Homework 2 Part B
Perspectives on the Evolution of Structures
(Analysis 1, Eiffel ++)
Analysis 1 and The Eiffel Tower structural study assignment

Eiffel Tower Structural Study Problems; In this assignment, you have the following tasks:
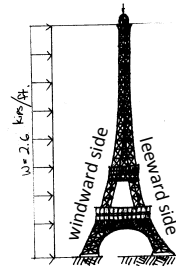**1. Calculate the force in the legs of the Eiffel tower due to wind**
(a) at the intermediate platform,
(b) the second platform,
(c) the first platform, and
(d) at the base.

Your answer should be formatted similar to the following:

Force in the Eiffel Tower due to Wind

	Windward Side	Leeward Side
	Legs 1 and 2	Legs 3 and 4
Location	(kip*)	(kip*)
Inter. platform		
2nd platform		
1st platform		
Support		

*kip=kilo-pound, 1 kip = 4.45 kN

2. Calculate the force in the legs of the Eiffel tower due to gravity (dead load)
(a) at the intermediate platform,
(b) the second platform,
(c) the first platform (NOTE: To get the dead load at the first platform you must interpolate from the diagram in Figure 3)
(d) at the base.

Your answer should be formatted similar to the following:

Force in the Eiffel Tower due to Gravity

	"Windward" Side	"Leeward" Side
	Legs 1 and 2	Legs 3 and 4
Location	(kip*)	(kip*)
Inter. platform		
2nd platform		
1st platform		
Support		

*kip=kilo-pound, 1 kip = 4.45 kN

3. Eiffel Alternate Design
Calculate what the force would be in the legs due to wind at the base if the tower legs did not spread out, but, instead, remained a constant 123 feet apart.

Finally, you should provide commentary on your results. Specifically,

4. Comment 1

Comment on the relative magnitude of the force in the legs at the base due to the wind and gravity loads, and

5. Comment 2

Comment on the comparison of the forces in the legs at the base due to wind when the tower legs either spread or do not.

In order to accomplish the tasks set out in this assignment, you should read carefully the attached description of the analysis of the Eiffel Tower. At the end of this description are the general equations for calculating the bending moment and the forces in the legs of the tower. Also shown, as an example, is the calculation at the level of the second platform. You should follow this example closely to calculate the tower leg forces at the intermediate platform, the first platform, and the base of the tower.

Formatting requirements: Show all work and include all calculations and sketches used in answering the questions. Draw a box around your numerical answers to each task. Write on only one side of the page. Start each task on a new page.

Optional supplementary information:

A much more detailed version of the Eiffel tower structural study is available at the course web site, www.ce.jhu.edu/perspectives. Read this if you would like a deeper understanding of the scientific function of the tower. Direct link:

(http://www.ce.jhu.edu/perspectives/studies/Eiffel%20Tower%20Files/ET_Introduction.htm)

Notes and help: Assume no wind pressure above top platform, use 906ft as the height; assume 2D, therefore only two legs, interpolate from Fig 3 to get dead load at first platform.

Historical Significance

At the 1889 International Exhibition of Paris, France planned to showcase its strong engineering and technological heritage. It commissioned a design competition for a "grand masterpiece" that would serve as the central landmark of the exhibition. Several hundred entries were submitted, and Gustav Eiffel, a successful engineer and metalworks company owner, emerged as the winner. Constructed in less than two years, The Eiffel Tower clearly demonstrates Gustav Eiffel's expertise in the design and construction of wrought iron structures.

Visual and Structural Influences

The Eiffel Tower stretches approximately 1000 feet from foundation to antenna, with four curved tower legs serving as the backbone of a wrought iron lattice structural network (figure 1). Wind is the dominant natural force on the Tower. The curved geometry of the main supporting legs is mathematically defined to efficiently carry the wind pressures. The use of wrought iron members minimizes the Tower's self weight and allows the wind to blow through the structure instead of bearing against it.

Table 1: Tower geometry

Location	Height (h) (ft)	Width (w) (ft)
Top platform	906	~0
Inter. platform	644	40
2nd platform	380	123
1st platform	186	216
Support	0	328

