Lab 8: Thin-Walled Section and Shear Center

Objective

Test open thin-walled sections and apply the theory learned in lecture to find their shear centers.

Introduction

Thin-walled sections are essential to aircraft structures. Understanding shear center is important when dealing with unsymmetric loading on these thin-walled structures. In Week 10 lecture, we have analyzed thin-walled sections and learned how to locate their shear centers. In this lab, you will apply this knowledge to do the same experimentally for open thin-walled beams (Fig. 1). Before the lab, you need to calculate the shear center of each of the specimens, based on their dimensions. In the lab, you will then measure the angle of twist per location in order to determine the shear center. In the report, you will compare the experimental data with your predictions, analyze the stress distribution of the section and calculate the deflection of one of the C-channel beams.

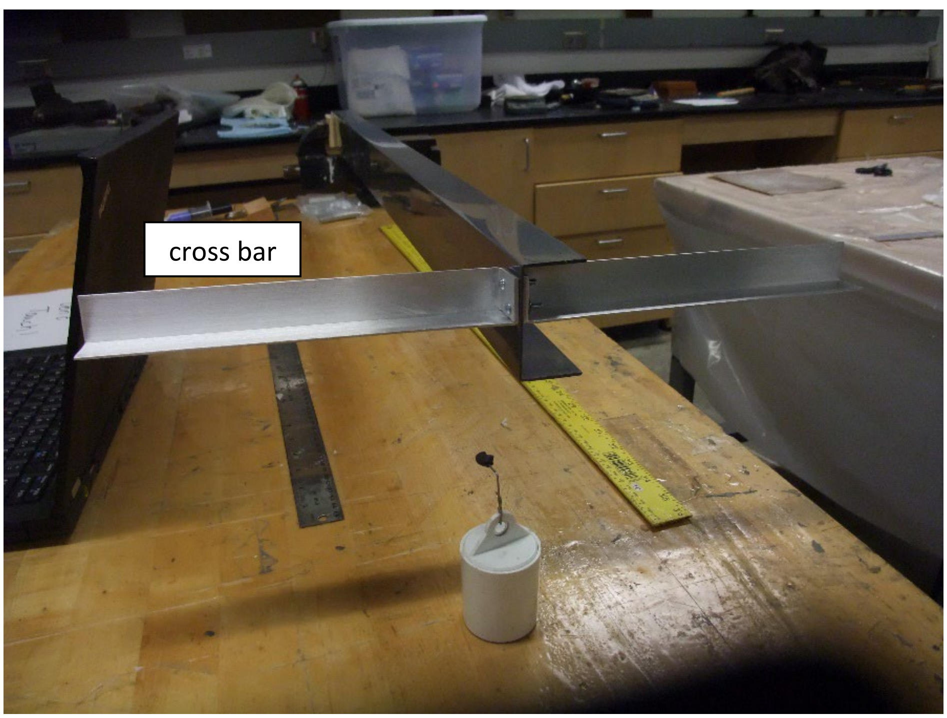

Figure 1 The plastic open thin-walled cantilever beam and load.

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References

[1] Week 10 lecture notes
[2] Peery, Ch. 6

Work to be done

You will test five open-channel samples in this lab: one plastic C-channel beam, one metal C-channel beam and three PVC circular open-channel pipes as shown in Fig. 2. The two types of cross section of the specimens are illustrated in Fig. 3, and the corresponding dimensional values are listed in Table 1.

1. Prelab

Given what you learned in Week 10 lecture, do the following for the prelab work:

(a) (30 points) For specimens I and II, derive an expression for the area moment of inertia *I* about its neutral axis in terms of h, b and t.

