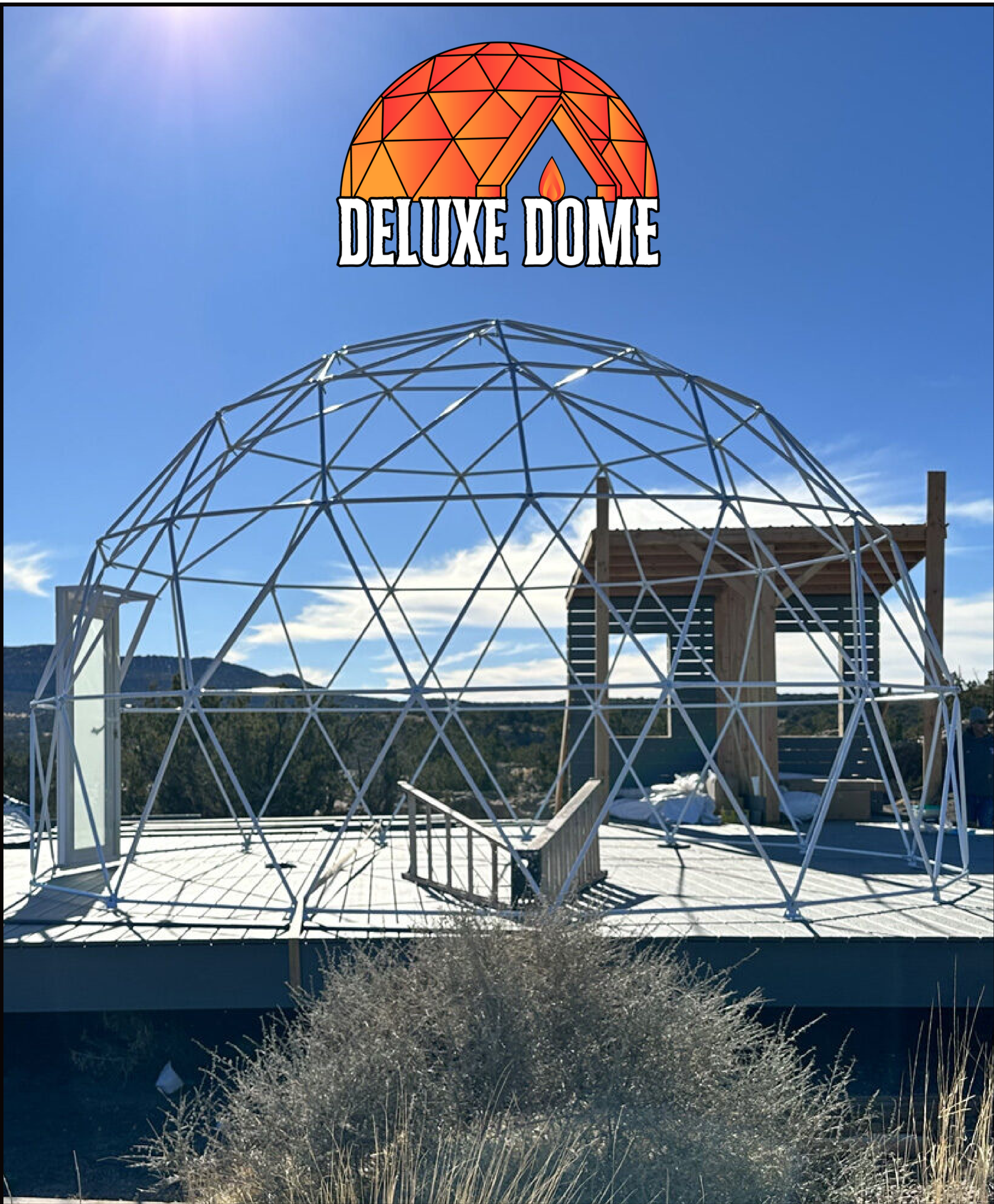


6-Meter Eco-Dome Engineering Report

Structural Engineering Calculations

Geodesic Dome 6m 3V 32mm x 2.0mm

Project: Dome Rating performed for DeLuxedome **Project Location:** Canada, USA

CONTENTS

SUMMARY

Finite element analysis was performed on a 6m 3V Geodesic Dome structure subjected to windloads from 125 to 200 mph and snow loads from 60 to 120 psf.

We found that 6m diameter geodesic dome with 32mm x 2.0mm Round Tube Strut Size can withstand wind of 200 mph and snow load of 120psf. Finally, the results are compared.

DESIGN CRITERIA

1. **Location:** Canada, USA
2. **Seismic:** Due to lightweight structure, seismic will not control
3. **Wind (Ultimate)*:** Ultimate Wind speed (mph): 125, 150, 175, 200, Ma
   Hourly wind pressure: 1.1967Kpa (q50) Max
   Exposure: Open Terrain
   Importance Factor: Normal
4. **Dead Load:** 1psf (=0.048Kpa, Fabric structure) + self-weight
5. **Roof Snow Load (psf):** 60, 80, 100, 120, Max

**Other criteria assumed as stated in design calculations.

Dome Analysis & Design

Load Combination Cases

To allow for the direct comparison of wind and snow loads, the combination factors recommended within the NBCC were factored from the ultimate limit state design to a limit state value equivalent to 1 in 50 year mean recurrence interval:

[1] Ultimate State Design: 1.5 S+0.4W

[2] Ultimate State Design: 1.4 W+0.5S

[3] Limit State Design: 1.0S +0.285W

[4] Limit State Design: 1.0W +0.33S

Assumptions

In order to determine the loading on the structure, the following assumptions were made based on conservative and reasonable considerations.

• The connections of the structure were assumed to be frictionless and will not carry any moment. The structure was treated as 3D space truss.

• The boundary conditions assume that the all the ground level nodes were fully fixed.

Q235 steel property (GB/T 700)

Elastic modulus	2e11 Pa,
Poisson's Ratio	0.3,
Density	7850 kg/m^3,
Tensile strength	370 MPa,
Yield strength	235 MPa

FEA result 1 (125mph, 60psf)

Basic wind parameters

Basic wind speed.

Basic wind speed is based on peak gust speed averaged over a short time interval of about 3 seconds and corresponds to 10m height above the mean ground level in an open terrain (Category II).

$$V_b = 125mph = 56m/s$$

Design wind speed.

