AUBURN UNIVERSITY
SAMUEL GINN COLLEGE OF ENGINEERING

MECH 3130
Mechanics-of-Materials

Spring 2009

Laboratory Manual
Volume - I

Prof. Hareesh Tippur

CONTENTS

MECH3130: MECHANICS OF MATERIALS LABORATORY

This laboratory is designed to provide students hands-on experience on Mechanics of Material. This lab has adequate equipments to complete the course successfully. Table 1 shows a list of the available equipments. This course is performed in two parts – experimental and simulation. In the experimental part students gets exposure of different techniques (strain gage method, photo-elasticity etc.) to measure normal stress, normal strain, shear stress, shear strain, force, deflection etc. Several experiments also performed to teach measuring techniques of different material behavior like elastic modulus, modulus of rigidity, poisons ratio etc. Some of the experiments are also designed to validate some important principles of mechanics of material like theories related to beam stress, beam strain, beam deflection etc. Students also learn application of photo-elastic techniques in mechanics of material. In the simulation part students learn details use of computer software like ANSYS to perform finite element analysis (FEA). Preprocessing, analysis and post-processing techniques of truss, beam, 2D solid, 3D solid FEA models are taught in this part. In the final lab students perform some experiment and then do FEA modeling of the experimental specimen to validate their experimental results. Overall this lab is very informative and provides students idea of some real life techniques and applications related to the solid mechanics field.

Table 1: List of equipments used in MECH 3130 laboratory

Laboratory	Equipment
Mechanics of Material Lab	• Strain gages, Kit boxes for strain gage mounting, Chemicals needed for surface preparation, Solder irons, Slide projectors, Slides on strain gage mounting. • Hydraulic tensile tester, Pressure gage, Strain Indicator, Switch balance unit. • Torsion testing machine, cylindrical specimens with mounted rosette. • Several I-beams with mounted strain gages on it. • Polariscope, Loading fixture, Overhead projector, Photo-elastic testing specimen. • Beam deflection measuring equipment, dial gages

FORMAT FOR FORMAL LAB REPORTS

ME 3130 - Mechanics of Materials

1. **TITLE PAGE:**
   - Show the lab number, title, your lab section, date due and your name **(5 pts)**
2. **PURPOSE:**
   - Briefly state the lab's objective and the methods used to achieve it **(5 pts)**
3. **THEORY:**
   - List the assumptions made **(5pts)**
   - State the theoretical equations to be tested **(5 pts)**
   - Include drawings as necessary **(5 pts)**
   - Define all symbols **(5 pts)**
4. **PROCEDURE:**
   - Describe the steps taken to perform the experiment **(10pts)**
   - Include schematics illustrating the location of strain gages, measurements taken, etc. **(5pts)**
5. **DATA:**
   - Tabulate all measurements taken in the lab **(5 pts)**
   - Include proper units **(-5 pts if improper or absent)**
6. **SAMPLE CALCULATIONS:**
   - For each experiment, show complete calculations using one set of data **(20pts)**
   - Calculate the percentage differences between experimental and theoretical values. **(5 pts)**
7. **RESULTS AND CONCLUSIONS:**
   - <u>Results:</u>
     - Tabulate all results. **(5 pts)**
     - Include relevant graphs. **(10pts)**
   - <u>Conclusions:</u>
     - Briefly explain what you learned from the lab. **(5 pts)**
     - Discuss the probable reasons for errors, if any. **(5 pts)**

LAB REPORT GUIDELINES:

ME 3130 - Mechanics of Materials

1. Lab reports are due at the subsequent lab period (normally one week later). A penalty of ten points for every day (including holidays or weekends) late will be assessed.
2. Begin each section of the report on a fresh page.
3. Use engineering paper stapled in the upper left corner.
4. Grading will also consider neatness, grammar, spelling, and adherence to format.
5. **Graphs:**
   - Must be done on computer.
   - Include a title.
   - Label the graph axes and include units.
   - Distinguish between curves on the same graph.
6. Cheating is a serious offense and will not be tolerated. Work that you hand in should be your own, and not copied from another student. Cheating could result in your appearance before the university disciplinary committee. You are strongly advised not to cheat in your labs or computer programs.

Lab-1

CENTROIDS AND MOMENTS OF INERTIA

Lab-1 Notes - Centroids and Moments of Inertia

MECH 3130 - Mechanics of Materials

PLANAR AREAS

The objectives of the current laboratory are to review the definitions and calculation procedures for centroids and moments of inertia of areas. A general planar area in the x-y plane is shown in Figure 1.

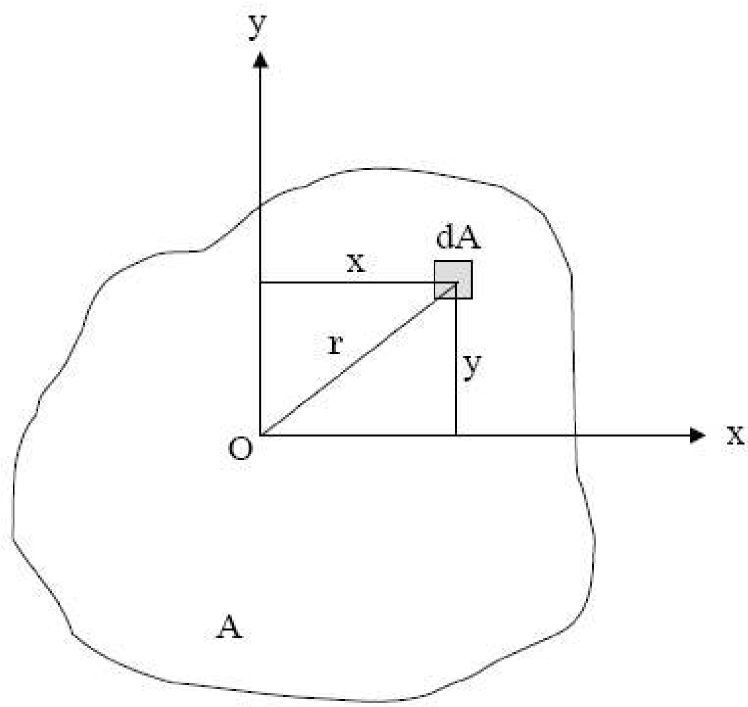


Figure 1 - General Planar Area

CENTROIDS

Definitions:

For a general area A such as shown in Figure 1, the first moments of area A about a given x-axis and y-axis are defined by

$$Q_x = \iint_A y \, dA \quad \text{(About the x-axis)}$$

$$Q_y = \iint_A x \, dA \quad \text{(About the y-axis)}$$

(1)

The centroid of the area has the coordinates:

$$\bar{x} = \frac{Q_y}{A} = \frac{\iint_A x \, dA}{A}$$

$$\bar{y} = \frac{Q_x}{A} = \frac{\iint_A y \, dA}{A}$$

(2)

Composite Areas

For a composite area A made up of several smaller parts Ai (i = 1, 2, 3, …, N), eq. (2) can be shown to simplify to:

$$\bar{x} = \frac{\sum_{i=1}^{N} A_i \bar{x}_i}{\sum_{i=1}^{N} A_i} = \frac{\sum_{i=1}^{N} A_i \bar{x}_i}{A}$$

$$\bar{y} = \frac{\sum_{i=1}^{N} A_i \bar{y}_i}{\sum_{i=1}^{N} A_i} = \frac{\sum_{i=1}^{N} A_i \bar{y}_i}{A}$$

(3)

Where $(\bar{x}_i, \bar{y}_i)$ are the coordinates of the centroid of each sub-area Ai. Note that a section with a cutout can also be treated as a composite area. In such a case, the areas of the cutouts are taken to be negative.

MOMENTS OF INERTIA

Definitions:

The moments of inertia of an area about the x and y axes are defined by

$$I_x = \iint y^2 \, dA \qquad \text{(About the x-axis)}$$

$$I_y = \iint x^2 \, dA \qquad \text{(About the y-axis)}$$

(4)

The product moment of inertia for the x and y axes is defined by

$$I_{xy} = \iint xy \; dA \tag{5}$$

and the polar moment of inertia is defined as

$$J_o = \iint r^2 \, dA = I_x + I_y \tag{6}$$

Composite Areas

For a composite area A made up of several smaller parts Ai (i = 1, 2, 3, …, N), eqs. (4-6) can be shown to simplify to:

$$I_x = \sum_{i=1}^{N} (I_x)_i$$

$$I_y = \sum_{i=1}^{N} (I_y)_i$$

$$I_{xy} = \sum_{i=1}^{N} (I_{xy})_i$$

$$J_o = \sum_{i=1}^{N} (J_o)_i \tag{7}$$

Note that a section with a cutout can also be treated as a composite area. In such a case, the moments of inertia of the cutouts are taken to be negative.

Parallel Axis Theorem

The parallel axis theorem relates the moment of inertia for an area about any given axis given to the moment of inertia about a parallel axis that passes through the centroid of the area and the distance between the axes. Referring to Figure 2, the parallel axis theorem can be stated as

$$I_{n'} = \overline{I}_n + Ad^2 \tag{8}$$

where In' is the moment of inertia about the n-axis, $\overline{I}_n$ is the moment of inertia about an axis parallel to the n-axis which also passes through the centroid (point C), A is the area, and d is the distance between the two axes. For the x'-y' axes and x-y axes shown in Figure 3 (the x-y axes pass through the centroid), the appropriate relations for the moments and products of inertia are:

$$I_{x'} = \bar{I}_x + Ad_x^2$$

$$I_{y'} = \bar{I}_y + Ad_y^2$$

$$I_{x'y'} = \bar{I}_{xy} + Ad_x d_y \tag{9}$$

Note that $d_x = \bar{x}'$ and $d_y = \bar{y}'$ can be negative numbers.

