

JHU Department of Civil Engineering
560.141: Perspectives on the Evolution of Structures
Spring 2006

Homework #3: The John Hancock Building
Due in class on Wednesday March 8th

Your task in this assignment is to evaluate the factor of safety of the columns of the John Hancock tower for resisting combined wind and gravity loads, and then determine what wind speeds would have to occur to create tension in the windward columns of the tower and also what wind speeds would have to occur to reduce the safety factor to 1.

The following pages contain an outline of a simplified analysis of the Hancock Tower. You should read this carefully to help you in completing the assignment.

Tasks:

1. For the base of the Hancock Tower, calculate the force in the columns due to combined wind and gravity loads along the windward and leeward sides of the building.
2. Calculate the factor of safety for each set of columns.
3. Comment on the factor of safety you have calculated. Does it seem large or small? What do you think is the relationship between the factor of safety and the economy and safety of a structure? Why do we not design structures with a factor of safety of 1?
4. The wind force of 10.6 k/ft that you have used in your calculations corresponds to a wind speed of 90 mph. The force is related to the wind speed by the equation

$$\text{Wind Force (k/ft)} = 0.0013(\text{Wind Speed (mph)})^2$$

Calculate the wind speed that would have to occur to reduce the minimum factor of safety to 1.

5. Calculate the wind speed that results in tension in the windward columns. That is, the wind speed for which the tension caused by the wind is equal to the compression caused by gravity.
6. Comment on the results of your calculations regarding the wind speed. Do these wind speeds seem likely to occur? Are they larger or smaller than you expected?

Formatting: Use engineering or graph paper for this assignment and staple all sheets together. Start each task on a new page, showing all calculations.

Objectives

The objectives of this structural study are to (1) discover how the John Hancock Building in Chicago resists wind and gravity loads, (2) how to combine structural effects of wind and gravity loads, and (3) learn how to calculate and interpret a structural factor of safety.

Project Influences

John Hancock Insurance commissioned the design of a Chicago skyscraper in 1966. Their vision was a grand commercial and residential structure serving in harmony with the existing skyline on Michigan Avenue. Their mixed-use criterion was not easily accommodated with traditional high-rise building forms, and therefore presented a unique structural and aesthetic challenge. Structural engineer Fazlur Kahn led the creative design effort of this new building with architect Bruce Graham while employed by the architecture and engineering firm Skidmore, Owings, and Merrill. Their solution, the John Hancock Tower (figure 1), combines a unique external structural form with a strong skyward elegance. In addition to the roughly 827,000 sq. ft. of office space, the Tower contains 711 apartments that have attracted such famous tenants as the late Chris Farley (Saturday Night Live, Tommy Boy) and Oprah Winfrey. When completed in 1969, the Tower was the second tallest building in the world.

