Lab #6

Buckling Analysis of an I-Beam

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Department of Mechanical Engineering

ME 37100 Computer Aided Design

Section 1EF

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Abstract

In this lab, mode of failure due to static and buckling loads will be examined for different geometrical configurations of a I beam. A U shaped I beam was seen to have failed first due to buckling load while a straight I beam was seen to have failed under the static loading. Such conclusion was made by either calculating or utilizing the FEA to determine factor of safety for both static and buckling cases.

Introduction

FEA is used as a way to determine failure modes and stress concentrations in a design to understand what to optimize for during operations. Proper conclusions to be drawn from such analysis is needed before accepting values seen from software. In such cases such as understanding the singularity caused by the constraints in necessary to avoid misleading calculations.

Modes of failure is different and important to understand based on the usage of the structure. FEA can be a method used to understand the point of failure but also a method to optimize design by looking for geometries that avoid the main usage of a design. Under high compressive loads, it would be optimal for using buckling analysis or torsional analysis needed for shafts. Determining materials, shape, profile can all be done by a preliminarily FEA study.

Theoretical Background

In determining whether the structure fails, it must be evaluated during a static and buckling study. To determine whether they fail, the factor of safety must be greater than 1.

To check for failure under static loading, the yield factor of safety can be found using the following equation, where σ_y represents ti yield stress of the material (260 MPa) and $\sigma_{y=}$

$$FOS_y = \frac{\sigma_y}{\sigma_{max}} \text{ (1)}$$

$$Buckling\ Load\ Factor = \frac{Buckling\ Load}{Applied\ Load} \text{ (2)}$$

$$P_{cr} = \frac{\pi^2 E\ I}{(L)^2} \text{ (3)}$$

$$FOS = \frac{P_{cr}}{P_{applied}} \text{ (4)}$$

Manual Calculations

The applied load used is 5000 N for both parts of the lab, with the opposite end being fixed. For the given material used for the analysis (Alloy Steel) the material and needed mechanical properties for the calculations are:

$$E = 210\ GPa$$

$$S_y = 620\ MPa$$

In the first portion of the lab, in determining the failure modes of a curved I beam, both a static and buckling analysis must be done. To determine the yield factor of safety, equation 1 is employed:

$$FOS_y = \frac{620\ MPa}{232.2\ MPa}$$

$$FOS_y = 2.67$$

In the case of buckling analysis, the FOS is determined through the simulation as the first number found through the FOS trials, which was found to be 0.4449. The buckling load can then be calculated using equations 2:

$$0.4449 = \frac{Buckling\ Load}{5000\ N}$$

$$Buckling\ Load = 2224.5\ N$$

The same process is done with the straight I beam under static loading:

$$FOS_y = \frac{620\ MPa}{653.7\ MPa}$$

$$FOS_y = 0.948$$

To find the critical force on the straight I beam, the moment of inertia is found to be:

$$I_x = 55484.22\ mm^4$$

To find the buckling load for the straight beam, the same method is applied:

$$2.092 = \frac{Buckling\ Load}{5000\ N}$$

$$Buckling\ Load = 10.46\ kN$$

From equation 3:

$$P_{cr} = \frac{\pi^2(210 * 10^3)(\ 55484.22)}{(1657)^2}$$

$$P_{cr} = 41.883\ kN$$

To determine the factor of safety, equation 4 is applied:

$$FOS = \frac{41883}{5000}$$

$$FOS = 8.38$$

Graphical Demonstrations of SolidWorks Results

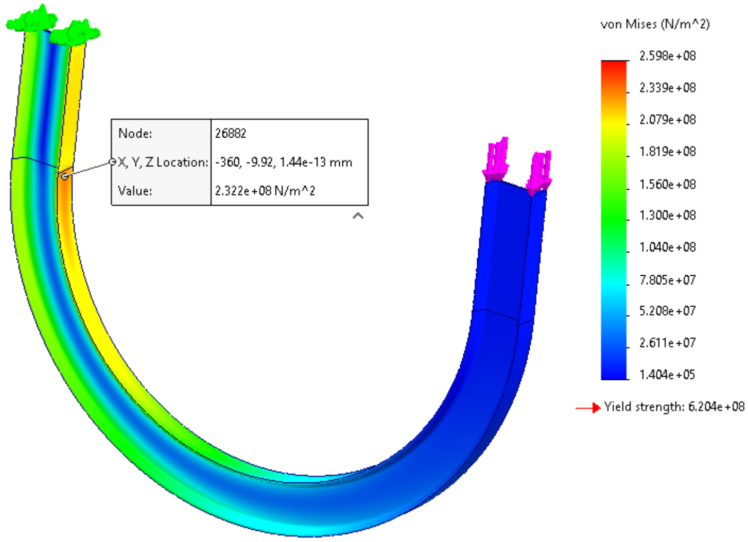

Figure 1: Max von Mises stress probed in u shaped I beam under a static load with a fixed end and 5000 N applied load.

