd^3

Fine aggregate = 599 lb/yd^3

10. Moisture Corrections

Coarse Aggregate: Need 2430 lb/yd^3 in dry condition, so increase weight by 1.0% for moisture

Weight of moist coarse aggregate = (2430) (1.01) = 2454 lb/yd^3

Fine Aggregate: Need 599 lb/yd^3 in dry condition, so increase weight by 3.67% for excess moisture

Weight of fine aggregate in moist condition = (599) (1.0367) = 621 lb/yd^3

Water: Reduce for free water on aggregates

= 240 - 2430 (0.01 - 0.001) - 599 (0.0367 - 0.002) = 197 lb/yd^3

Summary

Batch ingredients required for 1 yd^3 PCC	
Water	197 lb
Cement	564 lb
Fine Aggregate	621 lb
Coarse Aggregate	2454 lb
Admixture	5.1 fl oz

7.10. Coarse Aggregate: Need 1173 kg/m^3 in dry condition, so increase mass by 0.8% for excess moisture

Mass of moist coarse aggregate = (1173) (1.008) = **1182 kg/m^3**

Fine Aggregate: Need 582 kg/m^3 in dry condition, so increase mass by 1.1% for excess moisture

Mass of fine aggregate in moist condition = (582) (1.011) = **588 kg/m^3**

Water: Since absorption is larger than the available moisture content, increase mix water to allow for absorption by aggregates.

Mass of mix water = 157 + 1173 (0.015 - 0.008) + 582 (0.013 - 0.011) = **166 kg/m^3**

7.11. Using Tables 7.11 and 7.12:

Amount of Concrete	Cement	Wet Fine Aggregate	Wet Course Aggregate	Water
2000 kg	322 kg	604 kg	940 kg	134 kg
4400 lb	708 lb	1329 lb	2068 lb	295 lb
1 m^3	0.222 m^3	0.555 m^3	0.612 m^3	0.111 m^3
36 ft^3	7.992 ft^3	19.980 ft^3	22.032 ft^3	3.996 ft^3

Note that for proportioning by volume, the required concrete volume is multiplied by 1.5 before entering Table 7.12.

7.12. a. From Table 7.11

Weight of cement = 5000 x 0.170 = 850 lb
Weight of wet fine aggregate = 5000 x 0.320 = 1600 lb
Weight of wet coarse aggregate = 5000 x 0.442 = 2210 lb
Weight of water = 5000 x 0.068 = 340 lb

b. Sum of the original bulk volumes of the components = 1 x 1.5 = 1.5 yd^3
From Table 7.12:

Volume of cement = 1.5 x 0.153 = 0.23 yd^3
Volume of wet fine aggregate = 1.5 x 0.385 = 0.578 yd^3
Volume of wet coarse aggregate = 1.5 x 0.385 = 0.578 yd^3
Volume of water = 1.5 x 0.077 = 0.116 yd^3

7.13. See Section 7.2.7.

7.14. See Section 7.3.

7.15. See Section 7.3.

7.16. See Figure 7.22.

7.17. Concrete requires a small amount of water for hydration (see Section 6.8). Extra mixing water will leave air voids in place when it sets, which reduces the strength and worsen other concrete properties. During curing, however, extra water will prevent water in the concrete from evaporation, which ensures continuing the hydrating process of the concrete since hydration is a long-term process.

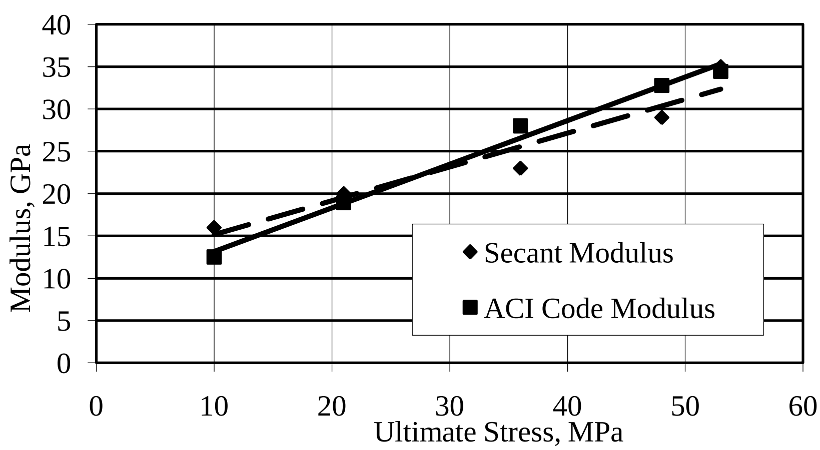
7.18. See Section 7.4.1.

7.19. See Section 7.4.2.

7.20. See Figure 7.32.

7.21.

Water-Cement Ratio	Ultimate Stress, MPa	40% Ultimate Stress, MPa	Secant Modulus, GPa	Compressive Strength (f_c'), MPa	Modulus from ACI Equation, GPa
0.33	53	21	35	53	34
0.40	48	19	29	48	32
0.50	36	14	23	35	28
0.67	21	8	20	16	19
1.00	10	4	16	7	13



The two relations have the same trend. They both show that the modulus increases when the ultimate stress increases. The ACI Building code provides slightly smaller moduli at low ultimate stresses and larger moduli at high ultimate stresses when compared to the secant moduli.

7.22. Using Equation 7.3, $E_c = 57{,}000\ (4500)^{1/2}$ = **3,824,000 psi**

7.23. See Section 7.5.1**.**

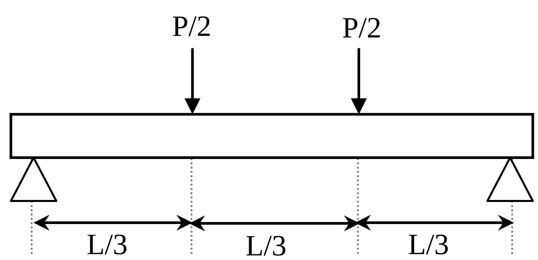
7.24. See Section 7.5.1**.**

7.25. P = (σ x A)/F.S. = (5000 x 12 x 12)/1.2 = 600,000 lb = **600 kips**

7.26. See Section 7.5.3**.**

7.27. See Section 7.5.3**.**

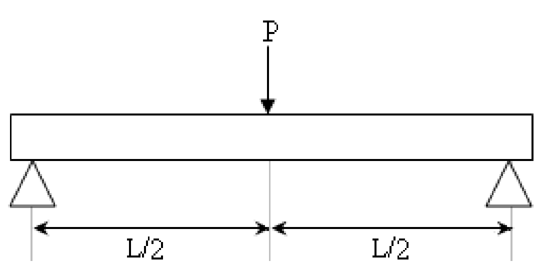
7.28. M = (P/2) (L/3) = PL/6
$I = a\ (a^3) / 12 = a^4/12$
C = a/2
Modulus of rupture = MC/I = (PL/6) (a/2) / $(a^4/12)$ = $\mathbf{PL / a^3}$



7.29. Using Equation 7.5, $R = P\ L / (b\ d^2) = (35{,}700 \times 450) / (150 \times 150^2)$ = **4.76 MPa**

7.30. Using Equation 7.5, $R = P\ L / (b\ d^2) = (6{,}000 \times 8) / (4 \times 4^2)$ = **750 psi**

7.31. Using Equation 7.5, $R = M\ c / I = 3\ P\ L / (2\ b\ d^2) = 3 \times (5{,}000 \times 8) / (2 \times 4 \times 4^2)$ = **937.5psi**



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7.32. Using Equation 7.6, R = 0.725 $(20)^{1/2}$ = **3.24 MPa**

7.33. See Sections 7.5.5 – 7.5.7.

7.34. See Section 7.5.7.

7.35. See Section 7.6.

7.36. See Section 7.6.1.

7.37. See Section 7.6.2.

7.38. See Section 7.6.6.

7.39. **a.** mild steel is stronger than PCC

b. mild steel has a higher modulus

c. PCC is more brittle

d. The range of compressive strength for a typical PCC is **3000 to 5000 psi**

e. The compressive strength for a high-strength concrete is usually **greater than 6000 psi**

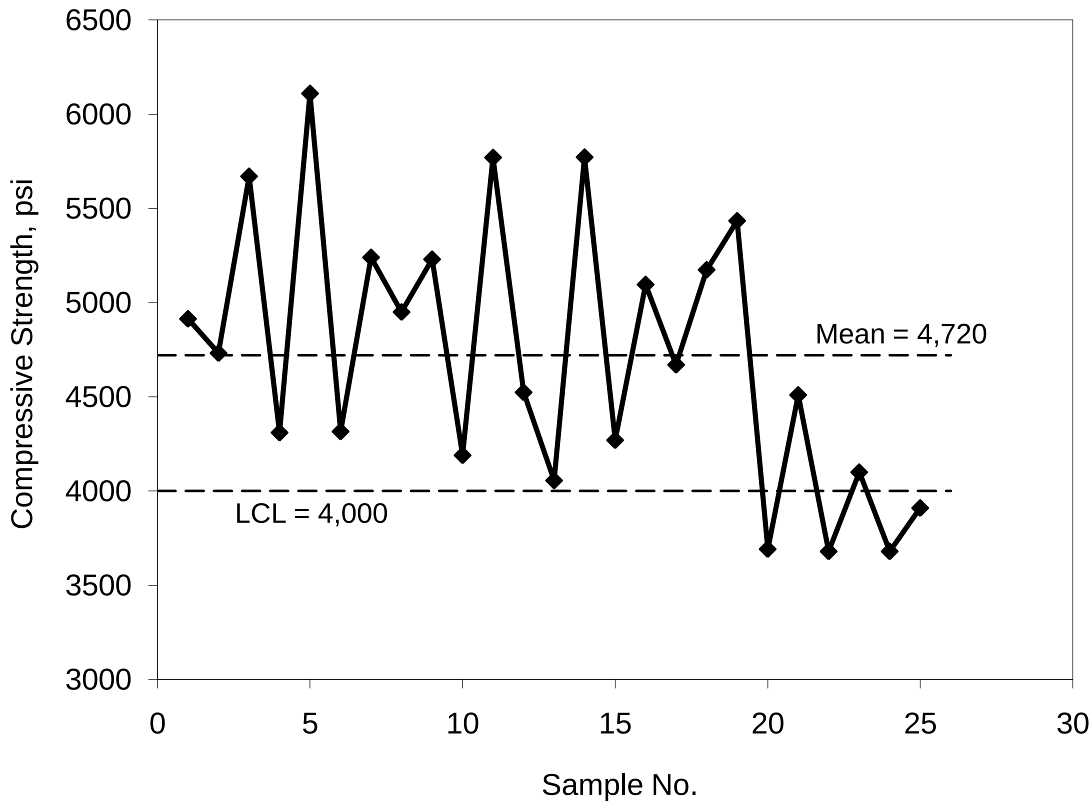
f. A reasonable range for PCC modulus is **2000 to 6000 ksi**

