STRAIN GAGES 1 & 2

Minster

ABSTRACT

INTRODUCTION

Define Young’s modulus, poisson;s ratio, bending moment, and area moment of inertia. \
Review the strain gage, Wheatstone bridge and gage factor.

7 To gain experience mounting a strain gage, and to measure strain due to bending, using a strain gauge and digital strain indicator. Students will also estimate material properties. Young’s modulus and Poisson’s ratio, using stain gages.

8 To use strain gage rosettes to investigate strain concentration due to a hole, as well as principal strains. The principal strain will be evaluated graphically (Mohr’s circle) and analytically.

Equation

$$\sigma = Mz/I$$

M = bending moment
z = z-dimension at location of interest, and
I = area moment of inertia of beam cross-section.

$$\sigma = 6PL/(bt^2).$$

P = applied force
L = lever arm from point of applied load to the gage
b = beam width
t = beam thickness

$$\varepsilon_{bottom-corrected} = \left[\frac{1-\nu_{gage}K_t}{1-K_t^2}\right]\left[\varepsilon_{bottom-observed} - K_t\varepsilon_{top-observed}\right]$$

$$\varepsilon_{top-corrected} = \left[\frac{1-\nu_{gage}K_t}{1-K_t^2}\right]\left[\varepsilon_{top-observed} - K_t\varepsilon_{bottom-observed}\right]$$

$$\nu_{Al-bar} = \frac{\varepsilon_{lateral}}{\varepsilon_{longitudinal}} = \frac{\varepsilon_{bottom-corrected}}{\varepsilon_{top-corrected}} = \frac{\left[\varepsilon_{bottom-observed} - K_t\varepsilon_{top-observed}\right]}{\left[\varepsilon_{top-observed} - K_t\varepsilon_{bottom-observed}\right]}$$

$$\sigma_{nom} = \frac{6P\ell}{(b-d)t^2}$$

$$k_t = \frac{\sigma_{hole-actual}}{\sigma_{hole-nom}} = \frac{\sigma_{hole-actual}}{\sigma_{far-from-hole-actual}} \approx \frac{\varepsilon_{hole-actual}}{\varepsilon_{far-from-hole-actual}} = \frac{\varepsilon_0}{\varepsilon_1}$$

$$\varepsilon = A + B\left[\frac{r}{x}\right]^2 + C\left[\frac{r}{x}\right]^4$$

where A, B, and C are unknown coefficients.

For the gages near the hole, the strains are:

$$\varepsilon_2 = A + B\left[\frac{r}{a}\right]^2 + C\left[\frac{r}{a}\right]^4 \qquad \varepsilon_3 = A + B\left[\frac{r}{b}\right]^2 + C\left[\frac{r}{b}\right]^4 \qquad \varepsilon_4 = A + B\left[\frac{r}{c}\right]^2 + C\left[\frac{r}{c}\right]^4$$

Discuss the relationship between Mohr's Circle for stress versus Mohr's circle for strain. Review the strain gage, Wheatstone bridge and gage factor. Identify one biomedical engineering application for which strain gage rosettes are appropriate.

METHOD

Experiment #7

One of the objectives of this lab is learning how to mount the strain gage. Students had two different strain gage setups as figure 1 and the writer's group selected the setup #2 which is perpendicular to the longitudinal axis of the bar length to mount strain gage.

The group obtained a strain gage (CEA-13-240UZ-120) from the TA. Make sure do not touch the metal parts of gages. This is a single gage, not a rosette, which is the lab #8. The gage specifications are R=120.0 Ohms ± 0.3%, G = 2.120 ± 0.5% abd Kt = +(0.6±0.2)%. Then the group got two solder tabs and an aluminum bar from the TA.

Then, the group prepared the bar. In the real lab, specimen preparation follows the exact steps. First, remove unnecessary particles on the par and spray the entire bar with degreaser. Wipe the degreaser with a clean gauze pad. In the gage and solder tab mounting areas, abrade bar with sandpaper (320-400 grit) to remove any surface oxide. Finish surface preparation by "wet sanding" with the sandpaper (320-400 grit) and M-Prep Conditioner A (Red Nozzle). Then remove excess conditioner using a clean gauze pad. The group wipe the bar with the gauze pad until the black residue from the sandpaper is no longer visible after wiping with the gauze pad. Lightly mark the location of strain gages on the bar with #2 pencil. The location of the strain gage is going to be 3.0 inches from the left side of the bar and 0.5 inches from the bottom of the bar (Figure 1). Thoroughly moisten the tip of a cotton swab with M-Prep Neutralizer 5 (Blue Nozzle) and scrub the mounting areas. Dry the bar completely, wiping a clean gauze pad across the surface in one slow sweep.

Then students are ready to mount gages. The group removed one gage from the packet with tweezers. Place the gage on the top of the gage case with the metal side up and the bond side down. Position a solder terminal (two tabs) with the bond side down approximately 1/16-1/18 below the gage. Place the middle of gages on the pencil mark on the bar so it is centered with the mark. Be careful not to touch the metal side with tweezers. Take 4-5 inches of cellophane tape from the PCT-2A tape dispenser. Positioned the tape over the gage and solder terminal, taking care to center the gage on the tape. Carefully put the tape over the gages and try not to make an angle between gages. Then gently peeled the tape up and fold the tape back to expose the back of the gage and terminal. When the group put M-bond 200 catalyst, make sure there is no excess catalyst on the brush. Thus, the group wiped the brush against the bottle interior 10-12 times to remove excess. Apply catalyst to the back of the gage and terminal. Allow the catalyst to dry for at least one minute before continuing. Lift the free end of the tape such that the gage/ terminal assembly is at a 90 degree angle with respect to the bar surface, holding the tape taut. On the tape side of the tape/bar, place a gauze pad. Apply 1-2 drops of M-bond 200 adhesive to the bar adjacent to tape/bar junction (approximately ½ inches from gage installation area). From now on, the steps should be performed in few seconds (3-5 seconds). The group immediately lower the tape to create a 30 degree angle with respect to the bar such that the gage/terminal assembly of above the installation area. Holding the tape taut with one hand, wipe the gauze pad over the top of the tape with your other hand thereby affixing the tape to the bar. Then apply firm thumb pressure to the gage and terminal for 2-3 min. Carefully and slowly remove the tape with steady speed.

