SE310 Design Project I:

Truss Analysis

Kevin Mai

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**Problem Description**

Cell phone towers are elevated, high-powered antennas that transmit radio frequency (RF) signals to mobile devices in the surrounding area. They enable phone communications across large areas. With increasing amount of cell phone usage, these towers are gaining more importance. During natural calamities these structures have to support load without collapse. During wars, the terrorists/enemies tend to destroy these towers to disrupt communication lines. So, our task is to design a strike resistant cell phone tower, which implies that if one of the truss elements is damaged, the entire structure is still stable.

Diagram

Description automatically generated

**Loads**

The loads acting on the cell tower are of two kinds: horizontal load D and vertical load W. The horizontal loads may be due to extreme wind conditions, and the vertical loads may be due to the combination of the antenna weight and other loads. The vertical loads are fixed at 80 kN, while the horizontal loads D = Last five digits of your UIN applied in N. The height of the truss structure is 50 m. Design a truss structure with a square cross section that supports these loads.

**Design Objectives**

Maximize the quality of the structure by minimizing the following function:

where n is the total number of joints, m is the number of elements, xi 2 is the cross-sectional area, and li is the length of the element. The quality function is total volume of the structure penalized by the number of joints introduced in the structure.

**Design Variables**

1. Number of joints, n > 3

2) Length of each elements li (i.e., location of joints)

3) Cross sectional area xi (square cross section)

**Design Parameters**

1. High strength steel (600 MPa yield strength) with Young’s modulus E = 200 GPa, and density rho of 8000 kg/m3

2) Square cross section, i.e., Ai = xi2

3) Effective length of each truss element is equal to the actual length of the truss, i.e., leffective = li

4) Factor of Safety for stress and buckling: 4 (For each truss, calculate the internal load. If the truss is in compression, then evaluate the critical buckling load. If the critical buckling load is less than the internal load / safety factor, the truss is assumed to fail).

**Boundary Condition**

1. All the joints on the ground should be pin joints.

**Design Constraints**

1) Each of the truss elements should satisfy design constraints (stress, strike resistance and slenderness ratio).

2) Slenderness ratio constraints should be less than or equal to 500 in both tension and compression

3) Top of the tower where the antenna is mounted should be 50 m above the ground at least.

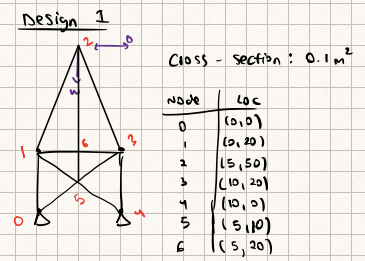
4) Width of the tower on the ground should be at least 5 m and no more than 20 m on the ground.

5) Between the top joint and the ground, there should exist at least one joint in the middle level.

6) Joints should be separated at least 2 m apart.

**Design I**

The initial design process I had started with trying to use as many triangles as possible. Since triangles only fail when an edge is removed, they are optimal in truss design. The image below is the first design.

****

The following image is the python generated structure.

Chart

Description automatically generated

The nomenclature of each beam is shown below.

Chart

Description automatically generated

The following chart is shown shows the criteria that must be met for each beam. The beams are in their respective order of the previous chart.

Graphical user interface

Description automatically generated with low confidence

We can see that the buckling, slenderness, and stress criteria are all met, however the objective function is at 169.5. The goal will be to attempt to bring this value down to about 70-100, essentially halving the current objective function value.

**Design II Design Process**

From the original design, we can see the horizontal beams coming out of node 6 can be modified to attain zero force members which results in the removal of two beams. If we remove the beam from node 6 to node 3, then node 6 to node 1 will be a zero-force member. We will try first by removing the horizontal beam at y = 20m. The resulting structure is shown below.

A picture containing text, device

Description automatically generated

The nomenclature of this structure is shown below.

A screenshot of a list

Description automatically generated with low confidence

The following chart is shown shows the criteria that must be met for each beam. The beams are in their respective order of the previous chart.

Graphical user interface, application

Description automatically generated

We can see the criteria are still satisfied and the objective function has gone down to 111.3. Unfortunately, we are unable to continue removing beams since this would result in a structure that would have no chance of being strike proof. The next approach is to lower the cross-sectional area of the beams. Looking at the stress values, we can see which values have the least amount of stress and adjust the cross-sectional areas of those beams. We will try changing all the cross-sectional areas of the beams with less than 500000 Pa of stress to 0.03m^2, and anything with less than 800000 Pa of stress to 0.05m^2. This means we will change the 5th and 10th row to 0.03m^2 and the 6th and 8th row to 0.05m^2.