7.40. a. $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{5\sum_{i=1}^{26} x_i}{25} = \frac{118{,}000}{25} = \mathbf{4720\ ksi}$

$$s = \left(\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1} \right)^{1/2} = \left(\frac{\sum_{i=1}^{25} (x_i - 4720)^2}{25-1} \right)^{1/2} = \mathbf{710.733\ ksi}$$

$$C = 100\left(\frac{s}{\bar{x}}\right) = 100\left(\frac{710.733}{4720}\right) = \mathbf{15.06\ \%}$$

b. The flow chart is shown below.



The results of the first 19 sample are higher than the minimum requirement. There was a sudden change starting with sample 20, indicating that there is something wrong in the material which needs to be corrected.

CHAPTER 8. MASONRY

8.1. See Section 8.1.1.

8.3. Percentage of net cross-sectional area = (447 / 960) x 100 = 46.56% < 75%
Therefore, the unit is categorized as hollow.
Net area = 130 x 0.466 = 60.58 in^2
Compressive stress = 120/ 60.58 = 1981 psi > 1700 MPa (Table 8.2)
Thus, the compressive strength satisfies the strength requirements.

8.4. Percentage of net cross-sectional area = (0.007/ 0.015) x 100 = 46.67% < 75%
Therefore, the unit is categorized as hollow.
Net area = 0.081 x 0.4667 = 0.0378 m^2
Compressive stress = 726 / 0.0378 = 19.21 kN/m^2 (19.21 MPa) > 11.7 MPa (Table 8.2)
Thus, the compressive strength satisfies the strength requirements.

8.5. a. Gross area compressive strength = P/A_{gross} = 51,000/(7.5 x 7.5) = **906.67 psi**

b. Net area compressive strength = P/A_{net} = 51,000/(5.5 x 5.5) = **1,685.95 psi**

8.6. a. Gross volume = 7-5/8" x 7-5/8" x 7-5/8" = 443.322 in^3
Percentage of net cross-sectional area = (348.1 / 443.322) x 100 = 78.5% > 75%
Therefore, the unit is categorized as **solid**.

b. Gross area compressive strength = P/A_{gross} = 98,000/(7.625 x 7.625) = **1,686 psi**

c. Net area compressive strength = P/A_{net} = 98,000/(348.1/7.625) = **2,147 psi**

8.7. a. Gross area compressive strength = P/A_{gross} = 296/(0.190 x 0.190) = **8,199 kN/m^2**

b. Net area compressive strength = P/A_{net} = 296/(0.114 x 0.114) = **22,776 kN/m^2**

8.8. Gross area = 0.290 x 0.190 = 0.0551 m^2
Net area = 0.250 x 0.150 = 0.0375 m^2
Percentage of net cross-sectional area = (0.0375 / 0.0551) x 100 = 68.1% < 75%
Therefore, the unit is categorized as hollow.
Compressive stress = 329 / 0.0375 = 8,773.33 kN/m^2 = **9.0 MPa**

8.9. a. $\mathbf{A_n = V_n / h = 312.7\ in^3 / 7.625\ in = 41\ in^2}$
$\mathbf{A_g = (7.625\ in)^2 = 58.14\ in^2}$
41 / 58.14 = <u>0.705</u> the unit is hollow because the net area is only 70% of the gross area.

b. Gross area compressive strength = 83 k / 58.14 in^2 = **<u>1.427 ksi</u>**

c. Net area compressive strength = 83 k / 41 in^2 = **<u>2.024 ksi</u>**

8.10. a. $\mathbf{A_n = V_n / h = 294.2\ in^3 / 7.625\ in = 38.6\ in^2}$
$\mathbf{A_g = (7.625\ in)^2 = 58.14\ in^2}$
38.6 / 58.14 = <u>0.663</u> the unit is hollow because the net area is only 70% of the gross area.

b. Gross area compressive strength = 81 k / 58.14 in^2 = **<u>1.393 ksi</u>**

c. Net area compressive strength = 81 k / 38.6 in^2 = **<u>2.098 ksi</u>**

8.11. a. To reduce the effect of weathering and to limit the amount of shrinkage due to moisture loss after construction (See Section 8.1.1).

b. $Absorption = \frac{W_s - W_d}{W_s - W_i} x62.4 = \frac{4.7 - 4.2}{4.7 - 2.1} x62.4 =$ **12.00 lb/ft³ < 13 lb/ft³**

Therefore, the absorption meets the ASTM C90 requirement for absorption for normal weight concrete masonry.

$$\text{Moisture content as a percent of total absorption} = \frac{W_r - W_d}{W_s - W_d} x100 = \frac{4.3 - 4.2}{4.7 - 4.2} x100 =$$ **20.0%**

8.12. $Absorption = \frac{W_s - W_d}{W_s - W_i} x1000 = \frac{5776 - 5091}{5776 - 2973} x1000 =$ **244.4 kg/m³ > 240 kg/m³**

Therefore, the absorption does not meet the ASTM C90 requirement for absorption for medium weight concrete masonry.

$$\text{Moisture content as a percent of total absorption} = \frac{W_r - W_d}{W_s - W_d} x100 = \frac{5435 - 5091}{5776 - 5091} x100 =$$

50.22%

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8.13. a. Absorption = 100 x $[(W_s - W_d) / W_d]$ = 100 x [(7401 - 6916) / 6916] **= 7.01%**

b. Moisture content as % of absorption = 100 x $[(W_r - W_d) / (W_s - W_d)]$ = 100 x [(7024 - 6916) / (7401 - 6916)] = **22.27%**

c. Dry density = $[W_d / (W_d - W_i)] \gamma_w$ = [6916 / (6916 – 3624)] x 1 = **2.1 Mg/m^3**

d. From Table 8.1: Based on the dry density the unit is **Normal Weight**.

8.14. a. A**bsorption = $(W_s - W_d) / W_d$ = (8652 g - 7781 g) / 7781 g = 871 g / 7781 g = 0.112 = 11.2%**

b. Moisture content as % of absorption = $(W_r - W_d) / (W_s - W_d)$ = (8271 g - 7781 g) / (8652 g - 7781 g) = 490 g / 871 g = 0.563 = **56.3%**

8.15. See Section 8.1.1.

8.16. See Section 8.1.2.

8.17. Absorption by 24-h submersion, % = [(2.453 – 2.186) / 2.186] x 100 = **12.2%**
Absorption by 5-h boiling, % = [(2.472 –2.186)/2.186] x 100 = **13.1%** < 20.0% (Table 8.4)

Saturation coefficient = (2.453 – 2.186) / (2.472 – 2.186) = 0.93 > **0.80** (Table 8.4)
Therefore, the brick **does not satisfy the ASTM requirements** since it fails the saturation coefficient requirement.

8.18. See Section 8.2.

8.19. See Section 8.3.

8.20. See Section 8.4.

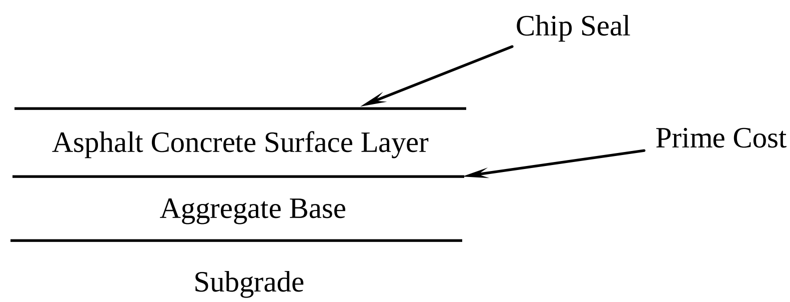
CHAPTER 9. ASPHALT AND ASPHALT MIXTURE

9.1. See introduction of Chapter 9.

9.2. See Section 9.2.

9.3. See Section 9.1.

9.4.



9.5. See Section 9.3.

9.6. See Section 9.3 and Figure 9.11.

9.7. See Section 9.4.

9.8. a. Meeting specification requirements (quality control and quality assurance) to ensure safety at the refinery and at the HMA plant.

b. Meeting specification requirements (quality control and quality assurance).
Simulation of short-term aging of the binder during mixing and construction.

c. Pumpability at the refinery.
Determining asphalt concrete mixing temperature at the HMA plant.
Determining asphalt concrete compaction temperature on the road.
Meeting specification requirements (quality control and quality assurance).
Ensuring appropriate viscosity for different climates.

d. Meeting specification requirements (quality control and quality assurance) to ensure appropriate performance of the HMA on the road.

e. Meeting specification requirements (quality control and quality assurance).
Selection of appropriate asphalt grades for different climates.