Now, the group needed to solder. Turn the soldering iron (Weller EC 1002) on and warmed it up. Moisten the sponge at the soldering station with tap water. The group needed two equal lengths of 134-AWP lead wire for the gage. The wires should be long enough to loop from the gage terminal to the solder tab terminal. Melt a small bead of solder onto the tip of the soldering iron. While holding the iron, carefully pick up one of the lead wires at its center with a pair of tweezers. Dip each end of the wire into the solder bead. Remove the remaining solder from the iron using the damp sponge. Repeat for the second lead wire. Carefully melt a small pool of solder on each of the gage terminals and terminal tabs. Heat each solder terminal individually with the soldering iron and solder the lead wires into place. The ends of the wires should be as close to the center of the solder pools as possible. Cut one 24 inches piece of 18 gauge wire and split the wire into two pieces. Solder these wires to each of the terminal tabs with a two wires at one of the tabs. Make sure solders do not touch other tabs. After soldering, apply a thin layer of M-Coat A to each solder connection. The protective coating should completely cover the joint and the first 1/8 inches or so of the lead wire.

After soldering is done, the group needs to test the strain gage that they made.
The group obtained a P-3500 digital strain indicator (amplifier, bridge, battery power, measurements group) from the TA. Press the Run button to power the amplifier, allow it to warm up for 15 min. Using a C-clamp to place the bar but make sure do not tighten up so much because the stain gage will sense that. There should be at least 1 inch between the end of the gage and the end of the table (Figure 2).

Then measure and record the distance from the center of the strain gage to the point of load application which was 20 cm. Also measure and record the width, 2.5cm, and the thickness, 6 mm of the bar. Connect the P+ (red) terminal with single lead. One of the double leads should be connected to the S- (white) terminal. The second lead of the double lead should be connected to D_{120}. This configuration wires the gage into one arm of a Wheatstone bridge, where the 3 remaining arm are 120 ohms resistors. The P+ terminal will display the resultant stain (micro strain). Press the gage factor button and set the gage factor to 2.120 and make sure that the gage factor dial is set to the appropriate range. To balance the bridge, press the AMP zero button and turn the amp zero dial until the strain reading on the LCD display is zero. In the lab, the group's bar did not show the zero which was the error of the strain gage. Press the run button and balance the bridge with the bar unloaded, but with the loading hanger in place. Load the bar in 2 pounds force increments to 20 pounds force. Record the strain from the LCD display for each load increment. Unload the bar and record the strain for each load increment of longitudinal and lateral.

Students estimated Poisson's ratio for aluminum of pre-built strain gages. Obtained an aluminum bar (bar #B-102) pre-built with two strain gages (gage type = 125AD, R=120.0 ohms, G = 2.095 ± 0.5%, Kf = +1.2 %). For the detail, please see the figure 3.

Students used the P-3500 digital strain indicator for signal conditioning. Because of the previous steps, it is not necessary to power up and to wait. Insert instrumented bar into the flexure apparatus (measurements group, S/N: 089119, Fig 3). Two red wires (ground) should be connected to #1 and #2. The green wire (bottom gage) should be connected to #5. The white wire (Top gage) should be connected to #6. Attach the lead wires from the flexure apparatus to the digital strain indicator so as to put the top gage in the active arm in a Wheatstone bridge (R2-R4 = 120 ohms). Flexure wire #1 (Ground) should be connected to the S-terminal. Flexure wire #2 (ground) should be connected to the D120. Flexure wire #6 (Top gage) should be connected to the P+ terminal. Press the gage factor button and set the gage factor (LCD) to 2.095. Make sure that the gage factor dial is set to the appropriate range. Balance the bridge: press AMP zero, turn the AMP zero dial until the LCD reads zero. Then press Run and turn the balance dial until the LCD read zero micro strain. Turn the strain gage amplifier off and disconnect the top stain gage lead wire (flexure wire #6) from the P+ terminal. Attach the single lead wire (flexure wire #5) from the bottom gage to the P+ terminal and press the Run button on the amplifier. Record the strain. Used a multimeter to measure the gage resistance. Slowly deflect the beam by turning the flexure screw until an additional 700 micro strain has been imposed. Also measure the gage resistance and bridge voltage.Unload the bar by turning the flexure screw until the bar is cleared. The stain indicator should read approximately zero micro strain, the initial value.

Experiment #8

Strain concentration

Obtained an aluminum bar with a hole (bar #B-104), instrumented with four strain gages (figure 1). Gage 1: gage type = 125 AD, R = 12- ohms, G = 2.095 ± 0.5% abd Kt = +1.2%. Gage 2-4: gage type = 031DE, R=120 ohms, G = 2.06 ± 0.5% , Kt = +1.1%.

Insert the beam into the flexure apparatus. The gages should be on the top surface. Gage 1 should be near the clamp. The connections should be as follows: #1,2=red, #5 = blue, #6 = white, #7 = green, and #8 = black. Connect one common lead (red = ground) to the S-terminal of the digital strain indicator. Connect the other common lead (red=ground) to the D_{120} terminal, thereby setting the bridge ground. Set the gage factor to 2.06 (gages 2-4). Balance the gage amplifier. Depress the AMP zero button and adjust the AMP zero dial until the LCD reads zero. Turn the strain indicator off and connect the lead wire for gage 2 to the P+ terminal. Press Run button. With the flexor screw clear of the beam, adjust the balance control of the strain indicator until the LCD reads exactly zero. Turn the strain indicator off and disconnect gage 2 from the P+ terminal. Connect gage 3 (green) to the same terminal. Press the Run button on the gage indicator. Without making any adjustments to the strain indicator, record the strain. Repeat for gage 4.
Set the gage factor to 2.095 and repeat for gage 1(blue).

After recording the initial strains for gages 1-4, turn the flexure screw until an additional 2000 $\mu\varepsilon$ has been added to gage 1. Turn the strain indicator off and disconnect gage 1. change the gage factor to 2.06. connect gage 2 (P+ terminal) and depress the Run button to measure the strain. Record strain 2 above. Record the strains for gages 3 and 4. Re-connect gage 1 (change the gage factor back to 2.095) to the strain indicator and turn the flexure screw until it clears the surface of the beam. If more than 20 με is observed, identify the source of the error and repeat the experiment.