$$V_z = 47.6m/s$$

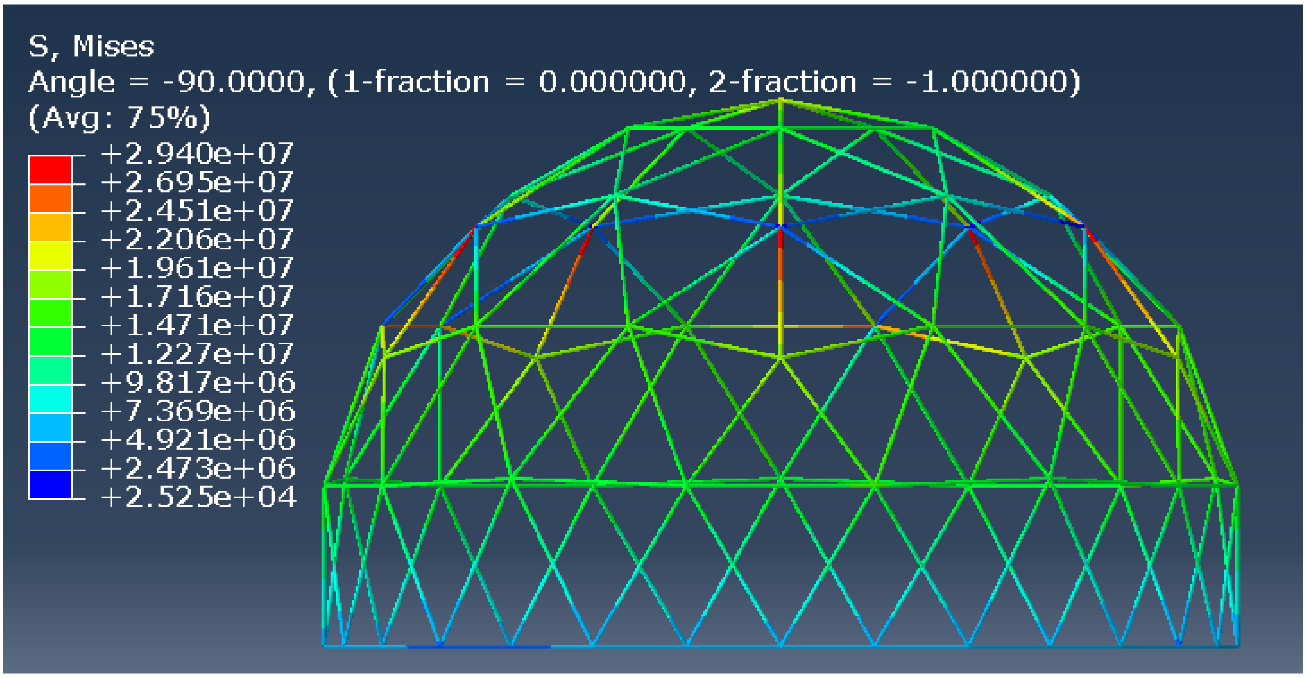
Design wind pressure

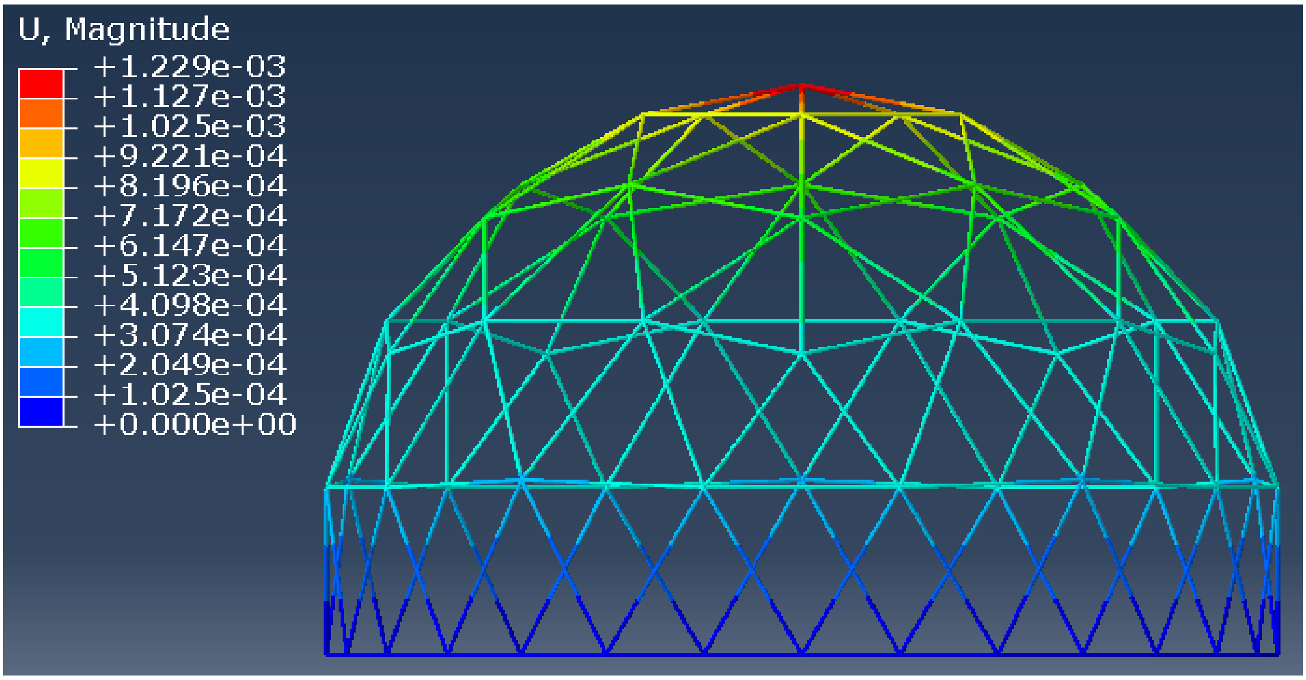
$$p_d = 1.36KPa$$

Tube Strut Size

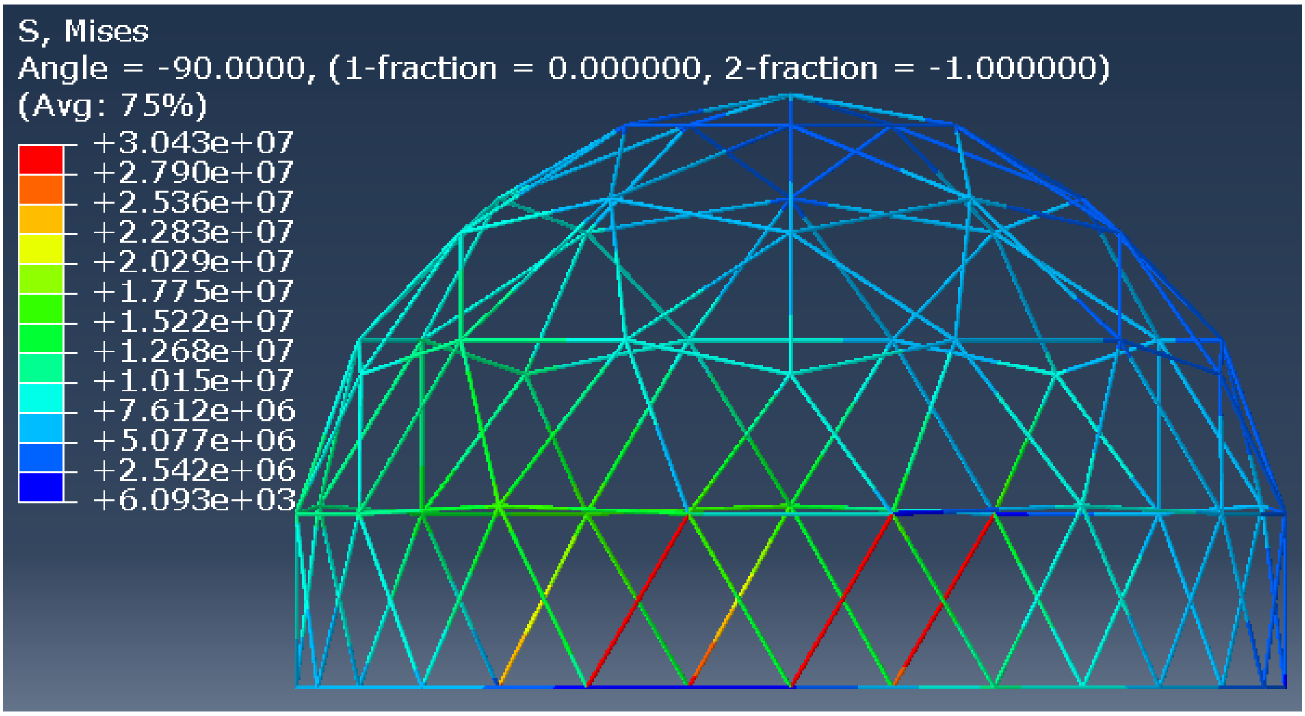
32mm x 2.0mm

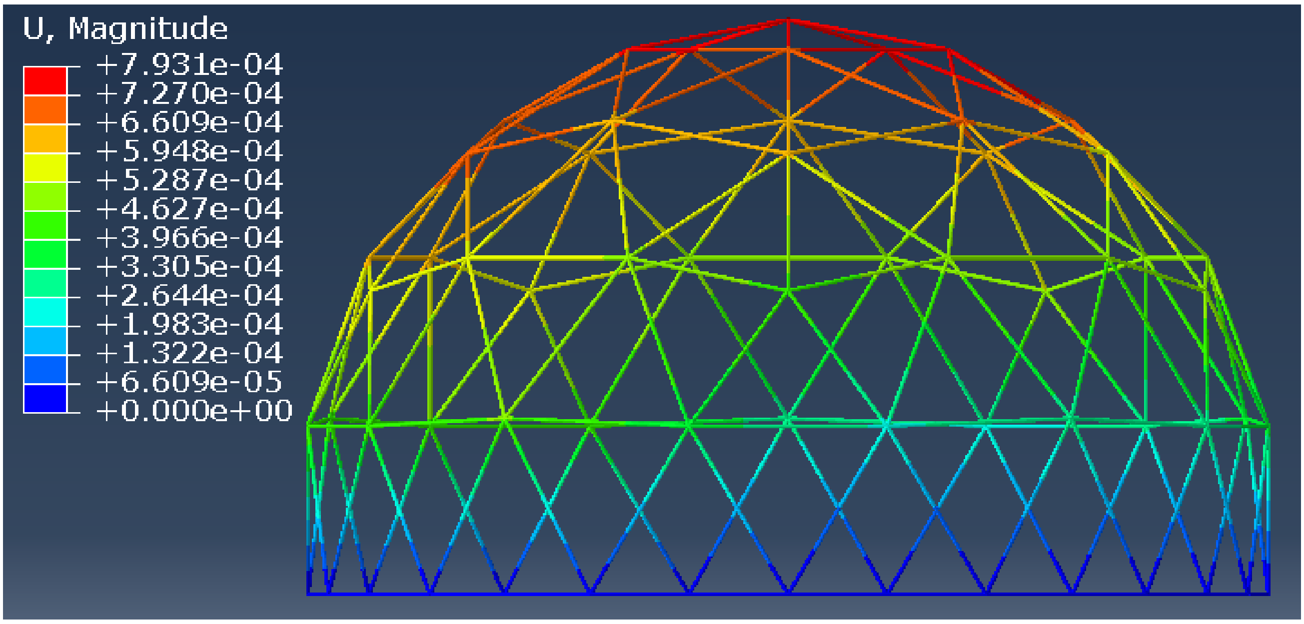
-**Load case 1(snow load only)**



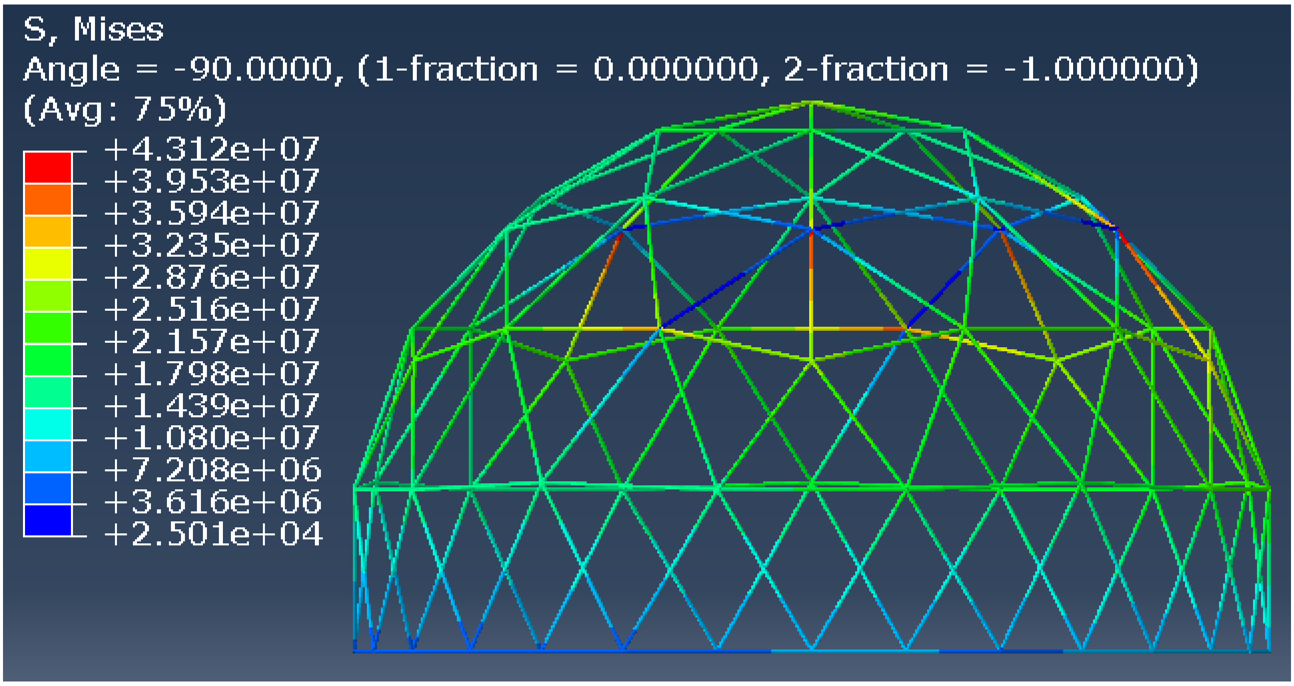


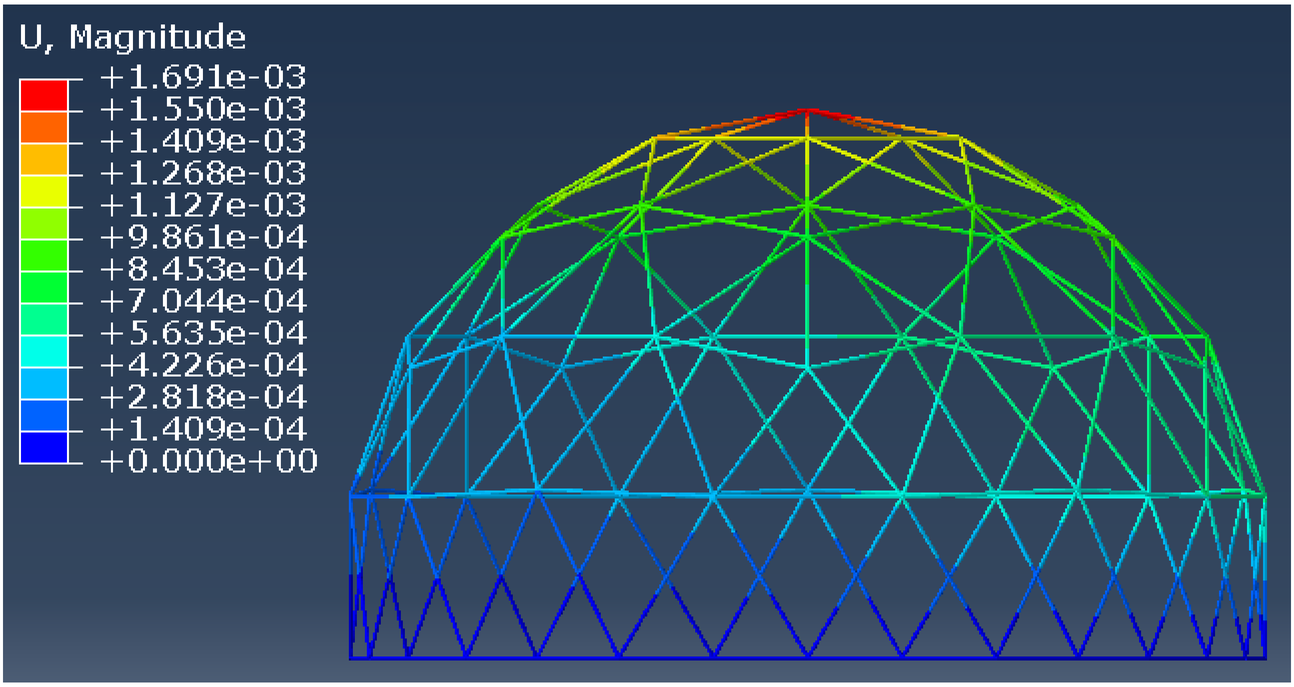
- **Load case 2(wind load only)**



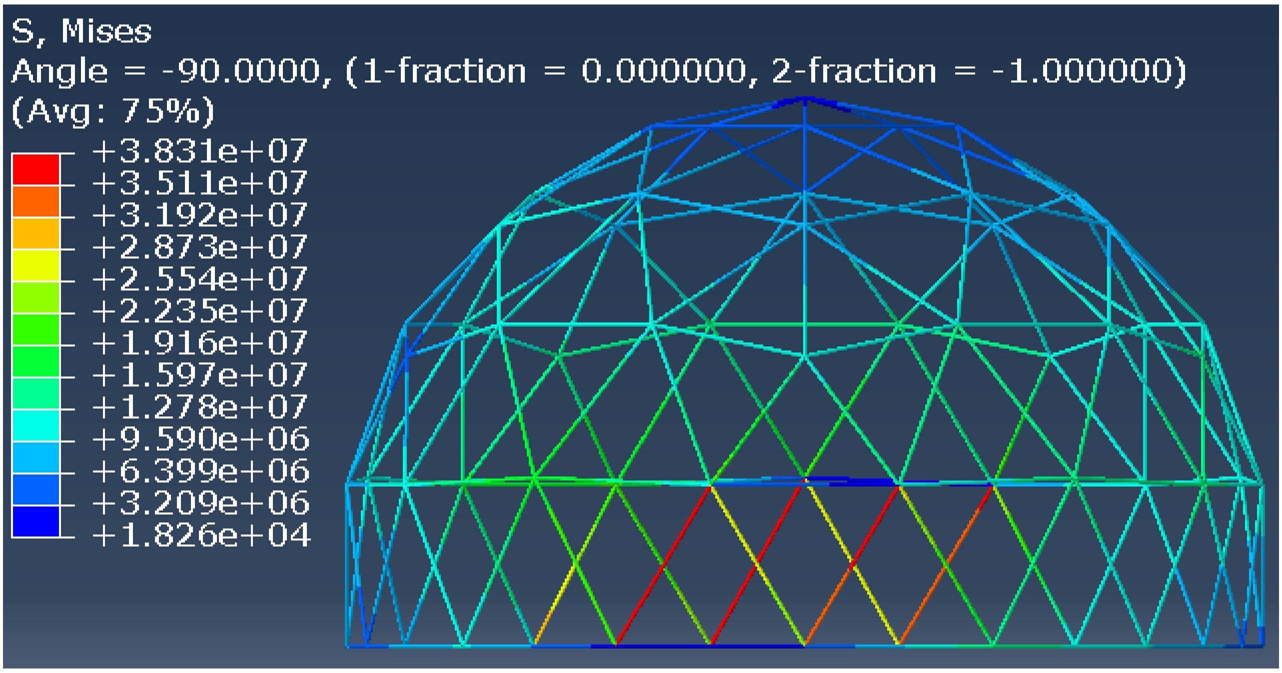


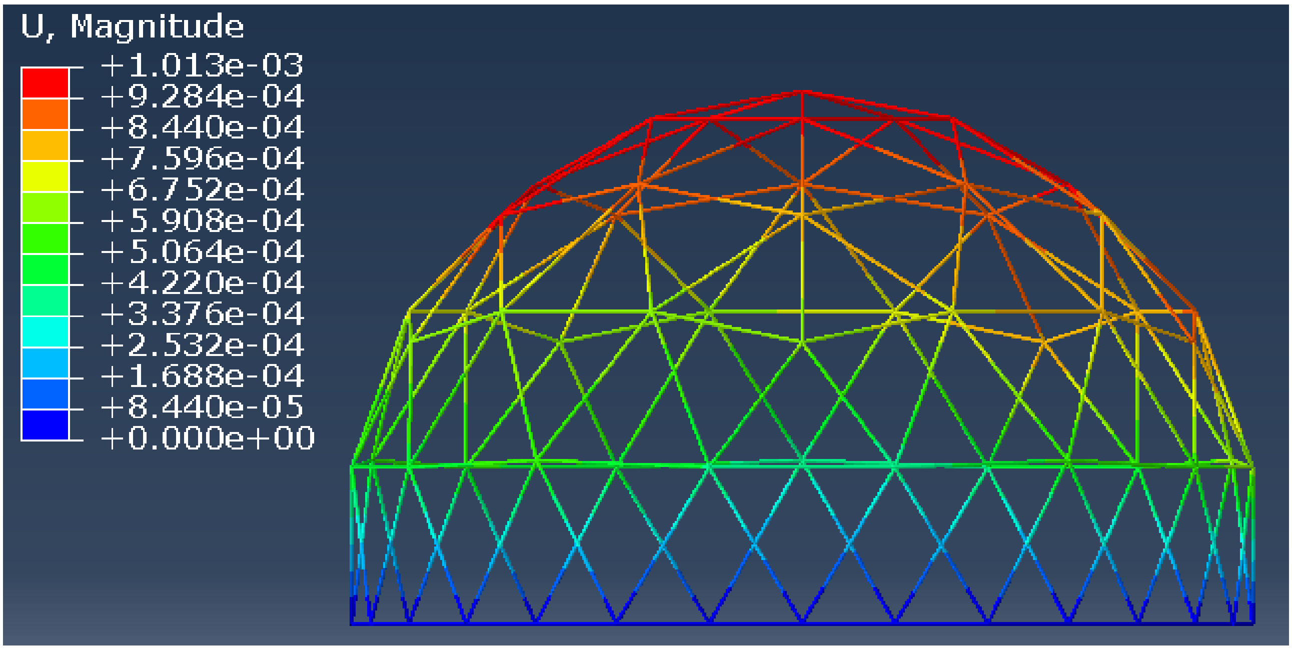
-Load case 3(1.5 S+0.4W**)**





-Load case 4(1.4 W+0.5S**)**





From the above figures, we can know maximum Von Mises stress and maximum displacement happens in the load case 3(1.5 S+0.4W).

This maximum Von Mises stress 43.12MPa is smaller than the yield strength of the struts material $F_y = 235Mpa$. So, this structure is safe. Maximum displacement is 1.7mm in this load case.

SAFE for tube size 32mm x 2mm