9.9. See Section 9.6.2.

9.10. See Sections 9.6.1 and 9.6.2.

9.11. See Section 9.7.1.

9.12. High temperature grade > 55 + (2 x 2.5) = 60 °C
Low temperature grade < -9 - (2 x 1.5) = -12 °C
The asphalt binder that satisfy the two temperature grades at 98 percent reliability is **PG 64-16.**

9.13. High temperature grade > 48 + (2 x 2.5) = 53 °C
Low temperature grade < -21 - (2 x 3.0) = -27 °C
The asphalt binder that satisfy the two temperature grades at 50 percent reliability is **PG 52-22.**
The asphalt binder that satisfy the two temperature grades at 98 percent reliability is **PG 58-28.**

9.14.

Case	Seven-Day Maximum Pavement Temperature, °C		Minimum Pavement Temperature, °C		Recommended PG Grade	
	Mean, °C	Std. Dev., °C	Mean, °C	Std. Dev., °C	50% Reliability	98% Reliability
1	43	1.5	-29	2.5	PG 46-34	PG 46-34
2	51	3	-18	4	PG 52-22	PG 58-28
3	62	2.5	10	2	PG 64-10	PG 70-10

9.15.

Case	Seven-Day Maximum Pavement Temperature, °C		Minimum Pavement Temperature, °C		Recommended PG Grade	
	Mean, °C	Std. Dev., °C	Mean, °C	Std. Dev., °C	50% Reliability	98% Reliability
1	39	1	-32	3.5	PG 46-34	PG 46-40
2	54	1.5	-17	2	PG 58-22	PG 58-22
3	69	2	5	2.5	PG 70-10	PG 76-10

9.16. CRS-2 is cationic, sets faster, and is more viscous than SS-1.

9.17. See Section 9.7.3.

9.18. See Section 9.8.

9.19. See Section 9.8.

9.20. See Section 9.9.

9.21. See Sections 9.8 and 9.9.

9.22. Equation 9.1, G_{mb} = 1353.9 / (1342.2-792.4) = **2.463**

9.23 a. Equation 9.1, G_{mb} = 1264.7 / (1271.9 – 723.9) = 2.308 **=**
b. Equation 9.8, VTM = 100 [1-(G_{mb}/G_{mm})] = 100 [1-(2.308/2.531)] = 8.811%

9.24. See Section 9.9.2.

9.25. Equation 5.19, $G_{sb} = \dfrac{1}{\dfrac{0.59}{2.635}+\dfrac{0.36}{2.710}+\dfrac{0.05}{2.748}}$ = 2.667

Since absorption is ignored, $G_{se} = G_{sb}$

Equation 9.3, $G_{mm} = \dfrac{100}{\dfrac{95}{2.667}+\dfrac{5}{1.088}}$ = 2.487

$G_{mb} = \dfrac{143.9}{62.4}$ = 2.306

Equation 9.8, $VTM = 100\left(1-\dfrac{2.198}{2.487}\right)$ = **11.6%**

Equation 9.9, $VMA = \left(100 - 2.198\,\dfrac{95}{2.667}\right)$ = **21.7%**

Equation 9.10, $VFA = 100x\dfrac{(0.217-0.116)}{0.217}$ = **46.5%**

9.26. Assume $V_t = 1$ ft^3

Determine mass of mix and components:

Total mass = 1 × 147 = 147 lb

Mass of aggregate = 0.94 × 147 = 138.2 lb

Mass of asphalt binder = 0.06 × 147 = 8.8 lb

Determine volume of components:

$$V_s = \frac{138.2}{2.65x62.4} = 0.836 ft^3$$

Ignore absorption, therefore $V_{be} = V_b$

$$V_b = \frac{8.8}{1.0x62.4} = 0.141 ft^3$$

Determine volume of voids:

$$V_v = V_t - V_s - V_b = 1 - 0.836 - 0.141 = 0.032\ ft^3$$

Volumetric calculations:

$$VTM = \frac{V_v}{V_t}100 = \frac{0.032}{1.00}100 = \mathbf{3.20\%}$$

9.27. a. Equation 9.8, $VTM = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right) = 100\left(1 - \frac{2.487}{2.561}\right)$ **= 2.89% < 4%**

b. The air voids is lower than the design air voids. Thus, there is not enough room for the binder to go when the pavement is compacted by traffic, which results in rutting and bleeding.

9.28. Equation 9.8, $VTM = 100\left(1 - \frac{2.475}{2.563}\right)$ = **3.4%**

Equation 9.9, $VMA = \left(100 - 2.475\frac{94.5}{2.689}\right)$ = **13.0%**

Equation 9.10, $VFA = 100x\frac{(0.130 - 0.034)}{0.130}$ = **73.8%**

9.29. Equation 9.8, $VTM = 100\left(1 - \frac{2.500}{2.610}\right)$ = **4.2%**

Equation 9.9, $VMA = \left(100 - 2.500\frac{95.0}{2.725}\right)$ = **12.8%**

Equation 9.10, $VFA = 100x\frac{(0.128 - 0.042)}{0.128}$ = **67.2%**

9.30. See Section 9.9.3.

9.31. An Excel sheet can be used.

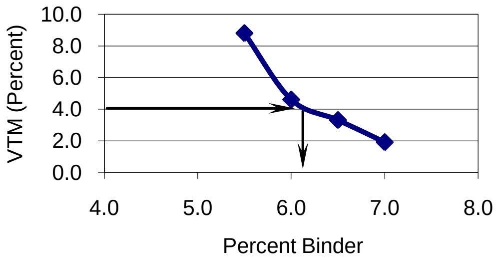
Volumetric Analysis					Criteria
Computed	Equation	Blend			
		1	2	3	
G_{se}	9.4	2.855	2.922	2.849	
VTM	9.8	5.2	7.1	4.5	
VMA	9.9	13.2	12.7	14.1	
VFA	9.10	60.6	44.1	68.1	
$\%G_{mm,Nini}$	9.11	84.4	78.4	90.9	≤ 91.5
P_{ba}	9.12	2.69	3.37	1.92	
P_{be}	9.13	3.37	2.32	3.99	
D/b	9.14	1.3	1.9	1.1	
Adjusted Values					
$P_{b,est}$	9.15	6.4	6.7	6.0	
VMA_{est}	9.16	13.0	12.1	14.0	≥ 13
VFA_{est}	9.17	69.2	66.9	71.4	70-80
$G_{mm, Nini, est}$	9.18	85.6	81.5	91.4	
$P_{be,est}$	9.19	3.9	3.6	4.2	
D/B_{est}	9.20	1.2	1.3	1.1	0.6-1.2

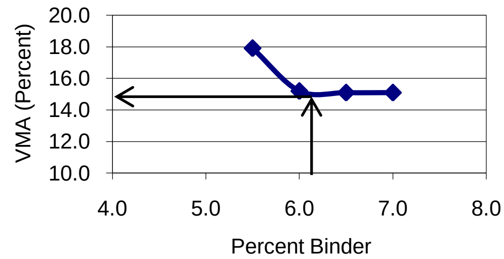
Select blend 3

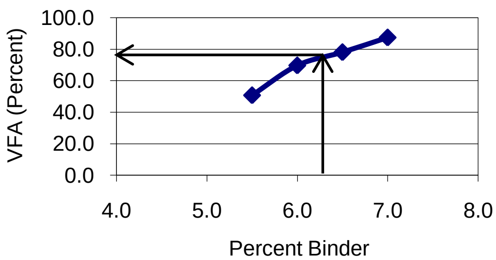
9.32. An Excel sheet can be used.

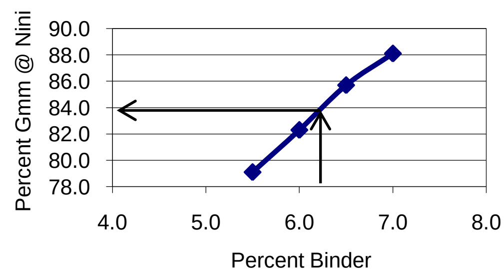
Volumetric Analysis

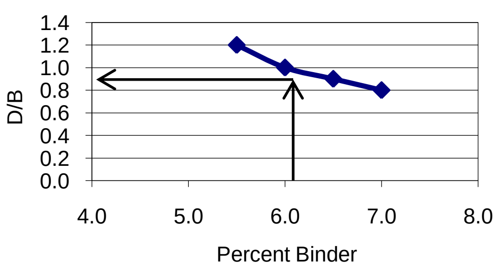
Computed	Equation				
G_{se}	9.4	2.828	2.828	2.828	2.828
VTM	9.8	8.8	4.6	3.3	1.9
VMA	9.9	17.9	15.2	15.1	15.1
VFA	9.10	50.8	69.7	78.1	87.4
$\%G_{mm,Nini}$	9.11	79.1	82.3	85.7	88.1
P_{ba}	9.12	1.65	1.65	1.65	1.65
P_{be}	9.13	3.94	4.45	4.96	5.47
D/B	9.14	1.1	1.0	0.9	0.8











Pb	6.1%
VMA	14.7
VFA	77
$\%G_{mm}$ @ N_{ini}	84.0
D/B	1.0

These results satisfy the design criteria shown in Table 9.10. Therefore, the design asphalt content is **6.1%.**

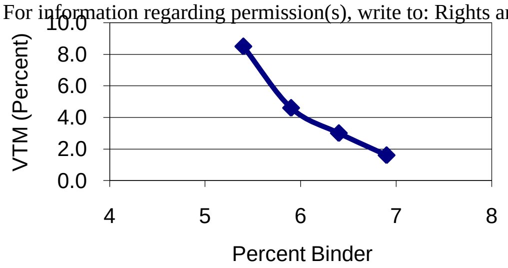
9.33. An Excel sheet can be used.