Principal Strains

Obtain an aluminum bar instrumented with a rectangular resette. The individual gages are: gage type = 120EA, R = 120.0 ohms, G=2.04±0.5% and Kt=+1.0%.

Turn on the digital strain indicator. Clamp the instrumented bar onto the edge of the lab table. The distance from the center on the gages to the fixed end, a, should be 1.5-2.0 inches. Insert the loading device onto the bar.

Measure and record the distance from the center of gage 2 to the point of load application (L). Also measure and record the width (b) and thickness of the bar (t).

Connect one of the common wires for the three gages to the S-terminal on the strain indicator. Connect the remaining common lead to the D_{120} terminal on the strain indicator. Set the gage factor to 2.04. Connect the independent lead from gage 1 (black wire) to the P+ terminal. With the beam unloaded, balance the bridge. Turn the strain indicator off. Disconnect gage 1, and connect the independent lead from gage 2 (white wire) to the P+ terminal. Turn the strain indicator on by depressing the run button. Without making any adjustments to the strain indicator, record the initial strain.

Repeat (G) for gage 3 – red wire. Do not disconnect the gage.

Using the cantilever flexure formula and Figure 2, determine the load P necessary to produce a 15,000 psi stress at the center of the rosette. Using the free weight in the lab, apply P determined above. Compute the actual stress for your P. Record the strain for gage 3 in the above table. Turn the strain indicator off and disconnect gage 3. Attach the lead wire for gage 2 to the P+ terminal. Depress the Run button and record strain 2. Repeat for gage 1. Do not disconnect the gage. Unload the bar and record the strain for gage 1. If this strain varies form the initial strain of this gage by more than 20 micro strain, identify the source of the error and repeat the experiment. Repeat steps for an offset load on the T, each collecting individual data.

RESULTS

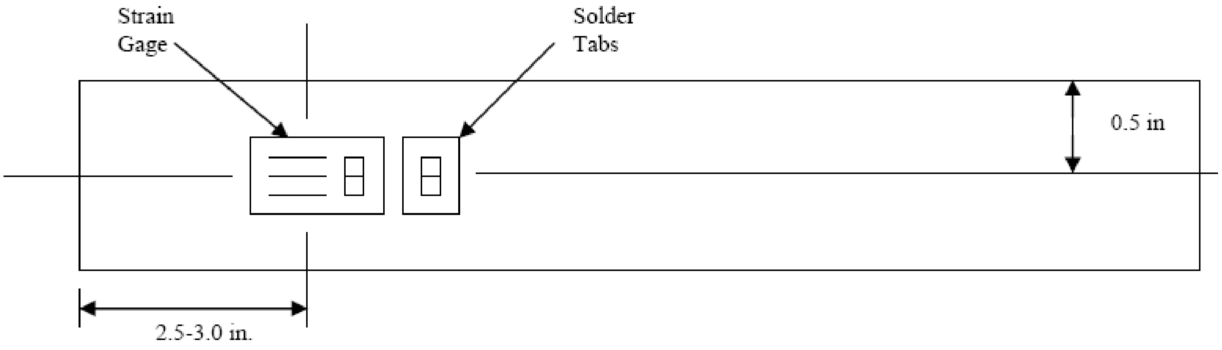
7-A. Calculation of the area moment of inertia, I, of your bar.

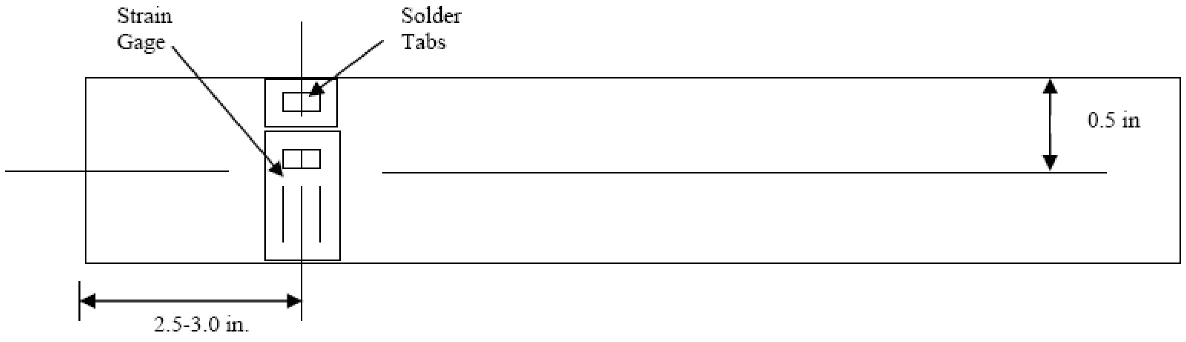
<Longitudnal Gauge>
I = beam width * Thickenss ^{3} /12 = $bt^3/12$ = $(1in)(0.1335in)^3/ 12$ = 0.0002 in^4

