Materials for Civil and Construction Engineers, Third Edition, by Michael S. Mamlouk and John P. Zaniewski. ISBN: 0-13-611058-4

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.

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CHAPTER 1. MATERIALS ENGINEERING CONCEPTS

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

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

1.4. $A = 201.06 \text{ mm}^2$
$\sigma = 0.945$ 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
$\Delta d = \varepsilon_L d_o = 0.000232 (6 \text{ in}) = 0.00139$ 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
$\Delta d = \varepsilon_L d_o = -0.000336 (0.5 \text{ in}) = -0.000168$ 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

$\varepsilon_x = [\sigma_x - \nu(\sigma_y + \sigma_z)]/E$
$\varepsilon_x = [100 \times 10^6 - 0.333(100 \times 10^6 + 100 \times 10^6)] / 70 \times 10^9 = 4.77 \times 10^{-4} = \varepsilon_y = \varepsilon_z = \varepsilon$
$\Delta L_x = \varepsilon \times L_x = 4.77 \times 10^{-4} \times 30 = 0.01431$ 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 mm³**

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 in³**

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 = $\dfrac{\Delta\sigma}{\Delta\varepsilon} = \dfrac{50{,}000}{3.75x10^{-3}}$ = **1.33×10^7 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.

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.

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

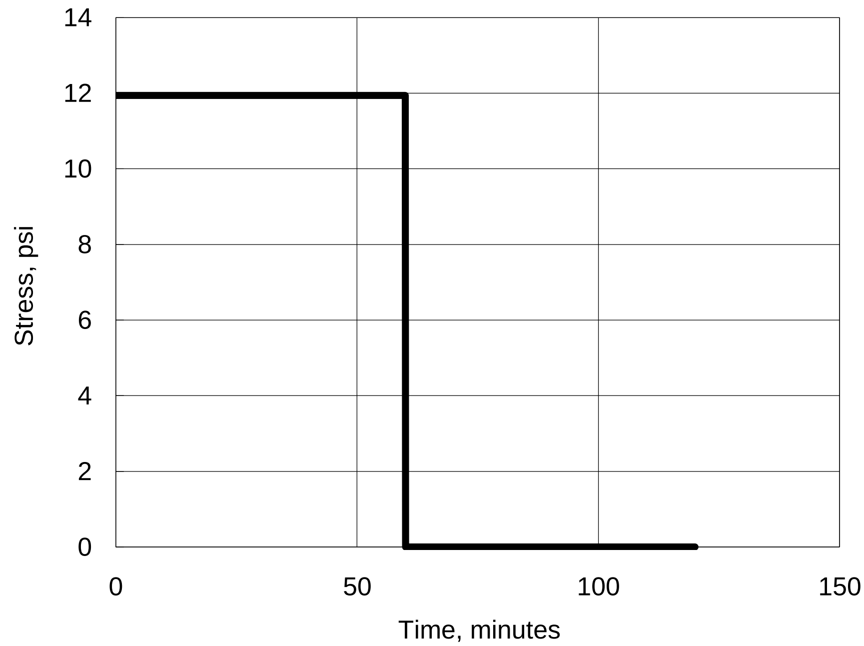
$\sigma = P/A_o = 150 / (\pi \times 2^2) = 11.94$ psi

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

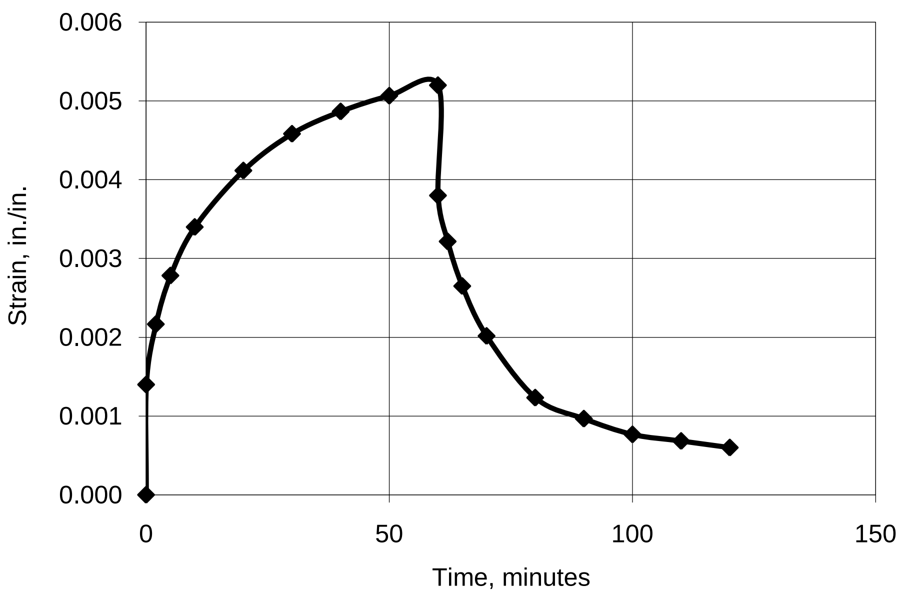
The stresses and strains are shown in the following table:

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.**

1.24. 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

$\sigma = \varepsilon E = 0.00125 \times 207{,}000 =$ **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

$\sigma = \varepsilon E = -0.000358 \times 200{,}000 = -77$ MPa

$P = \sigma \times A = -77 \times (100 \times 50) = -385{,}000$ 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.

$\sigma = \varepsilon E = -0.0005 \times 5{,}000{,}000 = -2{,}500$ 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

$\alpha = 0.05$

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

Degree of freedom = $\nu = n - 1 = 15$

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

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

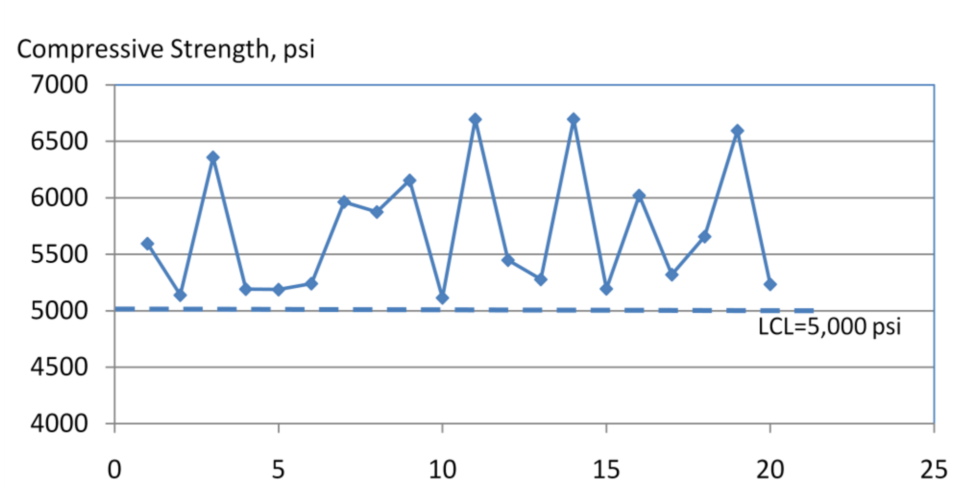
Therefore, **reject** the hypothesis. The contractor's claim is not valid.

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.



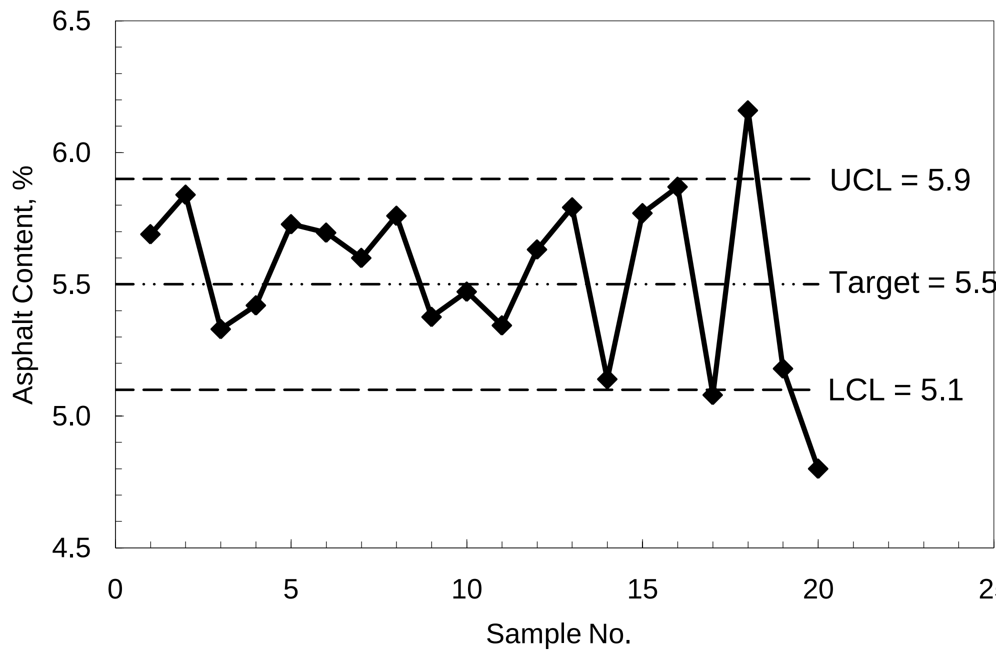
The target value is any value above the specification limit of 5,000 psi. The plant production is meeting the specification requirement.

