STABILITY & STRESS ANALYSIS FOR COMPRESSION MEMBERS IN THE BURNING MAN TENSEGRITY STRUCTURE

1. INTRODUCTION

A stability and stress analysis was performed for the aluminum compression strut members in the tensegrity structure that is planned to be constructed as an art installation in Black Rock City for Burning Man 2015. The aim of the analysis was to determine the margin of safety in the structural compression members, which are key to the total structural stability.

The proposed tensegrity structure consists of compression and tension elements. This analysis applies to the structural stability and strength of compression members in the structure. The analysis was performed using the commercially available ABAQUS v.6 finite element analysis software produced by Dassault Systemes.

Performed analysis takes into account both geometric and material non-linearities to achieve an accurate solution.

2. MATERIAL AND SECTION PROPERTIES

Compression members in the structure are 8ft long 2 ½” Schedule 40 6061-T6 aluminum pipes conforming with the ASTM B308/B308 M-10 Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles. The outer diameter of the pipe is 2.875” with a wall thickness of 0.203”. The ultimate tensile strength and yield strength of the material are reported as 45 ksi and 40 ksi, respectively, by the distributor, Alcobra Metals, Inc. Section and mechanical properties of the members are given in Fig. 1.

3. EULER BUCKLING LOAD FOR COMPRESSION MEMBERS

The Euler buckling load for the compression members can be computed as:

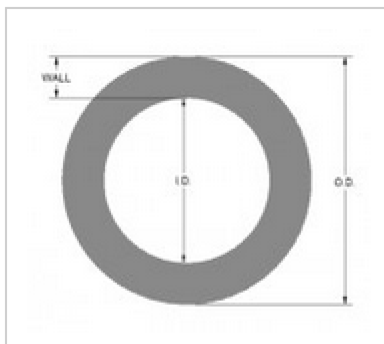
$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

where E is the modulus of elasticity of the section [ksi], I is the moment of inertia [in^4], L is the length of compression member [in] and K is the effective length factor.

For the analysis, the modulus of elasticity of aluminum, E, was taken as $10{,}100$ ksi, the moment of inertia of the pipe section, I, was computed as:

$$I_x = I_y = \pi \frac{\left(d_o{}^4 - d_i{}^4\right)}{64} = \pi \frac{(2.875^4 - 2.469^4)}{64} = 1.529\ in^4$$

The effective length factor, K, was taken as 1.0, typical for axial load transmitting truss members with both ends pinned.



Dimensions

O.D.	2.875"
Wall Thickness	0.203"
I.D.	2.469"

Mechanical Properties

Ultimate Tensile Strength	45 ksi
Yield Strength	40 ksi
Brinell Hardness	95
Elongation	10% in 2

Figure 1 – Section and mechanical properties of compression members in the tensegrity structure.

Using the parameters given above, the Euler buckling load was computed as:

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} = \frac{\pi^2 \times 10{,}1000 \times 1.529}{(1.0 \times 96)^2} = 16.5\ kips$$

This means the aluminum pipes in the structure will fail from buckling when 16,500 lbs of axial force is applied through the centroid of the sections. It should be noted that this buckling capacity will be reduced in the presence of geometric and material non-linearities.

4. GEOMETRIC AND MATERIAL NON-LINEARITY

The load capacity of a compression member depends on the Euler buckling load (from a stability point of view), as well as the yield strength of the material. However, geometric and material non-linearities should be taken into account for an accurate solution to the problem. The buckling phenomenon in a compression member is triggered by a geometric eccentricity in the load application points with respect to the centroid of the section. Another way to trigger buckling is by introducing a displacement normal to the longitudinal axis of the compression member, in order words a “disturbance”, causing a sag in the displaced shape. Due to the deformed shape of the member, the compression forces within the section cause 2nd order moment effects that may further decrease the ultimate compression load capacity. This is called the P-Δ effect.