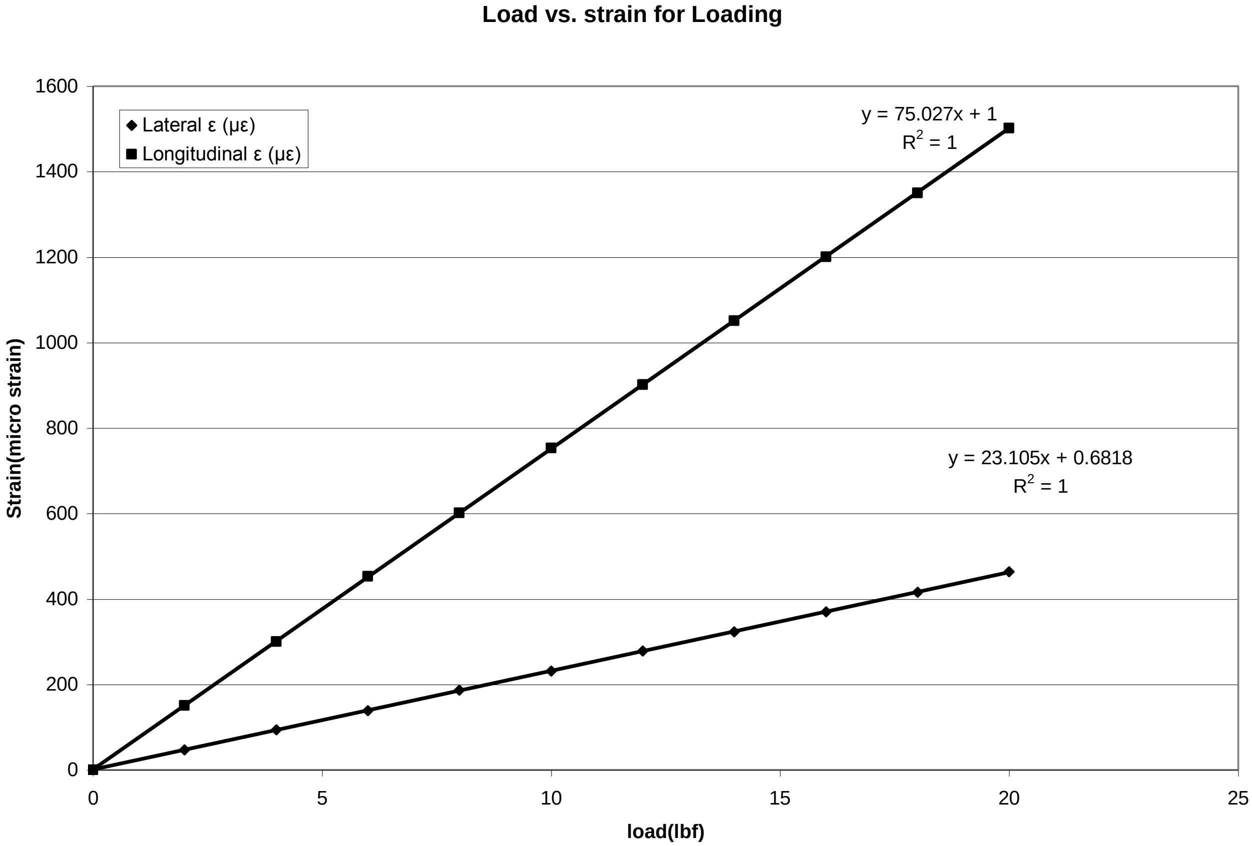
<Lateral Gauge>
I = $bt^3/12$ = (1\`in)$(0.1335in)^3/ 12$ = 0.0013 in^4

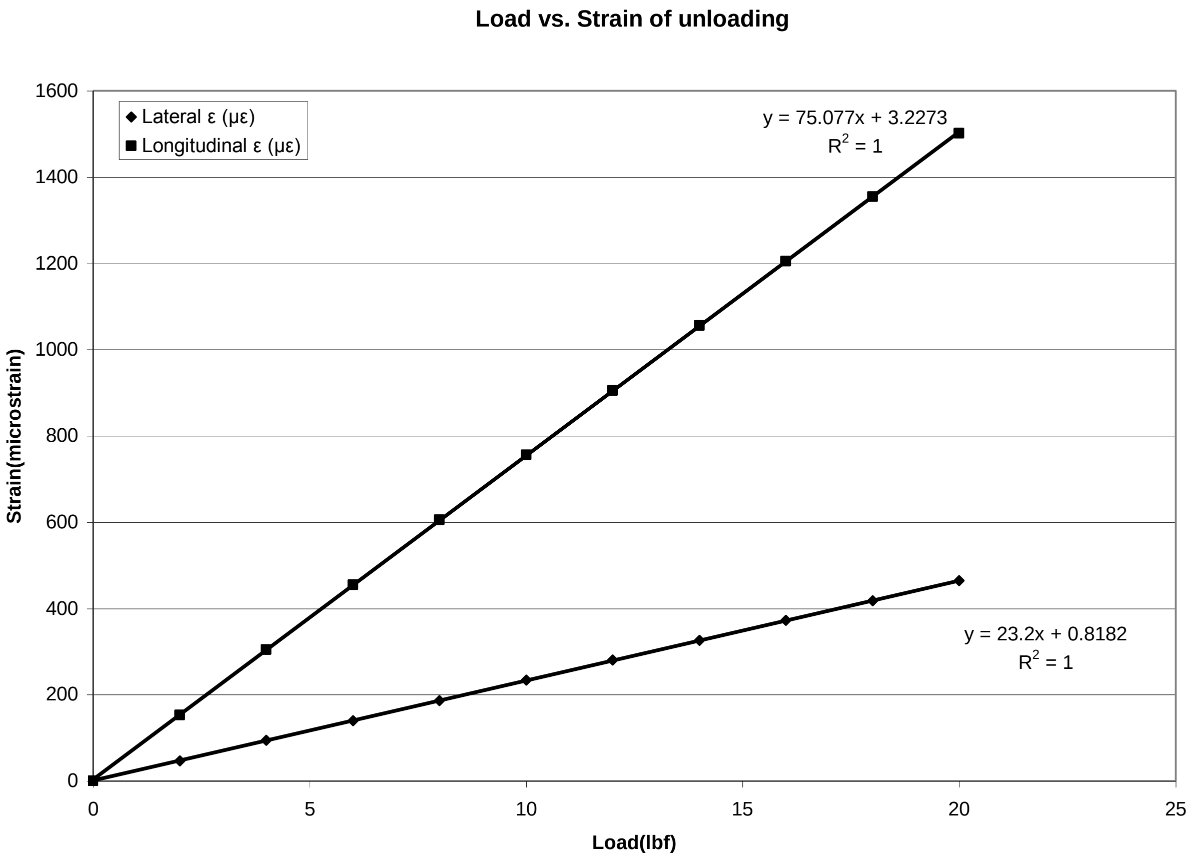
7-B. Table 1. Lateral and longitudinal loading loading and unloading strain values.

