Experiment #3

Stresses, Strains, and Deflection

Of Steel Beams in Pure Bending

MECH-237-007

Professor: Geraldine Milano

Date performed: 11/05/2019

Date submitted: 11/19/2019

Submitted By:

Peter Budzilovich

Yassar Khan

Anmol Sethi

Sundeep Singh

Abstract

It is important to understand the mechanical properties of materials for engineers to construct safe projects that will withstand the test of time. So, the main objective of this lab was to determine the neutral axis in the steel beam by measuring the strain and deflection on the beam. Then, the theoretical strain predictions with strain measurements obtained from the electrical strain gauge were compared to the experimental measurements. Afterward, the theoretically predicted deflections were compared to the measured experimental values. Finally, the validity of the assumptions made about the flexural analysis of beams was examined and tested. In order to complete the experiment, a steel beam with section S8x18.4 was used as well as 12 50-pound plates to load onto the beam. To measure the deflection, a deflection gauge was used and to measure the strain, the electrical strain gauges were used. The plates on the beam are 10 feet from the center of the beam on each side, creating a moment 10 times the total mass of the plate placed on the beam. Overall, the weights would create a bending stress that would act on the beam and because of this, the strain, as well as the deflection, will be produced. After conducting the experiment, the 3 tables and 5 graphs will be created: 1 table that compares the experimental strain and stress values for each loading and unloading, 1 table that compares the theoretical and experimental values of the deflection to the different loadings, 1 table to compare the theoretical and experimental strain at the top and the bottom of the beam, and a graph comparing the Strain (in µinches) to the Y Bar Location (in inches) for each of the loading and unloading values (excluding zero loading). In the experiment, it was shown that the neutral axis is located at 0.04 inches from the bottom of the beam. The average percent difference between the theoretical and experimental beam is 5% or 0.05. The standard deviation of the percent differences is 0.04. This is an allowable margin of error and still give values around the same ballpark, which is why this experiment would be considered a success.

Table of Contents

Introduction

The objective of this experiment is to determine the neutral axis on a steel beam by measuring the strain and deflection acting on the beam. In doing so, the experimental strain measurements obtained from the electrical strain gauge will be compared to the theoretical values. Afterward, the theoretical deflection points will be compared to the experimental. Finally, the validity of the assumption that cross-sections remain plane during bending will be tested.

Theory

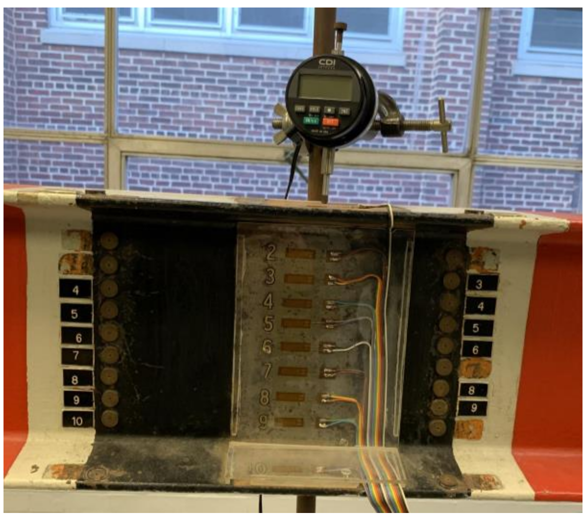
In order to develop safe engineering designs for all different kinds of products, engineers must understand the behavior of mechanical properties for different materials. To do this, some of the many important concepts that should be understood include bending stress, deflection, and strain on a beam. When the cross-section of a neutral beam is symmetrical about its neutral axis, the maximum tensile and compressive stresses are equal. Therefore, the bending stress (σ) can be written as: $\sigma_{t(at\ bottom)} = -\sigma_{c(at\ top)} = Mc / I = M / S = Pa / S$. Here σ_t is the maximum tensile stress, σ_c is the maximum compressive stress, S is the section modulus , $M = Pa$ is the bending moment about the z-axis with respect to the neutral axis, I is the moment of inertia of the cross-section, c is the distance from the neutral axis to the specific element, and a is the distance from the support to the applied load.