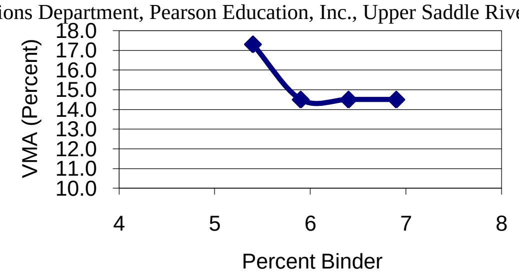
		Blend			
Data		1	2	3	
G_{mb}		2.457	2.441	2.477	
G_{mm}		2.598	2.558	2.664	
G_b		1.025	1.025	1.025	
P_b		5.9	5.7	6.2	
P_s		94.1	94.3	93.8	
P_d		4.5	4.5	4.5	
G_{sb}		2.692	2.688	2.665	
h_{ini}		125	131	125	
H_{des}		115	118	115	
Volumetric Analysis					
Computed	Equation				Criteria
G_{se}	9.4	2.875	2.812	2.979	
VTM	9.8	5.4	4.6	7.0	
VMA	9.9	14.1	14.4	12.8	
VFA	9.10	61.7	68.1	45.3	
$\%G_{mm,Nini}$	9.11	87.0	86.0	85.5	≤ 89.0
P_{ba}	9.12	2.42	1.68	4.05	
P_{be}	9.13	3.62	4.12	2.4	
D/b	9.14	1.2	1.1	1.9	
Adjusted Values					
$P_{b,est}$	9.15	6.5	5.9	7.4	
VMA_{est}	9.16	13.8	14.3	12.2	≥ 13
VFA_{est}	9.17	71.0	72.0	67.2	65-75
$G_{mm, Nini, est}$	9.18	88.4	86.6	88.5	
$P_{be,est}$	9.19	4.2	4.3	3.6	
D/B_{est}	9.20	1.1	1.0	1.3	0.6-1.2

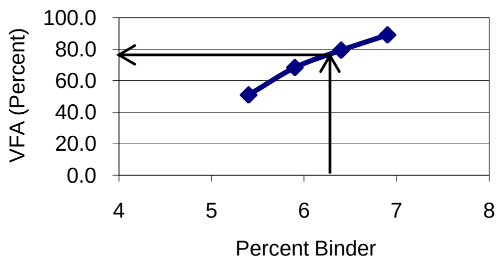
Select aggregate blend 2.

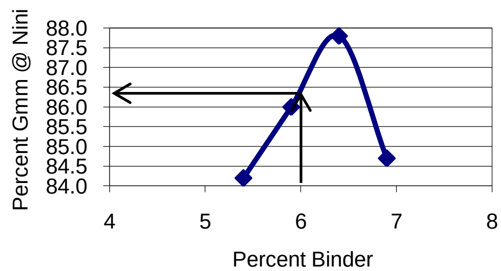
Design Binder Content

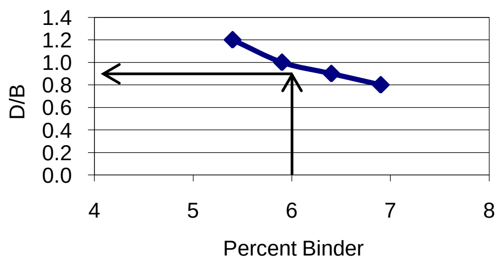
Data		Binder content			
		5.4	5.9	6.4	6.9
G_{mb}		2.351	2.441	2.455	2.469
G_{mm}		2.570	2.558	2.530	2.510
G_b		1.025	1.025	1.025	1.025
P_s		94.6	94.1	93.6	93.1
P_d		4.5	4.5	4.5	4.5
G_{sb}		2.688	2.688	2.688	2.688
h_{ini}		125	131	126	130
h_{des}		115	118	114	112
Volumetric Analysis					
Computed	Equation				
G_{se}	9.4	2.812	2.812	2.812	2.812
VTM	9.8	8.5	4.6	3.0	1.6
VMA	9.9	17.3	14.5	14.5	14.5
VFA	9.10	50.9	68.3	79.3	89.0
$\%G_{mm,Nini}$	9.11	84.2	86.0	87.8	84.7
P_{ba}	9.12	1.68	1.68	1.68	1.68
P_{be}	9.13	3.81	4.32	4.83	5.34
D/B	9.14	1.2	1.0	0.9	0.8











Pb	6.0%
VMA	14.2
VFA	70
$\%G_{mm,\ Nini}$	86.4
D/B	0.9

These results satisfy the design criteria shown in Table 9.10. Therefore, the design asphalt content is **6.0%.**

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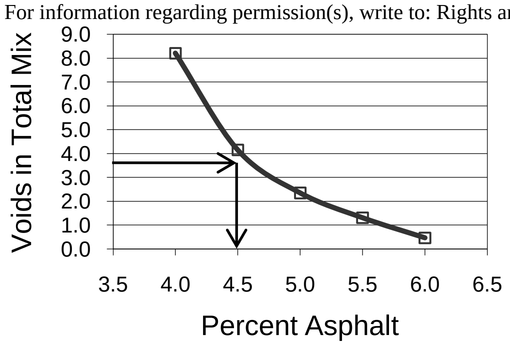
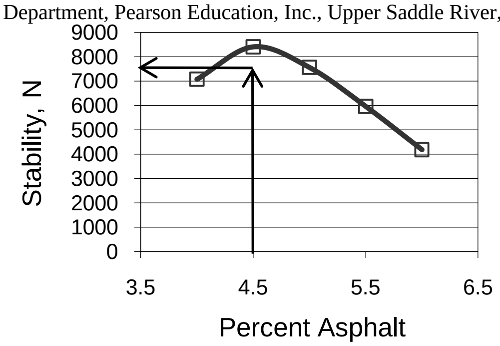
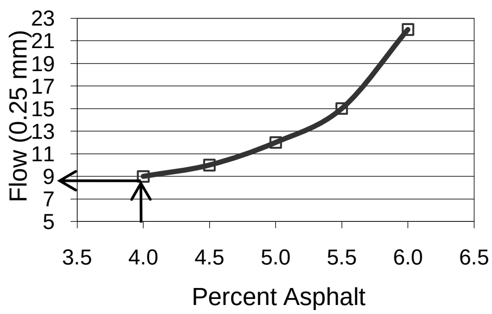
9.34. See Section 9.9.5.

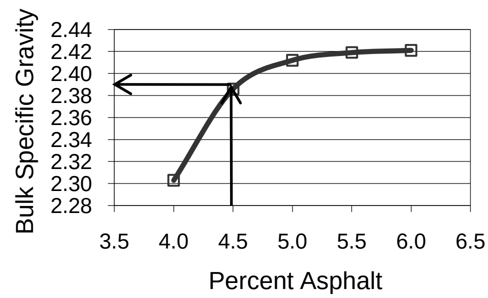
9.35.

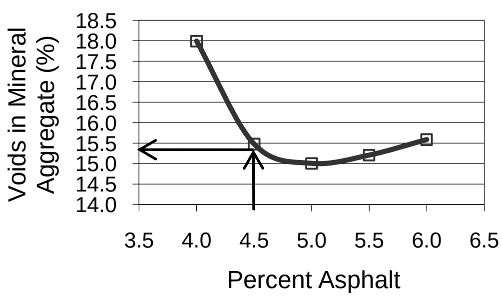
P_b (%)	G_{mb} (%)	Stability, N	Flow, 0.25 mm	G_{mm} (%)	G_{se} (%)	VTM (%)	VMA (%)	VFA (%)
4.0	2.303	7076	9	2.509		8.2	18.0	54.4
4.5	2.386	8411	10	2.489		4.1	15.5	73.2
5.0	2.412	7565	12	2.470	2.677	2.3	15.0	84.4
5.5	2.419	5963	15	2.451		1.3	15.2	91.4
6.0	2.421	4183	22	2.432		0.5	15.6	97.0

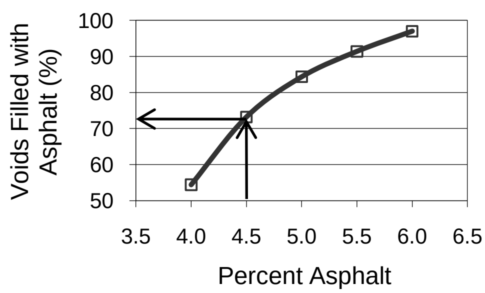












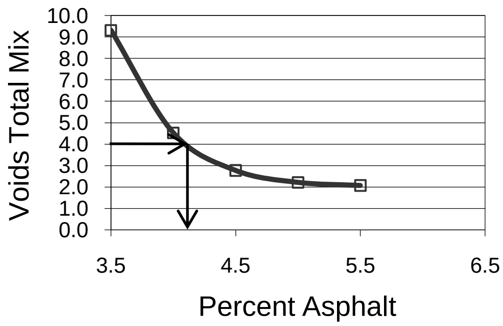
Determine the asphalt content that corresponds to 4% air voids and check with Marshall design criteria shown in Tables 9.14 and 9.15.

