University of Colorado - Boulder

ASEN 3112: Structures

ASEN 3112 Lab 4

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Nomenclature

E = Young's Modulus [psi]
L = Length of the specimen [in]
P_{cr} = Buckling Load [lb]
P = Axial Load [lb]
I = Moment of Inertia [in^4]
x = position along the sample [in]
δ = maximum deflection [in]
κ = curvature of the beam [in]
ϵ = yield strain

I. Buckling Load

Equation (1) is used to calculate the buckling load for each sample.

$$P_{cr} = \frac{\pi^2 EI}{L^2} \tag{1}$$

The results for calculated value and experimental value are displayed in table (1), where the experimental values are obtain from determine the maximum value from the data given. All four data sets were used for analysis, and then average them at the end.

Table 1 Buckling Loads

Specimen	Buckling Load Value [lb]
Predicted value for Rod	246.1986
Experiment value for Rod	219.3478
Predicted value for Bar	115.8582
Experiment value for Bar	115.4348

Table 2 Percent Errors between predicted and Experimental values

Specimen	Percent Error
Rod	10.9062 %
Bar	0.3654 %

The predicted buckling loads are in agreement with the experimentally measured buckling load. Yielding an error less than 15 % for both cases. This proved that the method is valid for emulation of results from this experimental process. The discrepancy between the experimental and the prediction is possibly due to initial imperfections of the bar/rod (i.e the waviness of the beam).

II. Post-Buckling Behavior

In figures 1 and 2 below, the deflection vs applied load is plotted for both bars. These plot the experimental data, the analytical model, the critical force, and the predicted beginning of plastic deformation in the post-buckling region. The predicted deflection corresponding to post-buckling was found to be about .8in and .4in for the thin and square bar respectively. Note that this deflection is aligned with the max applied load experienced by both bars. This marks the end of elastic and beginning of plastic deformation.

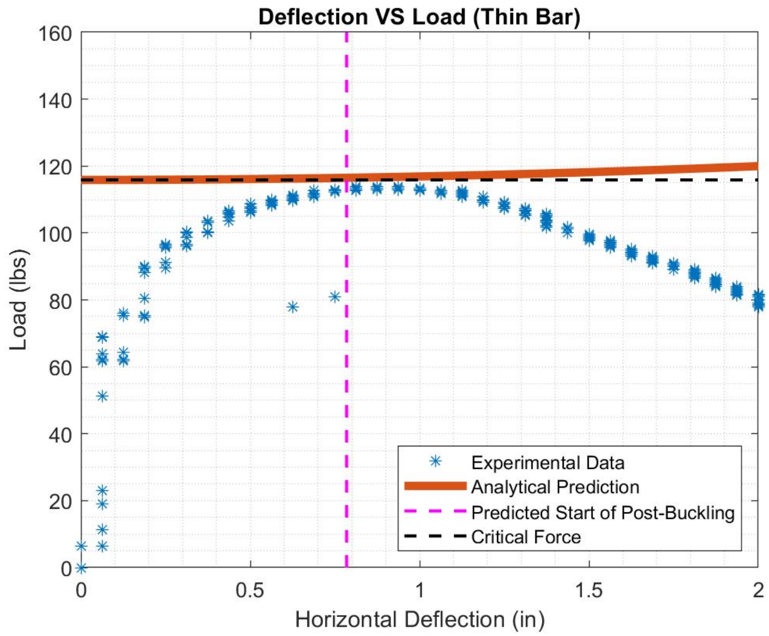

Fig. 1 Deflection VS Load (Bar)