Connection design

We should review the connection design, taking into account only load case 3 (1.5s + 0.4w).

Plate thickness (t) = 4mm plate width (b) = 38mm

Gross Area (A_g) =152 mm^2 Net Area (A_e) = 100 mm^2

Clear distance (L_c) = 14.3mm

Material Properties

$F_y = 235 Mpa$, $F_u = 370 Mpa$, $F_n = 415 Mpa$,

Bolt Size: M14

Diameter=12 mm,

Bolt Area= 113 mm^2,

Bolt Size: M12

Diameter=10mm,

Bolt Area= 78.5 mm^2,

A - Design strength of plate

- Tensile Yielding:

  $P_n / \Omega_t = \left(F_y \times A_g\right) / \Omega_t$ Ω_t =1.111 (LRFD)

  P_n / Ω_t =32.15KN

- Tensile Rupture

  $P_n / \Omega_t = \left(F_u \times A_e\right) / \Omega_t$ Ω_t =1.33(LRFD)

  P_n / Ω_t =27.82KN

B. Bearing Strength of Bolts

R_n / Ω (1.5* $L_c * t * F_u$)/ Ω (Ω =1.33)

R_n / Ω = 23.9KN (M14, M12),

R_n / Ω (3.0*Bolt Diameter*Thickness* F_u)/ Ω

R_n / Ω = 40.06KN (M14), R_n / Ω = 33.4KN (M12)

C. Shear Strength of Bolts