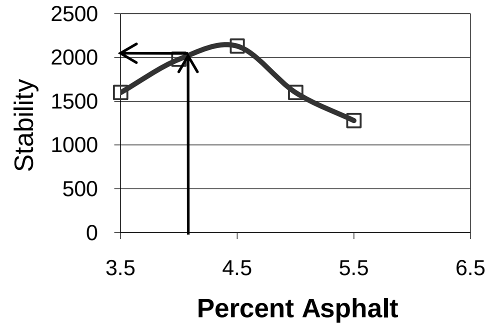
	From data	Criteria
P_b @ 4%	4.5	
Stability (kN)	8.4	5.34 (min)
Flow, (0.25 mm)	9	8 to 16
G_{mb} (%)	2.39	na
VMA (%)	15.6	13.0 (min)
VFA (%)	73	65 to 78

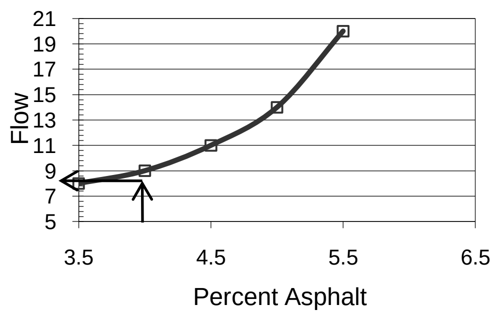
Design asphalt content = **4.5%**

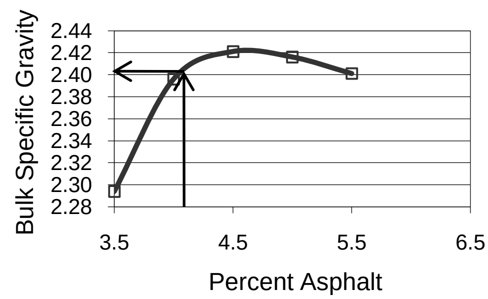
9.36.

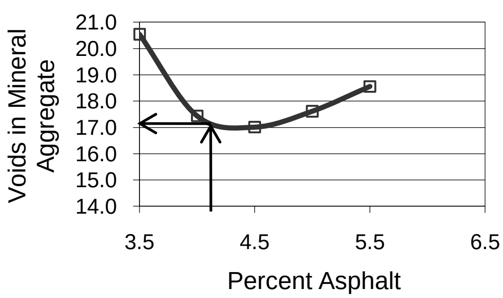
P_b (%)	G_{mb} (%)	Stability (lb)	Flow	G_{mm} (%)	G_{se} (%)	VTM (%)	VMA (%)	VFA (%)
3.5	2.294	1600	8	2.529		9.3	20.5	54.7
4.0	2.396	1980	9	2.510		4.5	17.4	74.0
4.5	2.421	2130	11	2.490	2.678	2.8	17.0	83.7
5.0	2.416	1600	14	2.471		2.2	17.6	87.4
5.5	2.401	1280	20	2.452		2.1	18.6	88.8

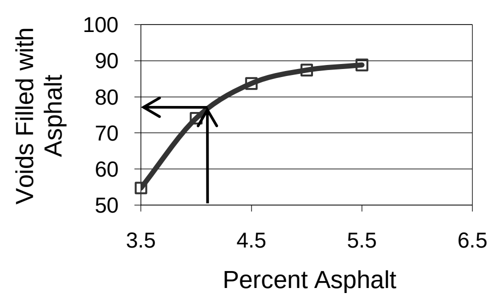












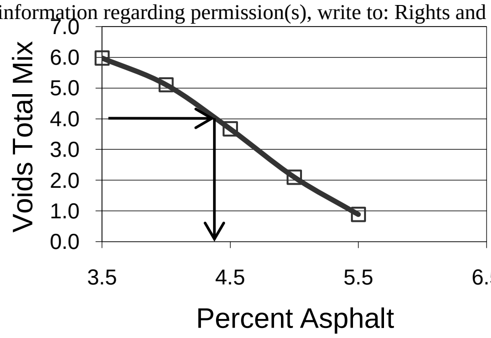
Determine the asphalt content that corresponds to 4% air voids and check with Marshall design criteria shown in Tables 9.14 and 9.15.

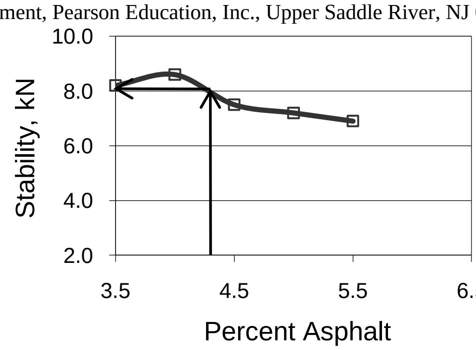
	From data	Criteria
P_b @ 4%	4.1	
Stability (lb)	2100	1200 (min)
Flow	9	8 to 16
G_{mb} (%)	2.405	na
VMA (%)	17.2	15.0 (min)
VFA (%)	77	65 to 78

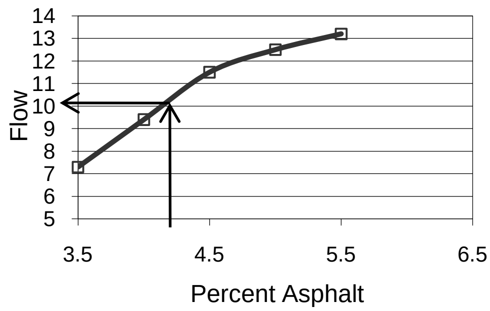
Design asphalt content = **4.1%**

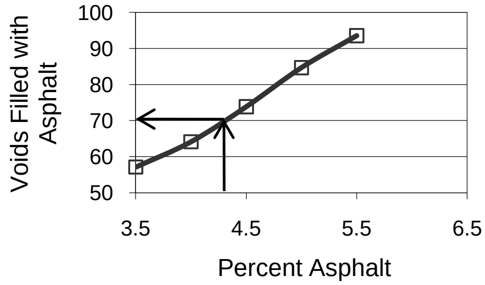
9.37.

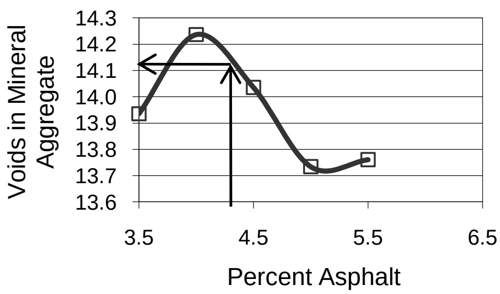
P_b (%)	G_{mb}	Stability (kN)	Flow (0.25 mm)	G_{mm} (%)	G_{se} (%)	VTM (%)	VMA (%)	VFA (%)
3.5	2.367	8.2	7.3	2.517		6.0	13.9	57.1
4.0	2.371	8.6	9.4	2.499		5.1	14.2	64.1
4.5	2.389	7.5	11.5	2.480	2.658	3.7	14.0	73.9
5.0	2.410	7.2	12.5	2.462		2.1	13.7	84.7
5.5	2.422	6.9	13.2	2.444		0.9	13.8	93.6

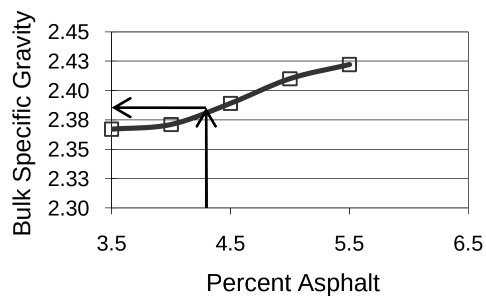












Determine the asphalt content that corresponds to 4% air voids and check with Marshall design criteria shown in Tables 9.14 and 9.15.

	From data	Criteria
P_b @ 4%	4.4	
Stability (kN)	8.05	8.01 (min)
Flow (0.25 mm)	10.8	8 to 14
G_{mb} (%)	2.38	na
VMA (%)	14.15	13.0 (min)
VFA (%)	70	65 to 75

Therefore the optimum asphalt content = **4.4%**

9.38. See Section 9.9.6.

9.39. See Section 9.10.2.

9.40. $M_R = \dfrac{P\,(0.27 + \upsilon)}{t\,.\,\Delta H} = \dfrac{628\,(0.27 + 0.35)}{2.514 \times 247 \times 10^{-6}}$ = **627,031 psi**

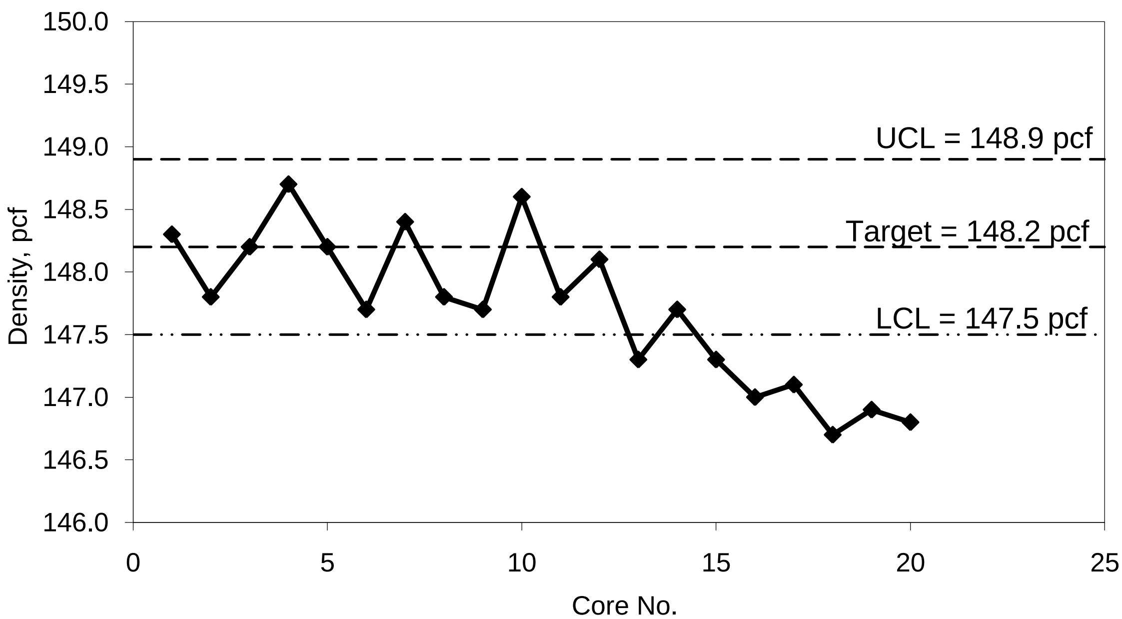
9.41. See Section 9.12.