For engineers, calculating deflection is an important part of structural analysis. Design engineers are normally supposed to determine the deflection under service loads and if they are under tolerable limits. In order to do this, Hooke's Law needs to be looked at: $E = \sigma / \varepsilon$. From this, it can be determined that $\sigma_{t(bottom)} = -\sigma_{c(top)} = Mc / EI = Pa / ES$, where E is Young's Modulus and ε is the maximum tensile/compressive strain. Moving forward, to determine the deflection on a beam through the double integration method, which gives the equation: $d^2y / dx^2 = M / EI$. From this, it can be found that $y = -Pa(cLx – 3x^2 – a^2) / 6EI$ and $y' = -Pa(L-2x) / 2EI$. Finally, we can say that $\delta_{max} = Pa(3L^2 – 4a^2) / 24EI$ and $\theta = Pa(L - a) / 2EI$. For reference, y is the deflection in the y-direction, y' is the slope of the deflection curve, δ_{max} is the maximum deflection and θ is the angle of rotation on either side of the beam.

Procedure

Data Acquisition:

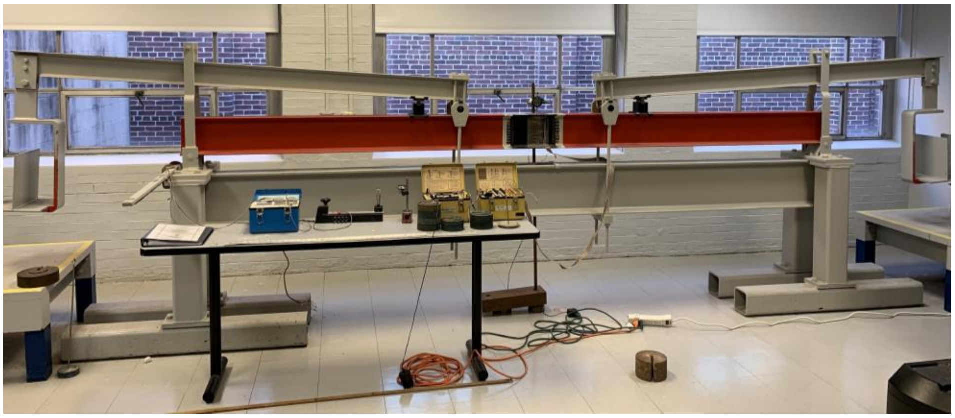
1. Zero the electrical gauge
2. Measure the gauge lengths
3. Zero the deflection gauge
4. Increase the weights in 200 pound increments on both sides until the maximum weight of 600 pounds is placed on both sides
5. Record the reading on the deflection gauge and record the strain gauges 2, 4, 6, 8, and 10 for every increment of 200 pounds.



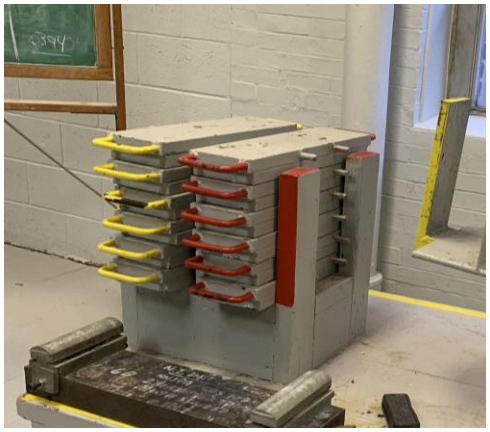
6. Remove the weights in 200-pound increments and repeat Step 5.
7. Create a graph for each of the 5 loadings (Strain vs Beam depth)
    a. Create Trendline
    b. Locate the neutral axis for each loading

Laboratory Equipment:

1. Beam tester



2. Weights (50 pound per plate)



Safety Precautions:

1. Crushing Hazard: Hands and other body parts should not be placed in the loading zone for those volunteering to place weights at the ends.