$R_n / \Omega = \left(F_n \times A_b\right) / \Omega$

R_n / Ω =35.2KN (M14), R_n / Ω =24.4KN (M12)

<u>Design Strength=23.9KN > Max Load as per=3.68KN</u>

D. Bearing Strength of Anchor Bolts

R_n / Ω (1.5* $L_c * t * F_u$)/ Ω (Ω =1.33)

R_n / Ω = 23.9KN (M14, M12),

R_n / Ω (3.0*Bolt Diameter*Thickness* F_u)/ Ω

R_n / Ω = 40.06KN (M14), R_n / Ω = 33.4KN (M12)

E. Shear Strength of Anchor Bolts

$$R_n / \Omega = \left(F_n \times A_b\right) / \Omega$$

R_n / Ω =35.2KN (M14), R_n / Ω =24.4KN (M12)

Design Strength=23.9KN > Max Load as per=6.23KN

SAFE for M12 and M14(Bolt and Anchor Bolt)

FEA result 2 (150mph, 80psf)

Basic wind parameters

Basic wind speed.

Basic wind speed is based on peak gust speed averaged over a short time interval of about 3 seconds and corresponds to 10m height above the mean ground level in an open terrain (Category II).

$$V_b = 150mph = 67m / s$$

Design wind speed.