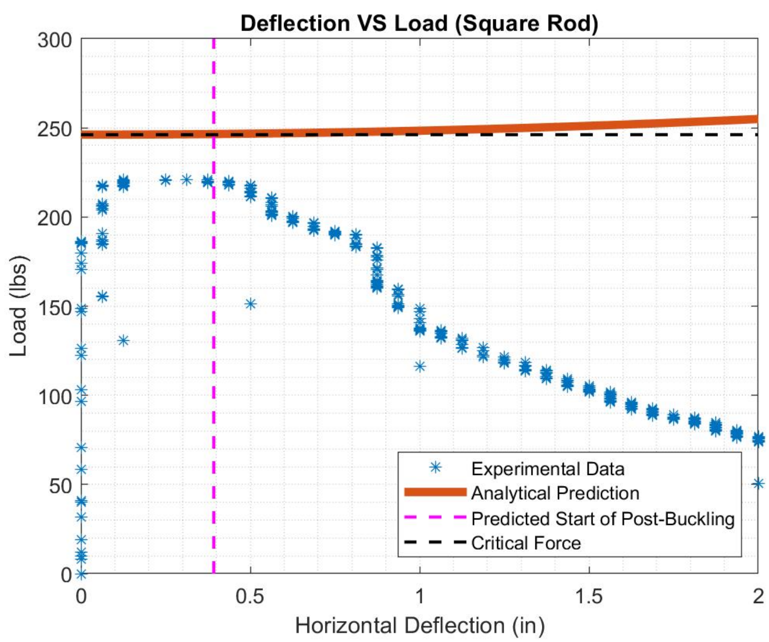

Fig. 2 Deflection VS Load (Rod)

III. Theoretical Design Study

The data used for this design study are as follows:

- Yong's modulus E = 10000000 psi ($6.895 \times 10^{1}0$ Pa)
- Yield stress σ_y = 35000 psi (2.413×10^{8} Pa)
- Beam cross-section dimension l = 0.125 in (0.0032 m)

- Beam cross-section dimension $w = 1$ in (0.0254 m)
- Beam second moment of area $I = 4.3357 \times 10^{-9}$ m^4)
- Beam query lengths: from 0.1 to 0.5 meters
- Effective length for simply supported case: $k = 0.7$
- Effective length for fixed support case: $k = 0.5$

Further, the critical load that will cause bucking can be computed per the equation:

$$P_{cr} = \frac{\pi EI}{(kL)^2} \tag{2}$$

The compressive applied force F that will cause yielding can be computed from:

$$F_y = \sigma_y A \tag{3}$$

Now, the buckling load and compressive stress yielding load can be plotted:

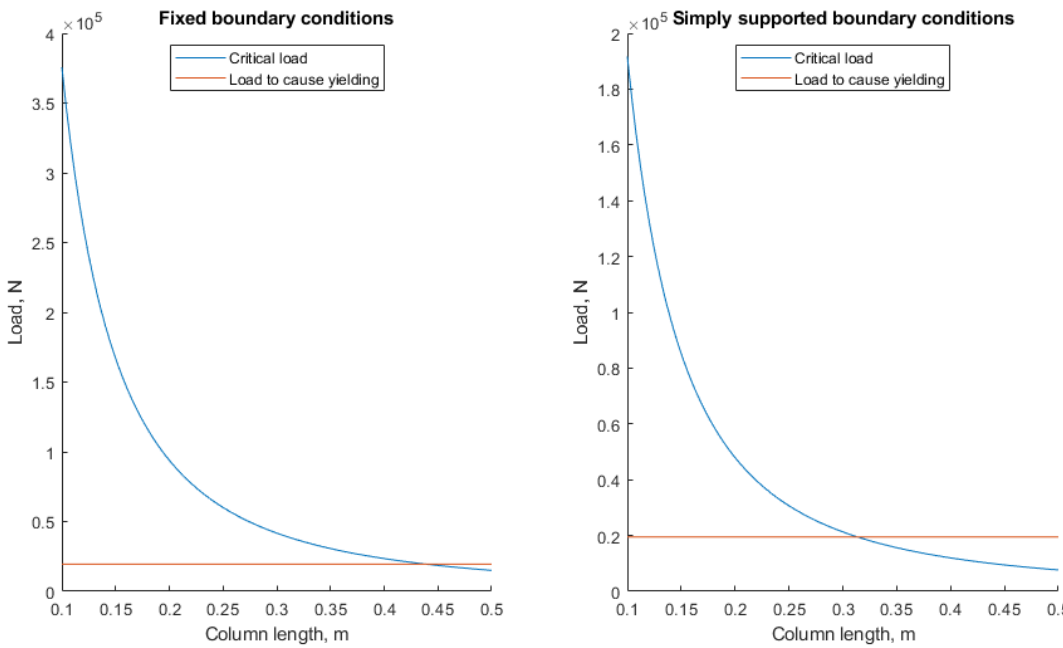

Fig. 3 Buckling load vs. length for differing boundary conditions

This figure shows that at shorter column heights, the column will fail due to reaching yield stress before it buckles. But, with taller columns, the column buckles before it fails under compressive stress. Further, in each case the load to cause yielding is identical since the cross-sectional areas and yield stresses are identical. However, for any given length, the simply supported beam requires less applied force to buckle. This is due to the fact that the simply supported beam has a longer effective length.