Data

Table 1

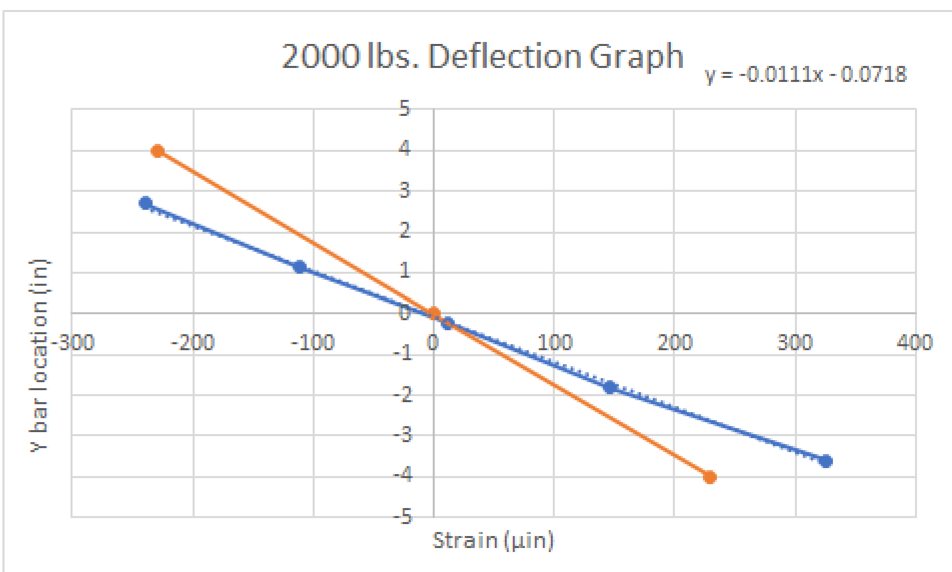
	0	2000 lbs.	4000 lbs.	6000 lbs.	4000 lbs.	2000 lbs.
δ (in)	0.004	0.130	0.260	0.395	0.270	0.140
ε_2 μin	0	-240	-480	-720	-480	-338
ε_4 μin	0	-111	-212	-314	-210	-102
ε_6 μin	0	11	24	45	31	19
ε_8 μin	0	147	297	459	309	160
ε_{10} μin	0	326	666	1009	681	348