FIGURE 1.
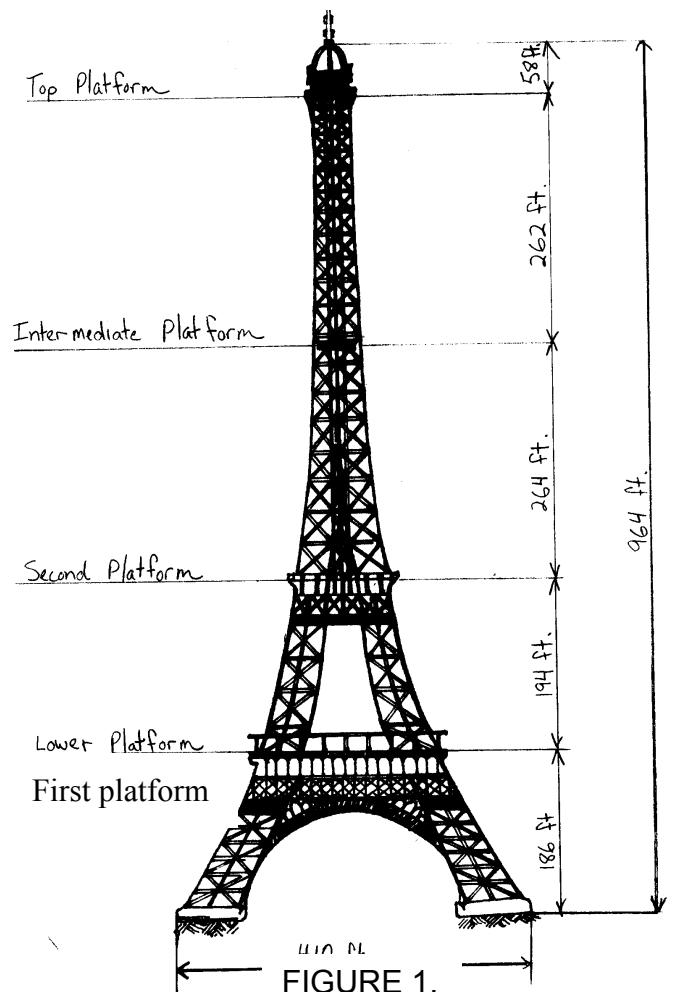
Simplifying the Structure

Before attempting to study the Eiffel Tower, a few simplifications of the Tower's geometry can be made. First, we can reduce the amount of structural members required in our analysis by assuming that the four Tower legs are the main load carrying members. Second, we can represent the thousands of individual wrought iron segments that make up each Tower leg as a set of four continuous curved columns (figure 2). **Finally, we can reduce the complexity of the three dimensional Tower geometry by compressing the four Tower legs into one two-dimensional plane as shown (figure 2).**
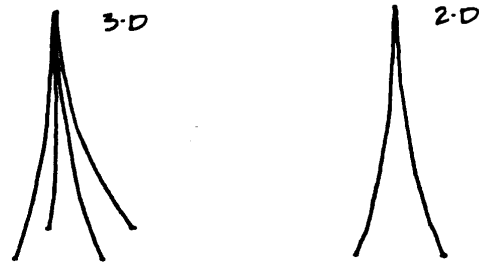

FIGURE 2.

Design Loads

The two dominant loads acting on the Eiffel Tower are its self weight and wind. The total vertical downward force from the self weight of the Tower is approximately 18,800 kips. The majority of this self weight is distributed near its base (figure 3).
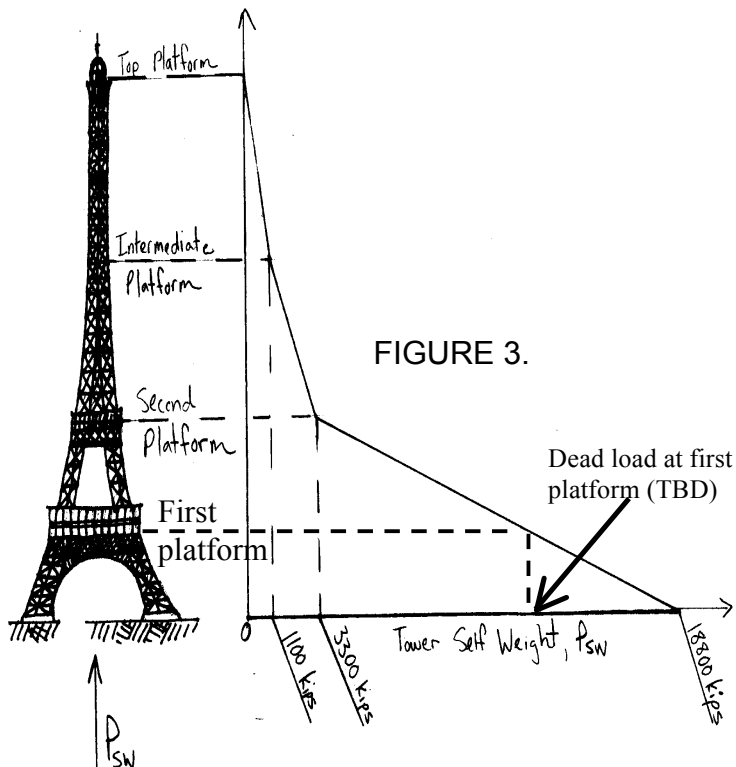

FIGURE 3.