$$V_z = 57m / s$$

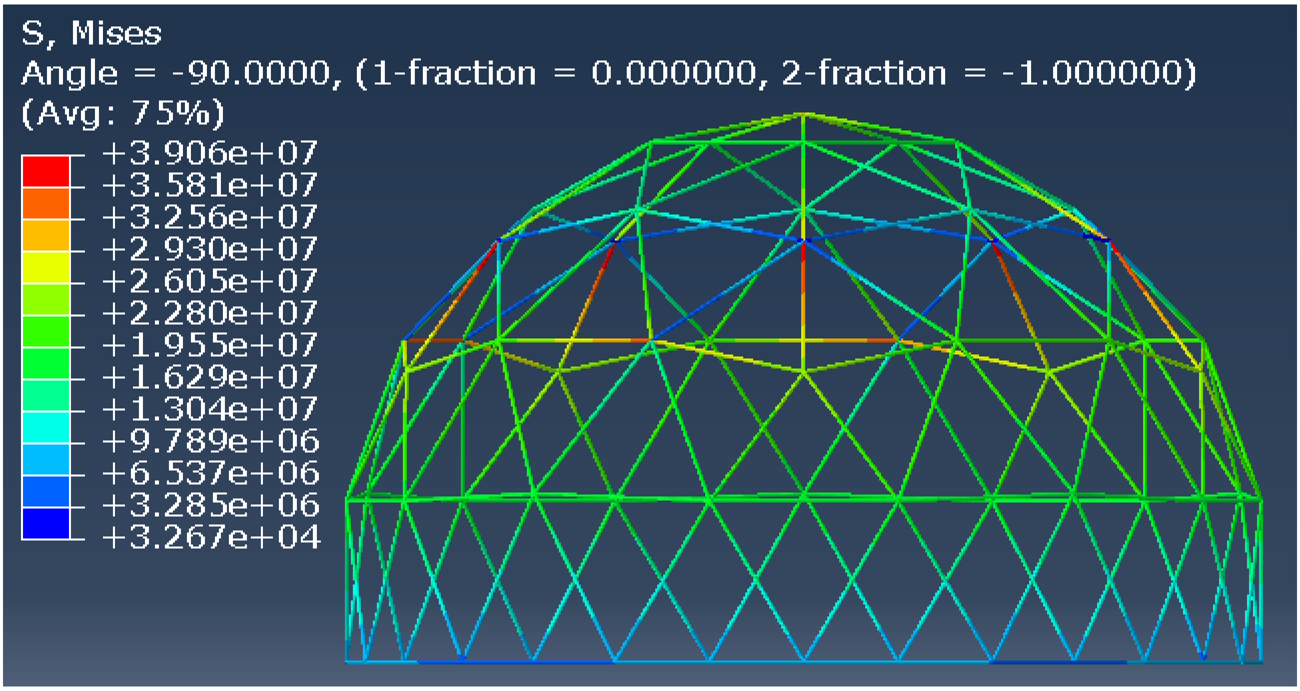
Design wind pressure

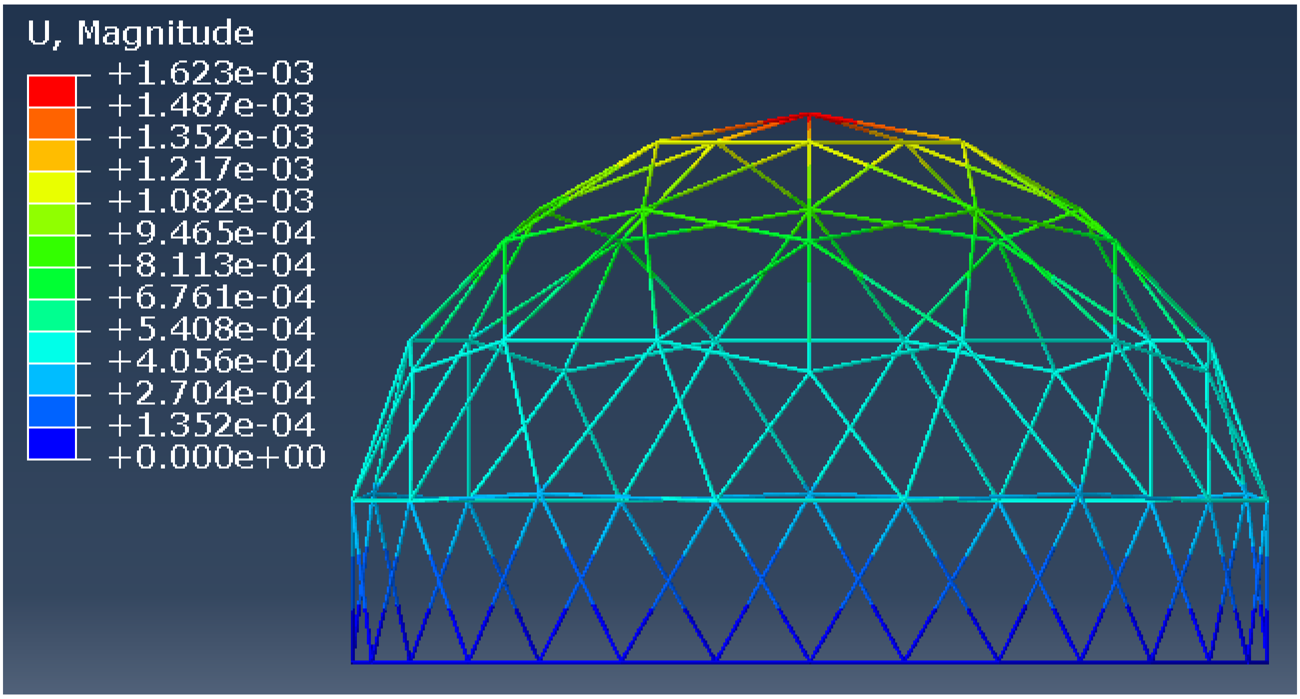
$$p_d = 1.95KPa$$

Tube Strut Size

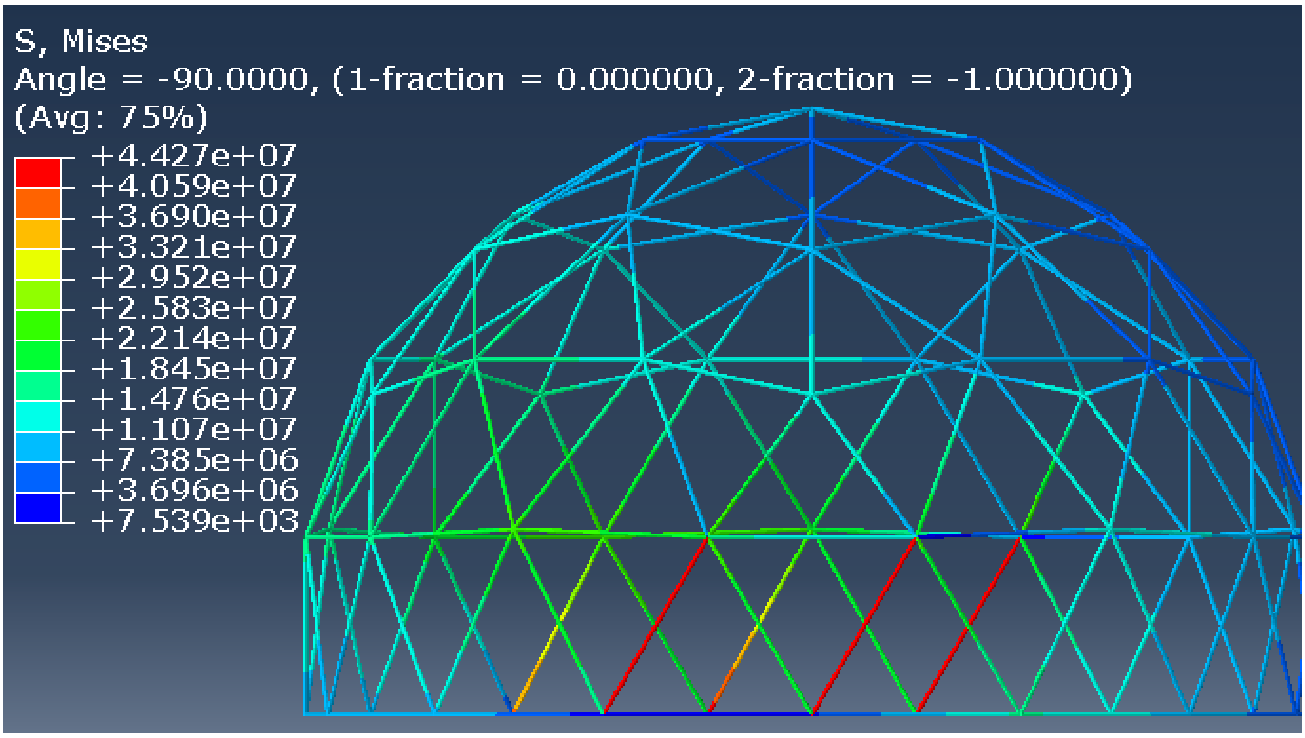
32mm × 2.0mm

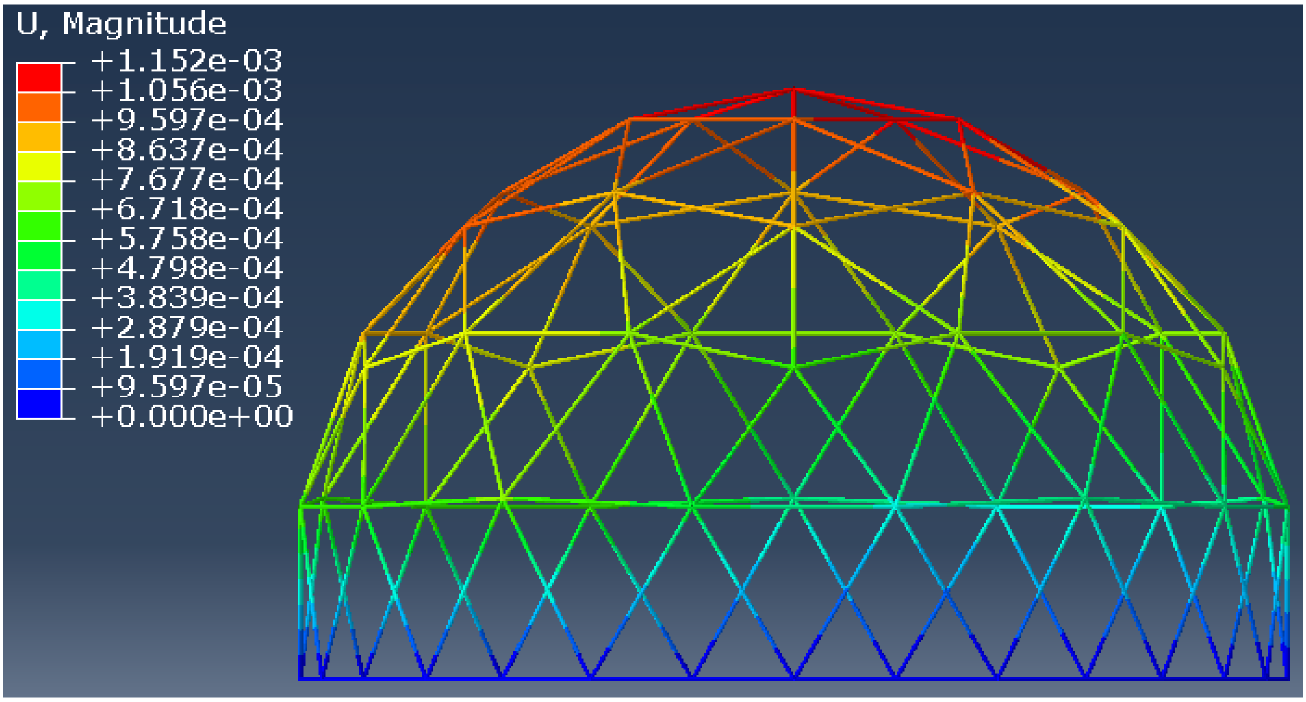
-**Load case 1(snow load only)**



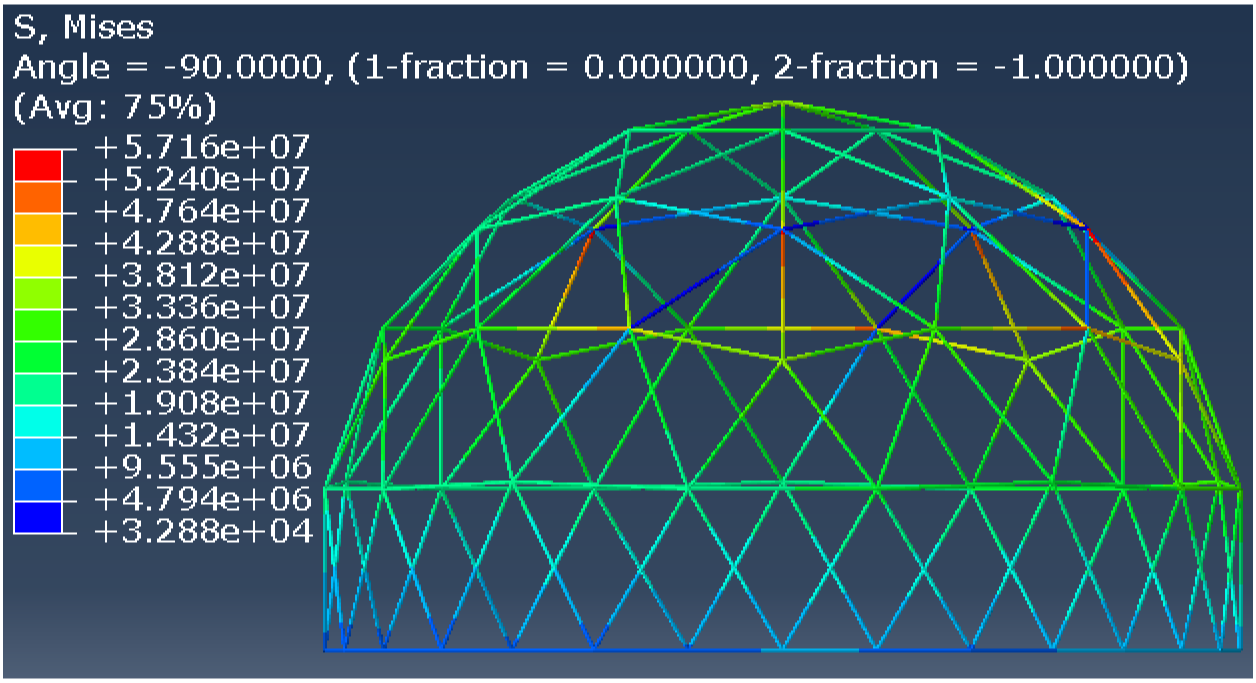