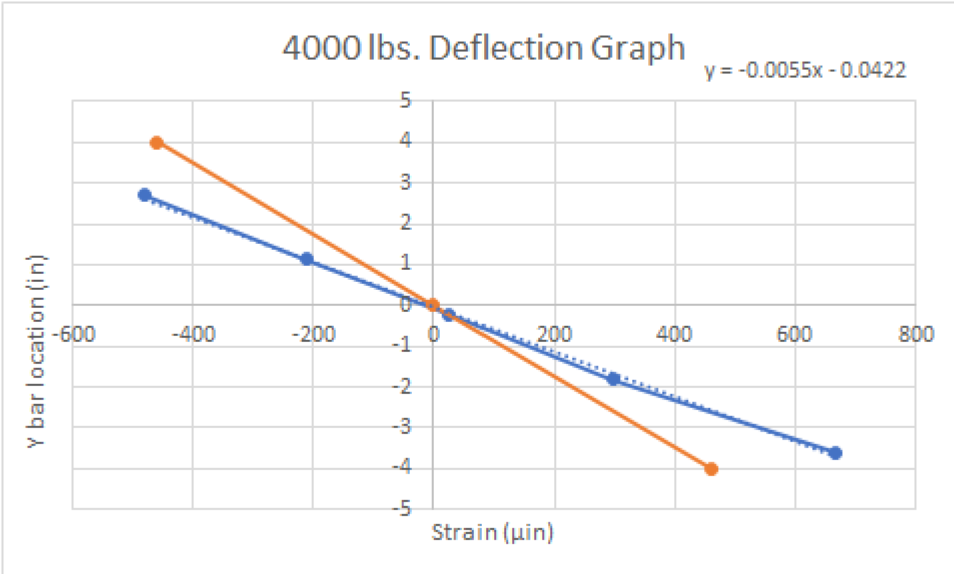
Table 2

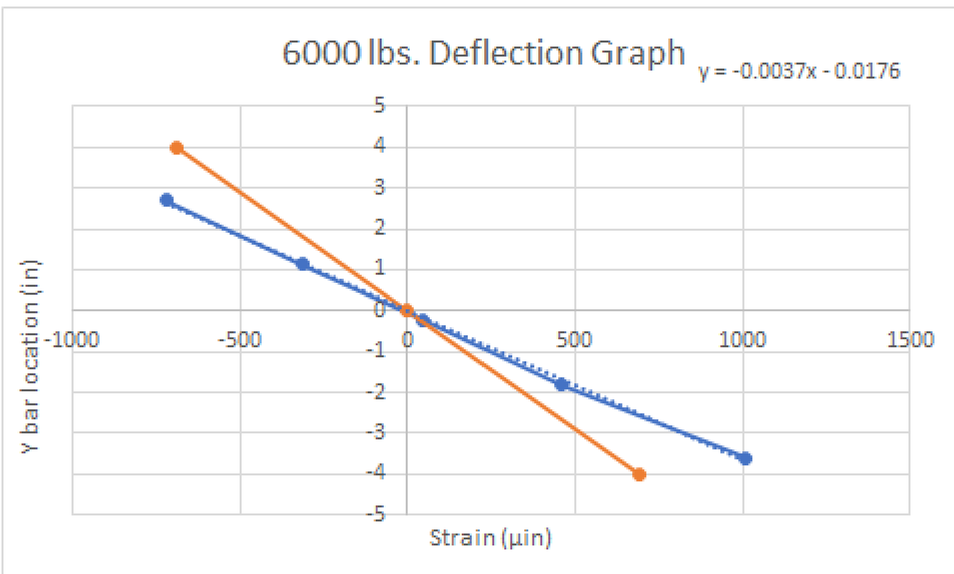
Loads, P (lbs.)		Strain at Top (μin)			Strain at Bottom (μin)		
		Theoretical	Experimental	Percent Error	Theoretical	Experimental	Percent Error
Loading	2000	-229	-240	5%	229	326	42%
	4000	-460	-480	4%	460	666	45%
	6000	-690	-720	4%	690	1009	46%
Unloading	4000	-460	-480	4%	460	681	48%
	2000	-229	-338	48%	229	348	52%
	0	0	0	0%	0	0	0%