Level	Weight above (kips)
Top platform	0
Int. platform	1100
Second platform	3300
Base	18800

Design Loads (cont.)

The horizontal wind pressure is highest at the top of the Eiffel 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 high pressure on the small bearing area (top of Tower) produces the same force as a lower pressure on the large area (near the ground), the wind pressure on the Tower can be approximated in two dimensions as a continuous line of equal horizontal point loads (figure 4). **In our analysis, we will neglect the wind pressure on the Tower above the Top Platform (figure 1). This means that in your calculations you can use 906 ft as the effective height of the tower.**
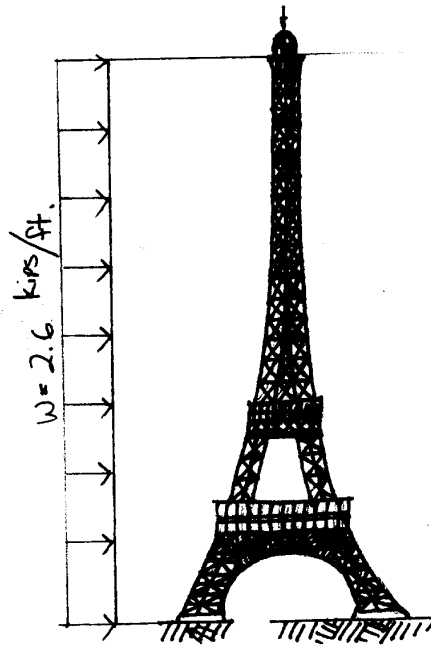

FIGURE 4.

Reactions

A free body diagram is used to graphically represent equilibrium on a structure, where the applied loads (wind and self weight in our case) are counterbalanced by equal and opposite forces called *reactions*. The Eiffel Tower is designed to transmit its own self weight and horizontal wind pressures to the ground through its internal framework. Reactions from the ground on the structure prevent the Tower from sinking into the soil or from tipping over.

Analysis

In this study, we will only concern ourselves with the behavior of the Tower as a cantilever under the influence of wind (figure 4). 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.* On the following page, general

equations are presented to calculate the moment and forces in the Tower from wind. Also, an example is provided for the moment calculation at the Second Platform.
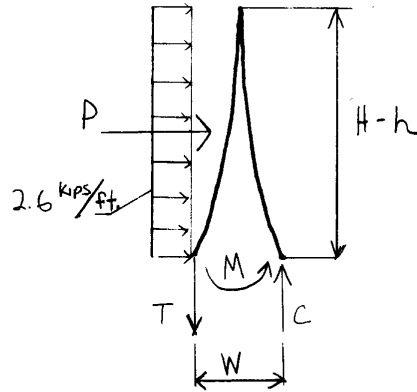
General equations for calculation of moment due to wind:

$$P = (2.6 \ ^k/_{ft})(H-h)$$

where H = tower height
h = height of section from ground

$$M = P \frac{(H-h)}{2} \qquad M \Rightarrow \text{moment}$$

$$C = -T = \frac{M}{W} \qquad \begin{array}{l} C \Rightarrow \text{compressive force} \\ T \Rightarrow \text{tensile force} \end{array}$$
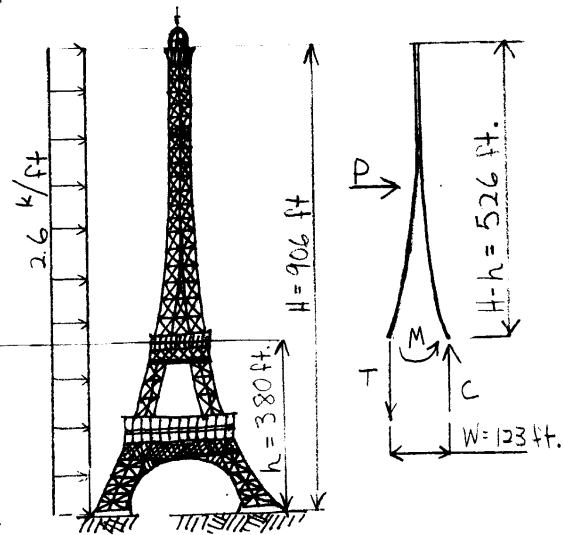
Example - calculate moment at Second Platform due to wind

$$H - h = 906 \text{ ft} - 380 \text{ ft} = 526 \text{ ft}.$$

$$P = (2.6 \ ^k/_{ft})(526 \text{ ft})$$
$$= 1368 \text{ kips}$$

$$M = \frac{(1368 \text{ kips})(526 \text{ ft})}{2}$$
$$= 359784 \text{ k·ft}$$

$$C = -T = \frac{359784 \text{ k·ft}}{123 \text{ ft.}}$$
$$= 2925 \text{ kips}$$

NOTE: Wind pressure is neglected above the Top Platform.