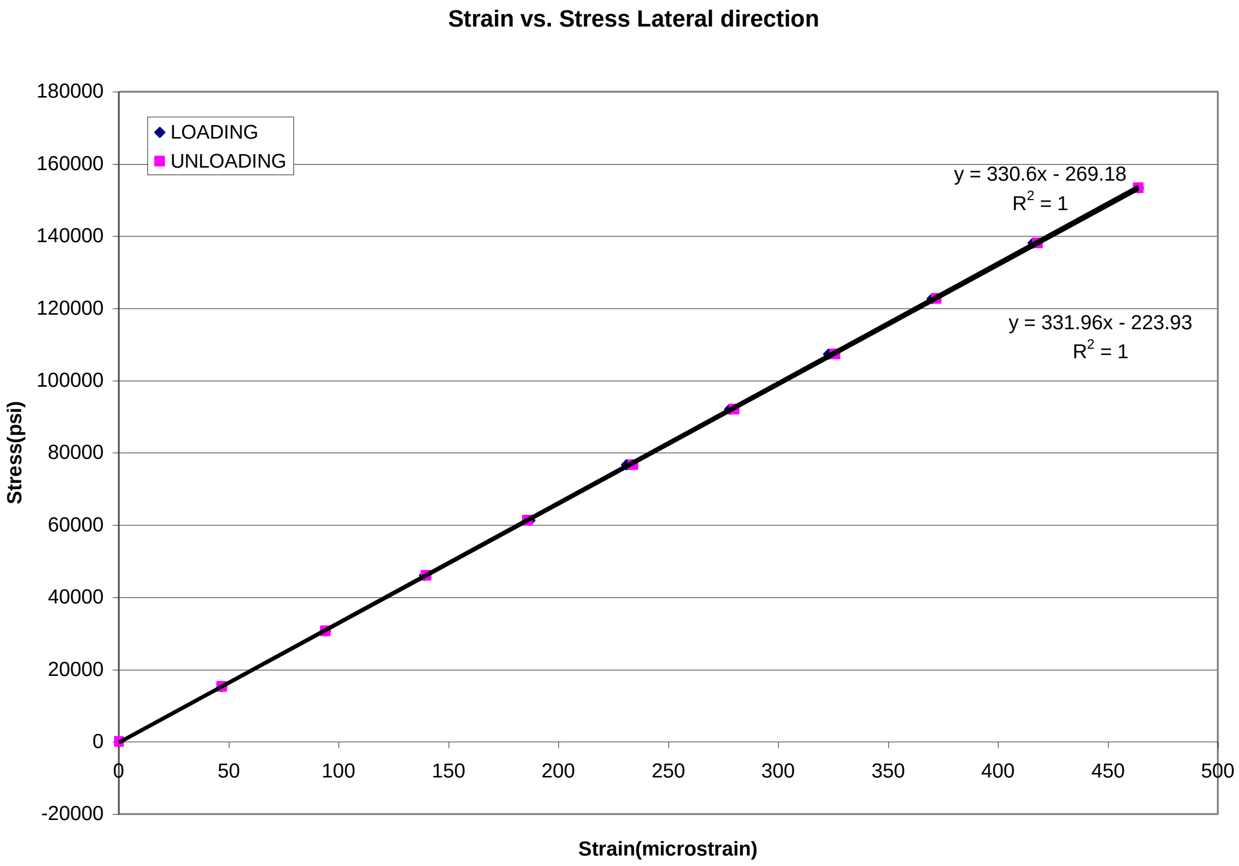
	LOADING		UNLOADING	
Load (lbf)	**Lateral ε (με)**	**Longitudinal ε (με)**	**Lateral ε (με)**	**Longitudinal ε (με)**
0	0	0	0	0
2	47	151	47	153
4	94	300	94	304
6	139	453	140	455
8	187	601	186	605
10	231	753	234	756
12	278	902	280	905
14	323	1051	326	1055
16	370	1201	372	1205
18	416	1350	418	1354
20	464	1502	464	1502






Load vs. strain for Loading
◆ Lateral ε (με)
■ Longitudinal ε (με)
y = 75.027x + 1
$R^2 = 1$
y = 23.105x + 0.6818
$R^2 = 1$
Strain(micro strain)
0
200
400
600
800
1000
1200
1400
1600
0
5
10
15
20
25
load(lbf)


Load vs. Strain of unloading
Strain(microstrain)
Load(lbf)
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
◆ Lateral ε (με)
■ Longitudinal ε (με)
y = 75.077x + 3.2273
R2 = 1
y = 23.2x + 0.8182
R2 = 1


Strain vs. Stress Lateral direction
LOADING
UNLOADING
y = 330.6x - 269.18
R2 = 1
y = 331.96x - 223.93
R2 = 1
Stress(psi)
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
-20000
0
50
100
150
200
250
300
350
400
450
500
Strain(microstrain)