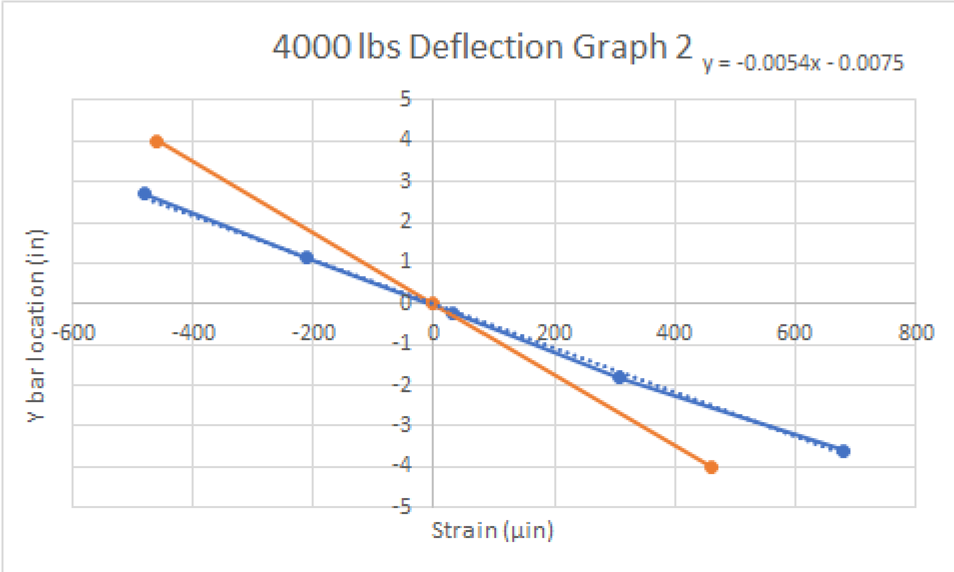
Table 3

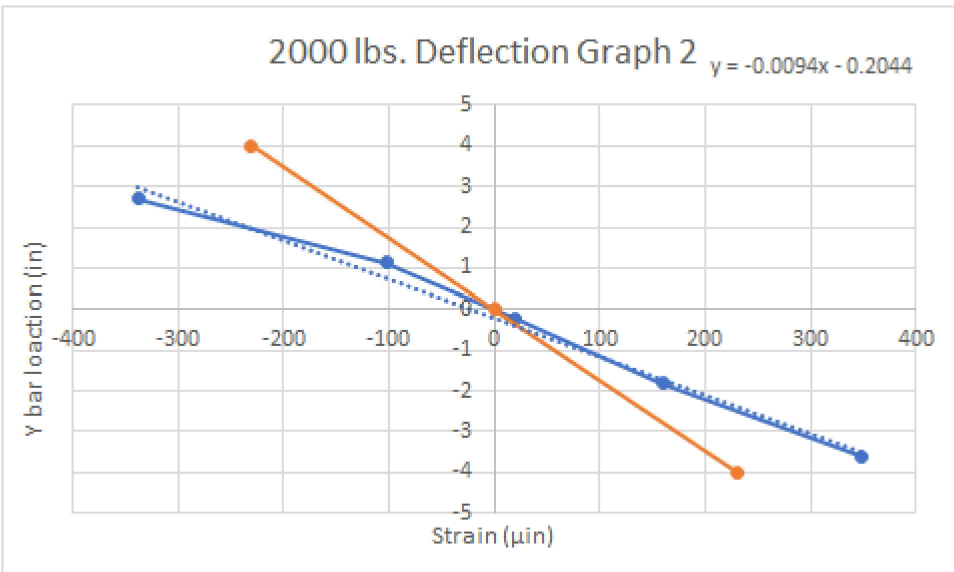
Loads, P (lbs.)		δ_c (in)		Percent Difference
		Theoretical	Experimental	
Loading	2000	0.141	0.130	8.08%
	4000	0.283	0.260	8.08%
	6000	0.424	0.395	6.91%
Unloading	4000	0.283	0.270	4.55%
	2000	0.141	0.140	1.01%
	0	0	0.004	0.00%
Average Value				0.05
Standard Deviation				0.04




4000 lbs. Deflection Graph
y = -0.0055x - 0.0422
Y bar location (in)
Strain (µin)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-600
-400
-200
0
200
400
600
800


6000 lbs. Deflection Graph
y = -0.0037x - 0.0176
Y bar location (in)
Strain (µin)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-1000
-500
0
500
1000
1500


4000 lbs Deflection Graph 2
y = -0.0054x - 0.0075
Y bar location (in)
Strain (μin)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-600
-400
-200
0
200
400
600
800


2000 lbs. Deflection Graph 2
y = -0.0094x - 0.2044
Y bar loaction (in)
Strain (μin)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-400
-300
-200
-100
0
100
200
300
400

Analysis

The equations used in this lab were δ=Pa/24EI*(3l^2-4a^2) and ϵ=Pa/ES.

- I = 57.4 in^4
- E = 29*10^6 psi
- L = 150.75 inches
- a = 48 inches
- S = 14.4 in^3

A simple beam (S 8*18.4) with two load points was used in this experiment. Table 1 in the data section is the data collected from the experiment using electrical gauges to measure strain in microinches for each different load. Table 2 contains data that was collected plus calculated strain values to compare the accuracy of the strain gauges on the beam using the formula $\epsilon = \frac{P*A}{E*S}$ and Percent error=((exp-theoretical)/theoretical)/100=PE% .