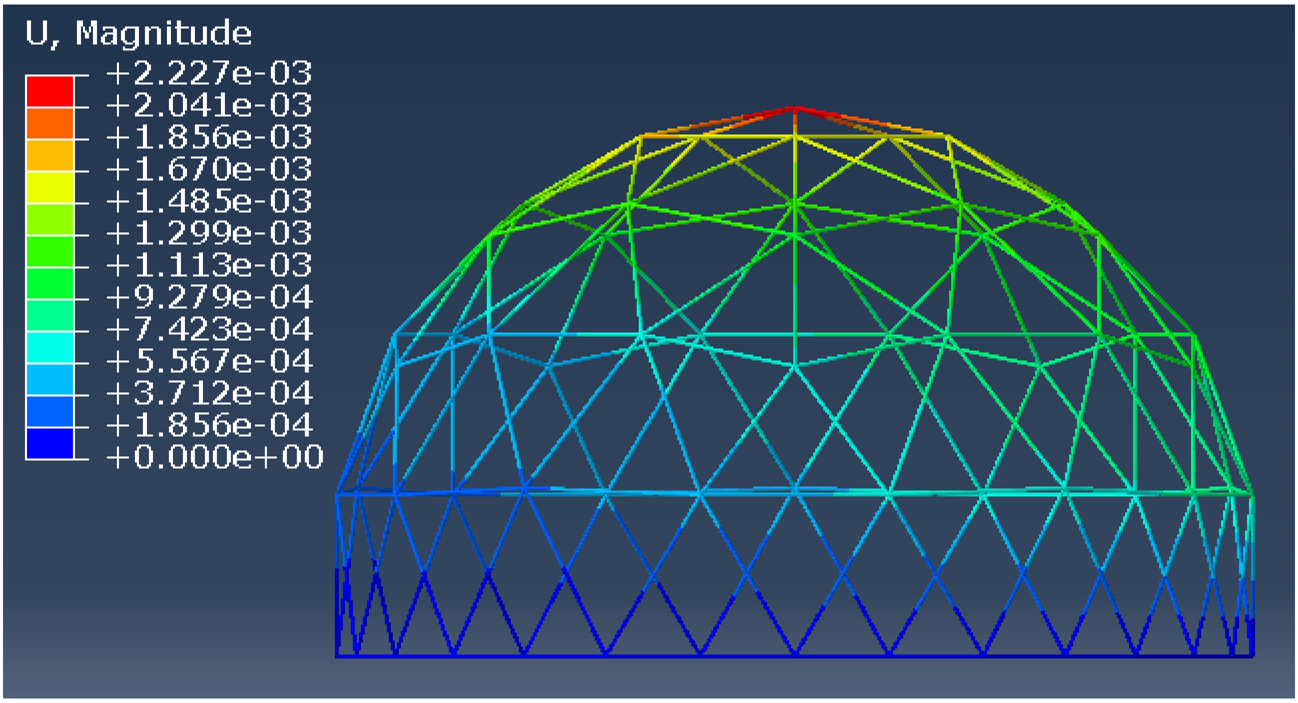
- **Load case 2(wind load only)**



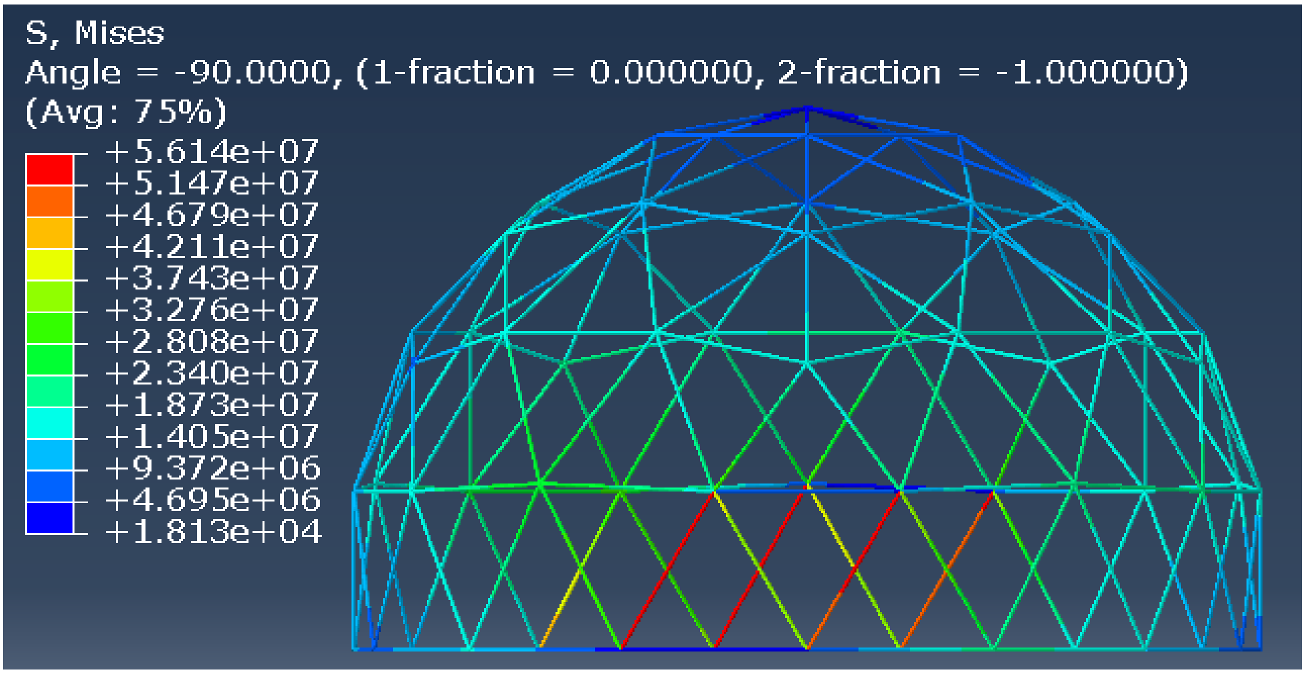


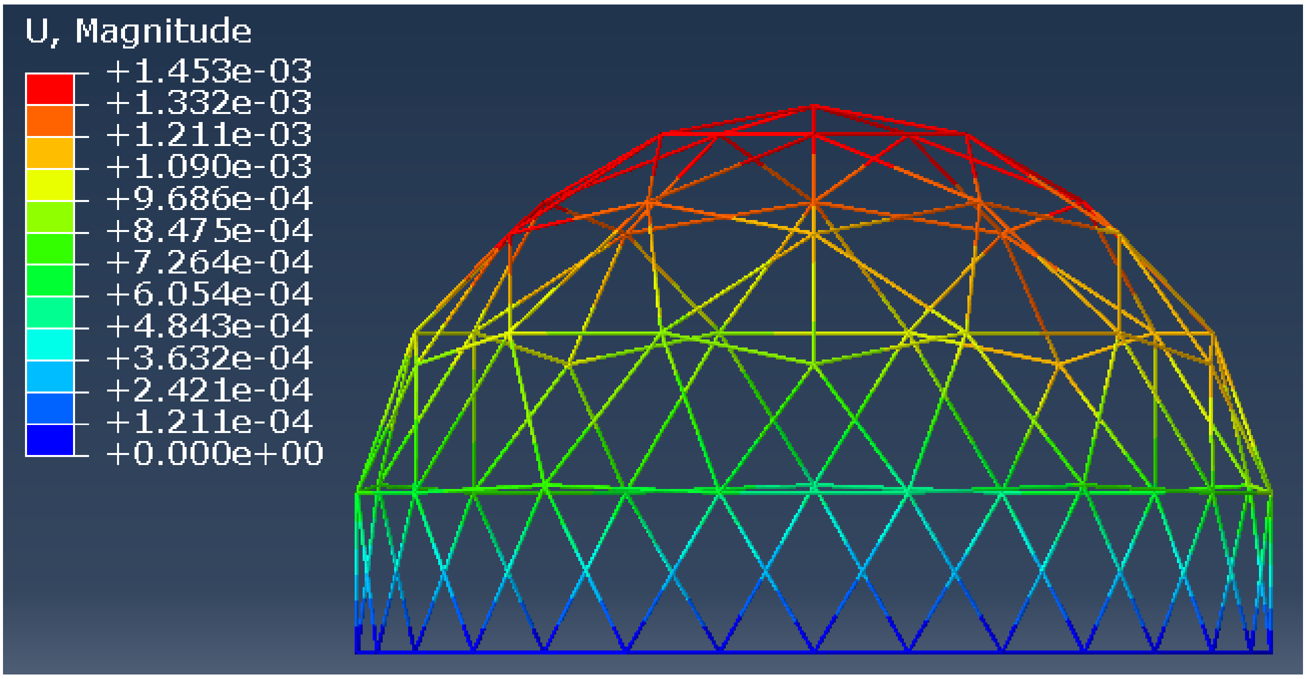
- **Load case 3(**1.5 S+0.4W**)**





-Load case 4(1.4 W+0.5S**)**





From the above figures, we can know maximum Von Mises stress and maximum displacement happens in the load case 3(1.5 S+0.4W).

