MATERIALS FOR CIVIL AND CONSTRUCTION ENGINEERS

4th Edition

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Solutions Manual

FOREWORD

This solutions 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.

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. $A = 0.6 \times 0.6 = 0.36 \text{ in}^2$
$\sigma = 50{,}000 / 0.36 = 138{,}888.9$ psi
$\varepsilon_a = 0.007 / 2 = 0.0035$ in/in
$\varepsilon_l = -0.001 / 0.6 = -0.0016667$ in/in
E = 138,888.9 / 0.0035 **= 39,682,543 psi = 39,683 ksi**
ν = 0.00166667 / 0.0035 **= 0.48**

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

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

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

$\varepsilon_x = [\sigma_x - \nu (\sigma_y + \sigma_z)] / E$

$\varepsilon_x = [100 \text{ x } 10^6 - 0.333 (100 \text{ x } 10^6 + 100 \text{ x } 10^6)] / 70 \text{ x } 10^9 = 4.77 \text{ x } 10^{-4} = \varepsilon_y = \varepsilon_z = \varepsilon$

$\Delta L_x = \varepsilon \text{ x } L_x = 4.77 \text{ x } 10^{-4} \text{ x } 30 = 0.01431$ mm

$\Delta L_y = \varepsilon \text{ x } L_y = 4.77 \text{ x } 10^{-4} \text{ x } 60 = 0.02862$ mm

$\Delta L_z = \varepsilon \text{ x } L_z = 4.77 \text{ x } 10^{-4} \text{ x } 90 =$ **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

$\varepsilon_x = [\sigma_x - \nu (\sigma_y + \sigma_z)] / E$

$\varepsilon_x = [15 - 0.49 (15 + 15)] / 1000 = 0.0003 = \varepsilon_y = \varepsilon_z = \varepsilon$

$\Delta L_x = \varepsilon \text{ x } L_x = 0.0003 \text{ x } 15 = 0.0045$ in

$\Delta L_y = \varepsilon \text{ x } L_y = 0.0003 \text{ x } 15 = 0.0045$ in

$\Delta L_z = \varepsilon \text{ x } L_z = 0.0003 \text{ x } 15 = 0.0045$ 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. $\varepsilon = 0.3 \text{ x } 10^{-16} \sigma^3$

At σ = 50,000 psi, $\varepsilon = 0.3 \text{ x } 10^{-16} (50{,}000)^3 = 3.75 \text{ x } 10^{-3}$ in./in.

Secant modulus = $\frac{\Delta\sigma}{\Delta\varepsilon} = \frac{50{,}000}{3.75x10^{-3}}$ = **1.33 x 10^7 psi**

$\frac{d\varepsilon}{d\sigma} = 0.9 \text{ x } 10^{-16} \sigma^2$

At σ = 50,000 psi, $\frac{d\varepsilon}{d\sigma} = 0.9 \text{ x } 10^{-16} (50{,}000)^2 = 2.25 \text{ x } 10^{-7}$ in.^{2}/lb

Tangent modulus = $\frac{d\sigma}{d\varepsilon} = \frac{1}{2.25x10^{-7}}$ = **4.44x10^6 psi**

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

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

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

1.12. ε_{axial} = 0.05 / 50 = 0.001 in./in.

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

Δd = $\varepsilon_{lateral}$ 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
The copper and aluminum can be eliminated because they have stresses larger than their yield strengths as shown in the table below.
For steel and brass, $\delta = \frac{PL}{AE} = \frac{24{,}500 lb x 380 mm}{\pi(5mm)^2 E(kPa)} = \frac{118{,}539}{E(MPa)}$ mm

Material	Elastic Modulus (MPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Stress (MPa)	δ (mm)
Copper	110,000	248	289	312	
Al. alloy	70,000	255	420	312	
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 ⇒ Stress < Yield Strength
b. Increase in length, δ < 0.9 mm
The only material that satisfies both conditions is **steel**.