(b) (25pts) Calculate the theoretical shear center of each of the five specimens using the following expressions as derived on pages 9 and 11 in lecture notes:

C-channel: $$e = \frac{h^2 b^2 t}{4I}$$

Circular open-channel: $$e = \frac{2r\left[\cos\theta_0(2\pi - 2\theta_0) + 2\sin\theta_0\right]}{2\pi - 2\theta_0 + \sin 2\theta_0}$$

See Fig. 3 for all the corresponding parameters *h, b, t, r* and θ_0. Note that the total opening angle is $2\theta_0$. Hint: to derive the expression for *I* for specimens I and II, you can do one of two ways: (1) calculate *I* for the horizontal flanges and vertical web individually and then sum up or (2) use "subtraction" method by calculating *I* for a larger "outer" rectangular area and then subtracting it from *I* of the smaller "inner" area. You will also need parallel axis theorem. Also, as indicated in Fig. 3, the shear center offset *e* for the C-channel beams is measured from the center of the vertical web, while *e* for the circular open-channel pipes is measured from the center of circular cross section. Likewise, height h is measured between mid-planes of top and bottom flanges, and r is mean radius, i.e. r=(OD-t)/2.

(c) (5 pts) tabulate the results.

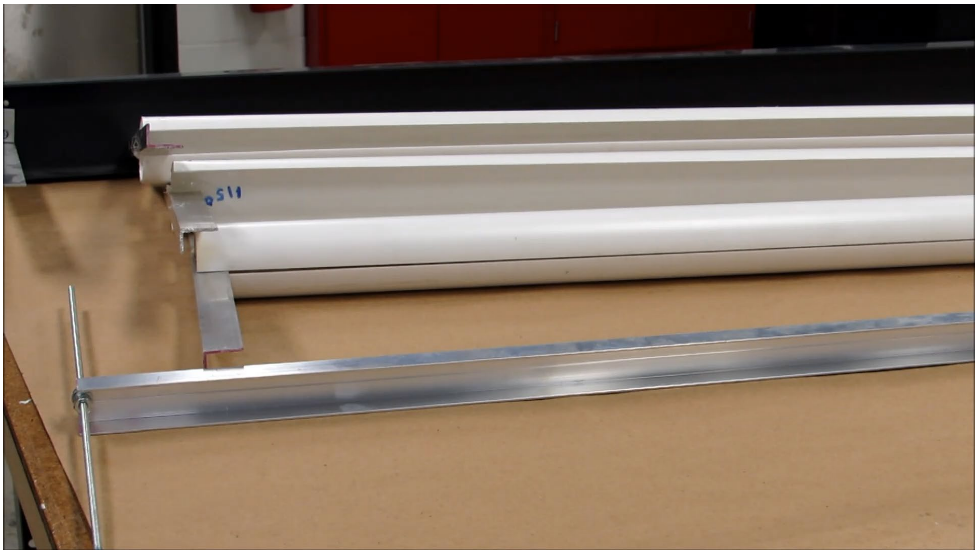


Figure 2. Five open-channel specimens for shear center testing

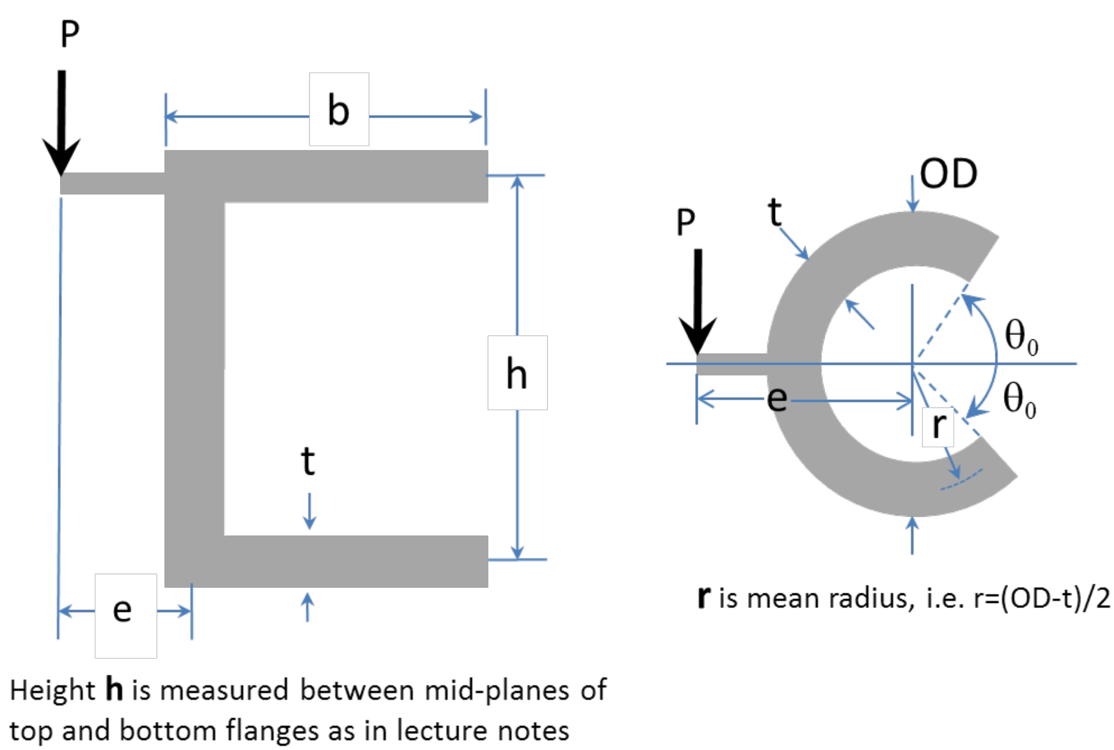


Figure 3. Schematic diagrams of the thin-walled cross section of specimen: (left) C-channel and (right) circular open channel

Table 1. Dimensions for the two types of cross sections of Fig. 3

Specimen ID	Cross section type	Height h (inch)	Width b (inch)	Thickness t (inch)	Outer diameter OD (inch)	Opening angle $2\theta_0$ (degree)
I	Plastic C-channel	2.43	1.456	0.08	NA	NA
II	Metal C-channel	0.84	0.56	0.055	NA	NA
III	PVC circular open	NA	NA	0.071	1.66	3.1
IV	PVC circular open	NA	NA	0.071	1.66	36.3
V	PVC circular open	NA	NA	0.071	1.66	103.7

The prelab is due online in Canvas by 11:59pm, the night before the lab.

2. In lab

As always, safety comes first. Wear safety goggle during the lab.

For each of the five samples, do the following:

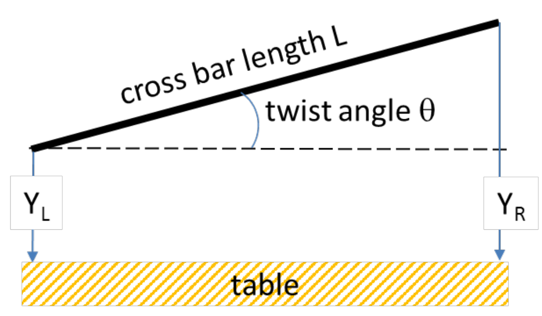
(a) If not already done, go mount the free end of beam sample into the table vice. Level the specimen along its length with respect to the bench top (do not use the bubble leveler as the bench top may not be leveled with gravity!). For the PVC circular open-channel specimens III-V, the free end should have been reinforced by a plastic collar which in turn is secured in the vise by two halves of foam blocks. *For specimen I, also measure (1) the length from the cross bar to the entrance to the vise and (2) the height to the bench top from a reference point having the same axial length as the cross bar, say, the bottom of the beam specimen right below the cross bar.*