h (ft)	W (ft)
0	165
400	140
600	130
800	120

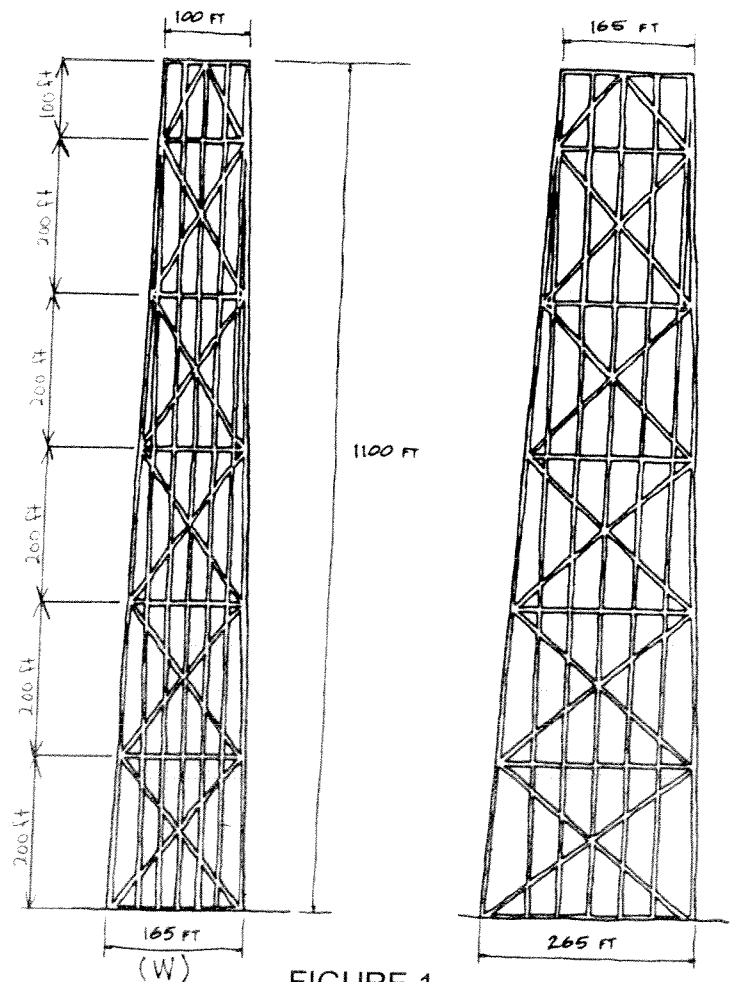


FIGURE 1.

Structural Characteristics

The Hancock Tower is a 100-story, 1127 ft. tall skyscraper. The building is designed to resist wind and gravity loads using an interior reinforced concrete core and an exterior steel frame which is incorporated into the facade. By shifting a large portion of the supporting structure to the outside skin of the building, interior columns are eliminated (figure 2). This allows maximum usability of the floor space at each story, one of the main criteria for a building accommodating both residential and commercial tenants.

The concrete core and steel frame work together as a column to transmit the weight of the individual floors to the ground. The steel frame behaves as a cantilever under the action of wind. Its network of vertical columns, horizontal beams, and diagonal struts stiffen the building and prevent excessive side sway at the higher stories.

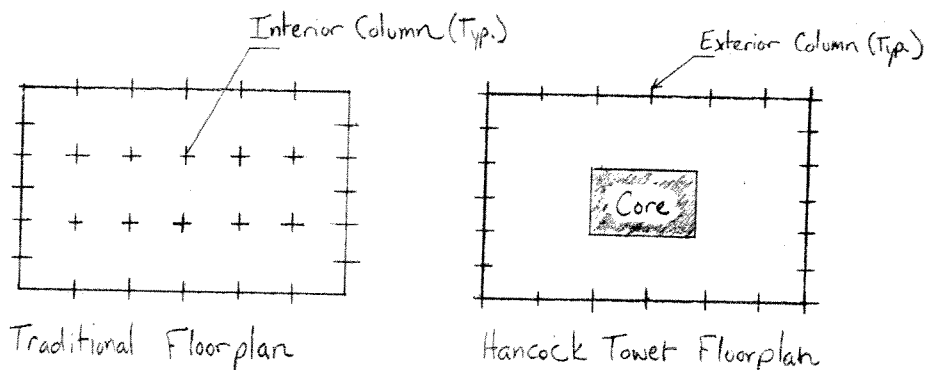


FIGURE 2.

Simplifying the Structure

In this study, we will concentrate our efforts on understanding the behavior of the most visible part of the structural system, the exterior steel frame. Two assumptions will be made that allow us to analyze the steel frame as its own structure, separate from the core. The first assumption is that fifty percent of the building's gravity load is carried by the external steel frame, and the other fifty percent is carried by the concrete core. The second assumption is that the steel frame resists the entire wind load applied to the structure.

Design Loads

The three dominant loads acting on the Hancock Tower are its self weight, the live or occupancy load, and wind. The total downward force from the self weight of the Tower is approximately 462,000 kips and for live load is approximately 140,000 kips (figure 3).

The horizontal wind pressure is highest at the top of the Hancock Tower, and decreases near the ground. The geometry of the Tower reflects an opposing trend, where its width (and wind bearing area) is smallest at the top and increases near the ground. If we assume that the highest pressure at the top of building produces the same force as the lowest pressure on base of the building, then the wind pressure can be approximated in two dimensions as a continuous line of equal horizontal point loads (figure 4). In this study, we will apply the wind pressure to the widest face of the building (figure 1).