Another pertinent parameter to the strength of the compression member is the stress-strain relationship of the material. In the consequent analysis, the aluminum material was assumed to have a bi-linear stress-strain curve with a yield strength of 40 ksi. Meaning, once the stress in the section reaches to 40 ksi, the member will go through infinite elongation, thus fail.

5. FINITE ELEMENT ANALYSIS OF THE COMPRESSION MEMBERS

The finite element analysis of the compression members was performed using a combination of geometric and material non-linearities to achieve the most accurate solution. The analysis assumes a point load of **500 lbs** applied as a live load at the midspan of a single aluminum pipe. This is to simulate people climbing the structure. Once the 500 lbs live load is applied, assuming a beam with pin supports, the midspan displacement can be computed as:

$$\Delta_{max} = \frac{PL^3}{48EI} = \frac{0.5 \times 96^3}{48 \times 10100 \times 1.529} = 0.6\ in$$

In order to compute the ultimate strength of the aluminum pipe compression elements in the ABAQUS software, the aluminum pipe was modeled using the section and material properties given by the distributor, as shown in Fig, 2.

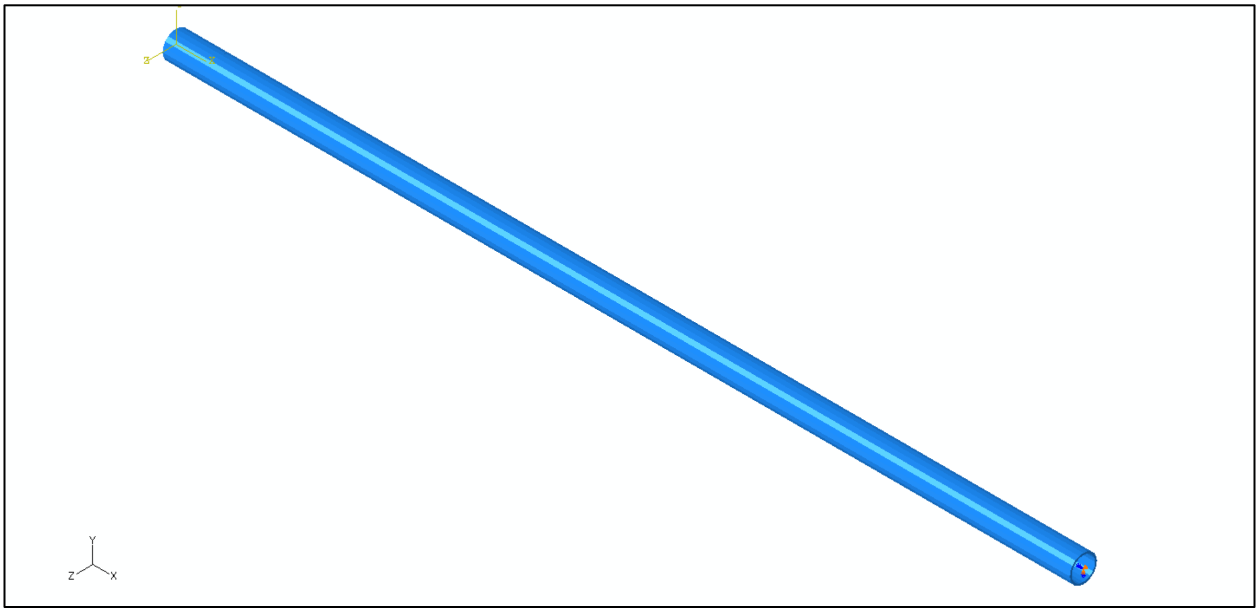


Figure 2 – Basic aluminum pipe model in ABAQUS FEA software.

For the analysis the 500 lbs load normal to the longitudinal axis of the pipe was applied to at the midspan to introduce an initial displacement to the system as a disturbance to trigger P-Δ effects, thus the buckling phenomenon. Next, the axial force that will be imposed through the turnbuckles was applied step by step to achieve the maximum axial load carrying capacity. Results from the non-linear finite element analysis with geometric non-linearity and material + geometric nonlinearities are shown in Fig. 3.