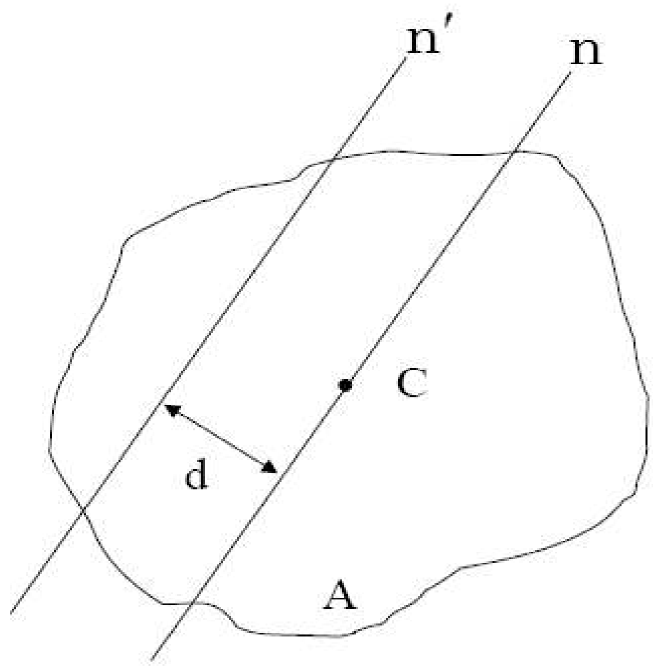


Figure 2 - Parallel Axes

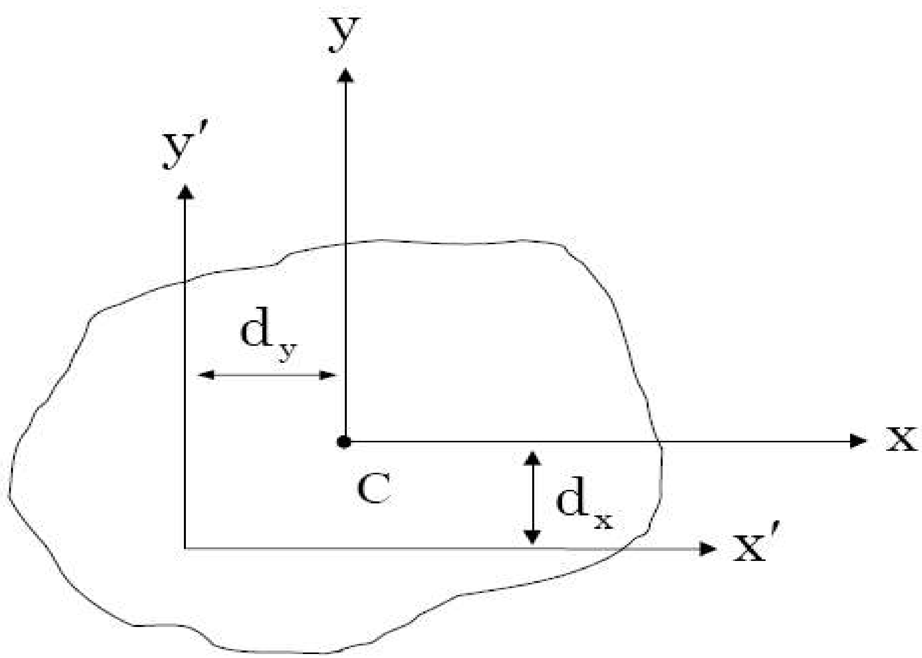


Figure 3 - Parallel x and y Axes

Example #1
Rectangle

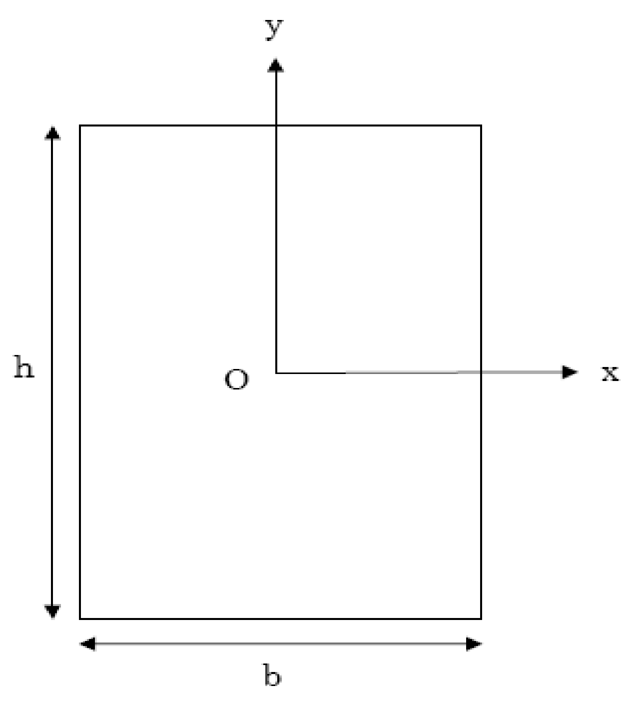


Figure 4 - Rectangular Area (Origin O is at the Centroid)

For this area, moment of inertia I_x is derived as follows:

$$I_x = \iint_A y^2 dA$$

$$I_x = \int_{-b/2}^{b/2} \int_{-h/2}^{h/2} y^2 dy dx$$

$$I_x = \int_{-b/2}^{b/2} \left. \frac{y^3}{3} \right|_{-h/2}^{h/2} dx$$

$$I_x = \frac{h^3}{12} \int_{-b/2}^{b/2} dx$$

$$\boxed{I_x = \frac{bh^3}{12}}$$

Similarly, it can be shown that

$$\boxed{I_y = \frac{b^3 h}{12}}$$

<u>I_{xy} Calculation:</u>

$$I_{xy} = \iint_A xy \, dA$$

$$I_{xy} = \int_{-b/2}^{b/2} \int_{-h/2}^{h/2} xy \, dy \, dx$$

$$I_{xy} = \int_{-b/2}^{b/2} x \left. \frac{y^2}{2} \right|_{-h/2}^{h/2} dx = \int_{-b/2}^{b/2} 0 \, dx$$

$$\boxed{I_{xy} = 0}$$

In fact, it is a general rule that when an area is symmetric about either the x-axis or the y-axis, the product moment of inertia $I_{xy} = 0$.

Example 2
Circle

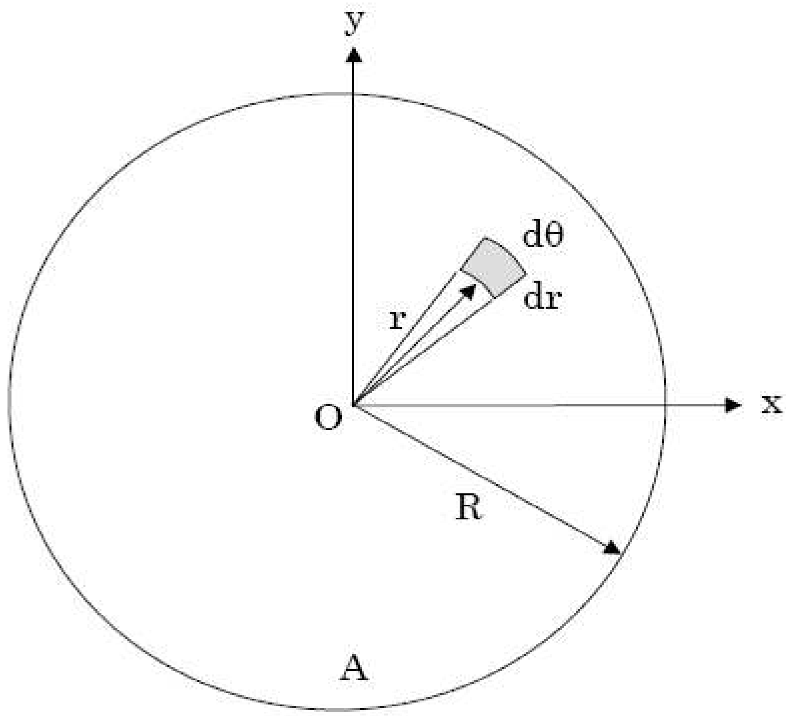


Figure 5 - Circular Area (Origin O is at the Centroid)

For this area, moment of inertia Ix is derived using polar coordinates as follows:

$$I_x = \iint_A y^2 dA \qquad \text{with } dA = r\,dr\,d\theta$$

$$I_x = \int_0^R \int_0^{2\pi} r^2 \sin^2\theta \; r \; d\theta \; dr = \int_0^R \int_0^{2\pi} r^3 \sin^2\theta \; d\theta \; dr$$

$$I_x = \int_0^R \left. \frac{r^3(\theta - \sin\theta\cos\theta)}{2} \right|_0^{2\pi} dr = \pi \int_0^R r^3 dr$$

$$\boxed{I_x = \frac{\pi R^4}{4}}$$

Using a similar approach, it can be shown that

$$\boxed{I_y = \frac{\pi R^4}{4}} \qquad \boxed{J_o = \frac{\pi R^4}{2}}$$

It is easy to show that Ixy = 0 since the area is symmetric about the x and y axes.

Example 3
Rectangle with Circular Cutout

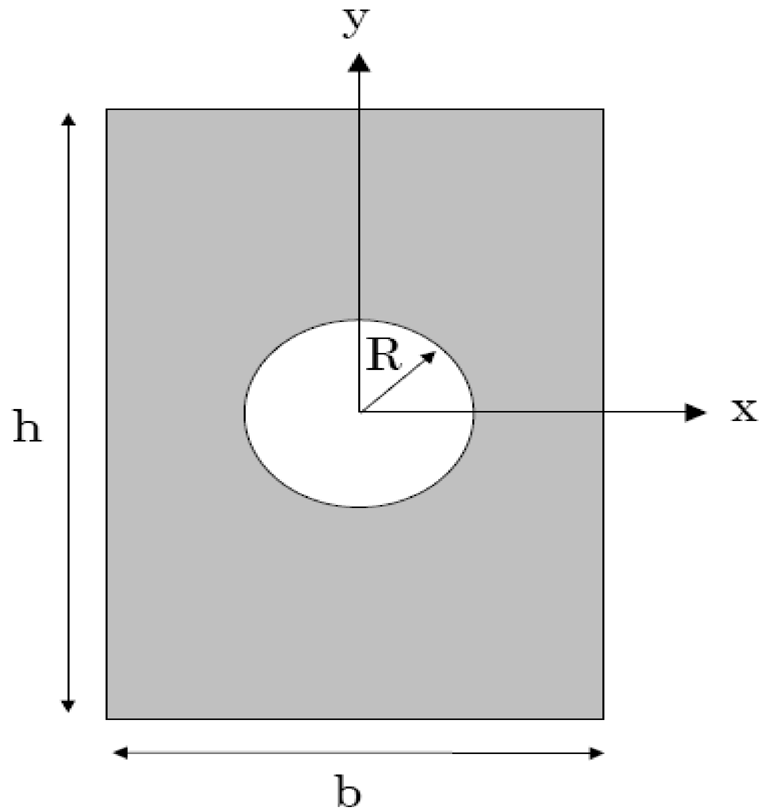


Figure 6 - Rectangular Area with Circular Hole

Calculate moment of inertia Ix using the composite area formula:

$$I_x = \sum_{i=1}^{N} (I_x)_i$$

$$I_x(\text{Entire Area}) = I_x(\text{Rectangle}) - I_x(\text{Circle})$$

$$\boxed{I_x = \frac{bh^3}{12} - \frac{\pi R^4}{4}}$$

Similarly,

$$\boxed{I_y = \frac{b^3 h}{12} - \frac{\pi R^4}{4}}$$

$$\boxed{I_{xy} = 0 - 0 = 0}$$

Example 4
"L" Shaped Area

Calculate the Position of the Centroid, and the Moments and Products of Inertia for a Set of x-y axes passing through the Centroid.

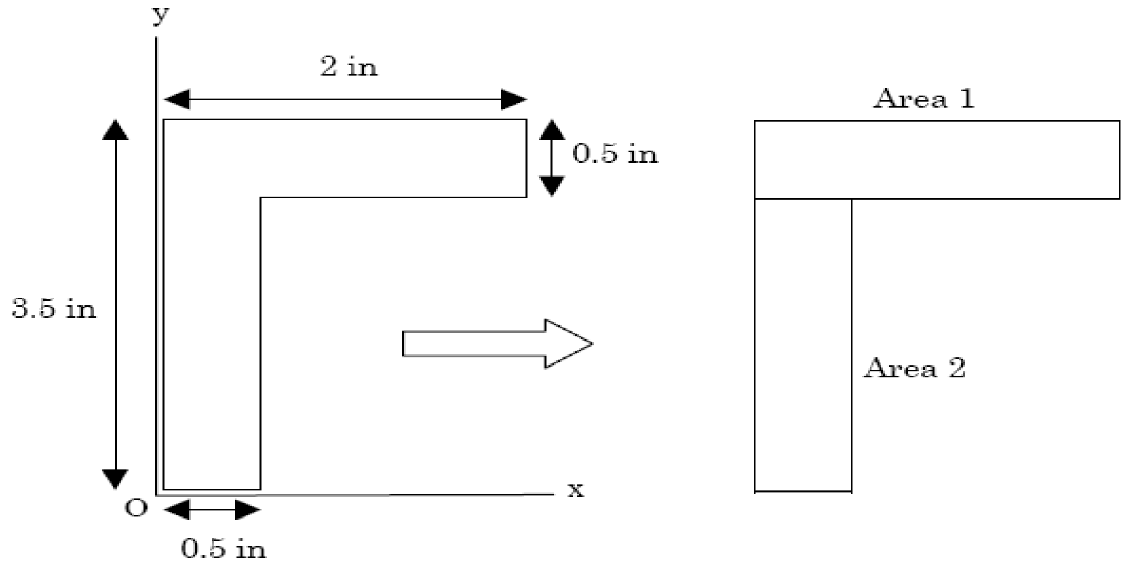


Figure 6 - "L" Shaped Area Divided Into Two Parts for Composite Area Calculations

Centroid Calculation:

For the purpose of calculations, the area has been split up into two parts as shown above.

$$A_1 = 0.5 \times 2 = 1 \qquad \bar{x}_1 = 1 \qquad \bar{y}_1 = 3.25$$

$$A_2 = 0.5 \times 3 = 1.5 \qquad \bar{x}_2 = 0.25 \qquad \bar{y}_2 = 1.5$$

The formulas for the centroid of a composite area are:

$$\bar{x} = \frac{\sum_{i=1}^{N} A_i \bar{x}_i}{\sum_{i=1}^{N} A_i} = \frac{\sum_{i=1}^{N} A_i \bar{x}_i}{A} \qquad \bar{y} = \frac{\sum_{i=1}^{N} A_i \bar{y}_i}{\sum_{i=1}^{N} A_i} = \frac{\sum_{i=1}^{N} A_i \bar{y}_i}{A}$$