Using the data from table 2, 5 graphs were created having 2 lines showing the theoretical strain vs. the experimental strain. Each graph shows theoretical lines having 3 points of data creating a straight line starting from the highest point on the beam going down to the lowest point on the beam. The experimental lines have 5 points of data which created semi-straight lines. Using the trendline function, an equation was computed to show the y-intercept. The y-intercept shows the experimental neutral axis.

Sample Calculations

- Deflection
- $\delta = \frac{P*A}{24(EI)}(3l^2 - 4A^2)$
- $\delta = \frac{2000*48}{24((29*10^6)(57.5))}(3(150.75)^2 - 4(48)^2) = 0.141\ in$
- Strain
- $\epsilon = \frac{P*A}{E*s}$
- $\epsilon = \frac{2000*48}{(29*10^6)*(14.4)} = 0.0002299$
- Percent Error
- Percent error=((exp-theoretical)/theoretical)/100=PE%
- Percent error=((-240+229)/-229)/100=5%

Discussion and Conclusion

Discussion:

In Experiment 3, a simply supported steel beam of 20 feet long was subjected to two loadings on both ends. The deflection was first measured with no loading on either end to set a base run and then the deflection was measured at a loading of 2000 pounds, 4000 pounds, and 6000 pounds on both ends. The center of the beam had various electrical strain gauges at different vertical positions measuring the strain at that position and it also had a deflection gauge measuring the deflection of the beam. When the loading was increased or decreased, the measurements given by gauges 2, 4, 6, 8, and 10 were recorded. In total, there were 5 loadings and a table was compiled from the data given by the gauges for each one of these loadings. From the data, 5 graphs were formulated for each loading. For each loading, when reading the strain gages from top to bottom, starting with gauge 2 and ending with gauge 10, where the strain reading changes from positive strain to negative strain, this is where the neutral axis is located.

This is reflected in the graphs as well, when the trendline crosses the y-axis, this is where the central axis is located. For example, taking a look at the 6000 pound loading, the strain value changes from positive strain to negative strain in between gauge 4 and 6, meaning that the neutral axis is located in between these gauges. Taking a look at the experimental strain values, the percent errors ranged from 4% to 52%. On one hand, some of the percent errors are exceptional while others seem to be exceedingly high. This could very well be due to machine error in the strain gauges or fatigue in the beam from being repeatedly loaded and unloaded.

As expected, the highest deflection occurs when the loading was the greatest, 6000 pounds on both sides. The deflection for the 6000 pound loading was 0.395 inches and the deflection for the smallest loading, 2000 pounds, was 0.130 inches. From this data, it can also be observed that there is a positive correlation between loading and deflection and the deflection is fairly proportional to the loading. When looking at the percent errors of the experimental deformation compared to the theoretical deformation, the percent errors range from 1.01% to 8.08% which are all exceptional percent errors.

Conclusion:

The objectives of Experiment 3 was to compare experimental strains and deflection to the theoretical strains and deflection. From the data received for this experiment, the objectives were only partly met. Comparing the experimental deflection to the theoretical deflection, this yielded an exceptional percent error, only going as high as 8.08%. On the other hand, when comparing the experimental strain values to the theoretical strain values, the percent error went high as 52% which is alarmingly high. If this experiment were to be repeated, most likely similar deformation percent errors will be received, but the strain value may still have an extremely high percent error. Over time, the percent errors may even be higher due to fatigue of the steel beam and being overused in lab experiments. Overall, the objectives of this laboratory experiment were only partially validated since the percent errors for the strains were too high, but the percent errors for deflection were exceptional.