This maximum Von Mises stress 57.16MPa is smaller than the yield strength of the struts material $F_y = 235Mpa$. So, this structure is safe. Maximum displacement is 2.23mm in this load case.

SAFE for tube size 32mm x 2mm

Connection design

We should review the connection design, taking into account only load case 3 (1.5s + 0.4w).

Plate thickness (t) = 4mm plate width (b) = 38mm

Gross Area (A_g) =152 mm^2 Net Area (A_e) = 100 mm^2

Clear distance (L_c) = 14.3mm

Material Properties

$F_y = 235Mpa$, $F_u = 370Mpa$, $F_n = 415Mpa$,

Bolt Size: M14

Diameter=12 mm,

Bolt Area= 113 mm^2,

Bolt Size: M12

Diameter=10mm,

Bolt Area= 78.5 mm^2,

A - Design strength of plate

- Tensile Yielding:

$P_n / \Omega_t = \left(F_y \times A_g\right) / \Omega_t$ Ω_t =1.111 (LRFD)

P_n / Ω_t =32.15KN

- Tensile Rupture

$P_n / \Omega_t = \left(F_u \times A_e\right) / \Omega_t$ Ω_t =1.33(LRFD)

P_n / Ω_t =27.82KN

B - Bearing Strength of Bolts

R_n / Ω (1.5* $L_c * t * F_u$)/ Ω (Ω =1.33)

R_n / Ω = 23.9KN (M14, M12),

R_n / Ω (3.0*Bolt Diameter*Thickness* F_u)/ Ω

R_n / Ω = 40.06KN (M14), R_n / Ω = 33.4KN (M12)

C- Shear Strength of Bolts

$R_n / \Omega = \left(F_n \times A_b\right) / \Omega$

R_n / Ω =35.2KN (M14), R_n / Ω =24.4KN (M12)

Design Strength=23.9KN > Max Load as per=4.89KN

D. Bearing Strength of Anchor Bolts

R_n / Ω (1.5* $L_c * t * F_u$)/ Ω (Ω =1.33)

R_n / Ω = 23.9KN (M14, M12),

R_n / Ω (3.0*Bolt Diameter*Thickness* F_u)/ Ω

R_n / Ω = 40.06KN (M14), R_n / Ω = 33.4KN (M12)

E. Shear Strength of Anchor Bolts

$$R_n / \Omega = \left(F_n \times A_b\right) / \Omega$$

R_n / Ω =35.2KN (M14), R_n / Ω =24.4KN (M12)

Design Strength=23.9KN > Max Load as per=9.13KN

SAFE for M12 and M14(Bolt and Anchor Bolt)

FEA result 3 (175mph, 100psf)

Basic wind parameters

Basic wind speed.

Basic wind speed is based on peak gust speed averaged over a short time interval of about 3 seconds and corresponds to 10m height above the mean ground level in an open terrain (Category II).

$$V_b = 175mph = 78m/s$$

Design wind speed.