Thus, for the "L" shaped area, the coordinates of the centroid are:

$$\boxed{\bar{x} = \frac{A_1\bar{x}_1 + A_2\bar{x}_2}{A_1 + A_2} = \frac{(1 \times 1) + (1.5 \times 0.25)}{1 + 1.5} = 0.55 \text{ in}}$$

$$\boxed{\bar{y} = \frac{A_1\bar{y}_1 + A_2\bar{y}_2}{A_1 + A_2} = \frac{(1 \times 3.25) + (1.5 \times 1.5)}{1 + 1.5} = 2.2 \text{ in}}$$

Moment of Inertia Calculation:

We again split up the area into sub-areas 1 and 2 as shown previously. The moment of inertia of the composite area is determined by

$$I_x = (I_x)_1 + (I_x)_2$$

Where (Ix)i is the moment of inertia of the sub-area i about the x-axis passing through the centroid of the entire composite area. Using the parallel axis theorem

$$(I_x)_1 = (\bar{I}_x)_1 + A_1 d_{x1}^2$$

$$(I_x)_2 = (\bar{I}_x)_2 + A_2 d_{x2}^2$$

Where $(I_x)_i$ is the moment of inertia of the sub-area i about an axis passing through its centroid. The length d_{xi} is the vertical distance between the centroid of sub-area i and the centroid of the entire composite area.

$$(\bar{I}_x)_1 = \frac{2\times 0.5^3}{12} = 0.02083$$

$$d_{x1} = 3.25 - 2.2 = 1.05$$

$$(I_x)_1 = 0.02083 + (2\times 0.5)\times 1.05^2 = 1.123 \text{ in}^4$$

$$(\bar{I}_x)_2 = \frac{0.5\times 3^3}{12} = 1.125$$

$$d_{x2} = 1.5 - 2.2 = -0.7$$

$$(I_x)_2 = 1.125 + (3\times 0.5)\times(-0.7)^2 = 1.86 \text{ in}^4$$

$$\boxed{I_x = 1.123 + 1.860 = 2.983 \text{ in}^4}$$

Using similar calculations:

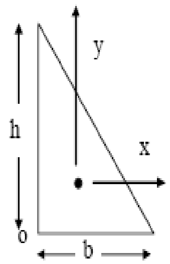
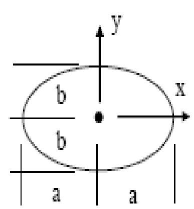
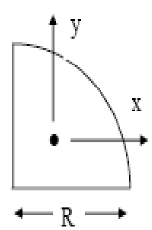
$$(I_y)_1 = 0.5358$$

$$(I_y)_2 = 0.1662$$

$$\boxed{I_y = 0.7020 \text{ in}^4}$$

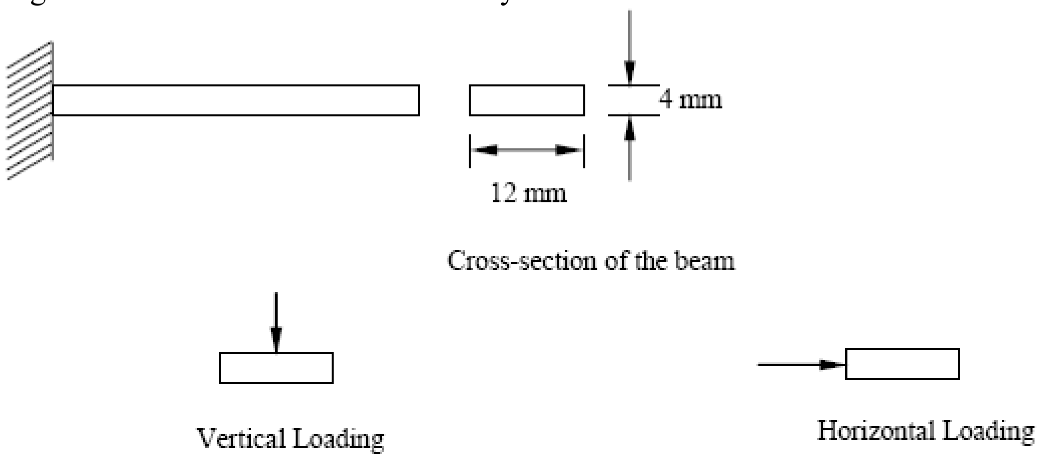
What is Ixy??

Appendix – Table of Section Properties

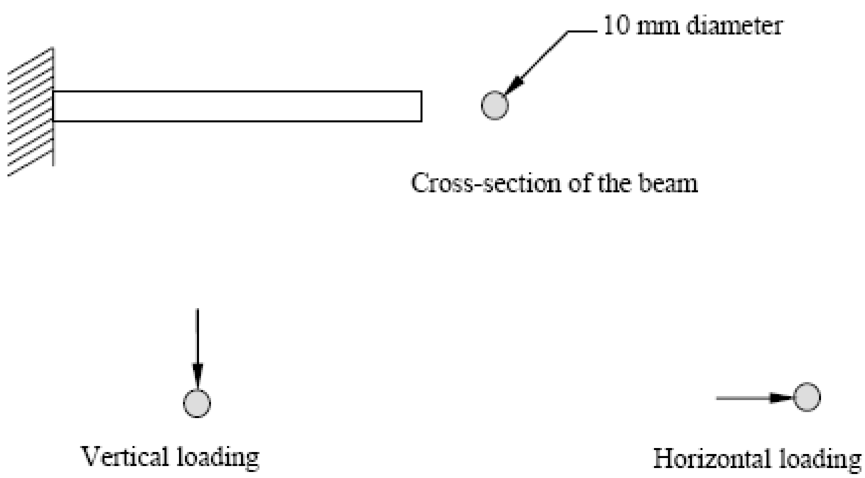
Section	$\overline{X}$	$\overline{Y}$	Area	I_x	I_y	I_{xy}
Right Triangle 	$\frac{b}{3}$	$\frac{h}{3}$	$\frac{bh}{2}$	$\frac{bh^3}{36}$	$\frac{b^3h}{36}$	$-\frac{b^2h^2}{72}$
Ellipse 	0	0	πab	$\frac{\pi ab^3}{4}$	$\frac{\pi a^3b}{4}$	0
Quarter Circle 	$\frac{4R}{3\pi}$	$\frac{4R}{3\pi}$	$\frac{\pi R^2}{4}$	$0.0549R^4$	$0.0549R^4$	$0.0896R^4$

Lab #1 Assignment - Moment of Inertia
MECH 3130

1. a) For the following cantilever beam with rectangular cross-section, discuss whether a horizontal or vertical transverse load on the end of the beam will give a greater magnitude of the end deflection and why?



   (b) For the following cantilever beam with circular cross-section, discuss whether a horizontal or vertical transverse load on the end of the beam will give a greater magnitude of the end deflection and why?

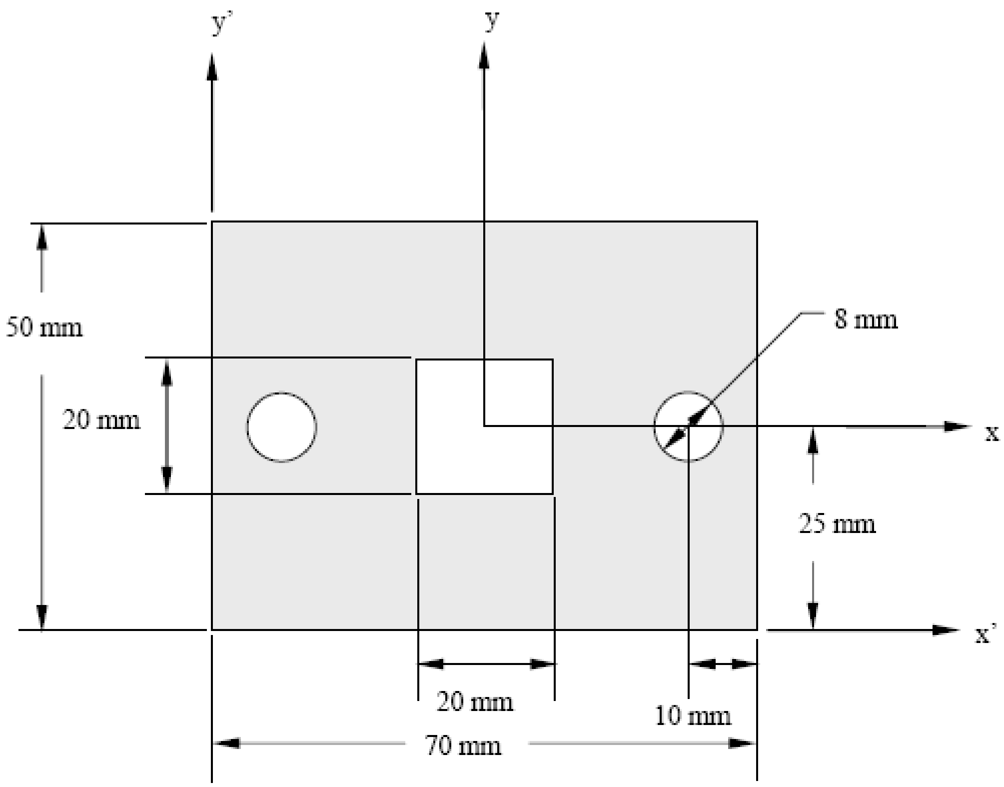


2. Approximate the aluminum I-beam cross-sectional area shown in lab as a set of rectangles. Find the centroid of the cross-section, and find the moments of inertia Ixx, Iyy and Ixy for a set of axes x and y passing through the centroid. Compare your approximate moments of inertia to the moments of inertia listed for I-beam cross sections in a table of properties for rolled metal structural shapes.

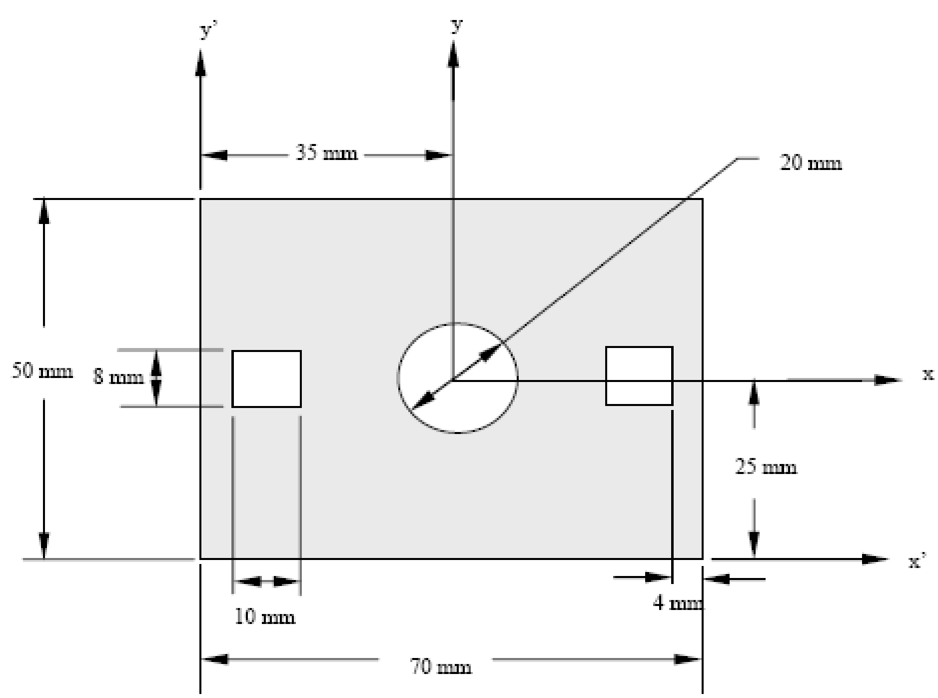
3. Approximate the aluminum "L" shaped cross-sectional area shown in lab as a set of rectangles. Find the centroid, and the moments of inertia Ixx, Iyy and Ixy for a set of x and y axes passing through the centroid.