1.14. $\sigma = \frac{F}{A_0} = \frac{7{,}000}{\pi(0.3)^2} = 24{,}757 \text{ psi} = 24.757\ ksi$
This stress is less than the yield strengths of all metals listed.
$\Delta l = \frac{\sigma L_0}{E}$

Material	E (ksi)	Yield Strength (ksi)	Tensile Strength (ksi)	ΔL (in.)
Steel alloy 1	26,000	125	73	0.014
Steel alloy 2	29,000	58	36	0.013
Titanium alloy	16,000	131	106	0.023
Copper	17,000	32	10	0.022

Only the steel alloy 1 and steel alloy 2 have elongation less than 0.018 in.

1.15. $\sigma = \frac{F}{A_0} = \frac{31{,}000\text{ N}}{\pi\left(\frac{15.24\times10^{-3}\text{m}}{2}\right)^2} = 169.9 = 170\text{ MPa}$

This stress is less than the yield strengths of all metals listed.

$\Delta l = \frac{\sigma L_0}{E}$

Material	E (GPa)	Yield Strength (MPa)	Tensile Strength (MPa)	ΔL (mm)
Steel alloy 1	180	860	502	0.378
Steel alloy 2	200	400	250	0.340
Titanium alloy	110	900	730	0.618
Copper	117	220	70	0.581

Only the steel alloy 1 and steel alloy 2 have elongation less than 0.45 mm.

1.16. 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**

1.17. 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**

1.18. 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.**

1.19.

	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	

1.20. 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.

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

$$\sigma = \varepsilon.E = \frac{\delta.E}{l} = \frac{7.6x105{,}000}{250} = 3{,}192 \text{ MPa}$$

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.

1.22. 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.:

ε = σ 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)

1.23. 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.

1.24. a. $\sigma_{max} = \frac{F}{A_o} = \frac{39{,}872\ N}{100\ x\ 10^6\ m^2}$ = 0.000399 Pa = 398 MPa

b. $E = \frac{\sigma}{\varepsilon} = \frac{\sigma\ x\ L_o}{\Delta L} = \frac{\sigma\ x\ L_o}{(L - L_o)}$

$E\ x\ (L - L_o) = \sigma\ x\ L_o$

$110x10^3\ MPa\ x\ (67.21\ mm - L_o) = 398\ MPa\ x\ L_o$

$L_o = 66.97\ mm$

1.25. a. $\sigma_{max} = \frac{F}{A_o} = \frac{8{,}944}{0.24} = 37{,}266.667$ psi

b. $E = \frac{\sigma}{\varepsilon} = \frac{\sigma \; x \; L_o}{\Delta L} = \frac{\sigma \; x \; L_o}{(L - L_o)}$

$$E \; x \; (L - L_o) = \sigma \; x \; L_o$$

$$16 \text{ x } 10^6 \; x \; (3.28 - L_o) = 37{,}266.667 x \; L_o$$

$$L_o = 3.27 \; in.$$

1.26. $\boldsymbol{\varepsilon_a} = \frac{-\varepsilon_l}{\nu} = \frac{\frac{-\Delta d}{d}}{\nu} = \frac{-\Delta d}{d\,\nu}$

$$\boldsymbol{E} = \frac{\sigma_a}{\varepsilon_a} = \frac{\frac{F}{(\frac{\pi d^2}{4})}}{\frac{-\Delta d}{d\,\nu}} = \frac{-4Fd\,\nu}{\pi d^2 \Delta d}$$

$$F = -\frac{-\,d\Delta d\,\pi E}{4\nu}$$

$$\text{F} = \frac{-(19 \times 10^{-3}\text{ m})(-3.0 \times 10^{-6}\text{ m})(\pi)\left(110 \times 10^{9}\frac{\text{N}}{\text{m}^2}\right)}{4(0.35)} = 14{,}070 \; N$$