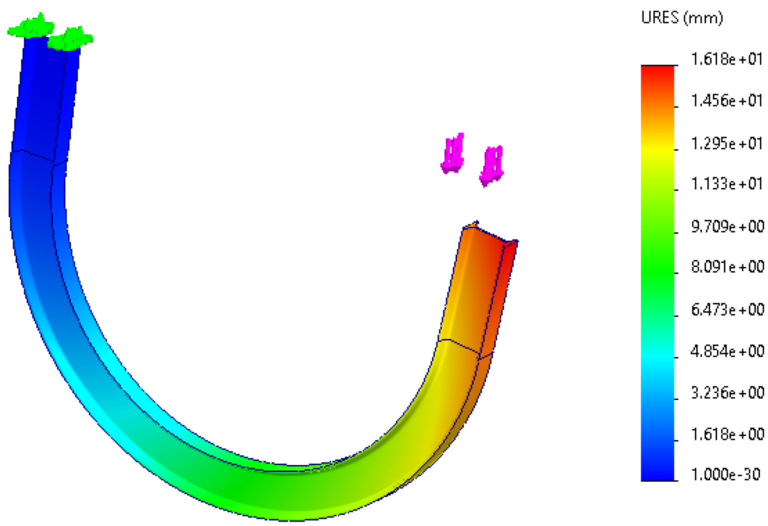

Figure 2: Max displacement plot in u shaped I beam under a static load with a fixed end and 5000 N applied load.

Mode No.	Buckling Factor of Safety
1	-8.3646

2	-3.4814
3	0.44908
4	2.751
5	6.103

Figure 3: Buckling factor of safety determined in U shaped I beam under 5 modes.

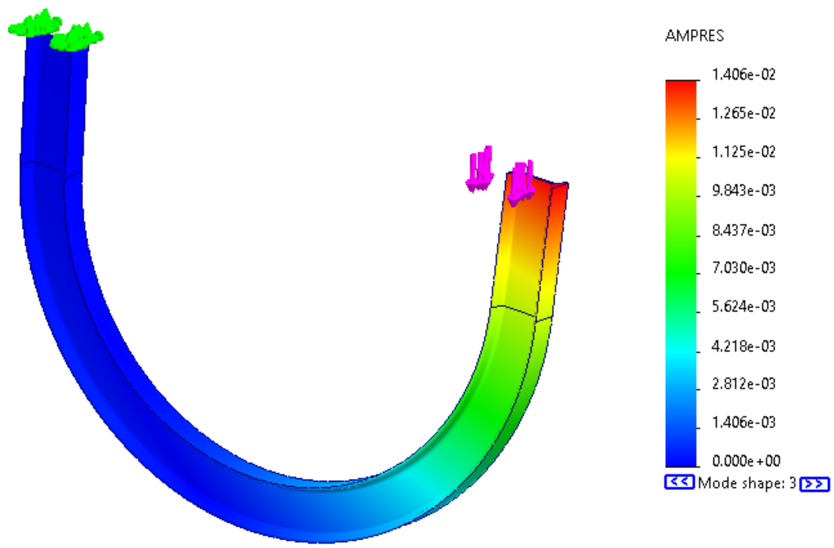

Figure 4: Max displacement plot in u shaped I beam under buckling during its 3rd mode shape with a fixed end and 5000 N applied load.

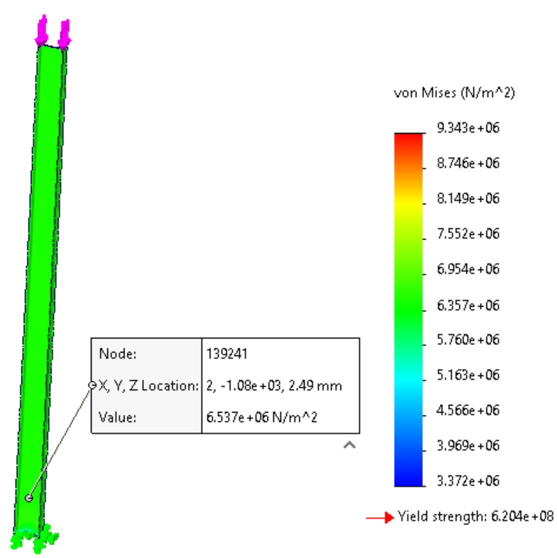

Figure 5: Max von Mises stress probed in straight 1657 mm I beam under a static load with a fixed end and 5000 N applied load.