9.42. See Section 9.12.

9.43. See Section 9.13.

9.44. See Section 9.13.1.

9.45.a. The control chart is shown below.



It is clear from the control chart that some of the cores have densities lower than the specification limits. Also the average density is 147.7 pcf which is less than the target value.

b. The control chart shows that there is a decrease in density values for the cores and this could be due to several factors such as problems with the paver, problems with the rollers, etc.

9.47. See Section 9.13.3.

9.48. See Section 9.14.

CHAPTER 10. WOOD

10.1. See introduction of Chapter 10**.**

10.2. See Section 10.1.1.

10.3. I would choose sample B because higher specific gravity indicates more cellulose and a denser piece of lumber. Therefore, this specimen would probably make a stronger, stiffer structural member.

10.4. See Section 10.1.2.

10.5. See Section 10.2.

10.6. Moisture content = [(317.5 - 203.9) / 203.9] x 100 = **55.7 %**

10.7. See Section 10.3.

10.8. According to Figure 10.5 the FSP = 28. The changes in dimensions are due to the reduction of moisture below the FSP.

From Figure 10.5 the percentage of shrinkage due the changes of moisture from 28% to 7% are as follows: tangential = 6 %, radial = 3.1 %, and longitudinal = 0.23 %. The new dimensions will be:

- Tangential = 38 x (1 - 0.06) = **35.7 mm**
- Radial = 89 x (1 - 0.031) = **86.2 mm**
- Longitudinal = 2.438 x (1 - 0.002) = **2.433 m**

10.9. a. No dimension change occurs above FSP.
Percent change in the wood diameter = (1/5) x (30 - 5) **= 5.0%**

b. **Swell**

c. New diameter = **1.050 in**

10.10. Assume a 30% FSP
The change of moisture content from 14% to 35% causes swelling. Swell does not occur above the FSP.
Assume a 1% swelling per 5% increase in moisture content below the FSP.
Increase in depth = (30-14) / 5 = 3.2%
New depth = 12 x 1.032 = 12.384 in.

10.11. See Section 10.4**.**

10.12. See Section 10.4.1**.**

10.13. See Section 10.4**.**

10.14. See Section 10.5**.**

10.15. See Section 10.6**.**

10.16. See Section 10.8 and Figure 10.12**.**

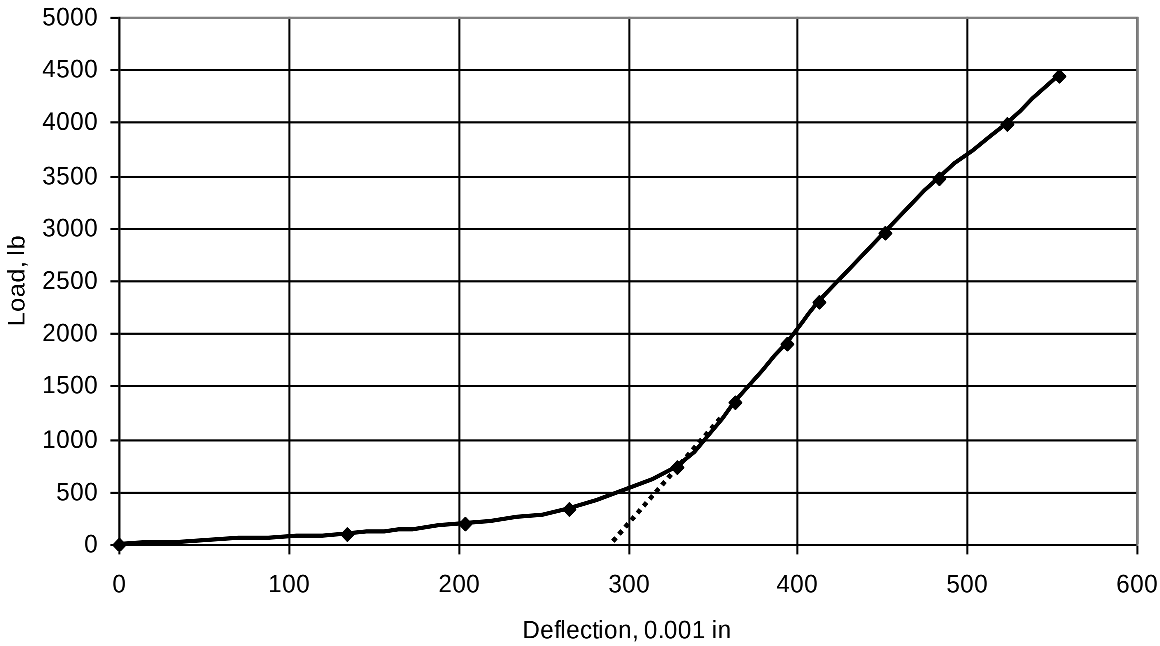
10.17. $E = \sigma / \varepsilon = 20 / (0.00225) =$ **8,889 MPa**
$E = \sigma / \varepsilon = 2.9 / (0.00225) =$ **1,289 ksi**
The results are within the range of values in Table 1.1.

10.18. The typical load duration used in designing wood structures is 10 years.
For a one-week event, the designer should increase the allowable fiber stress.
According to Fig. 10.13, the designer should increase the allowable fiber stress by 25%.

10.19. Testing of structural-size members is more important than testing small, clear specimens since the design values are more applicable to the actual size members. The bending test is more commonly used than the other tests. See Section 10.9.

10.20. The actual dimensions of the 2 x 4 lumber is 1.5" x 3.5".
Max bending moment = M = (240/2) x (16/2) = 960.0 in.kips
Moment of inertia = $I = (1.5 \times 3.5^3) / 12 = 5.36 \text{ in.}^4$
c = d/2 = 1.75 in.
Modulus of rupture = $\frac{Mc}{I} = \frac{960x1.75}{5.36}$ = **313.4 ksi**
Apparent modulus of elasticity = (P L^3) / (4 b h^3 x delta)
= (240.0 x 16^3) / (4 x 1.5 x 3.5^3 x 2.4) = **1.59 x 10^6 psi**

10.21. a. The actual dimensions of the 4 x 4 lumber is 3.5" x 3.5".
The load versus deflection is shown below.



b. By inspection, extend the straight line backward until it meets the x-axis and this will be the new origin. The proportional limit is at a load of 3479 lb and a deflection of 0.483 in.

c. Max bending moment = M = (3479/2) x (60/2) = 52,185 in.lb
Moment of inertia = I = (3.5 x 3.5^3) / 12 = 12.51 $in.^4$
c = d/2 = 1.75 in.
Modulus of rupture = $\frac{Mc}{I} = \frac{52{,}185 x 1.75}{12.51}$ = **7,300 psi**

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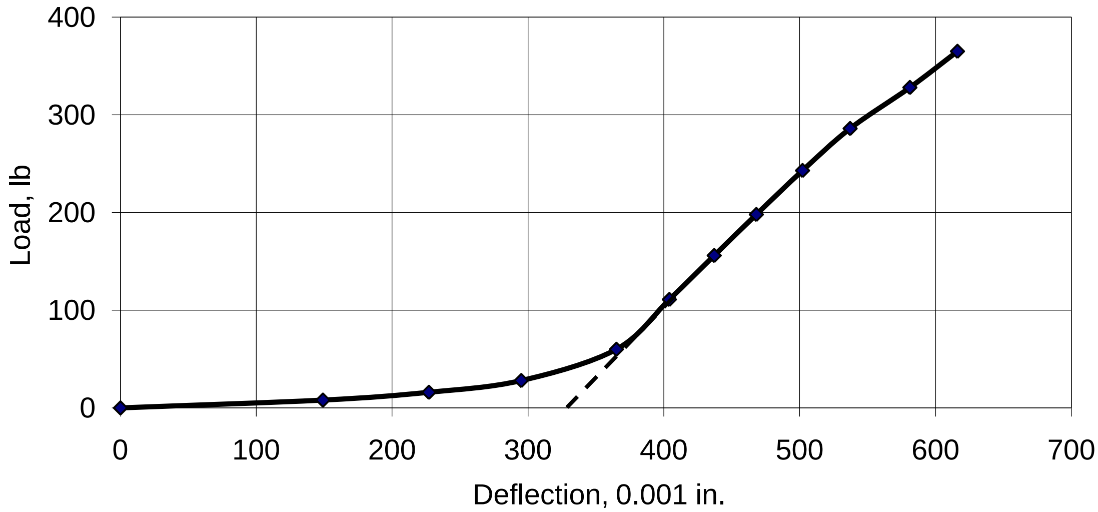
10.22. a. The load versus deflection is shown below.