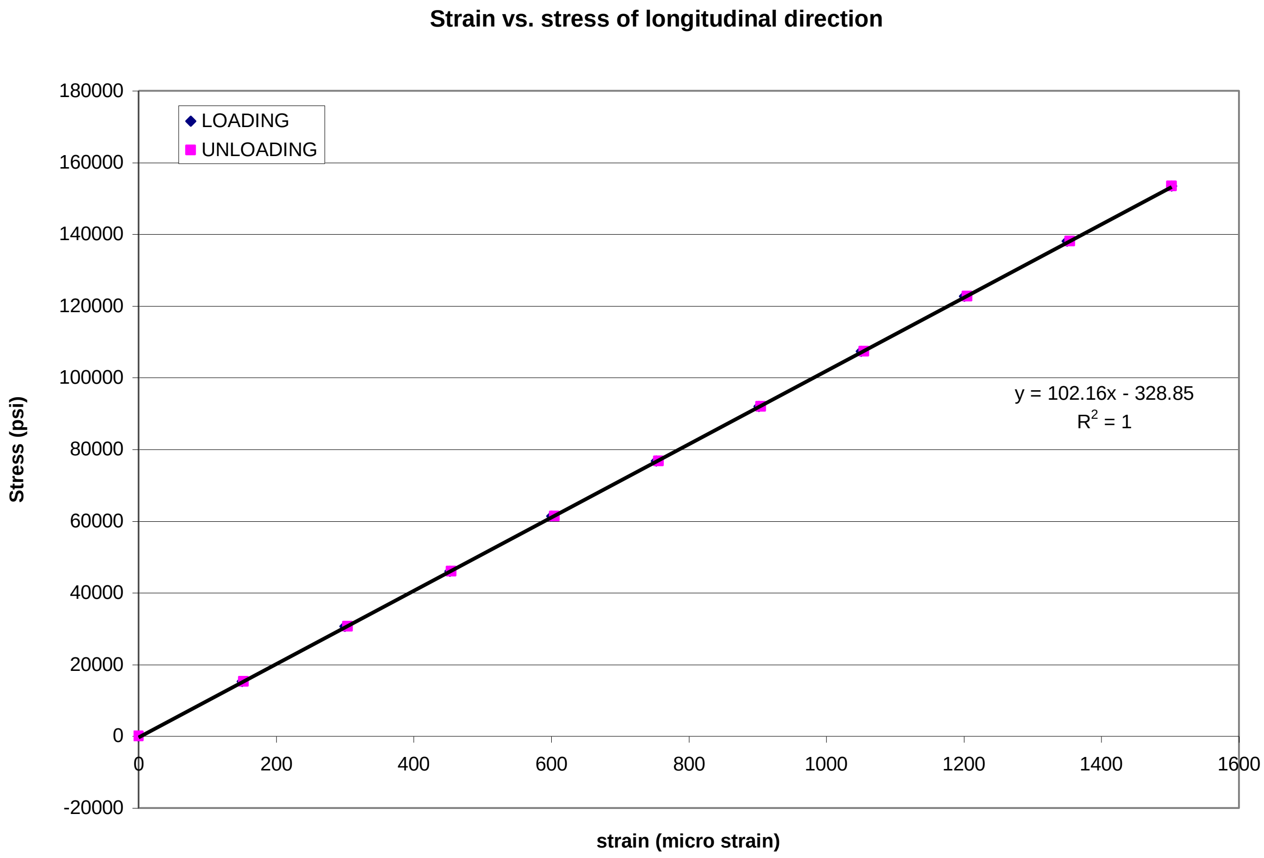


Table 2. Linear regression results from stress (sigma) versus strain (epsilon) curves.

<Linear regression equation>

	Longitudinal	Lateral
Unloading (regression equation)	y = 102.16x - 328.85	y = 330.6x - 269.18
Loading (regression equation)	y = 102.16x - 328.85	y = 331.96x - 223.93

X = Strain Y = Stress

<Young's modulus (modulus of elasticity) E >

	Longitudinal	Lateral
Unloading	102.16	330.6
Loading	102.16	330.6

** unit of psi/microstrain

<R^2 Values>

	Longitudinal	Lateral
Unloading	1	1
Loading	1	1

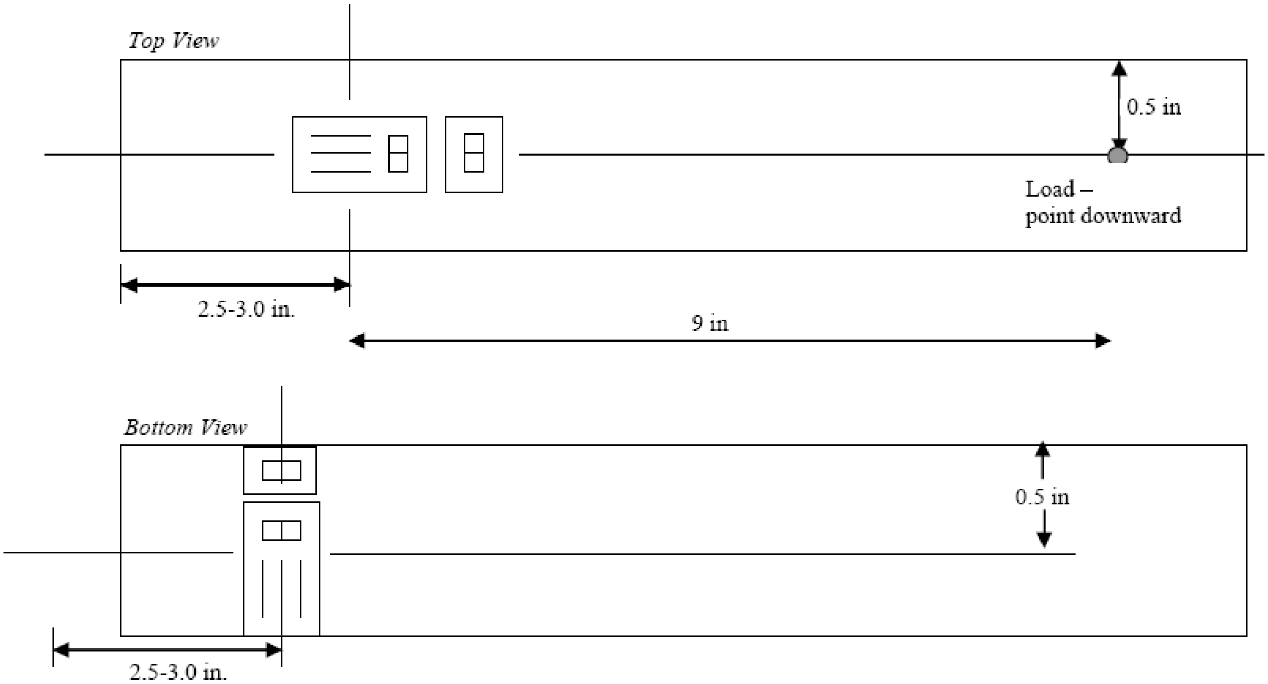


Table 3. Poisson's ratio of lateral and longitudinal Resultant error Sensitivity

<Measured Strain>

	Longitudinal	Lateral
ε bottom-corrected	0.819	-5.811
ε top-corrected	0.819	-5.811

<Poisson's ratio>

	Longitudinal	Lateral
ν al-bar	0.36	0.36

Table 4. Flexor test of top and bottom undeflected and deflected of aluminum bar.

	Top	**Bottom**		
	ε (με)	ε (με)	R(Ω)	V(mV)
Underflected	0.00	189.00	120.20	8.18
Deflected	2230.00	889.00	120.80	37.71

ε bottom-corrected = (1-0.285)(0.92)/(1-0.012 ^{2}) (826-(0.012)(2174)) = 797.176
ε top-corrected = (1-0.285)(0.92)/(1-0.012 ^{2}) (2174-(0.012)(826)) = 2156.69

ν al-bar = 797.176/2156.69 = 0.36

Resultant error of ν al-bar % = (0.33 – 0.36)/0.33 x 100% = 11.21%

8-A. Strain concentration.