The nomenclature of this structure remains the same, as shown below.

A screenshot of a list

Description automatically generated with low confidence

The following chart is shown shows the criteria that must be met for each beam. The beams are in their respective order of the previous chart.

Graphical user interface, application

Description automatically generated

We can see the objective function has gone down to 83.1 or an 51.0% decrease in value. While all the cross-sectional areas can be tweaked to lower this objective function even more, it is also important to note creating these dimensions in the real world can result in even higher production costs due to specificity. Since we do not know what the tradeoffs are for that context, we will not be adjusting the cross-sectional area anymore. This will be our current optimized design. We must now also make sure this design is strike resistant. In an event of damage to a beam, we want the structure to still be standing. The next section will test whether the structure is strike resistant or not.

**Strike Resistant Testing**

We will test whether this structure is strike resistant by removing each beam and seeing if the structure is still able to maintain the criteria. This may or may not end up increasing our objective function as the cross-sectional area might need to change.

1. **Removing Beam 0 – 1**

After removing the beam, all the criteria are not met. To fix this, the cross-sectional area for Beam 2 – 5 has been increased to 0.12m^2. The structure is shown below.

Chart, radar chart

Description automatically generated

The criteria results are shown below.

Table

Description automatically generated

Note our objective function will increase once the removed beam is placed back in with the newly changed cross-sectional area value.

1. **Removing Beam 1 – 2**

After removing the beam, all the criteria are met. The structure is shown below.

Chart

Description automatically generated

The criteria results are shown below.

Graphical user interface

Description automatically generated

1. **Removing Beam 3 – 4**

After removing the beam, all the criteria are met. The structure is shown below.

A screenshot of a graph

Description automatically generated with medium confidence

The criteria results are shown below.

Graphical user interface, text, application

Description automatically generated

1. **Removing Beam 4 – 5**

After removing the beam, all criteria are met. The structure is shown below.

**A screenshot of a graph

Description automatically generated with medium confidence**

The criteria results are shown below.

Table

Description automatically generated with medium confidence

1. **Removing Beam 5 – 1**

After removing the beam, the criteria are met. The structure is shown below.

A picture containing text, device

Description automatically generated

The criteria results are shown below.

Graphical user interface, application

Description automatically generated

1. **Removing Beam 3 – 5**

After removing the beam, the criteria are met. The structure is shown below.

A picture containing text, device

Description automatically generated

The criteria results are shown below.

Graphical user interface

Description automatically generated

1. **Removing Beam 5 – 0**

After removing the beam, the criteria are met. The structure is shown below.

A picture containing text, device

Description automatically generated

The criteria results are shown below.

Graphical user interface

Description automatically generated with medium confidence

1. **Removing Beam 2 – 3**

After removing the beam, the criteria are met. The structure is shown below.

Chart

Description automatically generated

The criteria results are shown below.

Graphical user interface, application

Description automatically generated

1. **Removing Beam 2 – 5**

After removing the beam, the criteria are met. The structure is shown below.

A screenshot of a graph

Description automatically generated with medium confidence

The criteria results are shown below.

Graphical user interface

Description automatically generated

**Recalculating Objective Value**

Since the original design was not strike resistant, some changes had to be made. These changes resulted in a new objective value.

The criteria results are shown below.

A screenshot of a computer

Description automatically generated with medium confidence

Here we can see the objective function has increased to 111.9 from the previous 83.1. This means from Design I, our current objective function decreased by 34.0% decrease.

**Discussion**

The resulting structure satisfies all the constraints; however, the objective function is not at where I expected it to be. The resulting value is a little over the range of where I wanted to. As previously mentioned, changing the cross-sectional area meticulously one by one is an option, but the time required, and the manufacturing of these dimensions might unwarranted tradeoffs in the real world.

**Reflection**

This project was interesting in the sense that is this something an engineer in the real world does. I am sure trial and error is a method that can be used in the real world, but to what extent and how specific do they apply these methods. The project had a learning curve as even the smallest change makes a big different in satisfying the criteria. This is important since this also shows that in the real world, small changes are important to consider.