4. Calculate Ix, Iy, Ixy, Ix', Iy', Ix'y' for the area shown below.

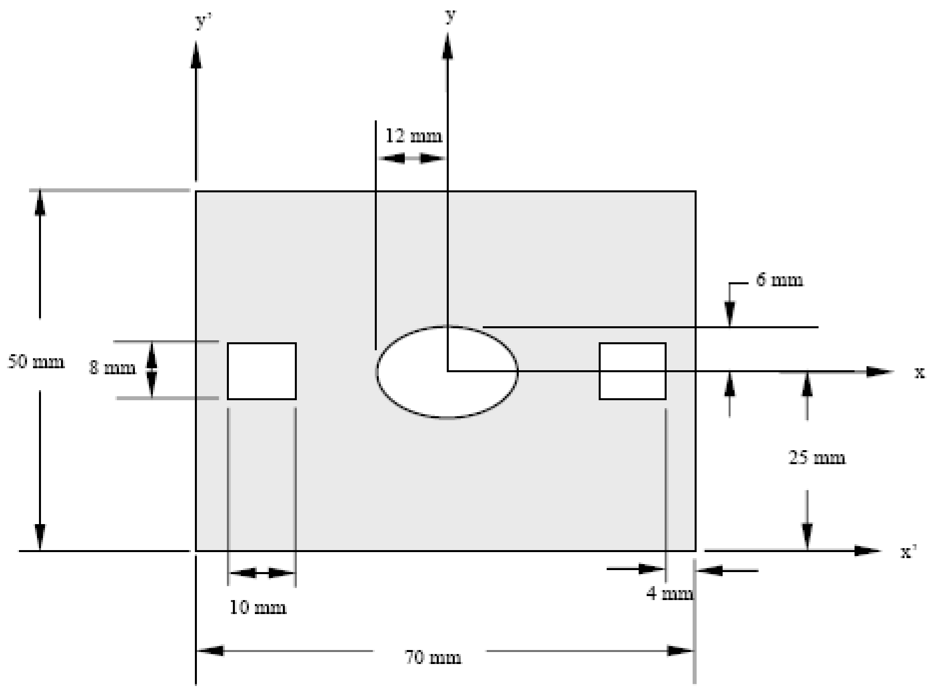
(a)



(b)

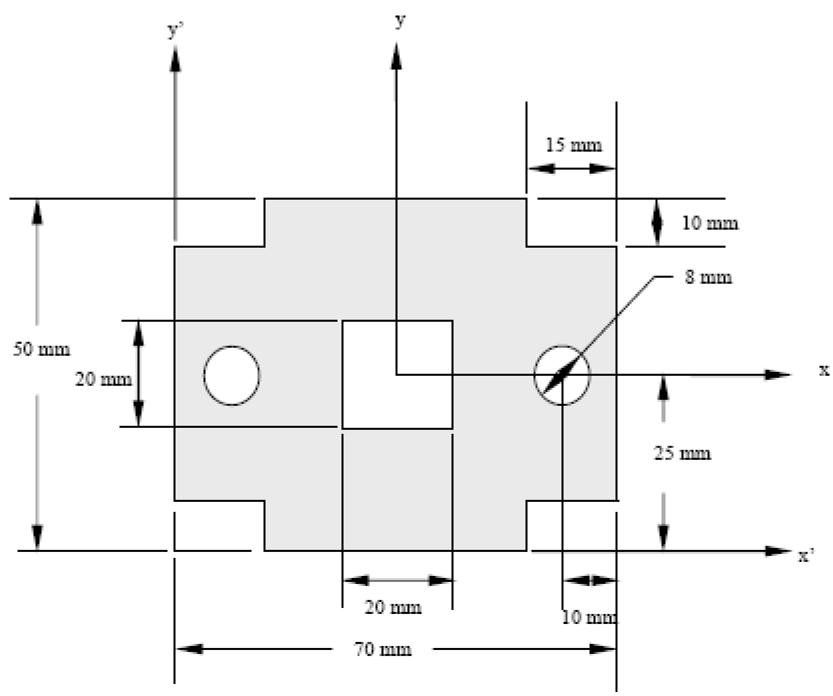


(c)



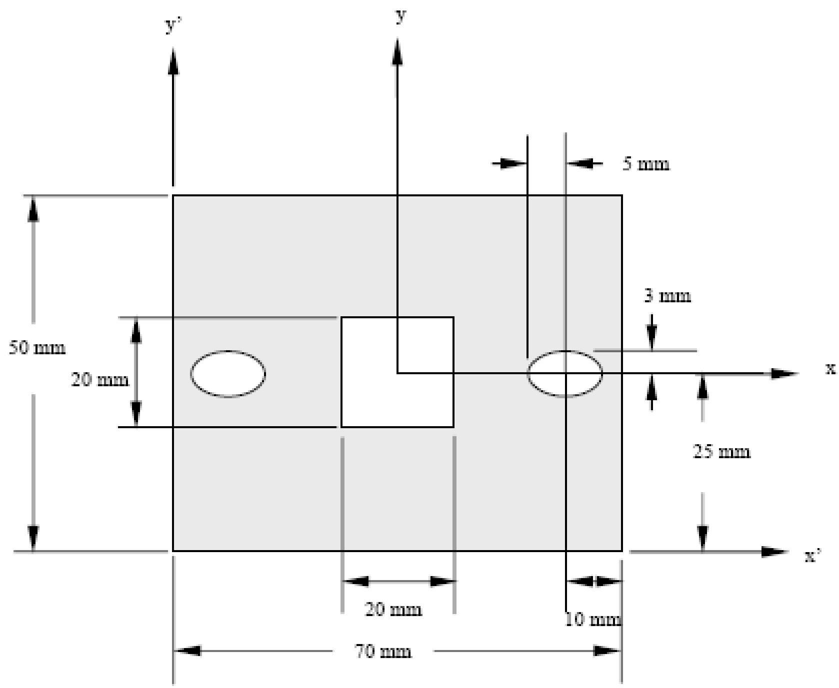
y'
y
12 mm
6 mm
50 mm
8 mm
x
25 mm
x'
4 mm
10 mm
70 mm

(d)



y'
y
15 mm
10 mm
8 mm
50 mm
20 mm
x
25 mm
x'
20 mm
10 mm
70 mm

(e)



<u>Lab-2</u>
STRAIN GAGE MOUNTING

LAB-2 - Strain Gage Mounting

MECH 3130 - Mechanics of Materials

Lab Objective:

To obtain a general understanding of strain gage technology and to successfully mount axial and transverse strain gages on a uniaxial test specimen.

Procedure:

1. Receive lecture material on the basics of resistance strain gages.

2. View and understand the instructional slide presentation on the strain gage mounting procedure. This procedure is also discussed in the Student Manual for strain gage technology.

3. Know the five basic steps in surface preparation done before strain gage mounting, and understand their purposes.

   a) Solvent Degreasing

   b) Surface Abrading

   c) Gage Location

   d) Surface Conditioning

   e) Neutralizing

4. Locate test specimen, strain gages, and necessary mounting materials.

5. Clean specimen thoroughly by removing old strain gages and adhesives.

6. Bond strain gages to your specimen in accordance to the steps previously obtained in 1 and 2.

7. Properly and neatly solder necessary lead wires to the strain gages.

8. Test the resistances of the mounted gages using a digital multimeter.

Note:

The following four pages are copies of the "Instruction Bulletin B-127-9" from Measurements Group, INC., which describes the steps in mounting a strain gage.

Strain Gage Installations with M-Bond 200 Adhesive

I. INTRODUCTION

Micro-Measurements Certified M-Bond 200 is an excellent general-purpose laboratory adhesive because of its fast room-temperature cure and ease of application. When properly handled, M-Bond 200 can be used for high-elongation tests in excess of +30 000 microstrain, for fatigue studies, for one-cycle proof tests to over +200°F *(+95°C)* or to below −300°F *(−185°C)*. The normal operating temperature range is −25°F *(−30°C)* to +150°F *(+65°C)*. M-Bond 200 is compatible with all Micro-Measurements strain gages and all common structural materials. For best reliability, it should be applied to surfaces between the temperatures of +70°F *(+20°C)* to +85°F *(+30°C)*, and in a relative humidity environment of 30% to 65%. M-Bond 200 catalyst has been specially formulated to control the reactivity rate of this adhesive. The catalyst should be used sparingly for best results. Excessive catalyst can contribute many problems; e.g., poor bond strength, age-embrittlement of the adhesive, poor glue-line thickness control, extended solvent evaporation time requirements, etc.

Since M-Bond 200 bonds are weakened by exposure to high humidity, adequate protective coatings are essential. This adhesive will gradually become harder and more brittle with time, particularly if exposed to elevated temperatures. For these reasons, M-Bond 200 is not generally recommended for long-term permanent installations; e.g., over one or two years.

II. SHELF AND STORAGE LIFE

M-Bond 200 adhesive has a shelf life of nine months when stored under normal laboratory conditions. Life can be extended if upon receipt the *unopened* material is refrigerated [+40°F *(+5°C)*]. Due to possible condensation problems which will degrade adhesive performance, care should be taken to insure that the M-Bond 200 has returned to room temperature equilibrium before opening. Refrigeration after opening is not recommended.

Gage Application Kit GAK-200, shown at right, contains all materials necessary for successful completion of a strain gage installation with M-Bond 200.

HANDLING PRECAUTIONS

M-Bond 200 is a modified methyl-2-cyanoacrylate compound. Immediate bonding of eye, skin or mouth may result upon contact. Causes irritation. The user is cautioned to: (1) avoid contact with skin; (2) avoid prolonged or repeated breathing of vapors; and (3) use with adequate ventilation.

III. GAGE APPLICATION TECHNIQUES

The installation procedure presented on the following pages is somewhat abbreviated and is intended only as a guide in achieving proper gage installation with M-Bond 200. *M-M Instruction Bulletin B-129* presents recommended procedures for surface preparation, and lists specific considerations which are helpful when working with most common structural materials.

Measurements Group, Inc. now has a series of instructional Tech-Slide Sequences available. This innovative product line consists of detailed close-up 35-mm slides accompanied by comprehensive step-by-step instructions, illustrating not only surface preparation techniques, M-Bond 200 and other M-Bond adhesive systems, but also numerous other aspects of the complete gage installation process. For further information on this new product line, request *Bulletin 303*.

Micro-Measurements Division
MEASUREMENTS GROUP, INC.
P.O. Box 27777
Raleigh, NC 27611, USA
(919) 365-3800

FIGURE 1

Step 1

Thoroughly degrease the gaging area with a solvent, such as Chlorothene SM or Freon TF (Fig. 1). The former is preferred, but there are some materials (e.g., titanium and many plastics) which react with chlorinated solvents. In these cases Freon TF is an excellent substitute. All degreasing should be done with uncontaminated solvents—thus the use of "one-way" containers, such as aerosol cans, is highly advisable.

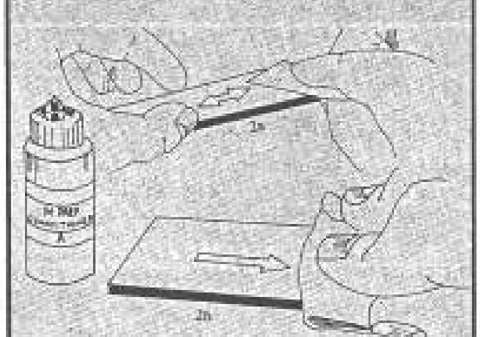


FIGURE 2

Step 2

Preliminary dry abrading with 220- or 320-grit silicon-carbide paper (Fig. 2a) is generally required if there is any surface scale or oxide. Final abrading is done by using 320- or 400-grit silicon-carbide paper on surfaces thoroughly wetted with M-Prep Conditioner A; this is followed by wiping dry with a gauze sponge. Repeat this wet abrading process, then dry by slowly wiping through with a gauze sponge, as in Fig. 2b.

With a 4H pencil (on aluminum) or a ballpoint pen (on steel), burnish *(do not scribe)* whatever alignment marks are needed on the specimen. Repeatedly apply M-Prep Conditioner A and scrub with cotton-tipped applicators until a clean tip is no longer discolored. Remove all residue and Conditioner by again slowly wiping through with a gauze sponge. Never allow any solution to dry on the surface because this invariably leaves a contaminating film and reduces chances of a good bond.

FIGURE 3

Step 3

Now apply a liberal amount of M-Prep Neutralizer 5 and scrub with a cotton-tipped applicator. See Fig. 3. With a single, slow wiping motion of a gauze sponge, carefully dry this surface. Do not wipe back and forth because this may allow contaminants to be redeposited.