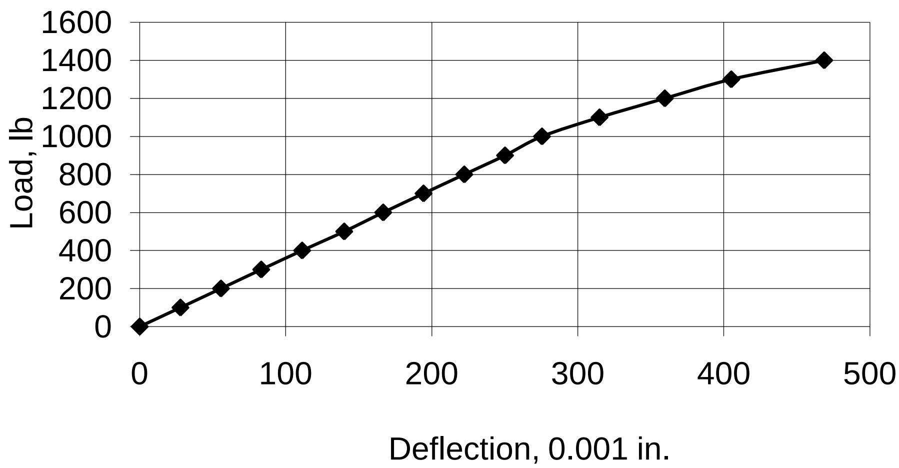


b. By inspection, extend the straight line backward until it meets the x-axis and this will be the new origin. The proportional limit is at a load of 280 lb and a deflection of 0.52 in.

c. Max bending moment = M = (365/2) x (14/2) = 1,277.5 in.lb
Moment of inertia = I = (1 x 1^3) / 12 = 0.08333 in.^{4}
c = d/2 = 0.5 in.

Modulus of rupture = $\frac{Mc}{I} = \frac{1{,}277.5x0.5}{0.08333}$ = **7,665 psi**

10.23. a. The load versus deflection is shown below.



b. By inspection, the proportional limit is at a load of 1,000 lb and a deflection of 0.275 in.

c. Bending moment at failure = M = 700 x 14 = 9,800 in.lb

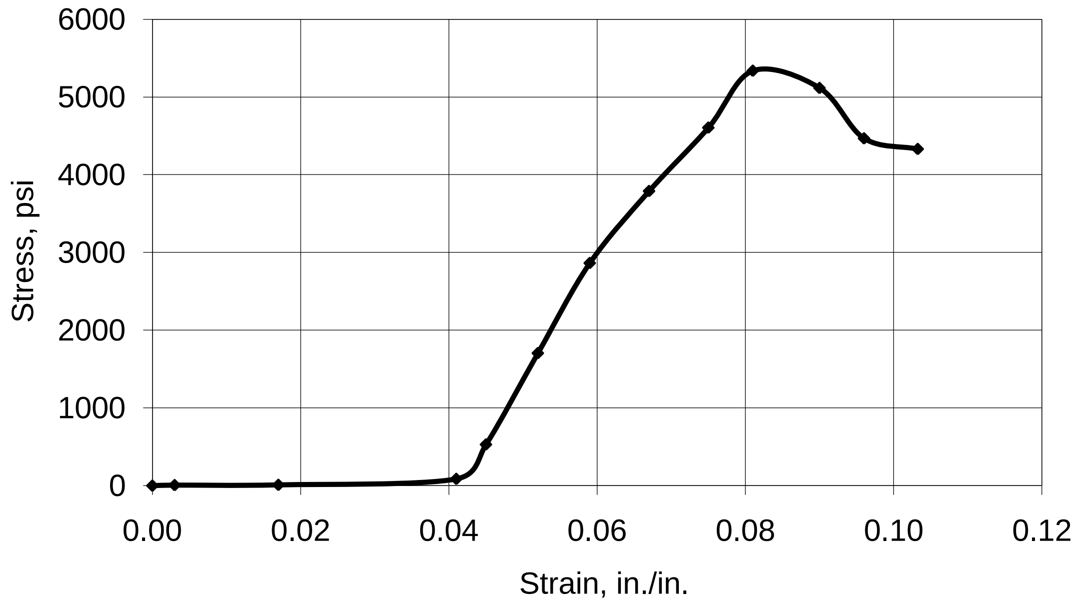
Moment of inertia = I = (2 x 2^3) / 12 = 1.333 in.^{4}
c = d/2 = 1 in.

Modulus of rupture = $\frac{Mc}{I} = \frac{9{,}800x1}{1.333}$ = **7,352 psi**

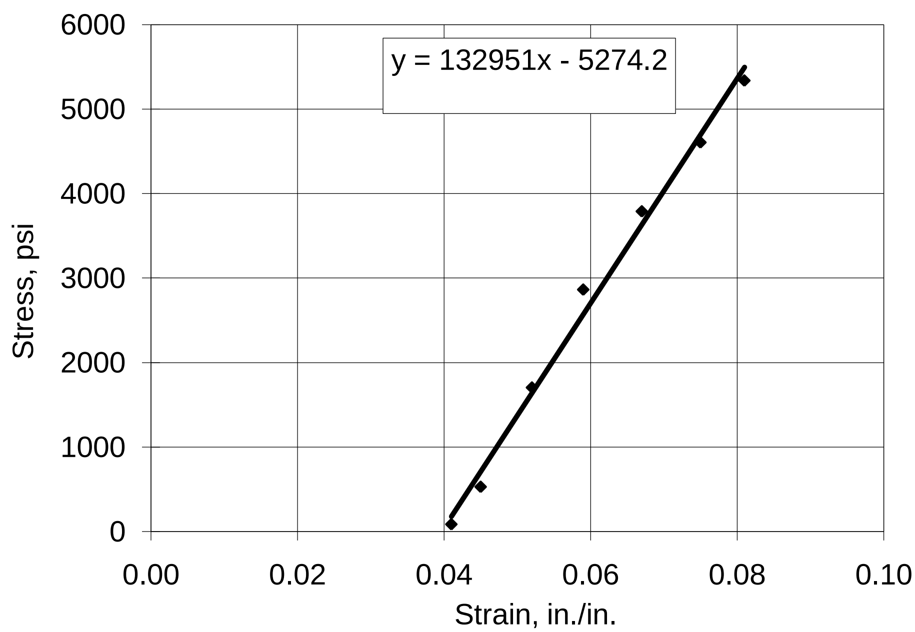
d. The modulus of rupture computed does not truly represent the extreme fiber stresses in the specimen because the assumptions used in the derivation of the equation consider that the material is elastic, homogeneous, and isotropic. These assumptions are not exactly satisfied.

10.24. a. Stress (psi) = Load (lb) / (1 in. x 1 in.)
Strain (in./in.) = Deformation (in) / 4 in

Load, lb	Displacement, in.	Stress, psi	Strain, in./in.
0	0.000	0	0.000
7	0.012	7	0.003
10	0.068	10	0.017
87	0.164	87	0.041
530	0.180	530	0.045
1705	0.208	1705	0.052
2864	0.236	2864	0.059
3790	0.268	3790	0.067
4606	0.300	4606	0.075
5338	0.324	5338	0.081
5116	0.360	5116	0.090
4468	0.384	4468	0.096
4331	0.413	4331	0.103



b. The modulus of elasticity is the slope of the stress-stain line. The first part of the curve includes an experimental error probably due to the lack of full contact between the machine head and the specimen. Therefore, ignore the first portion of the curve and draw the best fit straight line up to the maximum stress. The modulus of elasticity is the slope of the line as shown on the figure below:

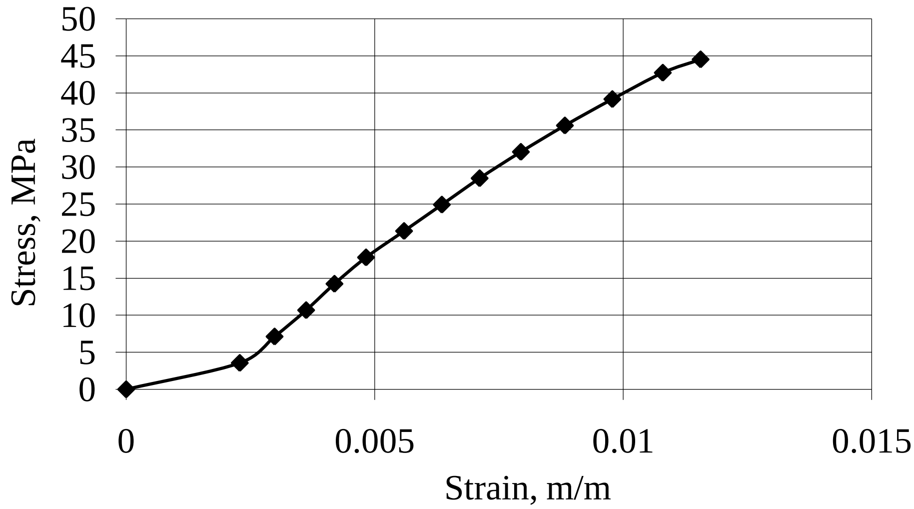


E= σ / ε = **132,951 psi**

c. Failure stress = **5,338 psi**

10.25. a. Stress (MPa) = Load (MN) / (0.05 m x 0.05 m)
Strain (m/m) = Deformation (mm) / 200 mm

Deformation, mm	Load kN	Strain	Stress (N/mm2)
0	0	0	0
0.457	8.9	0.002285	3.56
0.597	17.8	0.002985	7.12
0.724	26.7	0.00362	10.68
0.838	35.6	0.00419	14.24
0.965	44.5	0.004825	17.8
1.118	53.4	0.00559	21.36
1.27	62.3	0.00635	24.92
1.422	71.2	0.00711	28.48
1.588	80.1	0.00794	32.04
1.765	89	0.008825	35.6
1.956	97.9	0.00978	39.16
2.159	106.8	0.010795	42.72
2.311	111.3	0.011555	44.52



b. The modulus of elasticity is the slope of the stress-stain line. The first part of the curve includes an experimental error probably due to the lack of full contact between the machine head and the specimen. Therefore, ignore the first portion of the curve, draw the best fit straight line, and extend the line backward until it meets the x-axis. The intersection of the line and the x-axis (0.002 m/m) is the new origin. The modulus of elasticity is the slope of the line, say at a stress of 40 MPa.