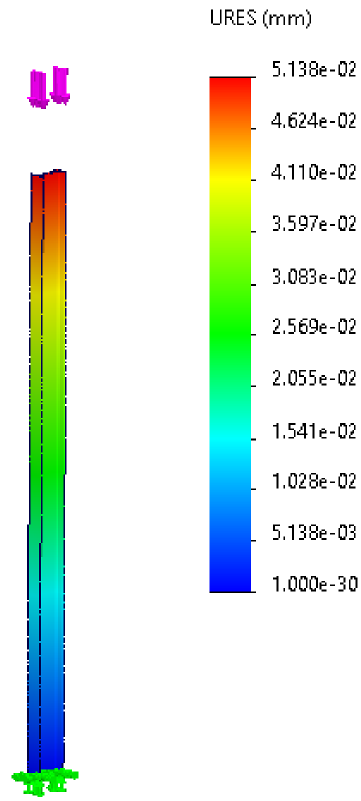

Figure 6: Max displacement plot of straight 1657 mm I beam under a static load with a fixed end and 5000 N applied load.

Mode No.	Buckling Factor of Safety
1	2.092
2	18.773
3	29.097

Figure 7: Buckling factor of safety of straight 1657 mm I beam under the first 3 modes.

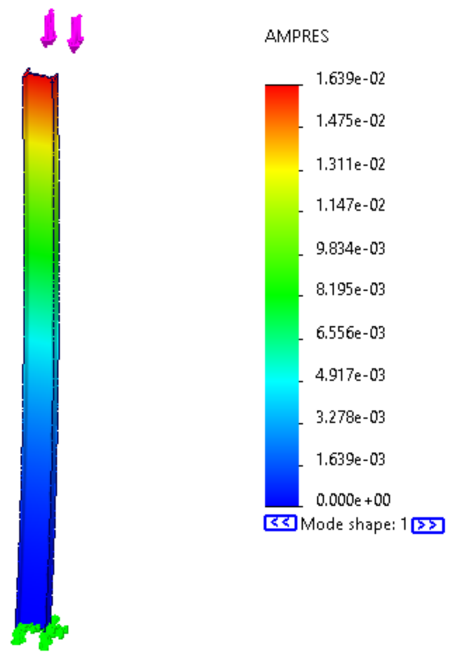

Figure 8: Max displacement plot in straight shaped I beam under buckling during its 1st mode shape with a fixed end and 5000 N applied load.

Discussion and Interpretation of Results

In the u shaped I beam, while under static load, it was determined that the structure would hold up, however by applying a buckling study, it can be observed to have failed (Figure 3). In analyzing the factor of safety under static load, the maximum stress was determined at a distance away from the fixed end, where stress is most concentrated. However due to singularity convergence of the model, the max stress was taken to be around 232 MPa. Using equation 1, the factor of safety was seen to be 2.67, meaning the structure would hold up due to a static load. With the bucking analysis, the factor of safety was seen to be at 0.4449, meaning the structure will fail due to buckling first before reaching failure due to the static loading. In the second portion of the lab, analyzing the failure in the straight I beam, it can be seen that the I beam will yield prior to buckling failure for the applied force with a factor of safety 0f 0.948 under static loading and 2.092 (Figure 6) under buckling. Though, depending on the material's material property, the beam may not necessarily fail under static load but more so deform (reaches its plastic region).

Such different results yielded by the two shaped despite the same load conditions, materials and profile is due to the fact that a u shaped I beam experiences more deflections prior to yielding. The I beam is susceptible to torsion and cannot resist torque. In such cases which such high torque, buckling will often be the deciding mode of failure. For a straight I beam profile, its higher moment of inertia about the x axis makes it significantly more resistant to buckling under the compressive loading. As seen in the calculations, the critical force for the straight beam was found to be 41.883 kN, higher than the 10.46 kN buckling load. an important note of this analysis is the displacement plots seen in figures 2,4,6 and 8 are for linear cases but due the torsional effects, the displacements may be out of plain, yielding the results not important.

Conclusions

Understanding the loading cases necessary to study is crucial even prior to utilizing FEA. It is important to understand the possible loading failure or yielding rather than testing for all possible cases to save both time and cost. In this analysis two shapes were compared under static and buckling loading. The straight I beam was seen to yield due to static loading prior to buckling, in the case of the U shaped I beam. Based on the applications of the shape, its important to consider the moment of inertia maximizations to be able to hold more compressive loading.

References

[1] Engineering Analysis with SolidWorks Simulation 2024, by Paul Kurowski (2024), ISBN-10: 1630576298.

[2] A First Course in the Finite Element Method, Enhanced Edition, 6th Ed., by Daryl Logan (2022), ISBN-10: 0357884140