Title: Structural Analysis of the Washington Monument

1. Description of structure:

Historic Significance:

The Washington Monument is one of our nation's greatest and most famous landmarks. The structure was built in the 1800's to commemorate America's first president, George Washington. The monument was the tallest man-made structure in world when it was completed. The Washington Monument is located only a few blocks from the White House in our nation's capital, Washington, D.C., where many tourist come from around the world to see it every year.

Complexity of Structure:

While the general obelisk shape of the structure is not very complex, the main complexity of the structure lies in the materials it is constructed of. Due to limited resources during the American Civil War the structure was built in two separate phases. The bottom 150 feet of the structure was built between 1848-1854 and was constructed of a stone mortar compound on the inside and large marble bricks on the outside set in mortar. After the war, the washington monument was completed between 1877-1888 but the material on the inside was changed to granite stones for the remainder of construction. The different materials used during construction increases the complexity of structure.

In addition to the materials, several features of the washington monument increase the structure's complexity. For example, a shaftway was built at the center of the monument in order to allow people to see the view from the top. This shaftway originally held a staircase but an elevator was later installed. The width of shaft was tapered during the second phase of construction. In addition to the shaftway, another complex feature of the monument is top pyramid section. This section is basically hollow and was built using a rib structure.

Relevant Engineering Properties:

Dimensions:

Base Width = 55' (square)
Base Area = 3025 ft2
Top Width = 34.5' (square)
Top Area = 1190.25 ft2
Height of Trapezoid = 500
Trapezoid Volume = 1,053,812.5 ft3
Height of Pyramid = 50'
Volume of Pyramid = 19837.5 ft3
Overall Height = 550' (measurements range from 554'-7 11/32" to 555'-5 1/8")
Overall Volume = 1,073,650 ft3

Materials:

(0'-150') Bluestone gneiss rubble in mortar Interior with white marble exterior (14"-18" thick). Includes 25' by 25' interior well (houses staircase)
(150'-450') Granite Interior with white marble exterior (18" thick)
Includes 32' by 32' interior well (houses staircase)
(450'-500') Marble exterior and interior
(500'-550') Marble capstone (rib structure) with aluminum apex
25' by 25' interior well with trapezoidal section (houses staircase)

Material Properties:

Rubble with Mortar:
E = 305 Mpa

Granite: (From https://www.makeitfrom.com/compare/Granite/Marble)
E = 70 Gpa
v = .25
G = 27 Gpa
F'c = 2200 Mpa

White Marble: (From https://www.makeitfrom.com/compare/Granite/Marble)
E = 54 Gpa
v = .2
G = 27 Gpa
F'c = 540 MPa

2. **Loading conditions:**

Static:
- Gravity loads

Quasi Static:
- Wind Loads

3. **Analysis methods**

Hand Calculations to Determine:
- Deflections at critical areas due to each loading condition.
- Internal stresses and forces at critical areas due to each loading condition.

Finite Element Analysis using the program "Abaqus" to Determine:
- Deflections at critical areas due to each loading condition.
- Internal stresses and forces at critical areas due to each loading condition.

4. Critical areas of the structure that will be analyzed in detail

Three critical areas have been identified to be analyzed:

1. At 150' - where the internal materials change from the stone mortar composite to granite.
2. At 500' - where the shape of the structure changes to the pyramid section.
3. At 550' - The top of structure where deflection should be greatest.

5. Matrix of Tasks:

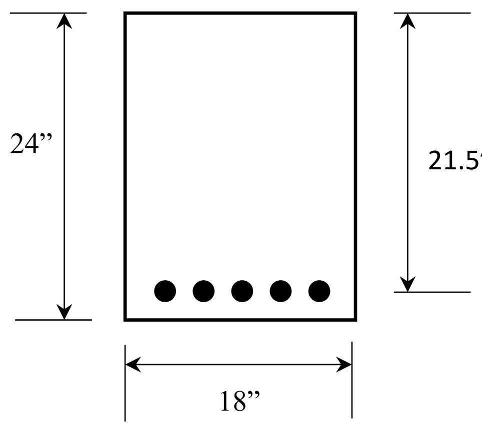
Group Members - Task(s):

Blake Huntsman - proposal, presentation powerpoint, presentation
Steven Corcoran - report, presentation
Joseph Gatto - hand calculations, presentation
Chandu Kommini - hand calculations, presentation
Daniel Offenbacker - finite element analysis, presentation
Miken Shah - hand calculations, presentation

Reinforced Concrete
Spring 2018
Homework #2

For the problems below only consider flexural stresses – you do not need to consider shear.