6. CONCLUSION

Based on the material and section properties reported by the distributor and the non-linear finite element results from ABAQUS, in presence of 500 lbs of live load (representing people climbing the structure) the axial capacity of the 8ft long 2 ½” Schedule 40 6061-T6 aluminum pipe was found to be around 12,000 lbs. This value takes into account both the buckling phenomenon and the material yield strength at the same time. In other words, the compression members will remain stable up to an axial load of 12,000 lbs.

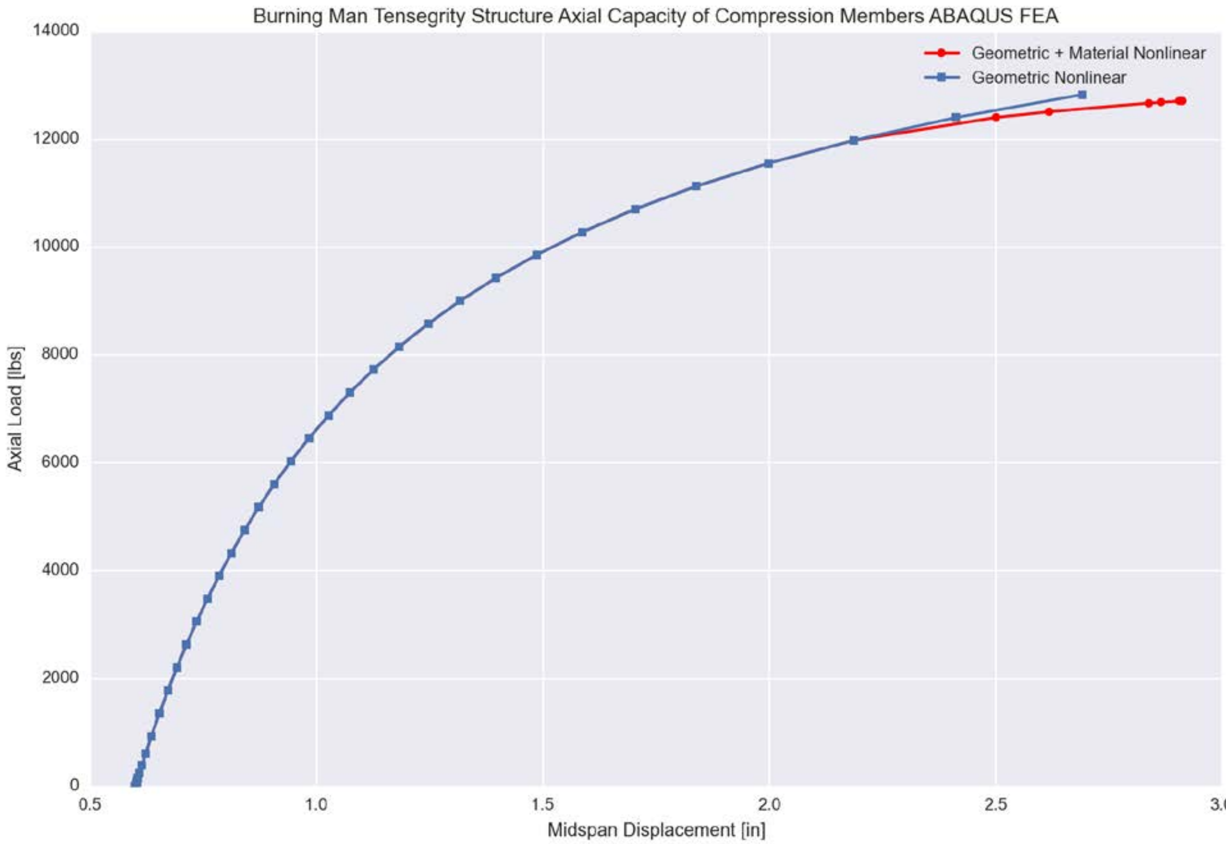


Figure 3 – Compression Capacity of Aluminum Tensegrity Members