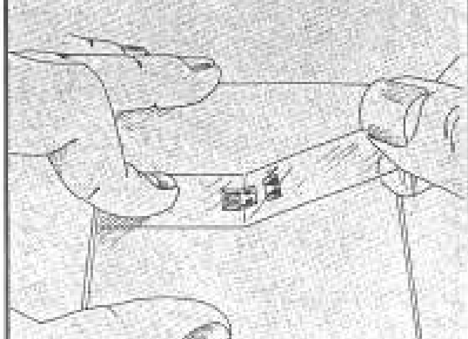


FIGURE 4

Step 4

Using tweezers to remove the gage from the acetate envelope, place the gage (bond side down) on a chemically clean glass plate or gage box surface. If a solder terminal is to be incorporated, position it on the plate adjacent to the gage as shown. A space of approximately 1/16 in *(1.6 mm)* should be left between the gage backing and terminal. Place a 4-in to 6-in *(100-mm to 150-mm)* piece of M-M No. PCT-2 cellophane tape over the gage and terminal. Take care to center the gage on the tape. Carefully lift the tape at a shallow angle (about 45 degrees to specimen surface), bringing the gage up with the tape as indicated in Fig. 4.

Step 5

Position the gage/tape assembly so that the triangle alignment marks on the gage are over the layout lines on the specimen (Fig. 5). If the assembly appears to be misaligned, lift one end of the tape at a shallow angle until the assembly is free of the specimen. Realign properly, and firmly anchor down at least one end of the tape to the specimen. This realignment can be done without fear of contamination by the tape mastic if the M-M No. PCT-2 cellophane tape is used. This tape will retain its mastic when removed.

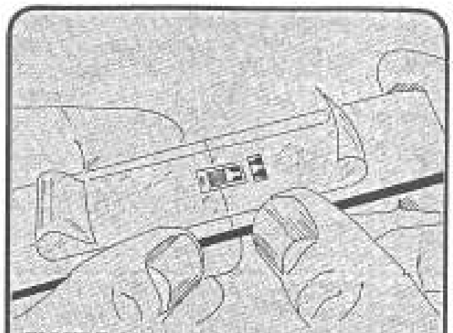


FIGURE 5

Step 6

Lift the gage end of the tape assembly at a shallow angle to the specimen surface (about 45 degrees) until the gage and terminal are free of the specimen surface (Fig. 6a). Continue lifting the tape until it is free from the specimen approximately 1/2 in *(13 mm)* beyond the terminal. Tuck the loose end of the tape under and press to the specimen surface (Fig. 6b) so that the gage and terminal lie flat, with the bonding surface exposed.

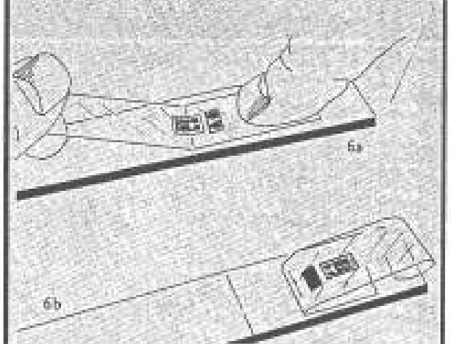


FIGURE 6

Step 7

M-Bond 200 catalyst can now be applied to the bond surface of the gage and terminal. M-Bond 200 adhesive will harden without the catalyst, but less quickly and reliably. Very little catalyst is needed and should be applied in a thin, uniform coat. Lift the brush-cap out of the catalyst bottle and wipe the brush approximately 10 strokes against the lip of the bottle to wring out most of the catalyst. Set the brush down on the gage and swab the gage backing (Fig. 7). Do not stroke the brush painting style, but slide the brush over the entire gage surface and then the terminal. Move the brush to the adjacent tape area prior to lifting from the surface. Allow the catalyst to dry at least one minute under normal ambient conditions of +75°F *(+24°C)* and 30%–65% relative humidity before proceeding.

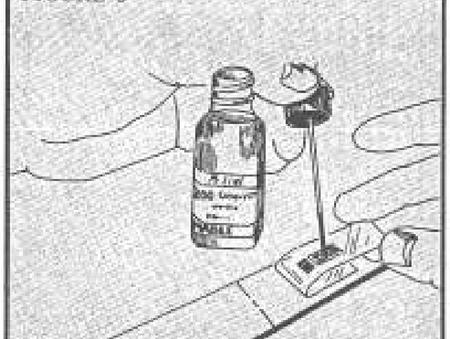


FIGURE 7

Note: The next three steps must be completed in the sequence shown, and within 3 to 5 seconds. Read Steps 8, 9, and 10 before proceeding.

Step 8

Lift the tucked-under tape end of the assembly, and, holding in the same position, apply one or two drops of M-Bond 200 adhesive at the fold formed by the junction of the tape and specimen surface (Fig. 8). This adhesive application should be approximately 1/2 in *(13 mm)* outside the actual gage installation area. This will insure that local polymerization, taking place when the adhesive comes in contact with the specimen surface, will not cause unevenness in the gage glue line.

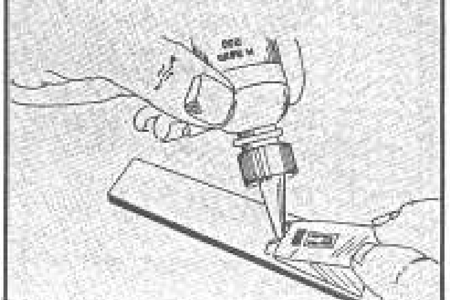


FIGURE 8

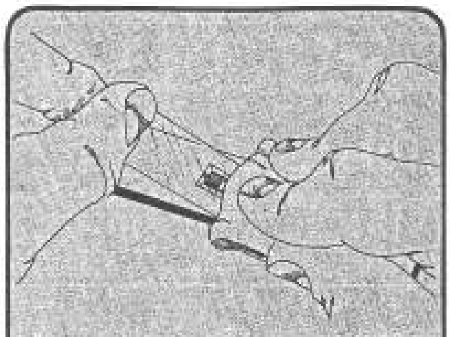


FIGURE 9

Step 9

Immediately rotate the tape to approximately a 30-degree angle so that the gage is bridged over the installation area. While holding the tape slightly taut, slowly and *firmly* make a single wiping stroke over the gage/tape assembly with a piece of gauze (Fig. 9) bringing the gage back down over the alignment marks on the specimen. Use a firm pressure with your fingers when wiping over the gage. A very thin, uniform layer of adhesive is desired for optimum bond performance.

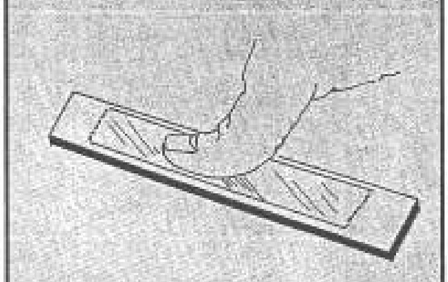


FIGURE 10

Step 10

Immediately upon completion of wipe-out of the adhesive, firm thumb pressure must be applied to the gage and terminal area (Fig. 10). This pressure should be held for at least one minute. In low humidity conditions (below 30%) or if the ambient temperature is below +70°F *(+20°C)*, this pressure application time may have to be extended to several minutes. Where large gages are involved, or where curved surfaces such as fillets are encountered, it may be advantageous to use preformed pressure padding during the operation. Pressure application time should again be extended due to the lack of "thumb heat" which helps to speed adhesive polymerization. Wait two minutes before removing tape.

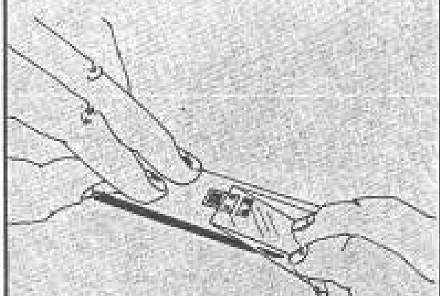


FIGURE 11

Step 11

The gage and terminal strip are now solidly bonded in place. To remove the tape, pull it back directly over itself, *peeling* it slowly and steadily off the surfaces (Fig. 11). This technique will prevent possible lifting of the foil on open-faced gages or otherwise damaging the installation. It is not necessary to remove this tape immediately after gage installation. If a time lapse is anticipated prior to continuation of gage wiring, the tape will offer mechanical protection for the grid surface if left in place.

V. FINAL INSTALLATION PROCEDURE

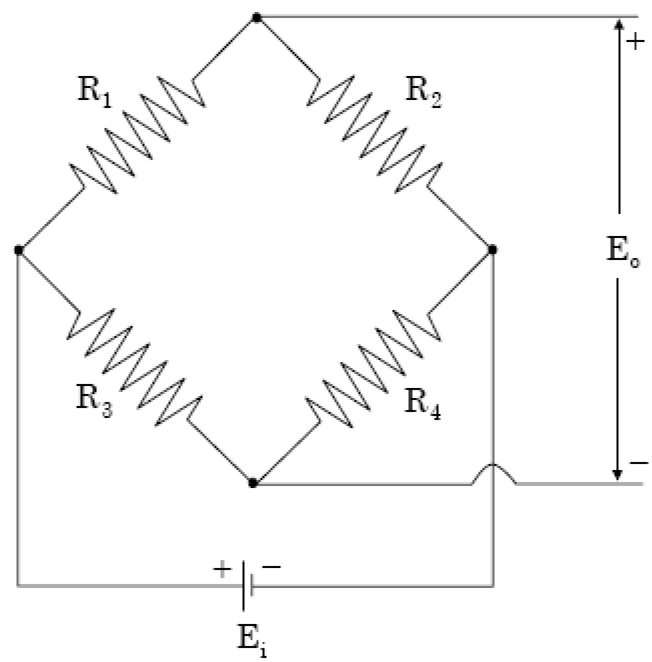
1. Select appropriate solder, referring to *M-M Catalog A-110*, and attach lead-in wires. Prior to any soldering operations, open-faced gage grids should be masked with PDT-1 drafting tape to prevent possible damage.
2. Remove the solder flux with M-Line Rosin Solvent, RSK-1.
3. Select and apply protective coating according to *M-M Catalog A-110*.
4. Micro-Measurements gages have been treated for optimum bonding conditions and require no precleaning before use unless contaminated during handling. If contaminated, the back of any gage can be cleaned with a cotton applicator slightly moistened with M-Prep Neutralizer 5.

Lab-3
UNIAXIAL TENSILE TESTING

LAB-3 - Uniaxial Tensile Testing
MECH 3130 - Mechanics of Materials

Wheatstone Bridge Circuit

From our lecture at the last laboratory, the normalized resistance change of a strain gage is given by $\frac{\Delta R}{R} = S_g \varepsilon$. To get the strain we need to accurately measure the normalized resistance change. This can be accomplished by using an electric circuit called the *Wheatstone Bridge*.