IV. Conclusion

In this lab an investigation was conducted regarding the buckling of beams. This involved the analysis of buckling load of two different beams, analyzing the post-buckling behaviour, and the theoretical design study regarding boundary conditions.

For the first part, when comparing analytical and experimental buckling loads, the values are relatively close to each other. The rod has a higher percent difference than the bar however. This could be due to initial imperfections of the rod. Regardless, the equation used to derive the predicted buckling load value is in agreement with the experimental values

Analysis of the post-buckling behaviour shows a disconnect between the analytical prediction and experimental prediction. This is due to the non-linear nature of buckling behavior with a clear elastic and plastic region. However, the predicted start of post-buckling corresponded well to the experimental values.
The design study showed how boundary conditions and length affects the buckling load. Notably, a shorter column length means that the critical load will be higher, but fixed boundary conditions will have higher critical loads than simply supported boundary conditions.

Acknowledgements

Special thanks to the following for their help during the challenging portions of this lab.
Dr. Hussein
All TAs

V. Appendix

A. Participation Report

Team Member	Experiment	2.1	2.2	2.3	Report	Total Score
Matthew Bridges:	2	1	2	1	1	100
Marin Grgas:	2	1	1	1	2	100
John Hugo:	2	1	1	1	1	100
Aidan Sesnic:	2	2	1	1	1	100
Chris Nylund:	2	1	1	2	1	100
Panitnan Yuvanondha:	2	2	2	1	1	100
Joshua Seedorf:	2	2	2	1	1	100

Table 3 Participation table is scored as follows: 2 - Lead Section, 1 - Worked On, 0 - Not Responsible For. Total Score is a numerical reflection of team members' contributions out of 100.

B. Code

C. Code to perform analysis for question 3

```
%% Script for question 3 of ASEN3112 Lab 4

% Aidan Sesnic
% 26-April-2020

% Housekeeping
clear
clc
close all

%% Define parameters of columns

% Baseline parameters
E = 10000000; %Young's modulus in PSI
sigma_y = 35000; %Yield stress in PSI
l = 0.125; %Cross section dimension 1, in
w = 1; %Cross section dimention 2, in

% Convert to SI units
E = E * 6895;
sigma_y = sigma_y * 6895;
```

```
l = l * 0.0254;
w = w * 0.0254;

% Find beam parameters
A = l*w;
I = (w^3*l)/12;

% Query lengths
L = linspace(0.1, 0.5, 100); %Query from 10cm to 0.5m

%% Analysis for different boundary conditions

% Simply-supported / simply-supported
k_ss = 0.7; %From lecture notes
Pcr_ss = (pi*E*I) ./ ((k_ss .* L).^2);

% Fixed / fixed
k_fixed = 0.5; %From lecture notes
Pcr_fixed = (pi*E*I) ./ ((k_fixed .* L).^2);

% Force to cause yielding in compressive loading
F_y = sigma_y * A;

%% Plots
figure

% Simply supported
subplot(1, 2, 1);
hold on
plot(L, Pcr_fixed);
plot([L(1), L(end)], [F_y, F_y]);
title('Fixed boundary conditions');
xlabel('Column length, m');
ylabel('Load, N');
legend('Critical load', 'Load to cause yielding', 'location', 'best');

% Fixed
subplot(1, 2, 2);
hold on
plot(L, Pcr_ss);
plot([L(1), L(end)], [F_y, F_y]);
title('Simply supported boundary conditions');
xlabel('Column length, m');
ylabel('Load, N');
legend('Critical load', 'Load to cause yielding', 'location', 'best');
```

References

[1] Hussein, Mahmoud "ASEN 3112 Lab 3" published on Apr. 23, 2020, pp.1-9.