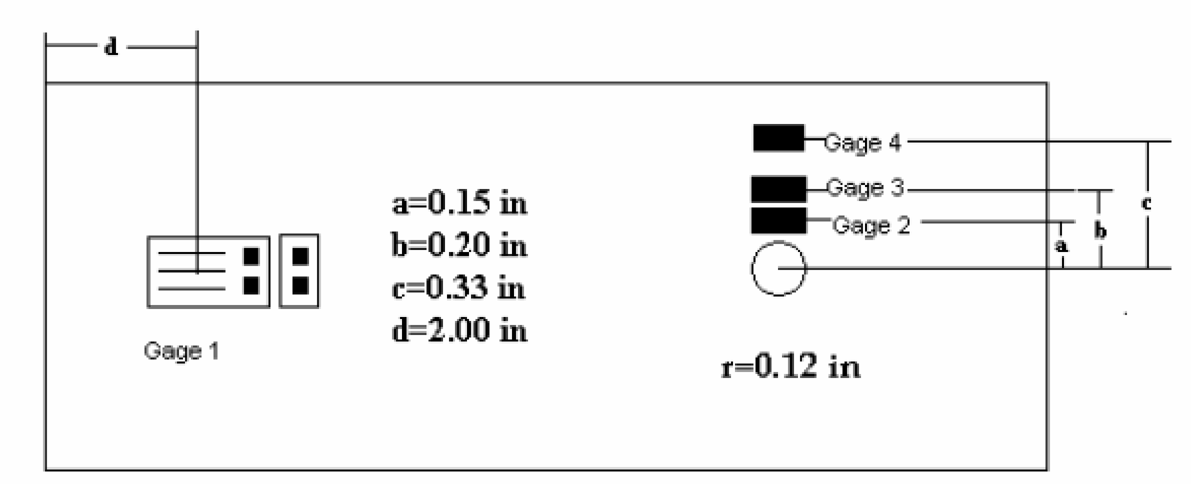


Table 5. Strain values for different gages and loading and unloading situation

Gage	Initial Load (με)	Loaded (με)	Unloaded(με)
1	-367	1633	-368
2	0.0	2395	NA
3	-310	1691	NA
4	-247	1646	NA

Table 6. Principal strain data

Gage	Initial Load (με)	Loaded(με)	Unloaded(με)	Offset Loaded
1	0.0	414	545	371
2	-250	869	N/A	985
3	-88	284	N/A	403

** offset is 7.5 inches from the center of gauge (lateral direction) and 1inches from the center of the gauge (longitudinal direction)

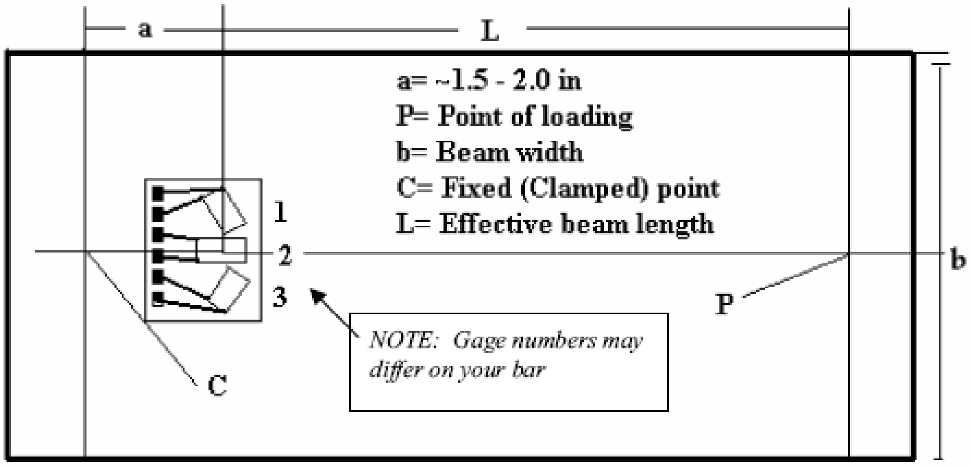
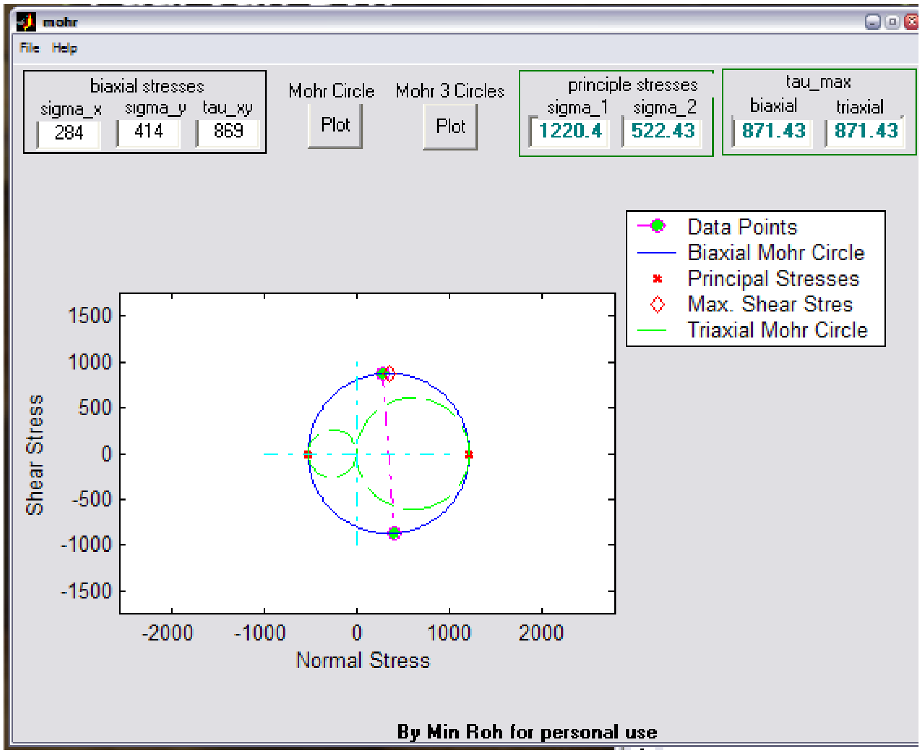


Table 7. Strain coefficients A-C

A	1837.07
B	-2048.26
C	562.54



biaxial stresses
sigma_x 284
sigma_y 414
tau_xy 869

principle stresses
sigma_1 1220.4
sigma_2 522.43

tau_max
biaxial 871.43
triaxial 871.43

Principal strain = A+B+C = 351.35

Principal stress sigma 1= 1220.4 psi
Principal stress sigma 2 = 522.43 psi
Principal strain1 =
Principal strain2 =