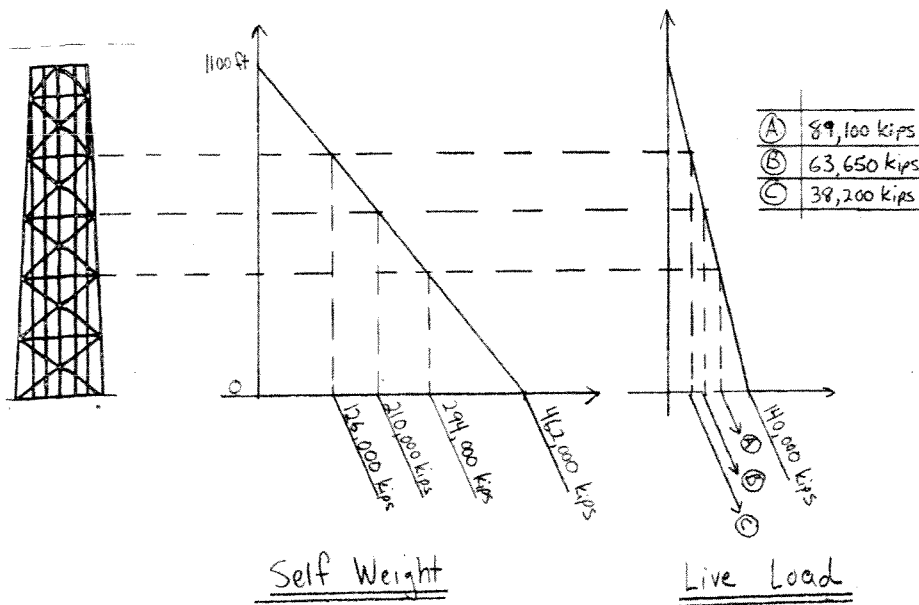


FIGURE 3.

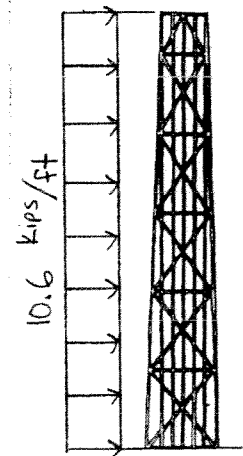
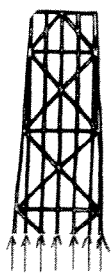


FIGURE 4.

Analysis

We will begin our analysis by determining the axial forces in the vertical steel columns due to the combination of self weight and live load. These loads accumulate, story by story, until they are transferred to the ground at the foundation (figure 3). We will assume that these vertical loads are distributed equally to the steel columns around the perimeter of the building (24 columns in total). A general equation for the axial force per column due to self weight and live load is provided (figure 5).



General Equation:
 Axial Force per Column (SW+LL)

$$F_G = \frac{(P_{SW} + P_{LL}) \times 0.5}{24}$$

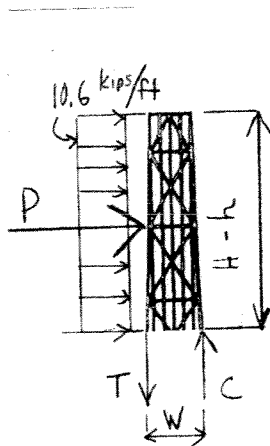
Note: 0.5 factor shares load between core and exterior tube.

(See Figure 3 for P_{SW} and P_{LL})

FIGURE 5.

Next, we will calculate the axial forces in the columns due to the horizontal wind pressure. As the wind blows, internal forces develop to resist the tendency of the Tower to tip over on its side. These resisting internal forces can be characterized as a *moment*. We will assume that only the columns in the two building faces perpendicular to the wind pressure (7 columns per face) will be active to resist the wind's overturning moment. This is a reasonable assumption since these columns are the farthest from the centerline of the building, and so will do most to resist the wind load. A general equation for the axial force per column due

to wind is provided (figure 6), where P is the total wind force, M is the moment due to wind, C and T are the total tension and compression forces to counteract this moment, W is the width of the building, and F_w is the force per column.