In the above figure, R1, R2, R3, R4 are arbitrary resistors, Ei is the known input voltage (from a battery or power supply), and Eo is output voltage (that we will measure). Using Ohm's Law (V = IR) and circuit theory, you can show that:

$$E_o = \left[\frac{R_1R_3 - R_2R_4}{(R_1+R_2)(R_3+R_4)}\right]E_i \tag{1}$$

When we use a Wheatstone Bridge, normally the resistors are chosen so that the bridge is "balanced" and Eo = 0. This requires:

$$R_1R_3 = R_2R_4 \tag{2}$$

Once the bridge is balanced, the output voltage will change if the resistance of one or more of the resistors changes (for example, one of the resistors might be a strain gage and its resistance will change as the specimen strain changes). For this case, the output voltage is given by:

$$E_o = E_i \frac{R_1 R_2}{(R_1 + R_2)^2}\left[\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right] \tag{3}$$

Quarter Bridge : (Strain Gage = R1, "Dummy Gage" = R2)

If we use a Wheatstone Bridge based Strain Gage Indicator (e.g. Measurements Group Model 3800) to measure the resistance change experienced by a single strain gage, the circuit is set up so that R1 = Rgage, and so that R2 = R1 (either 120 or 350 ohms). Once the test begins, the resistors R2, R3, and R4 are considered to have fixed resistance. Thus:

$$\frac{\Delta R_1}{R_1} = \frac{\Delta R_{gage}}{R_{gage}} = S_g \varepsilon \quad \text{and} \quad \frac{\Delta R_2}{R_2} = \frac{\Delta R_3}{R_3} = \frac{\Delta R_4}{R_4} = 0 \tag{4}$$

$$\frac{R_1 R_2}{(R_1 + R_2)^2} = \frac{R_{gage}^2}{(2R_{gage})^2} = \frac{1}{4} \tag{5}$$

For this case, eq. (3) becomes:

$$E_o = \frac{E_i}{4}(S_g \varepsilon) \tag{5}$$

For typical student strain gages, Sg = 2. If we choose the input excitation voltage as Ei = 2 Volts, eq. (5) simplifies to:

$$E_o = \varepsilon \tag{6}$$

This means that a strain of $\varepsilon = 1 \times 10^{-6} = 1\ \mu\varepsilon$ will produce a Wheatstone Bridge output voltage of 1 μV. Most low cost digital voltmeters can't measure voltages that small (microvolts), but can measure 1 mV (millivolts). Thus, an operational amplifier with an amplification of 1000 is usually added to the Wheatstone Bridge circuit to make the signal easy to measure. With the addition of the amplifier, the output of the Bridge/Amplifier becomes:

$$E_o = 1000\ \varepsilon \tag{6}$$

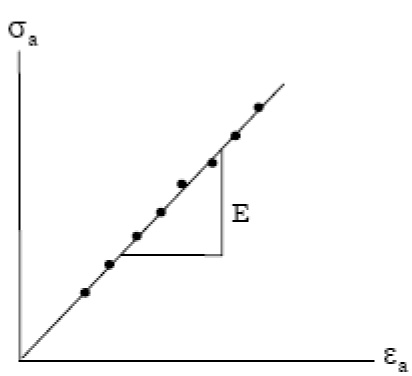
Thus, a strain of $\varepsilon = 1 \times 10^{-6} = 1\ \mu\varepsilon$ will produce a Bridge/Amplifier output voltage of 1 mV. In the instruments we use in class, the red digital readout is actually measuring the output of the Bridge/Amplifier in millivolts. If everything is configured correctly, this number will also be the strain in the gage in microstrain.

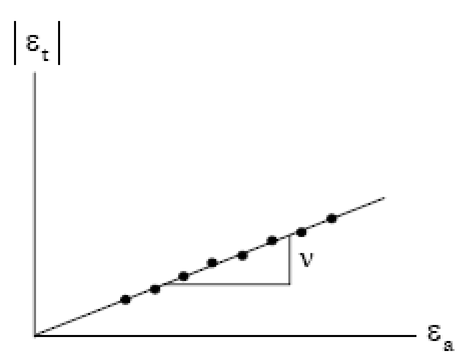
Lab Objective:

To perform a uniaxial tension test on a standard test specimen, and to use the measured stress-strain data to determine the Elastic Modulus (E) and the Poisson's Ratio (ν) of the specimen material. To gain a simple understanding of the theory and operation of the Wheatstone Bridge circuit used in strain gage measurements.

Procedure:

1. Receive lecture material on the Wheatstone Bridge circuit, and its use in strain gage measurements.
2. Retest the resistances of the mounted strain gages on your test specimen prepared in the last lab session using a digital multimeter.
3. Mount the specimen into the uniaxial tensile test apparatus.
4. Apply several loads on the tensile sample, and record the values of load, axial strain, and transverse strain.
5. Calculate the values of axial stress on the test specimen at each of the utilized test loads.
6. Plot graphs of the axial stress vs. axial strain (σ_a vs. ε_a) and transverse strain (absolute value) vs. axial strain ($|\varepsilon_t|$ vs. ε_a). Use least squares fitting to calculate the elastic modulus (E) and Poisson's ratio (ν).





7. Compare the experimental values of E and ν to the published values for your specimen material. Calculate the percent differences between the measured and published values.
8. Identify sources of errors in your measurements.

Note:

Prepare a complete lab report on your results for Labs #2 and #3. **Use the provided Lab Format** as a guideline for preparing your report.

Lab-4

TORSION TESTING

LAB-4 - Torsion Testing

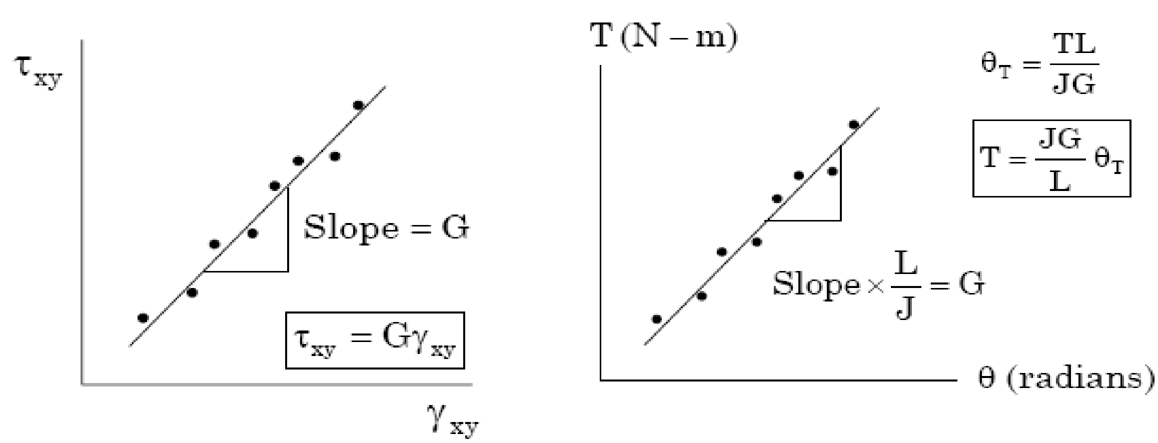
MECH 3130 - Mechanics of Materials

Lab Objective:

To perform a torsion (shear) test on a shaft with a circular cross-sectional area, and to apply torsion theory learned in lecture, and to measure the shear modulus of a material using two different methods.

Procedure:

1. Receive lecture material on two basic methods for experimentally measuring the shear modulus G of a material using torsion testing and computations involving the applied torque, shear strain, and angle of twist.
2. Prepare the torsion test experimental setup including:
   a) Torsion testing machine
   b) Strain indicator
   c) Switch and balance unit
   d) Properly prepared cylindrical shaft sample(s) with mounted three element (0-45-90) strain gage rosettes.
3. Apply loads to the torque arm in increments of 5 N (e.g. P = 5, 10, 15, 20, …).
4. At each load, record the three strains at the gage locations, and the vertical deflection of the torque arm. Use this data to determine the torque, shear strain, and angle of twist at each load. Tabulate all of your measurements and calculations.
5. Use the measured data to generate plots of Shear Stress vs. Shear Strain (τ_{xy} vs. γ_{xy}), and Torque vs. Angle of Twist (T vs. θ_T).

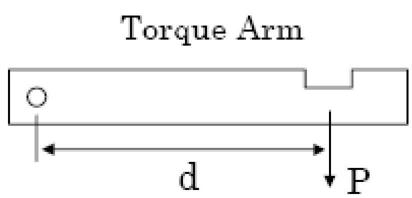


6. Using linear regression fits to the data in each plot, calculate two different values of the shear modulus.
7. Compare the experimental values of G to the published value for your specimen material. Calculate the percent differences between the measured and published values.
8. Identify sources of errors in your measurements.

Prepare a complete lab report on your results for Lab #4. Use the provided Lab Format as a guideline for preparing your report.

Notes on the Torsion Experiment

1. Calculation of Applied Torque:

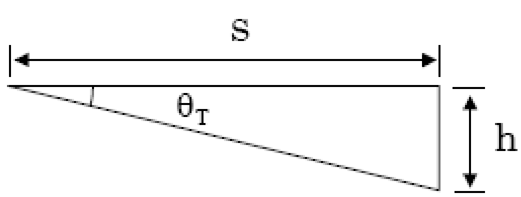


The torque is given by

T = Pd

Where, P is the applied load, and d is the length of the torque arm.

2. Calculation of the Angle of Twist

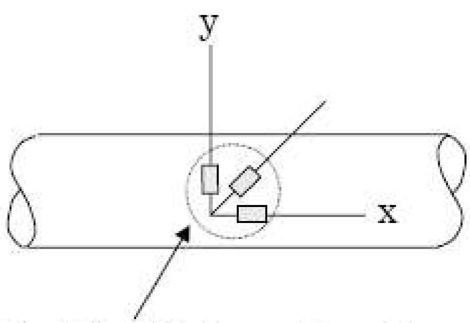


The angle of twist is given by

$$\tan \theta_T = \frac{h}{s}$$

Where, h is the vertical deflection of the torque arm measured using a deflection dial gage and s is the distance between the center of the shaft and the dial gage.

3. Calculation of Shear Strain from the 0-45-90 Strain Gage Rosette Data



$0° - 45° - 90°$ Strain Gage Rosette

It can be shown that the normal strain at a point is a function of orientation given by

$$\varepsilon_n(\theta) = \varepsilon_x \cos^2\theta + \varepsilon_y \sin^2\theta + \gamma_{xy} \sin\theta\cos\theta$$

Applying this relation at each of the gage angles leads to:

$$\varepsilon_0 = \varepsilon_x$$

$$\varepsilon_{45} = \frac{\varepsilon_x + \varepsilon_y + \gamma_{xy}}{2}$$

$$\varepsilon_{90} = \varepsilon_y$$

These expressions can be rearranged to solve for the shear strain in terms of the gage normal strains:

$$\gamma_{xy} = 2\varepsilon_{45} - \varepsilon_0 - \varepsilon_{90}$$

<u>Lab-5</u>

BEAM STRESSES AND STRAINS

(STRAIN GAGES)

LAB -5 - Beam Stresses and Strains (Strain Gages)

MECH 3130 - Mechanics of Materials

Lab Objectives:

To perform experimental strain measurements on aluminum beams using strain gages mounted at various locations. To verify the theoretical equations for the normal stresses and strains in beams loaded in bending.

Procedure:

1. Receive lecture material covering the beam configurations to be tested, including derivation of the shear force and bending moment distributions.
2. Prepare the beam test experimental setups including:
   e) Beams with properly mounted strain gages
   f) Dead weight loads
   g) Strain indicators
   h) Switch and balance units
3. Measure dimensions on your test configurations needed for beam stress and strain calculations (e.g. lengths of beam, cross-sectional dimensions, precise locations of supports, precise locations of applied concentrated loads, precise location of each strain gage, etc.)
4. Test each of the three beams by applying various loads and recording the strain gage data. Use the formulas

$$\sigma_x(x,y) = \frac{M(x)\,y}{I} \qquad \varepsilon_x(x,y) = \frac{M(x)\,y}{EI}$$

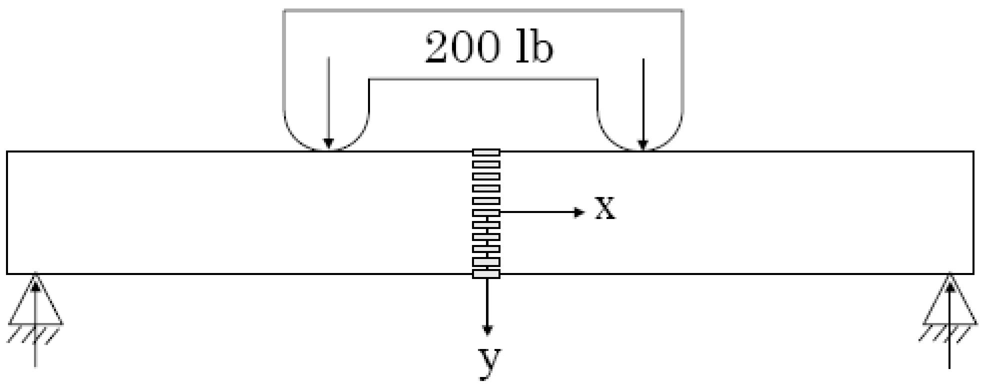
to calculate the theoretical strains at each of the gage locations and compare to your experimental data. Calculate the percent errors and discuss possible reasons for the discrepancies. Prepare tables to present your numerical results in a logical format. Also, generate graphs that show both your experimental measurements (as data points) and theoretical predictions (as solid lines/curves). Further details and discussions on the beam test configurations are given below.

Prepare a complete lab report on your results for Lab #5. Use the provided Lab Format as a guideline for preparing your report.

Notes on the Beam Experiments

Beam #1

This experiment consists of a simply supported I-Beam loaded in four point bending. As shown below, a total of 11 strain gages have been mounted in the center of the beam at various heights on the cross-sectional area. The concentrated loads on the top of the beam are applied using a 200 lb weight (each load is 100 lb).



