Assignment 5 – Design and Stress and Buckling Analyses of a Beam Structure

Referring to the design space shown in **Figure 1**, your goal is to design a tower that will support a certain amount of dead load mass at the top of the tower. The tower must be composed solely of beam members that fit in the given space and supports a mass of 36,000 kg that is elevated at 20 m. The tower must also support its own weight and a given wind load. The design space occupies a 5 m x 5 m x 20 m volume. In so doing, you should be driving your structural design to a *mass budget of 3600 kg* without compromising its structural integrity that is defined below. In other words, your structure's mass may not exceed 3600 kg. In addition, your beam member cross sections must be square and hollow and limited to 2 sizes: Large and Small, as indicated in the figure. It is your task to determine the unknown dimensions X, T, x, and t.

The tower members are made of Structural Steel found in the Engineering Data tool: Modulus of elastic is 200 GPa, Poisson's ratio 0.3, density 7850 kg/m3, and yield strength, S_y, 250 MPa.

Its structural integrity is defined by two quantities: The strength of its individual structural members determined by static stress analysis, and its buckling strength defined by linear (Eigenvalue) buckling analysis.

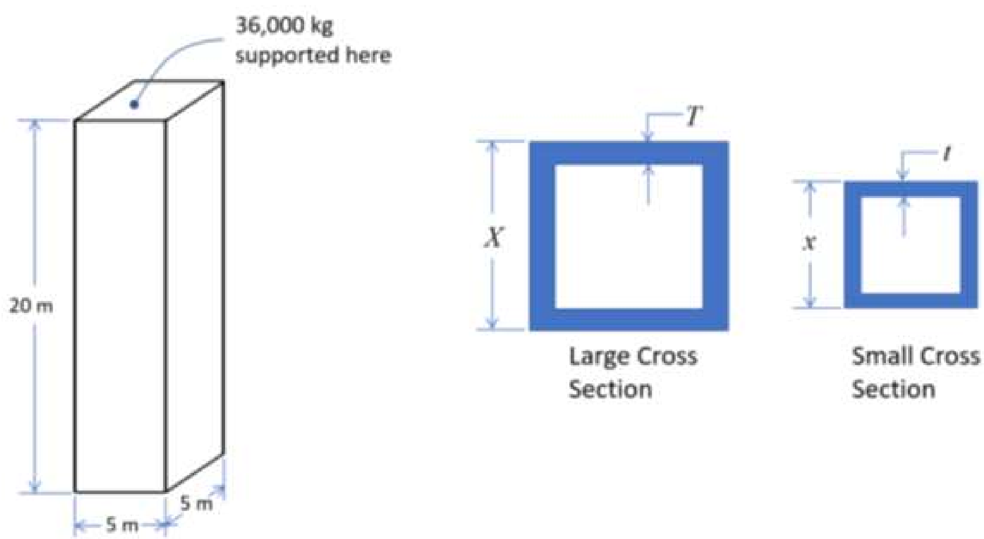


Figure 1

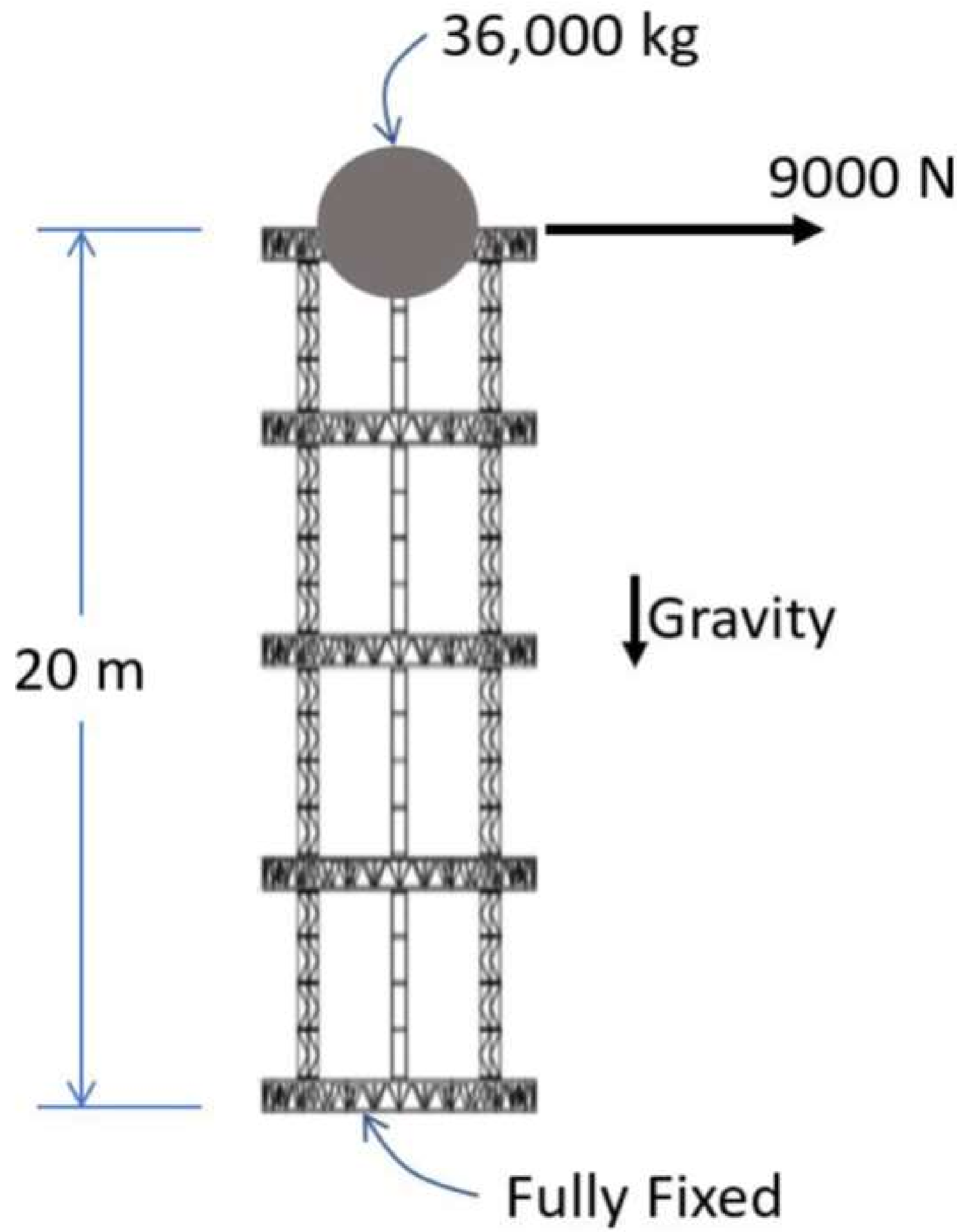


Figure 2

Stress Analysis

Referring to **Figure 2**, the base of your beam model should be fully fixed. *(please note, this is purely a schematic of the tower – your chosen geometry can be completely different)*

Specifically, all 6 nodal DOFs are fixed for any beam member or beam vertex that touches the ground. The dead load is gravity that is applied simultaneously to the structure (its dead weight) and to the 36,000 kg supported mass at the top of the structure. There is also a live wind load of 9000 N applied horizontally to the top of the structure. The supported mass should be evenly disturbed via point masses on the very top plane of the structure. Likewise, the wind load should be applied evenly to the top of the structure.

Use the Beam Tool to determine the direct, bending, and minimum and maximum combined stresses in all beam members. The combined stresses are the direct plus minimum bending stress and the direct plus maximum bending stress. These are referred to as “Minimum Combined Stress” and “Maximum Combined Stress” in the Beam Tool.

Structural integrity is achieved when the combined stresses for all beam members are less than the yield strength with a safety factor of 5. That is, combined stresses for all beams are less than $S_y/5$ = 50 MPa. Calculate and report the minimum stress factor of safety, FS_{stress}, for your structure as follows:

$$FS_{stress} = \min_{\substack{\text{For all beam}\\ \text{elements}}} \left\{ \frac{S_y}{|Min\ \ Combined\ \ Stress|}, \frac{S_y}{|Max\ \ Combined\ \ Stress|} \right\}$$

$$FS_{stress} > 5$$

Linear, Eigenvalue Buckling Analysis

Again, the base of your beam model should be fully fixed. You won’t need to apply this constraint nor any loads because you will use the prestress load and solution from your stress analysis above to set up your buckling analysis. Compute the minimum buckling load, which needs to be greater than 10. This is referred to as the “Load Multiplier” in the Mechanical Solution folder, and you should report the minimum Load Multiplier as the buckling factor of safety, $FS_{buckling}$, and that value must be greater than 10:

$$FS_{buckling} > 10$$

Notes and Guidance

1) Write a summary report (no more than 5 pages in Word docx/pdf format, including a title page), showing and explaining your design, your assumptions, your analysis approach, and primary results (See note 6 below). You may attach extra graphical result displays to your report's appendix (strictly optional).

2) The height of your beam structure must be exactly 20 m tall. Its width and depth must fit in the 5 m by 5m space indicated in Figure 1. In addition, your structure must have at least 30 distinguishable load-bearing members, and it must be fixed to the ground with at least 2 points. All ground support points must be separated by at least 1 m.

3) 40% of your grade, 40 points, will be based on your engineering approach, achieving the mass budget of 3600 kg (or less), and how well it is documented. 20-30 points for achieving a high stress factor of safety ($FS_{stress} > 5$). 20-30 points for achieving a high buckling factor of safety ($FS_{buckling} > 10$). **The higher safety factors will receive the higher points**.

4) No mesh convergence studies are needed. Use the default FE mesh. For this assignment, we are not interested in high accuracy because we have very high factors of safety.

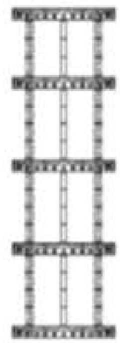
5) With the given mass budget, it might or might not be possible to design a structure that satisfies the conservative factors of safety (5 and 10) without a few design choices and iterations

6) *At the front of your report indicate your tabulated results, final design, and selected cross-section dimensions in the format suggested below*. All numbers in **Figure 3** are "made up."

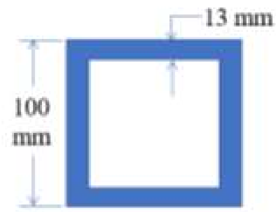
7) You are free to choose the cross-section/profile shape of the tower. The profile need not be constant throughout the height. Innovative profile designs (and justification) will receive extra points.

Mass (kg)	3378
FS_{stress}	17.2
$FS_{buckinng}$	12.6

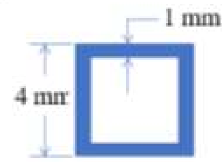
Mass and Factors of Safety
(*Purely made up numbers!*)



Our Structure
(310 members)



Large Cross
Section (140
members)



Small Cross
Section (170
members)

Figure 3