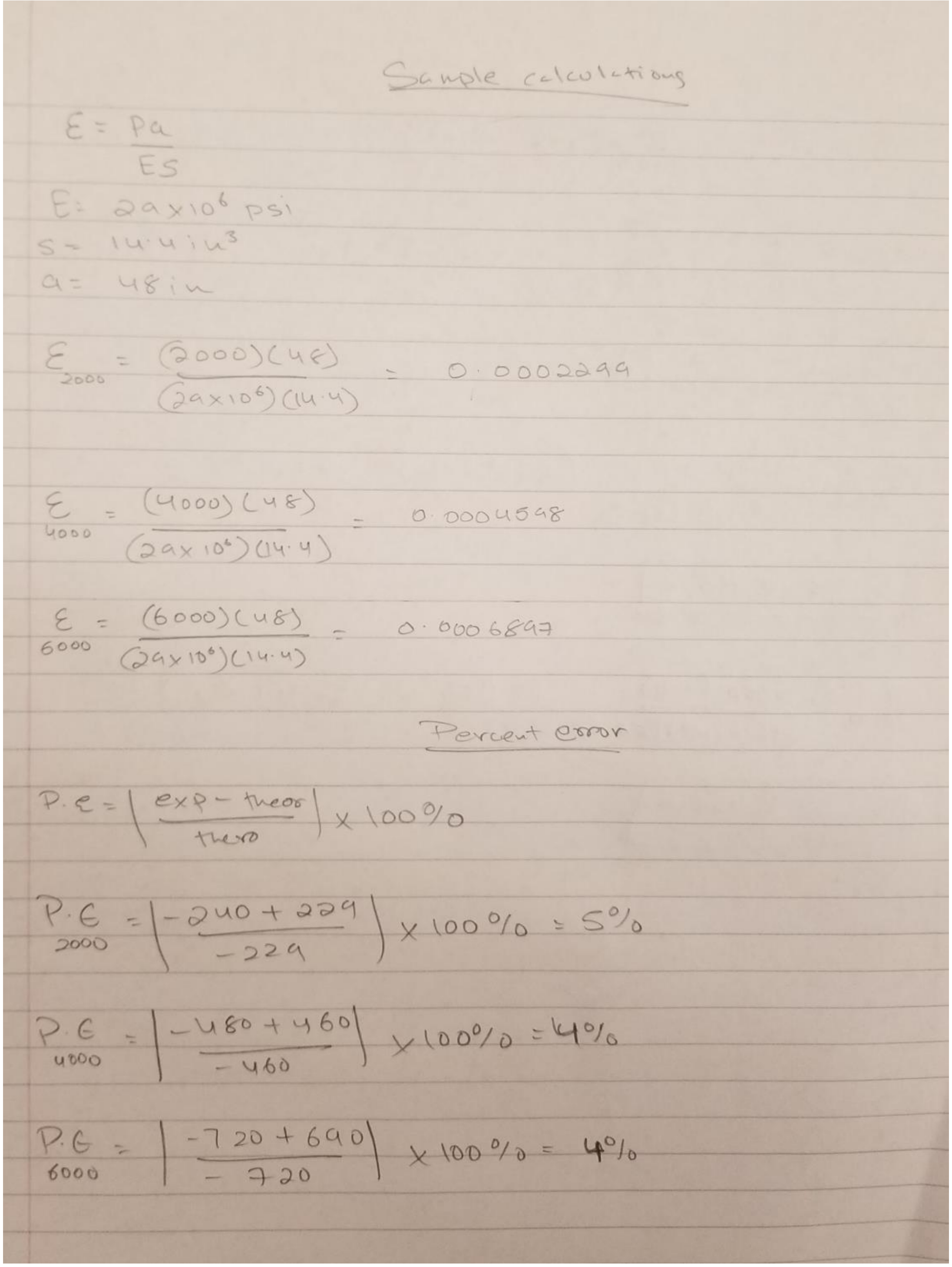
Bibliography

Beer, F. P., Johnston, E. R., DeWolf, J. T., & Mazurek, D. F. (2020). *Mechanics of materials* (Eighth). New York, NY: McGraw-Hill Education.

Ciesla, M. (2017). *Strength of Materials Laboratory Manual*. (C.-T. Thomas, A. C. Luke, G. Milano, & L. Martin, Eds.) (First). Newark, NJ: NJIT Press.