E= σ / ε = 40 / (0.009 – 0.002) = **5,714 MPa**

c. Failure stress = **44.52 MPa**

10.26.

Observation No.	P (lb)	ΔL (in.)	σ (psi)	ε (in./in.)	u_i (psi)
0	0	0.000	0	0.00000	N/A
1	720	0.020	720	0.00500	1.800
2	1720	0.048	1720	0.01200	8.540
3	2750	0.076	2750	0.01900	15.645
4	3790	0.108	3790	0.02700	26.160
5	4606	0.140	4606	0.03500	33.584
6	5338	0.164	5338	0.04100	29.832
7	6170	0.200	6170	0.05000	51.786
8	6480	0.224	6480	0.05600	37.950
9	5400	0.253	5400	0.06325	43.065
				u_t =	**248.3620**

10.27. $P_{max} = \sigma \times A = 4.3 \times (\pi \times 5^2) = 702.10$ kips
For F.S = 1.3, P_{max} =702.10/1.3 = **540.1 kips**

10.28. See Section 10.10.

10.29. See Section 10.11.

10.30. See Section 10.12.

10.31. See Section 10.13.

10.32. See Section 10.13.

CHAPTER 11. COMPOSITES

11.1. See introduction of Chapter 11**.**

11.2. See introduction of Chapter 11**.**

11.3. See Section 11.1**.**

11.4. See Section 11.1**.**

11.5. See Section 11.1.1**.**

11.6. See Section 11.1**.**

11.7. See Section 11.1**.**

11.8. See Section 11.2.1**.**

11.9. See Section 11.2.3**.**

11.10. See Section 11.2.4**.**

11.11. Equation 11.6, $E_c = 0.65 \text{ x } 0.5 \text{ x } 10^6 + 0.35 \text{ x } 50 \text{ x } 10^6 =$ **17.80 x 10^6 psi**
Equation 11.7, $F_f/F_c = (50 \text{ x } 10^6 / 17.80 \text{ x } 10^6) \text{ x } 0.35 \text{ x } 100 =$ **98.3%**

11.12. Equation 11.6, $E_c = 0.55 \text{ x } 0.5 \text{ x } 10^6 + 0.45 \text{ x } 50 \text{ x } 10^6 =$ **22.8 x 10^6 psi**
Equation 11.7, $F_f/F_c = (50 \text{ x } 10^6 / 22.8 \text{ x } 10^6) \text{ x } 0.45 \text{ x } 100 =$ **98.7%**

11.13. Equation 11.18, $E_c = \dfrac{E_m E_f}{\nu_m E_f + \nu_f E_m} = \dfrac{0.5 \text{ x } 10^6 x 50 \text{ x } 10^6}{0.5x50 \text{ x } 10^6 + 0.5x0.5 \text{ x } 10^6}$ = **0.99 x 10^6 psi**
Because of the isostress condition, both fibers and polymer carry the same load.

11.14. Equation 11.6, $E_c = 0.6 \text{ x } 3.5 + 0.4 \text{ x } 350 =$ **142.1 GPa**
Equation 11.7, $F_f/F_c = (350 / 142.1) \text{ x } 0.4 \text{ x } 100 =$ **98.52%**

11.15. Equation 11.6, $E_c = 0.65 \text{ x } 3.5 + 0.35 \text{ x } 350 =$ **124.8 GPa**
Equation 11.7, $F_f/F_c = (350 / 124.8) \text{ x } 0.35 \text{ x } 100 =$ **98.16%**

11.16. Equation 11.18, $E_c = \dfrac{E_m E_f}{\nu_m E_f + \nu_f E_m} = \dfrac{3.5x350}{0.5x350 + 0.5x3.5}$ = **6.93 GPa**
Because of the isostress condition, both carbon fibers and epoxy carry the same load.

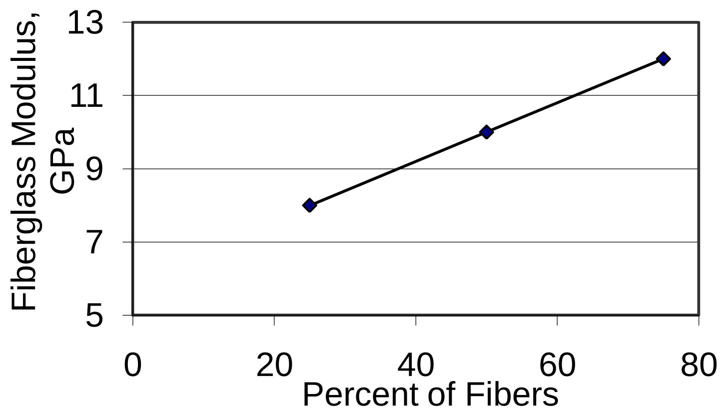
11.17. Equation 11.20, $E_c = V_m \,.\, E_m + K \,.\, V_f \,.\, E_f$

a. For 25% glass fiber, E_c = 0.75 x 6 + 0.2 x 0.25 x 70 = **8.0 GPa**

b. For 50% glass fiber, E_c = 0.50 x 6 + 0.2 x 0.50 x 70 = **10.0 GPa**

c. For 75 % glass fiber, E_c = 0.25 x 6 + 0.2 x 0.75 x 70 = **12.0 GPa**

The figure below shows that increasing the percent of fibers increases the modulus of elasticity of the fiberglass.

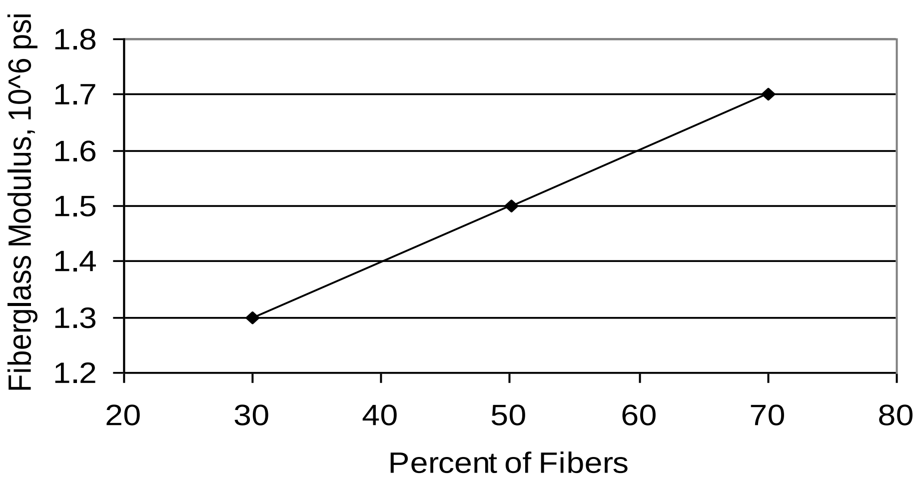


11.18. Equation 11.20, $E_c = V_m \,.\, E_m + K \,.\, V_f \,.\, E_f$

a. For 30% glass fiber, E_c = 0.70 x 1 x 10^6 + 0.2 x 0.30 x 10 x 10^6 = **1.3 x 10^6 psi**

b. For 50% glass fiber, E_c = 0.50 x 1 x 10^6 + 0.2 x 0.50 x 10 x 10^6 = **1.5 x 10^6 psi**

c. For 70 % glass fiber, E_c = 0.30 x 1 x 10^6 + 0.2 x 0.70 x 10 x 10^6 = **1.7 x 10^6 psi**



Increasing the percent of fibers increases the modulus of elasticity of the fiberglass.

11.19. a. Equation 11.6, $E_{RC} = \nu_{PC} E_{PC} + \nu_S E_S$ = (0.98 x 25) + (0.02 x 207) = **28.64 GPa**

b. Equation 11.7, $\frac{F_S}{F_{RC}} = \frac{E_s}{E_{RC}} \nu_s = \frac{207}{28.64}(0.02)$ = 0.145 = 14.5%

F_S = 0.145 x 1000 = **145 kN**

F_{PC} = 1000 – 145 = **855 kN**

c. $A_{column} \approx A_{PC} = \frac{F_{PC}}{\sigma_{allowable}} = \frac{855x10^3}{20x10^6}$ = **0.0475 m²**

11.20. a. Equation 11.6, $E_{RC} = \nu_{PC} E_{PC} + \nu_S E_S$ = (0.98 x 5 x 10^6) + (0.02 x 30 x 10^6) = **5.50 x 10^6 psi**

b. Equation 11.7, $\frac{F_S}{F_{RC}} = \frac{E_S}{E_{RC}} \nu_S = \frac{30 \text{ x } 10^6}{5.01 \text{ x } 10^6}(0.02)$ = 0.109 = 10.9%

F_S = 0.109 x 600 = **65 kips**

F_{PC} = 600 – 65 = **535 kips**

c. $A_{column} \approx A_{PC} = \frac{F_{PC}}{\sigma_{allowable}} = \frac{535000}{5000}$ = **107 in.²**