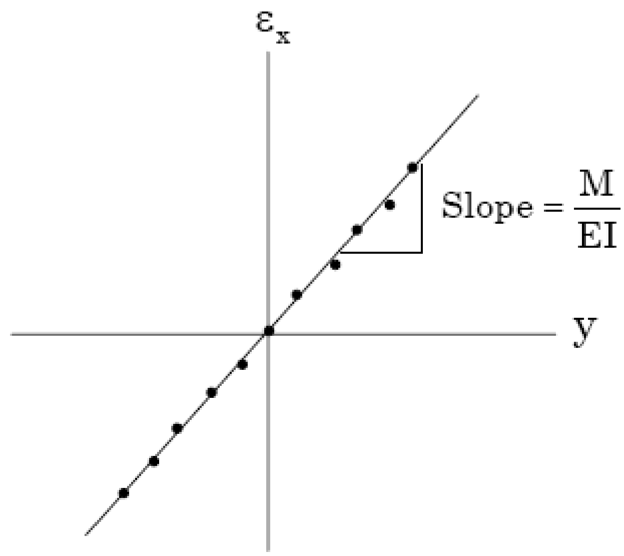
At the center of the beam (location of all of the gages), the bending moment is a fixed value. Thus, the theoretical strain distribution on the cross-sectional area is given by:

$$\varepsilon_x(y) = \left[\frac{M}{EI}\right] y = C_1 y$$

Where, $C_1 = M/EI$ is a constant that can be calculated. As part of this experiment, you should generate a table such as shown below, which lists the measured and predicted strains at each gage location.

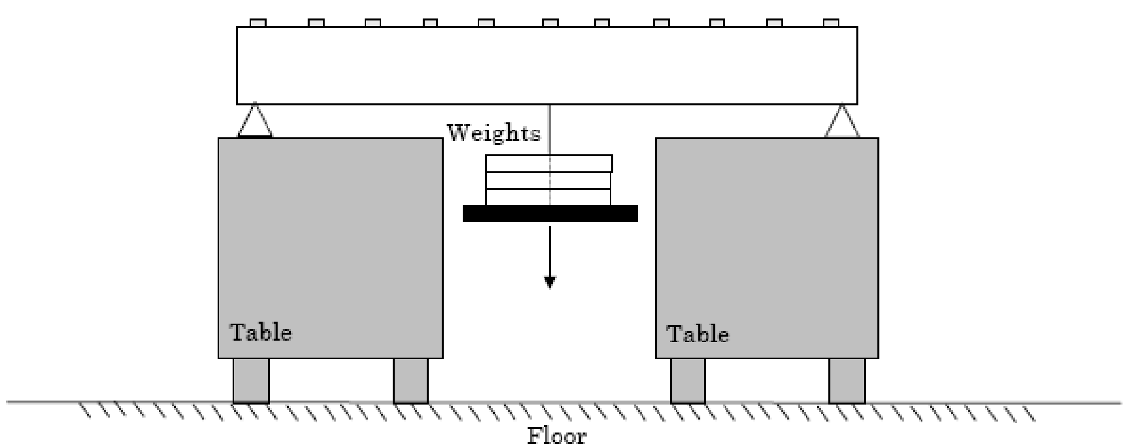
Strain Gage Number	y (inches)	ε_x (μ) [Measured]	ε_x (μ) [Predicted]	Percent Difference
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				

Also, you should plot ε_x vs. y, to graphically compare the theoretical and experimental results. In your graph, use data points for your experimental measurements and a solid line for you theoretical prediction as shown below.



Beam #2

This experiment consists of a simply supported I-Beam loaded by a central concentrated load (caused by hanging several "dead" weights at the center of the beam). As shown below, a total of 11 strain gages have been mounted in on the top of the beam at various horizontal positions.



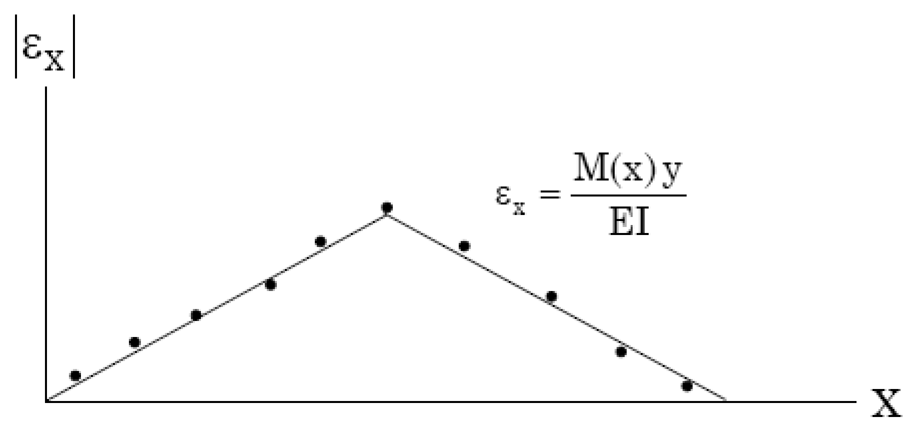
Along the top of the beam where the gages are all located, the value of "y" is fixed. Thus, the theoretical strain distribution for points on the top of the beam is given by:

$$\varepsilon_x(x) = M(x)\left[\frac{y}{EI}\right] = C_2\ M(x)$$

Where, C_2= y/EI is a constant that can be calculated. As part of this experiment, you should generate a table such as shown below, which lists the measured and predicted strains at each gage location.

Strain Gage Number	x (inches)	M(x) (in-lb)	ε_x (μ) [Measured]	ε_x (μ) [Predicted]	Percent Difference
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					

Also, you should plot ε_x vs. x, to graphically compare the theoretical and experimental results. In your graph, use data points for your experimental measurements and a solid line for you theoretical prediction as shown below.



Lab-6

BEAM STRESSES AND STRAINS

(PHOTOELASTICITY)

LAB-6 - Beam Stresses and Strains (Photoelasticity)

MECH 3130 - Mechanics of Materials

Lab Objectives:

To perform experimental stress measurements on a polycarbonate beam subjected to four-point bending using photoelasticity. To measure the normal stress variation across the cross-sectional area of a beam, and compare the obtained data to the results predicted by beam theory.

Procedure:

1. Receive lecture material covering an introduction to photoelasticity, and discussion of the beam configurations to be tested.
2. Prepare the beam test experimental setup including:
   a) Polariscope and overhead projector
   b) Load frame with screw driven application of load and dial indicator load cell
   c) Plastic beam with four-point bending fixture
3. Measure dimensions on your test configuration needed for beam stress calculations (e.g. length of beam, cross-sectional dimensions, precise locations of supports, precise locations of applied concentrated loads, etc.)
4. Test your beams by applying selected loads, and recording the photoelastic stress data (trace the photoelastic fringe patterns onto a piece of paper). At each fringe location, calculate the experimental normal stress value using the formula

$$\sigma_x = \frac{Nf_\sigma}{b} = \pm N\,(160) \quad \text{psi} \tag{1}$$

5. Use the formula

$$\sigma_x(x, y) = \frac{M(x)y}{I} \tag{2}$$

   to calculate the theoretical stress distribution over the cross-sectional area (center of the beam), and compare your results to the photo elastic experimental measurements. Calculate the percent errors and discuss possible reasons for the discrepancies. Prepare tables to present your numerical results in a logical format. Also, generate graphs that show both your experimental measurements (as data points) and theoretical predictions (as solid lines/curves).

LAB-6 - Beam Stresses and Strains (Photoelasticity)

The Photoelastic Method:

Photoelasticity is an experimental full field optical technique, which can be used to determine states of stress at various points in a loaded structure. The name of the method comes from the fact that it involves the interaction of light and optics (photo) with the stresses and strains (elasticity) in certain plastic materials that exhibit the phenomena of *stress-induced birefringence*. In laymen's terms, the stresses acting on certain transparent plastics will cause changes in the light waves that pass through them. In more detail, stress causes directionally dependent changes in the indices of refraction of the plastic material. In such plastics, the material changes from being optically isotropic (unstressed state) to optically anisotropic (stressed state). Therefore, stress measurements in loaded plastic structures can be made using optical measurements of the indices of refraction of the plastic material and the appropriate theoretical equations relating stress to the change in index of refraction.

Measurements of the stress-induced optical changes in the plastic materials can be made using an optical device called a polariscope, consisting of a set of optical filters (polarizing plates and quarter wave plates) in a particular configuration. When a plastic material is placed in the middle of a so-called circular polariscope, no light will pass through it (i.e. it appears totally dark). Once the plastic is stressed, colored bands of light (contours) called photoelastic fringes will appear across the specimen. When these fringes are viewed through a monochromatic filter (single color), they appear as black fringes on a single color specimen (we use yellow-green filters).

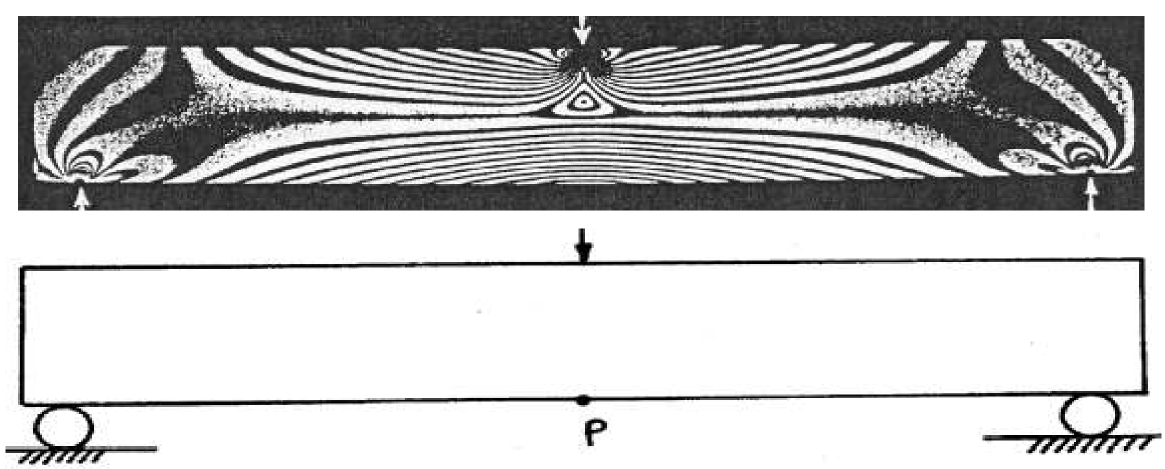


Fig: Typical photoelastic fringes for a plastic simply supported beam with central load

Using the Theory of Photoelasticity (no details given here), it can be shown that the following equation holds on every black fringe:

$$2\sqrt{\left(\frac{\sigma_x+\sigma_y}{2}\right)^2+\left(\tau_{xy}\right)^2}=\frac{Nf_\sigma}{b} \tag{3}$$

where N is some integer (N = 0, 1, 2, 3, …), b is the thickness of the plastic material (thickness that the light passes through), and f_σ is an material constant.

For the polycarbonate plastic and yellow-green filter used in our laboratory, $f_\sigma = 40$ psi − in. Also, the plastic beams have a thickness of b = .25 inches. Thus, eq. (3) simplifies to

$$2\sqrt{\left(\frac{\sigma_x+\sigma_y}{2}\right)^2+\left(\tau_{xy}\right)^2}=N\,(160)\quad \text{psi} \tag{4}$$

In all beams, the vertical normal stress is negligible ($\sigma_y \approx 0$). In addition, the shear force is zero (V = 0) in the center region of the four-point bending beam specimen geometry considered in this experiment. Thus, $\tau_{xy}= 0$ in the center of the beam, and the equation for the stress σ_x on a black fringe becomes

$$\sigma_x = \pm N\ (160)\quad \text{psi} \tag{5}$$

To determine the precise value of stress on a particular fringe, one must use intuition or other knowledge of the structure to choose the value of the fringe order N. In the four-point beam bending experiment, we can use the fact that the stress is known to be zero on the neutral axis. Also, the stress σ_x should increase in magnitude as we get farther away from the neutral axis. Finally, the stress should be tension on one side of the neutral axis and compression on the other.

Notes on the Photoelastic Beam Experiment

The experiment consists of using the fixture shown below in Figure 1 to load a polycarbonate plastic beam in four-point bending. This fixture is put into a uniaxial tensile loading frame, which is capable of applying known forces (P). These forces are transferred to the plastic beam specimen by the steel bars and the four short two-force members having pinned ends.