1.27. $\boldsymbol{\varepsilon_a} = \frac{-\varepsilon_l}{\nu} = \frac{\frac{-\Delta d}{d}}{\nu} = \frac{-\Delta d}{d\,\nu}$

$$\boldsymbol{E} = \frac{\sigma_a}{\varepsilon_a} = \frac{\frac{F}{(\frac{\pi d^2}{4})}}{\frac{-\Delta d}{d\,\nu}} = \frac{-4Fd\,\nu}{\pi d^2 \Delta d}$$

$$F = -\frac{-\,d\Delta d\,\pi E}{4\nu}$$

$$\text{F} = \frac{-(0.5\text{ in.})(-1 \times 10^{-4}\text{ in.})(\pi)(16 \times 10^{6}\text{ psi})}{4(0.35)} = 1{,}795 \; lb$$

1.28. See Sections 1.2.3, 1.2.4 and 1.2.5.

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

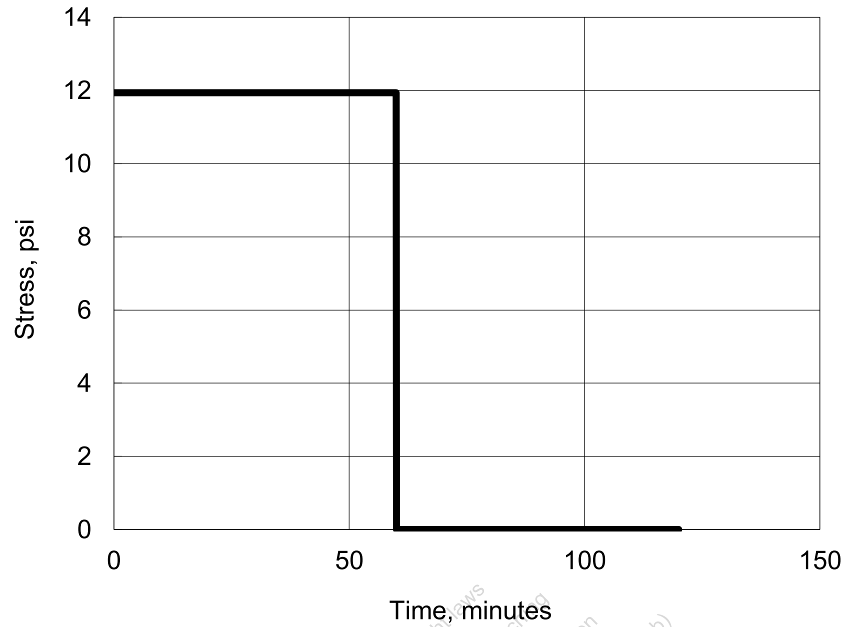
$\sigma = P/A_o = 150 / (\pi \times 2^2) = 11.94$ psi

$\varepsilon = (H_o - H)/H_o = (6-H)/6$

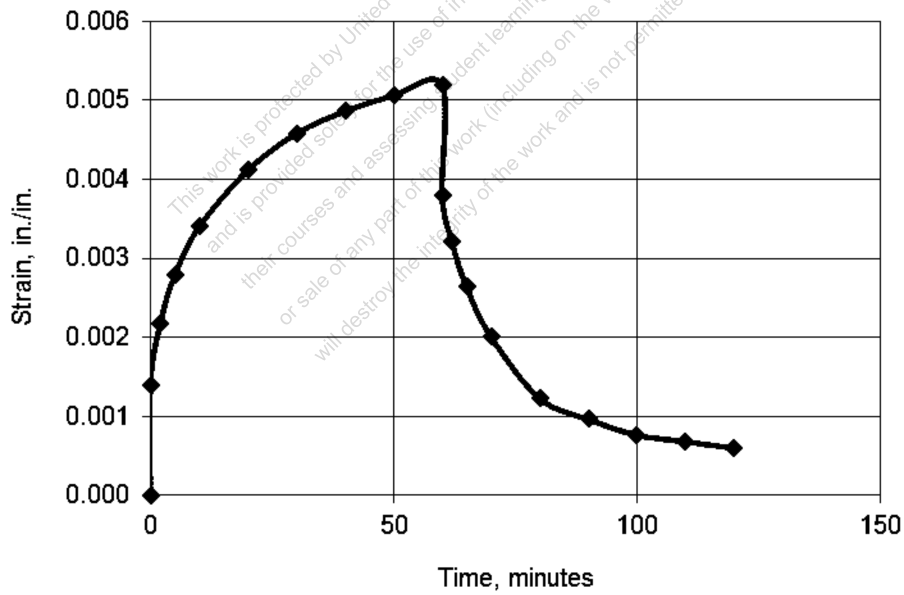
The stresses and strains are shown in the following table:

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.**

1.30. See Figure 1.12(a).

1.31. a. For $F \le F_o$: $\delta = F.t / \beta$
For $F > F_o$, movement

b. For $F \le F_o$: $\delta = F / M$
For $F > F_o$: $\delta = F / M + (F - F_o)\, t / \beta$

1.32. See Section 1.2.7.

1.34. 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**

1.35. See Section 1.2.8.

1.36.

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

1.37. See Section 1.3.2.

1.38. $\delta L = \alpha_L \; x \; \delta T \; x \; L$ = 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.

1.39. 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.

1.40. 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**

1.41. 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.

1.43. See Section 1.7.

1.44. See Section 1.7.1

1.45. H_o: $\mu \geq 32.4$ MPa

H_1: $\mu < 32.4$ MPa

$\alpha = 0.05$

$$T_o = \frac{\bar{x}-\mu}{(\sigma/\sqrt{n})} = -3$$

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.

1.46. 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, $T_{\alpha,\upsilon} = T_{0.05,19} = -1.729$

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

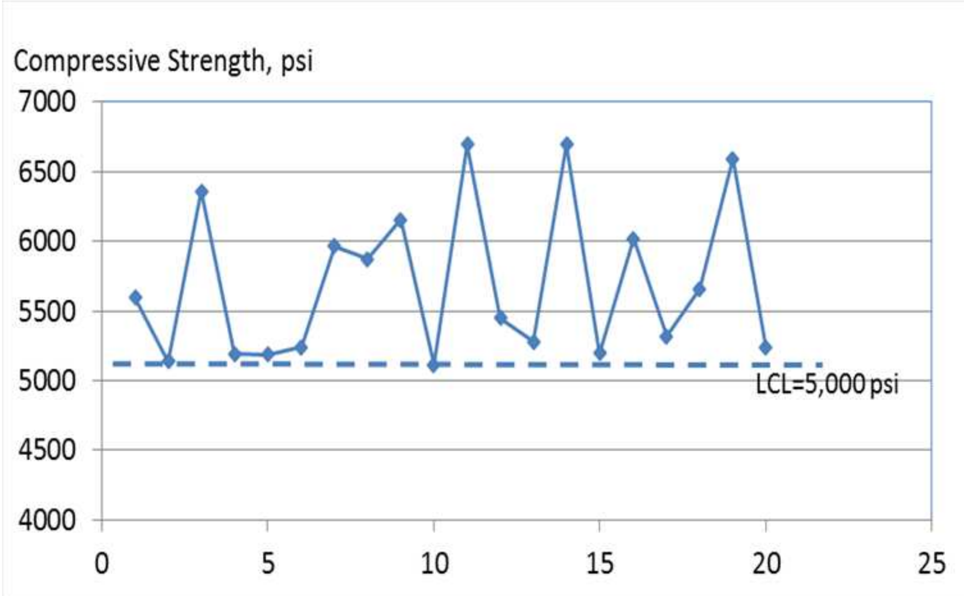
Therefore, **reject** the hypothesis. The contractor's claim is not valid.

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

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

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

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.