General Equations:

Axial Force per Column (Wind)

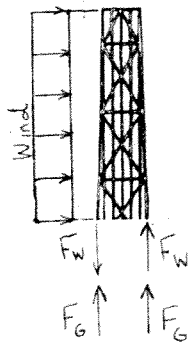
$$D = \frac{(10.6 \text{ k/ft})(H-h)}{2} \quad \text{where } H = \text{tower height}$$

$$M = \frac{P(H-h)}{2} \quad h = \text{height of section from ground}$$

$$C = -T = \frac{M}{W}$$

$$F_w = \frac{C}{7} \quad (\text{Axial force per column from wind})$$

Finally, we can calculate a *factor of safety* for columns of interest by comparing their *demand* loads to the *capacity* of a column. The factor of safety gives us a measure of the efficiency of the structure since it describes how close the calculated force is to the allowable force of the column. The allowable force is calculated by combining the allowable stress with the column area. A general equation for the factor of safety is provided (figure 7). Note particularly in the below expressions that on one face of the building the wind adds to the compressive force to due gravity, and on the other it subtracts it.



General Equations:

Factor of Safety (FS)

$$FS_{\max} = \frac{F_A}{F_G - F_w}$$

$$FS_{\min} = \frac{F_A}{F_G + F_w}$$

where $F_A = 35000$ kips
is the allowable axial
force in one column

Note:

$$F_A = 20 \text{ kips/in}^2 \cdot 1750 \text{ in}^2$$

allowable stress area of one column

FIGURE 7.

A sample calculation is provided which determines the maximum and minimum column forces due to the combination of self weight, live load, and wind at $h=600$ ft. (figure 8). The calculation then determines the minimum and maximum factors of safety for the columns at this building height.

Sample Calculation @ $h = 600$ ft:

Column Axial Force from SW + LL:

$$F_G = \frac{(210,000 \text{ kips} + 63,650 \text{ kips}) \times 0.5}{24}$$
$$= 5701 \text{ kips / column}$$

Column Axial Force from Wind:

$$P = (10.6 \text{ k/ft})(500 \text{ ft})$$
$$= 5300 \text{ kips}$$

$$M = \frac{(5300 \text{ kips})(500 \text{ ft})}{2}$$
$$= 1,325,000 \text{ k}\cdot\text{ft}$$

$$C = -T = \frac{M}{W} = \frac{1,325,000 \text{ k}\cdot\text{ft}}{130 \text{ ft.}}$$
$$= 10,192 \text{ kips}$$

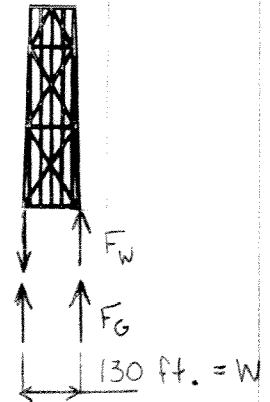
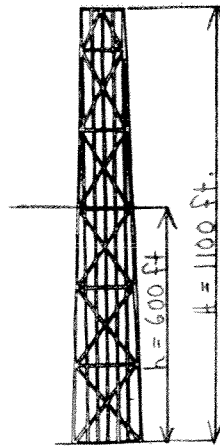
$$F_W = \frac{10,192 \text{ kips}}{7}$$
$$= 1,456 \text{ kips / column}$$

Factor of Safety:

$$FS_{\max} = \frac{35,000 \text{ kips}}{5701 \text{ kips} - 1,456 \text{ kips}} = 8.24$$

$$FS_{\min} = \frac{35,000 \text{ kips}}{5701 \text{ kips} + 1,456 \text{ kips}} = 4.89$$

at $h = 600$ ft.



Designer's Thoughts

The following quotations give us some insight into the motivations of the designers.

"It was as essential to us to expose the structure [the Hancock Tower] of this mammoth as it is to perceive the structure of the Eiffel Tower, for Chicago, honesty of structure has become a tradition."

Bruce Graham

"The technical man must not be lost in his own technology. He must be able to appreciate life; and life is art, drama, music, and most importantly, people."

Fazlur Kahn