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.

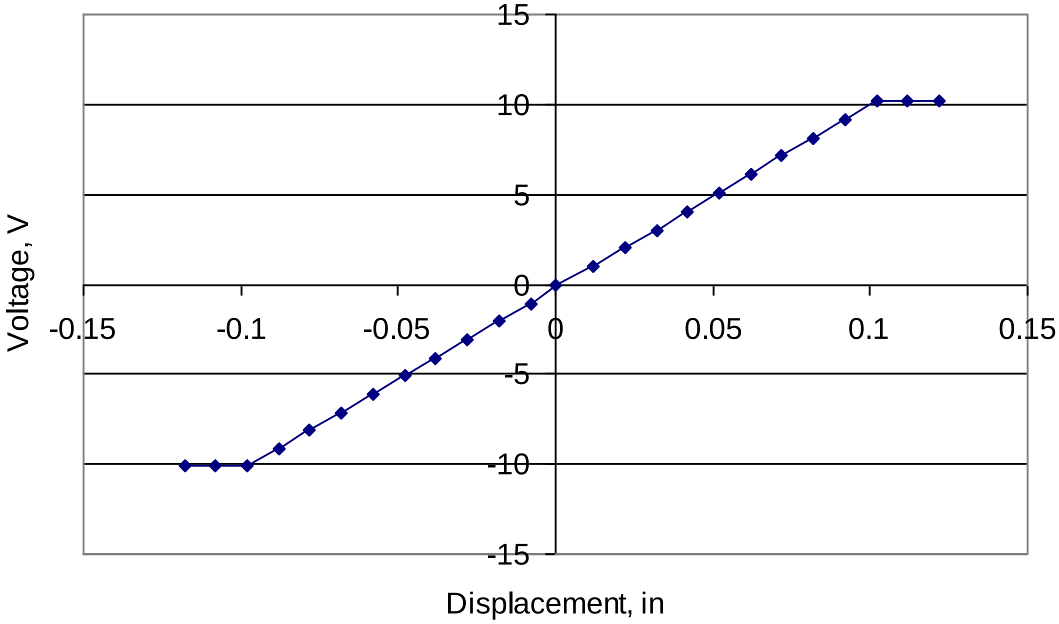
b. Sensitivity == **0.001 in.**

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

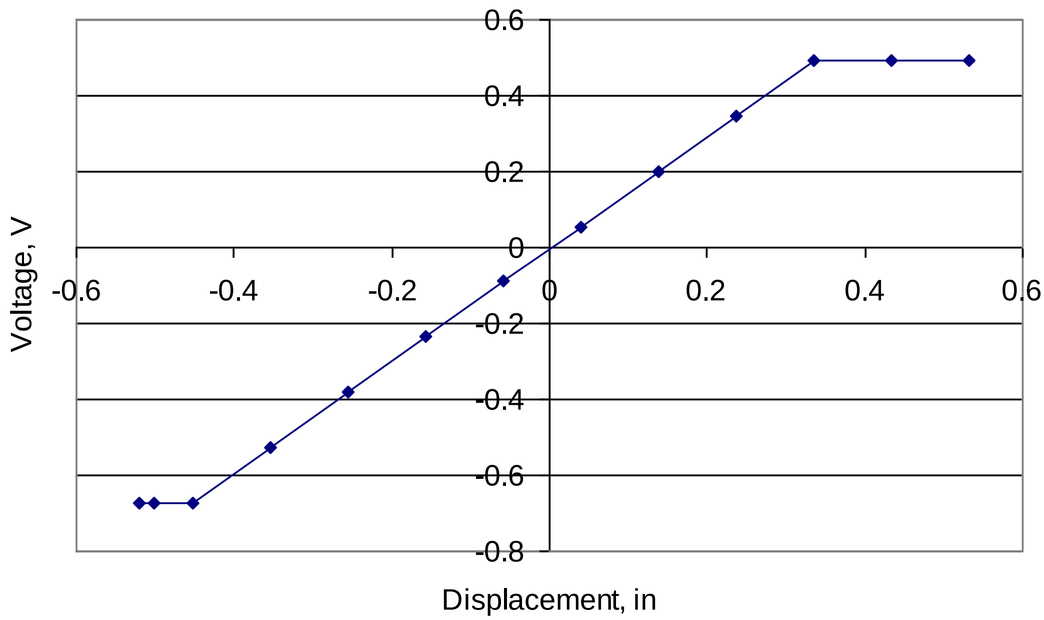
1.46 The voltage is plotted versus displacement is shown below.



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.