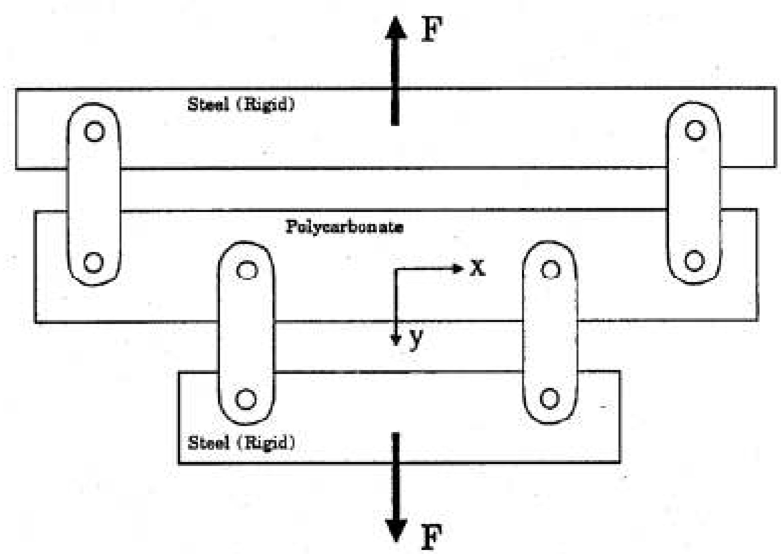


Figure 1 - Four-Point Bending Loading Fixture

As shown in Figure 2, each two-force member transfers a force of F/2 to the polycarbonate beam. This results in a constant bending moment in the center region of the beam (between the inner two forces) with a value of

$$M = \frac{Fd}{2}$$

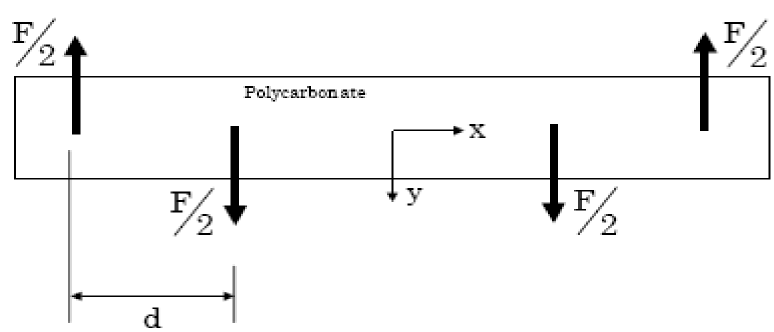


Figure 2 - Loads on the Polycarbonate Beam

The theoretical stress distribution on any cross-sectional area in the center region of the beam is given by:

$$\sigma_x(y) = \frac{My}{I} = \left[\frac{Fd}{2I}\right] y = Cy \tag{6}$$

where C is a constant that can be calculated. The shear stress $\tau_{xy} = 0$ as the shear force is zero in the center of the beam. In addition, the vertical stress in beams is typically neglected ($\sigma_y \approx 0$). As mentioned previously, these conditions cause the photoelasticity relation for the stress σ_x on a black fringe in the four point bending specimen to become:

$$\sigma_x = \pm N\ (160) \quad \text{psi} \tag{7}$$

Theoretically (eq. (6), σ_x is constant at various vertical positions y. Thus, the photoelastic pattern for the four point bending specimen should be a set of horizontal fringes (in the region of pure bending).

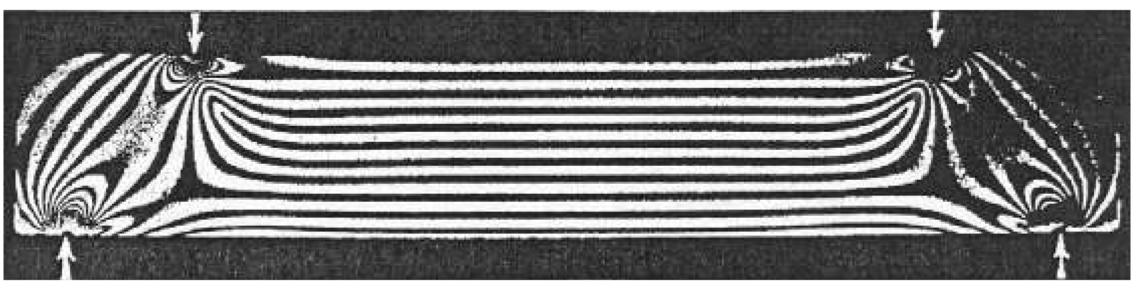
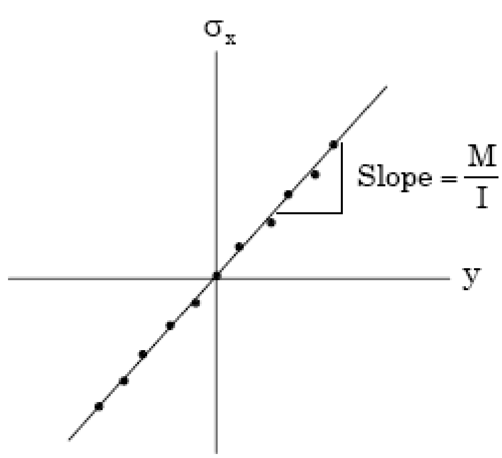


Figure - Typical Photoelastic Fringe Pattern for a Beam in Four Point Bending

Using your recorded photoelastic fringe pattern, experimental values of stress σ_x can be calculated at various vertical positions y. Using eq. (6) and the known applied forces, theoretical values of stress σ_x can be calculated at various vertical positions y. As part of this experiment, you should generate a table (format shown below), which lists the measured and predicted stresses at the various photoelastic fringe locations.

Fringe Location y (inches)	σ_x [Measured]	σ_x [Predicted]	Percent Difference

Also, you should plot σ_x vs. y, to graphically compare the theoretical and experimental results. In your graph, use data points for your experimental measurements and a solid line for you theoretical prediction as shown below.



Lab-7

BEAM DEFLECTIONS

Lab-7 - Beam Deflections

MECH 3130 - Mechanics of Materials

Lab Objectives:

To perform experimental deflection measurements on statically determinate and statically indeterminate beams and to compare the obtained data to beam theory predictions. To verify the principle of superposition for beam deflections.

Procedure:

1. Receive lecture material covering a review of beam deflection theory, and a discussion of the beam configurations to be tested.
2. Prepare the beam test experimental setup including:
   a) Beam deflection test stand
   b) Aluminum beams to be tested (36 x 1 x 0.25 inches)
   c) End supports for the beam (cantilever and roller)
   d) Displacement gages
   e) Dead weight loads
3. Measure the dimensions on your test configurations needed for calculating beam deflections (e.g. length of the beam between the supports, positions of the displacement gages, etc.)
4. For each of your beam configurations, apply the loads and record the beam deflections at each of the dial gage locations. Using beam theory, calculate analytical values of the beam deflections at each dial gage location. Compare your measured deflection values with your predicted values. Calculate the percent errors and discuss possible reasons for the discrepancies. Prepare tables to present your experimental and theoretical results in a logical format. Also generate graphs that show both your experimental measurements (as data points) and theoretical predictions (as solid lines/curves). Further details and discussions on the beam test configurations are given below.

   Prepare a complete lab report on your results for Lab #7. Use the provided Lab Format as a guideline for preparing your report.

Notes on Beam Deflection Experiment

Beam #1 (Statically Determinate):

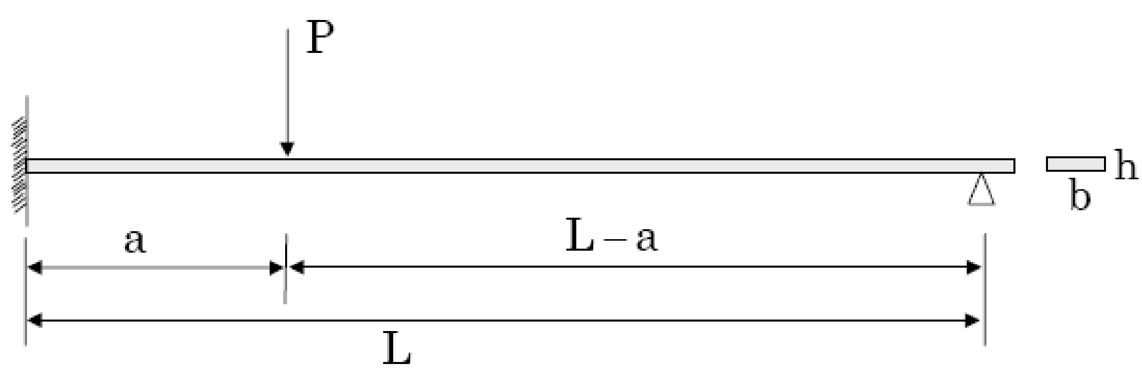
This experiment consists of a simply supported beam with rectangular cross-sectional area that is loaded with intermediate concentrated load as shown below.

Measure the displacements at each of the dial gage locations. Compare your experimental data to predicted values generated using beam theory.

Displacement Gage	x (in)	v (in) [Measured]	v (in) [Predicted]	Percent Difference
A				
B				
C				
D				
E				
F				

Beam #2 (Statically Indeterminate)

This experiment consists of a beam with rectangular cross-sectional area that has a clamped support on its left end and a roller support on its right end, and that is loaded with intermediate concentrated load as shown below.

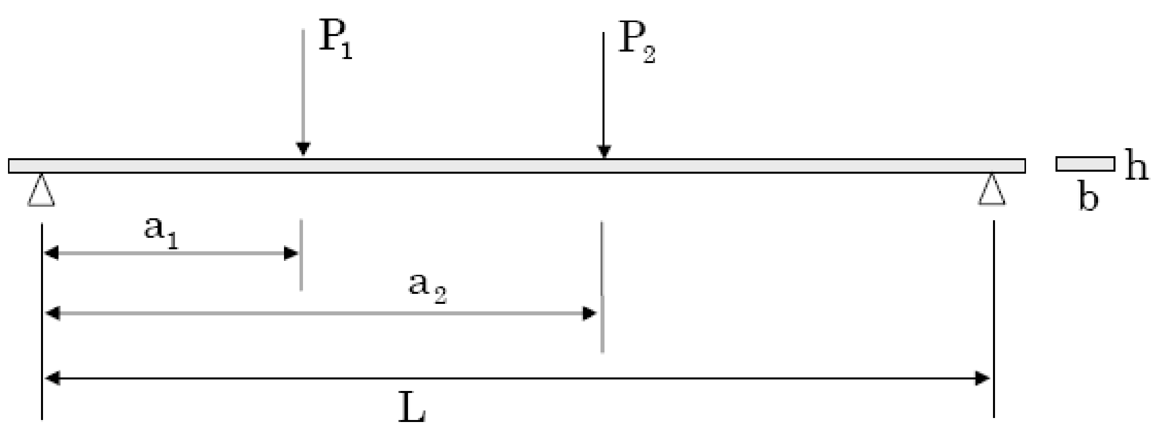


Measure the displacements at each of the dial gage locations. Compare your experimental data to predicted values generated using beam theory.

Displacement Gage	x (in)	v (in) [Measured]	v (in) [Predicted]	Percent Difference
A				
B				
C				
D				
E				
F				

Beam #3 (Method of Superposition):

This experiment consists of a simply supported beam with rectangular cross-sectional area that is loaded with two intermediate concentrated loads as shown below.



Apply each of the loads separately, and measure the displacements caused by each load (v_1 and v_2 for loads P_1 and P_2, respectively). When two or more loads are applied on any beam, the Principle of Superposition states that the resultant deflection at any point is equal to the summation of the deflections at that point caused by each of the loads acting separately. The only restriction on this method is that the effect produced by each load must be independent of that produced by the other loads; i.e. each separate load must not cause an excessive change in the original shape or length of the beam. Using the Method of Superposition, predict the displacements that should occur when both loads are applied simultaneously to the beam considered above (v1 + v2). Then, apply both loads simultaneously, and measure the resulting displacements. For the case of both loads being applied, compare your predicted displacements with your measured values.

Displacement Gage	x (in)	v_1 (in) [Measured]	v_2 (in) [Measured]	$v_1 + v_2$ [Superposition]	v (in) [Measured]	Percent Difference
A						
B						
C						
D						
E						
F						