1. For the beam section below (f'_c=4000 psi, f_y=60 ksi) determine:
   a. M_{cr} based on gross section properties
   b. M_{cr} based on transformed section properties
   c. The cracked, transformed section moment of inertia, I_{cr}
   d. The normal stress in the steel and in the concrete at a moment of 200 ft-kip
   e. The allowable moment if the concrete stress is limited to $0.4f'_c$ and the steel stress is limited to $0.5f_y$.



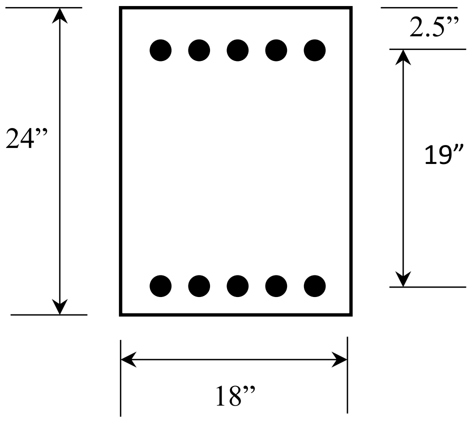
Reinforcement is 5 #10 bars (A_s = 6.35 in^2)

Stirrups not shown

2. Assuming the previous beam section is simply supported with a span of 28 feet, what uniform load could be applied to the section without exceeding the stress limits of the previous problem.

3. Assuming the beam from problem #1, what uniform load could be supported considering the stress limits from problem #1 and also concern for a brittle tensile failure in a 28 foot span with fixed end supports? Comment on any concerns you have with using that beam design with those support conditions.

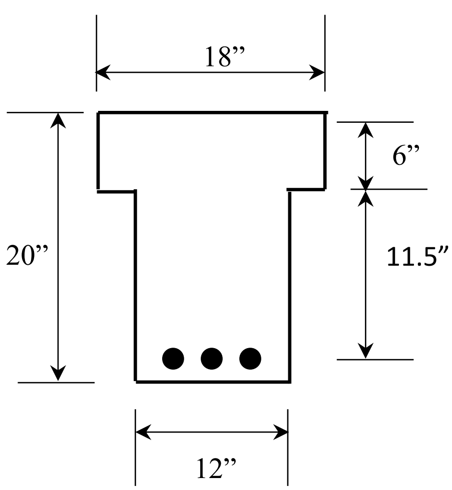
4. For the beam section below (f'_c=4000 psi, f_y=60 ksi) determine:
   a. M_{cr} based on transformed section properties
   b. The cracked, transformed section moment of inertia, I_{cr}, assuming the applied moment is positive and tension is on the lower face.



Reinforcement is 5 #10 bars (A_s = 6.35 in^2), top and bottom

Stirrups not shown

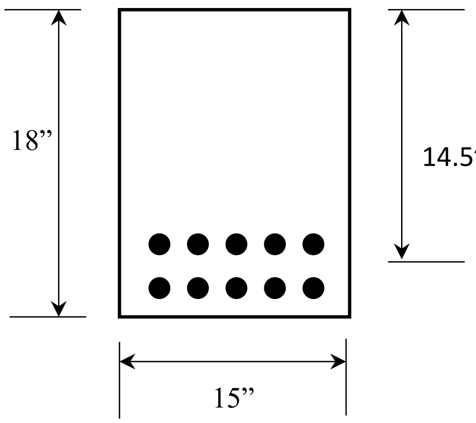
5. For the beam section below (f'_c=5000 psi, f_y=60 ksi) determine:
   a. M_{cr} based on gross section properties
   b. M_{cr} based on transformed section properties
   c. The cracked, transformed section moment of inertia, I_{cr}
   d. The normal stress in the steel and in the concrete at a moment of 150 ft-kip



Reinforcement is 3 #11 bars (A_s = 4.68 in^2),

Stirrups not shown

6. The beam shown below is simply supported and spans 15'. The beam is reinforced with bamboo rods with a total cross-sectional area of 8 in^2. What is the largest uniform load you would permit to be applied to the beam based on flexural stresses? Assume the concrete has a compressive strength of 3500 psi. You will need to find the properties for the bamboo reinforcement, establish the stress limits you'll use for the design check and justify your final decisions.



Bamboo reinforcement with a total area of 8 in^2

Stirrups not shown