Appendix

Calculations:



Sample calculations

$$\varepsilon = \frac{Pa}{ES}$$

$E = 29 \times 10^6$ psi

$S = 14.4 \, in^3$

$a = 48 \, in$

$$\varepsilon_{2000} = \frac{(2000)(48)}{(29 \times 10^6)(14.4)} = 0.0002299$$

$$\varepsilon_{4000} = \frac{(4000)(48)}{(29 \times 10^6)(14.4)} = 0.0004598$$

$$\varepsilon_{6000} = \frac{(6000)(48)}{(29 \times 10^6)(14.4)} = 0.0006897$$

Percent error

$$P.e = \left| \frac{exp - theor}{thero} \right| \times 100\%$$

$$P.E_{2000} = \left| \frac{-240 + 229}{-229} \right| \times 100\% = 5\%$$

$$P.E_{4000} = \left| \frac{-480 + 460}{-460} \right| \times 100\% = 4\%$$

$$P.E_{6000} = \left| \frac{-720 + 690}{-720} \right| \times 100\% = 4\%$$

$$\delta_c = \delta_{max} = \frac{Pa}{24EI}\left(3L^2 - 4a^2\right)$$

$$\delta_{2000} = \frac{(2000)(48)}{24(29\times10^6)(57.5)}\left(3(150.75)^2 - 4(48)^2\right)$$

$$\boxed{\delta_{2000} = 0.141\text{ in}}$$

$$\delta_{4000} = \frac{(4000)(48)}{24(29\times10^6)(57.5)}\left(3(150.72)^2 - 4(48)^2\right) =$$

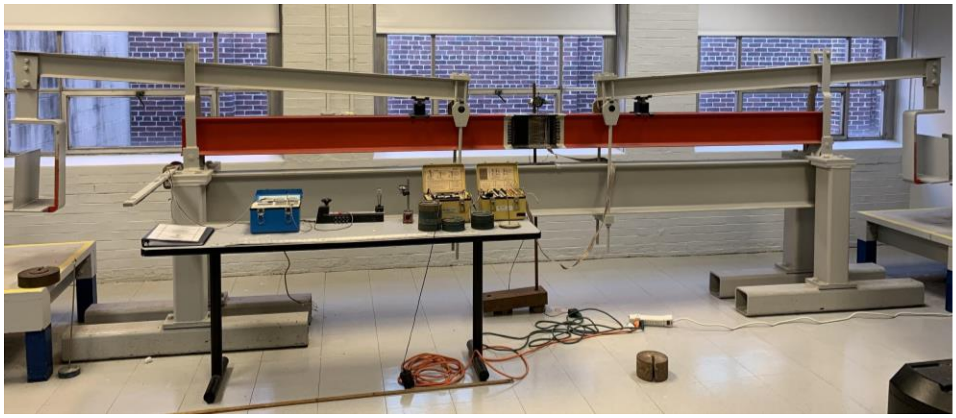
$$\boxed{\delta_{4000} = 0.283\text{ in}}$$

$$\delta_{6000} = \frac{6000(48)}{24(29\times10^6)(57.5)}\left(3(150.72)^2\right) - 4(48)^2) =$$

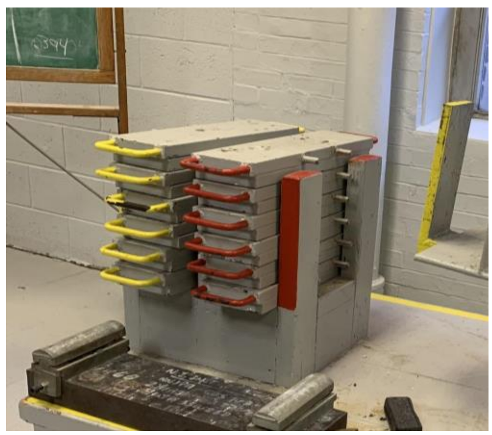
$$\boxed{\delta_{6000} = 0.424\text{ in}}$$

Performing the Experiment:

Machine Used: Beam Testing



The 20 feet I beam used to measure deflection under specific loads



Weights that go on each side (50 pounds each