Strain max =
Strain min =
Shear max = Shear strain / 2 =
Shear min = Shear strain /2 =
Tan^{-1} (shear strain/(strain x – strain y)) = 2θ, θ =

$$\epsilon_{\max} = \frac{\epsilon_x + \epsilon_y}{2} + \frac{\sqrt{(\epsilon_x - \epsilon_y)^2 + \gamma_{xy}{}^2}}{2}$$

$$\epsilon_{\min} = \frac{\epsilon_x + \epsilon_y}{2} - \frac{\sqrt{(\epsilon_x - \epsilon_y)^2 + \gamma_{xy}{}^2}}{2}$$

$$\epsilon_1 = \frac{\epsilon_x + \epsilon_y}{2} + \frac{\epsilon_x - \epsilon_y}{2} \cos 2\varphi_1 + \frac{\gamma_{xy}}{2} \sin 2\varphi_1$$

$$\epsilon_2 = \frac{\epsilon_x + \epsilon_y}{2} + \frac{\epsilon_x - \epsilon_y}{2} \cos 2\varphi_2 + \frac{\gamma_{xy}}{2} \sin 2\varphi_2$$

$$\epsilon_3 = \frac{\epsilon_x + \epsilon_y}{2} + \frac{\epsilon_x - \epsilon_y}{2} \cos 2\varphi_3 + \frac{\gamma_{xy}}{2} \sin 2\varphi_3$$

Assumption

Poission’s ratio is 0.33 and young’s modulus is 10 Mpsi in the calculation.

DISCUSSION

7-1. Compare your resultant Young's modulus with the expected value for aluminum
Discuss potential explanations for the observed variation

Young's modulus was expected as 10Mpsi for aluminum bar. However, through the experiment, Young's modulus was very large as 102.16 Mpsi for longitudinal direction and 330.6Mpsi for lateral direction. Those numbers were calculated with slope of stress vs. strain graph due to the linear relationship between stress and strain. Stress is equal to 6 times applied force and lever arm from point of applied load to the gage divided by multiplication of beam width and square of thickness. There is a huge percent error between actual and experimental because of the amplifier of the strain gage. Also strain gage sensitivity values are going to be large when the direction perpendicular to gage axis because of the bigger moment arm to create bending moment. Moment is equal to moment arm cross product of force. Thus, bigger moment arm gives bigger moment. Resistance is equal to resistivity times length over area. When force is applied the length of strain gage is changed that causes resistance increases. Gage factor is delta L/ L = 1+ 2xpoisson's ratio + normalized resistivity/length term. Therefore, this can be potential errors as well.

7-2 If the gage was positioned such that L was decreased how might your sigma/strain results differ? Be specific and justify your answer

Strain gage senses bigger moment with bigger moment arm and smaller moment with smaller moment arm. When L (lever arm from point of applied load to the gage) decreases, the moment arm decreases. Thus, this decreases stress because stress is equal to moment time location of interest over area moment of inertia of bean cross section. Strain does not matter with decreases of L because strain measures changing length of initial length which is already decreased in measurement. Thus, the Young's modulus (modulus of elasticity) will decrease because it is equal to sigma/strain. This makes sense because it is difficult to bend aluminum bar with shorter moment arm.

7-3 If a second active arm is added to the bridge to increase the output in response to bending where should the second gage be placed on the beam? How should it be aligned? And where should it be in the Wheatstone bridge?

The second active arm is added to the bridge then the second gage need to be place to the perpendicular to the second active arm and not overlapped with the direction of the first arm. In other words, the second active gage should represent the different axis which forms 90 degrees with the first gage. Then strain gage have two axis to analyze two dimensional analysis.

7-4 Contrast the experimentally derived Poisson's ratio for aluminum with that reported in the literature. V=0.33 determined the percent error, and hypothesize potential sources of experimental error that would account for the observed variation

Poisson's ratio is measure of lateral strain relative to the axial strain. For isotropic material, such as bone, poisson's ratio is between zero and 0.5. The result of the calculation 0.36 falls in this region. However, there is the resultant error existed. Resultant error of ν al-bar % is calculated with this equation (0.33 – 0.36)/0.33 x 100% = 11.21%. Potential error of this can be errors from measurement of strain due to amplifier, sensitivity due to moment, resistivities, etc.

8-1 Discuss the proximal femur in terms of trabecular bone alignment and the lines in principal stress.

The inner cup of femur head boundary would be forced to conform itself to the spherical contour. It can be solved with allowing only compressive stress to the head and cup connection as in a contact problem. Hip joint load is then applied to the stem and the femoral head then transfers the load to the cup in such a way that the head is constrained to be in contact with the cup at all times. The stress transferred across the connection surface can be represented by a normal stress perpendicular to the plane, and two shear stress components. However, when the stem is unbonded and frictionless, there is no more shear stresses. The stem must subside into tubular bone to develop and interface compression stress at the surface of the surrounding bone. Although the components may vary with the specific coordinate system chosen, the state of stress remains the same. In other words, the state of stress within an object does not depend on a specific chosen coordinate system. It depends solely on the loading, geometry, and material properties of the object. The connection between femur head and trabecular bone, the interface aligned with the external coordinate system or the principal stress direction to eliminate the shear stress.

8-2 Identify one biomedical engineering situation in which strain/stress concentration are relevant.

Modeling for artificial cartilage would be one example that biomedical engineers deal with stress and strain concentration. Cartilage in knees is a perfect example of compressional behavior. During the gait, cartilage in knees are compressed and relaxed and the length of the cartilage is changed. Thus, it is very important to understand the behavior of strain and stress concentration to develop artificial cartilage.

8-3 Contrast the principle strains determined using graphical and analytic techniques. Identify and discuss advantages/ disadvantages of the two methods.

Graphical analysis would be using Mohr's circle. It is better for overall picture to see the maximum and minimum strain and shear strain than analytical analysis. However, it needs an orientation and axis before draw Mohr's circle.

Analytical analysis would be very accurate and detail information. However, it takes a lot of time and calculations.

8-4 Discuss how redundant gage might be used to improve estimates of the principle strains.

There is no need for more gages than three. Because three gages represent three dimension strains for two normal strains and shear strain. Therefore, the fourth strain gage repeats measurements.

CONCLUSION