(b) Level the cross bar the best you can. For the specimens III-V, this can be easily done by rotating the pipe specimen within the collar. Measure heights of both ends of the cross bar relative to the bench top. Calculate the initial angle of twist. This can be done by calculating arctangent between the difference of height at ends and the length of cross bar as shown in Fig. 4. Note that the angle is measured from the horizontal axis counterclockwise as positive. If the initial angles of twist for specimens I and II are greater than 1 degree, record and subtract them from succeeding angle of twist measurements.

(c) Apply the weight at several locations along the cross bar. You should take at least two measurements each on both left and right sides of cross bar. At every location, record the location on the cross bar (using the small short ruler) and the height of each end of the bar (using the 1-foot ruler), and calculate the angle of twist as in step (b). Recall that the shear center offset e for the C-channel beams is measured from the center of the vertical web, while *e* for the circular open-channel pipes is measured from the center of circular cross section. For the circular PVC pipe specimens III-V, you will find it difficult to accurately measure the cross bar locations with respect to their centers of circular cross section, as the pipe wall blocks your access to the full length of the cross bar. As shown in Fig. 5, a good way to resolve this is to measure the locations separately with respect to either the inner or outer surface of the pipe where the cross bar is connected. For the left side (negative) locations, the reference point is the outer surface of the pipe, and pipe's inner surface is for the right side (positive) locations. You may want to apply this technique to the C-channel specimens I and II as well. You can then shift the location measurements back to the theoretical reference points, i.e. centers of vertical web or circular cross sections, by accounting for the web thickness (specimens I and II) or pipe's outer diameter and thickness (specimens III-V). For example, the negative side measurements of specimens III-V should be offset further by subtracting half of the pipe's outer diameter OD (see Table 1). The positive side measurements should also subtract OD/2 but add back the pipe thickness t. Be sure to check the level of the cross bar each time after you remove the weight. Re-level if necessary.

(d) Make a scatter plot of twist angle vs. the cross bar locations, and fit a line through the data points. From the fitted line, determine the shear center at the zero crossing, i.e. the shear center should be the point at which the twist angle is zero (if you have corrected the initial twist angle offset for specimens I and II in step (b)).

(e) For specimen I, with the weight at shear center (i.e. no twist), measure the new height of the same reference point you chose in step (a), and from this determine the beam deflection.



$$\theta = sin^{-1}\left(\frac{Y_R - Y_L}{L}\right) \approx tan^{-1}\left(\frac{Y_R - Y_L}{L}\right)$$

Figure 4. Geometry for determining twist angle using end height and cross bar length

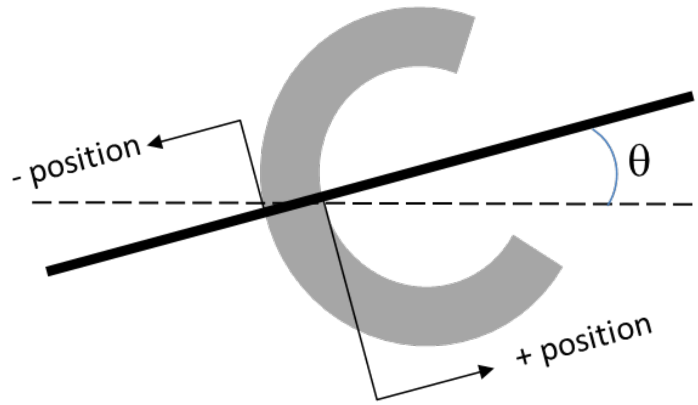


Figure 5. Left (negative) and right (positive) reference points for measuring cross bar positions of the circular open sections

3. After Lab

Work out the following problems for the Analysis or Data sections of the lab report.

3.1 (25%) Compare the experimental shear center locations of each of the specimens obtained from In Lab with your theoretical predictions from Prelab. Tabulate your results.

3.2 (15%) For specimen I (E=3Gpa), apply the beam deflection theory (as you learned from EM 324) to predict the end deflection of the cantilever beam. Does your calculation agree with the measurement you obtained from step (e) in In Lab?

3.3 (20%) Following the Q line integral shown on pages 8 and 9 of the lecture notes, determine the shear stress distribution of the horizontal flange of the C-channel section (i.e. specimens I and II). Similarly, determine the stress distribution of the vertical web. Plot the stress distribution throughout the section. Hints: the stress of the web reaches maximum at the neutral axis and the stress distribution is continuous from flanges to web.

3.4 (10%) Draw a grid by the C-channel section (as shown on page 9 of lecture notes) and indicate the <u>exact</u> location (x,y) of the shear center. State your reasoning why it is the correct location.

3.5 (15%) For C-channel sections, if the length of vertical web h increases significantly, say a hundredfold, what would the physical look of the C-channel section become? How would the shear center offset e (i.e. the loading location of external force P) be affected? Can you see what limiting value e should approach and prove it? Hint: take the expression you derived in prelab for I, plug it in the shear center formula and let h approaches infinity.

3.6 (15%) For circular open-channel sections, let both the opening angle $2\theta_0$ and the radius r increase at the same time. What would the physical look of the section become?

When θ_0 gets close to the limit of π, what limiting value the shear center offset e would approach? Justify your answers and draw necessary illustrations to make your points. Hint: see any similarity to Problem 3.5 above? Again, note that e is measured from the center of the circular section.

4. Report

Formal full report due in Canvas as usual.