$$V_z = 66.5m/s$$

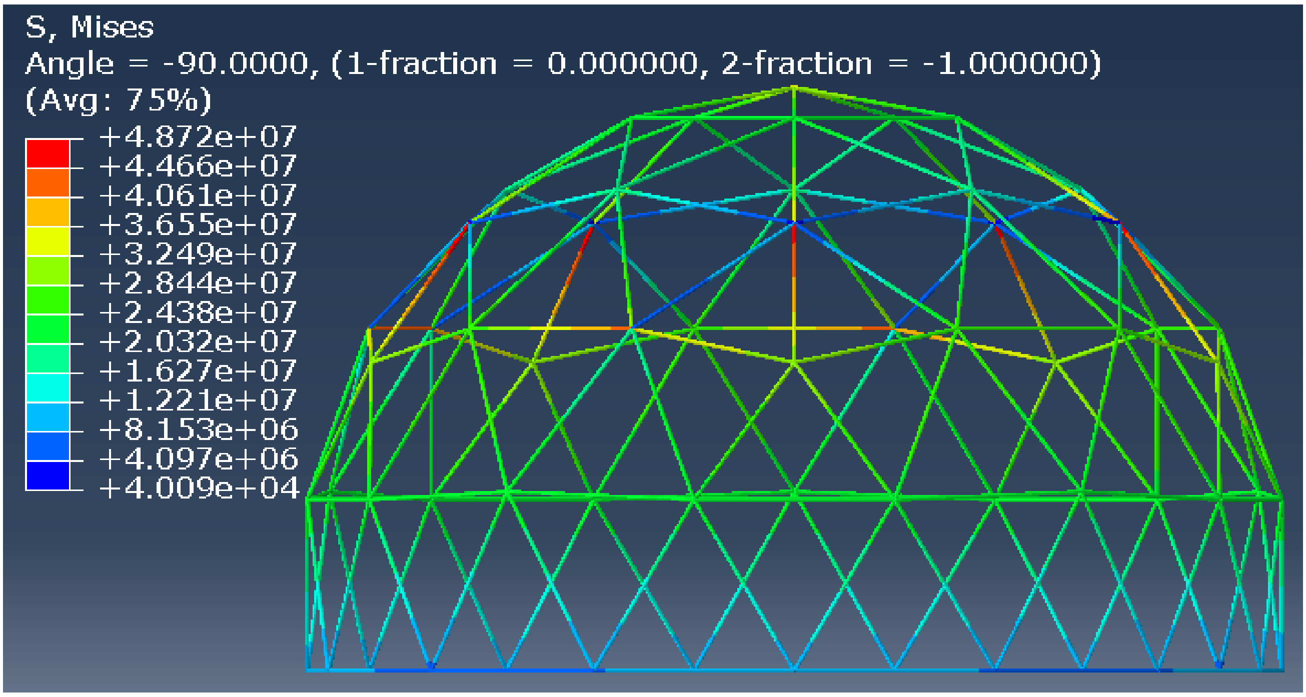
Design wind pressure

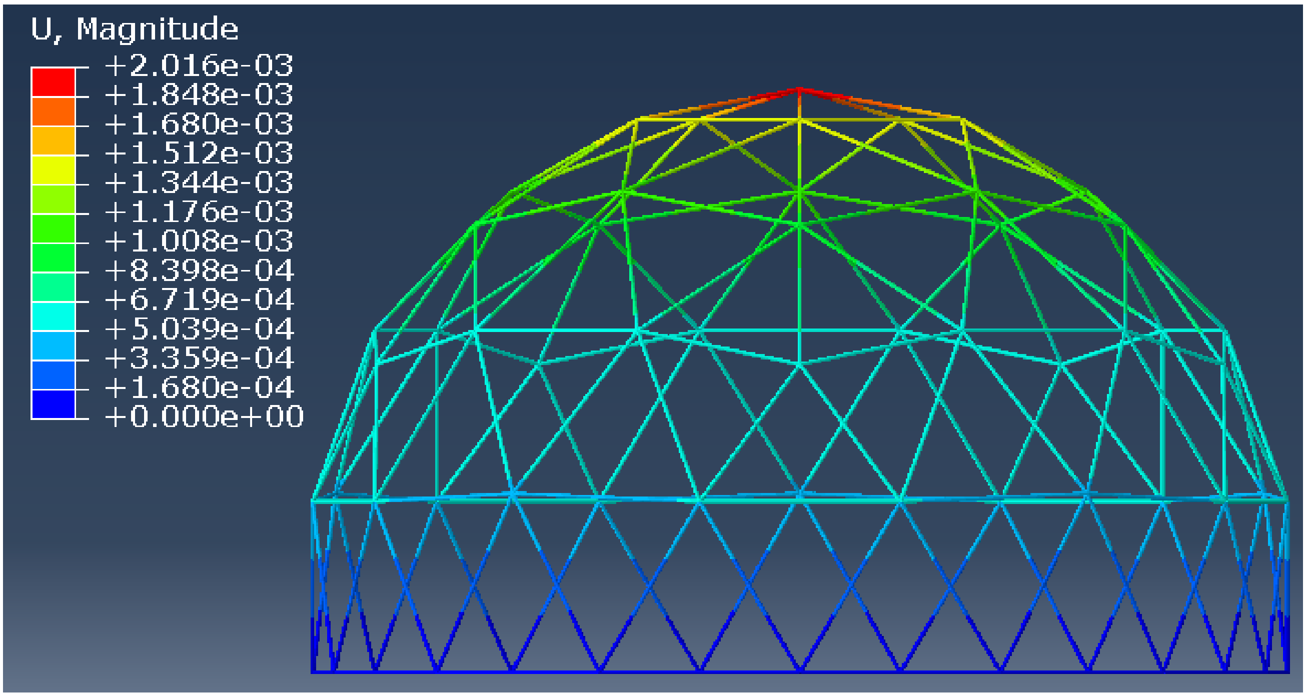
$$p_d = 2.653KPa$$

Tube Strut Size

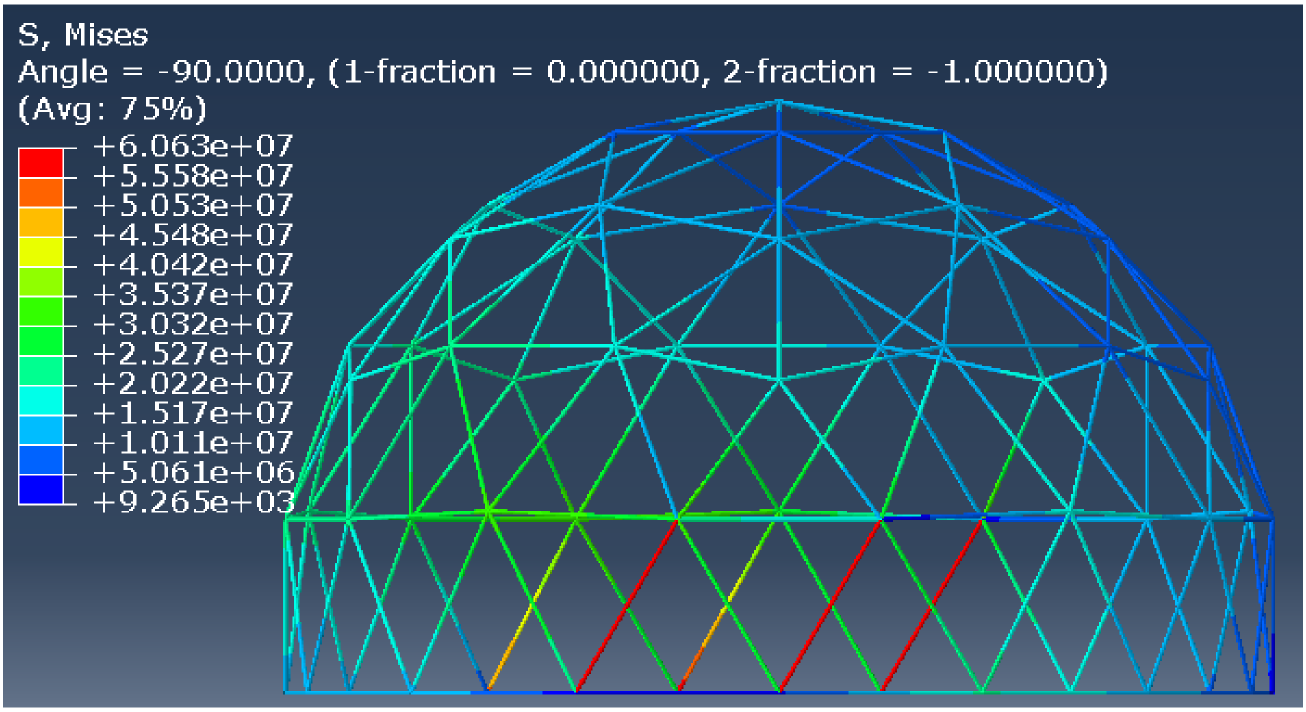
32mm x 2.0mm

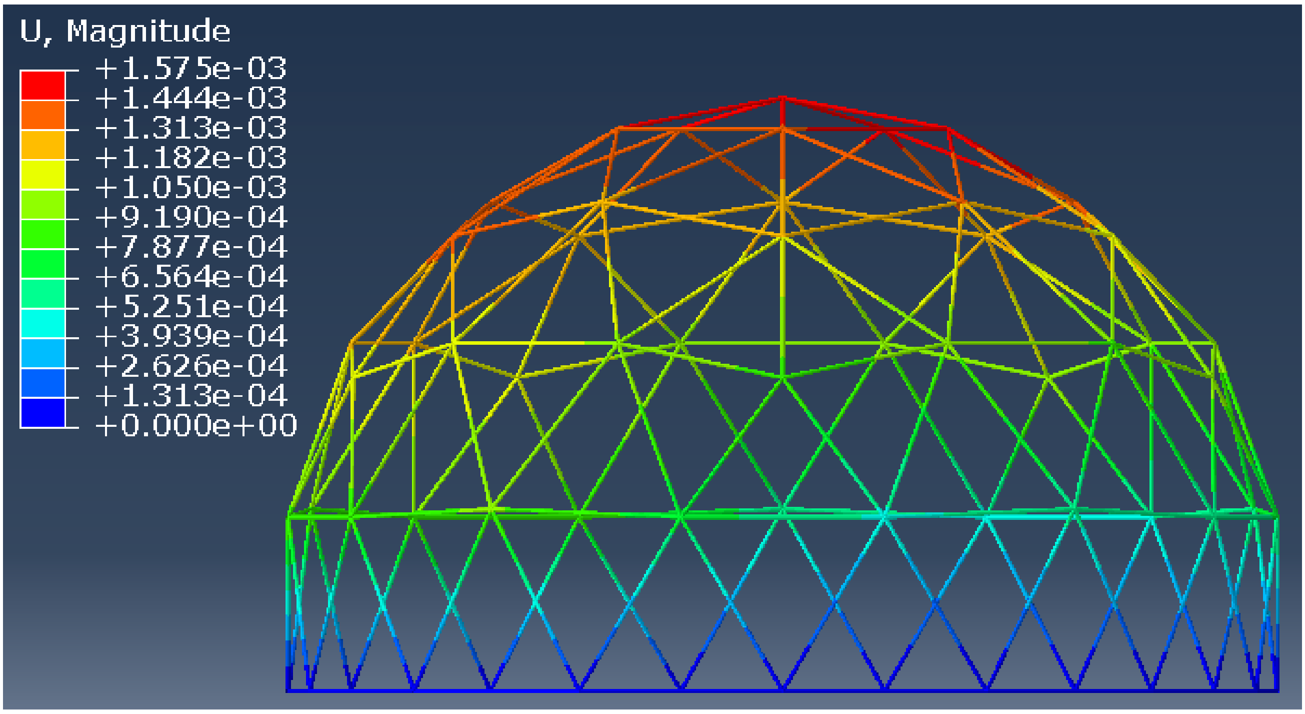
-**Load case 1(snow load only)**



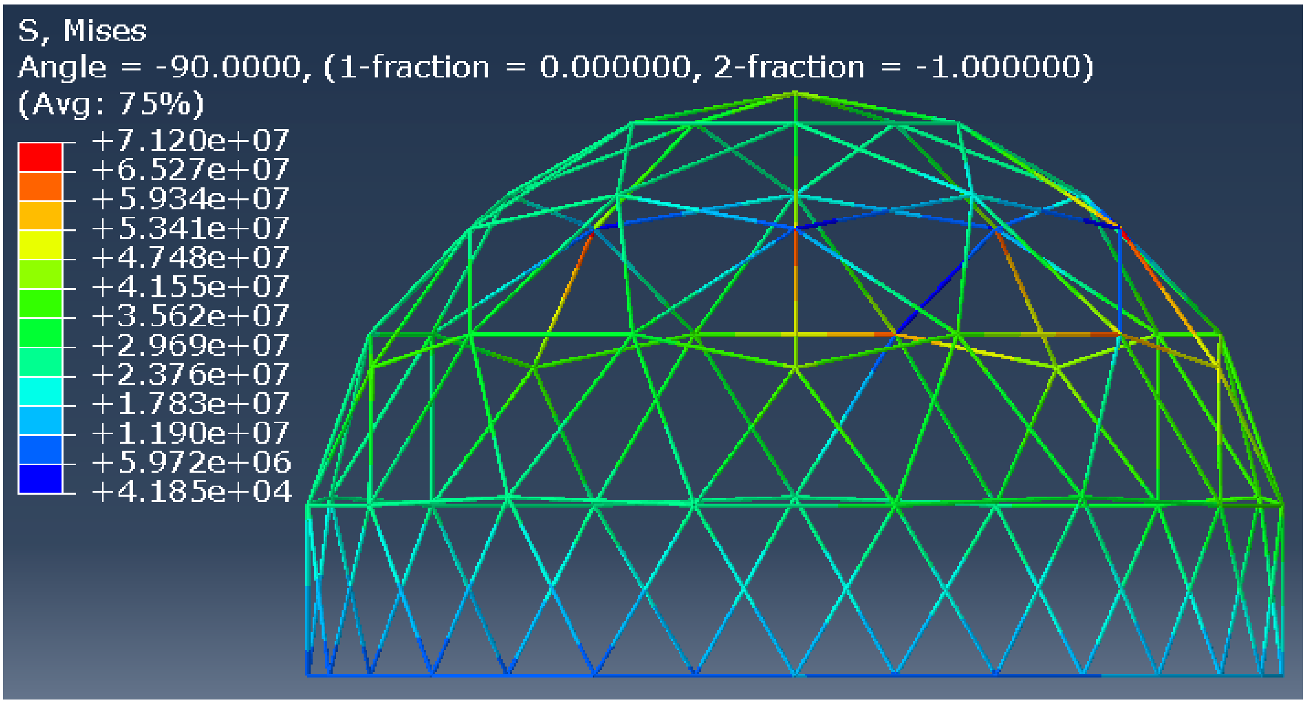


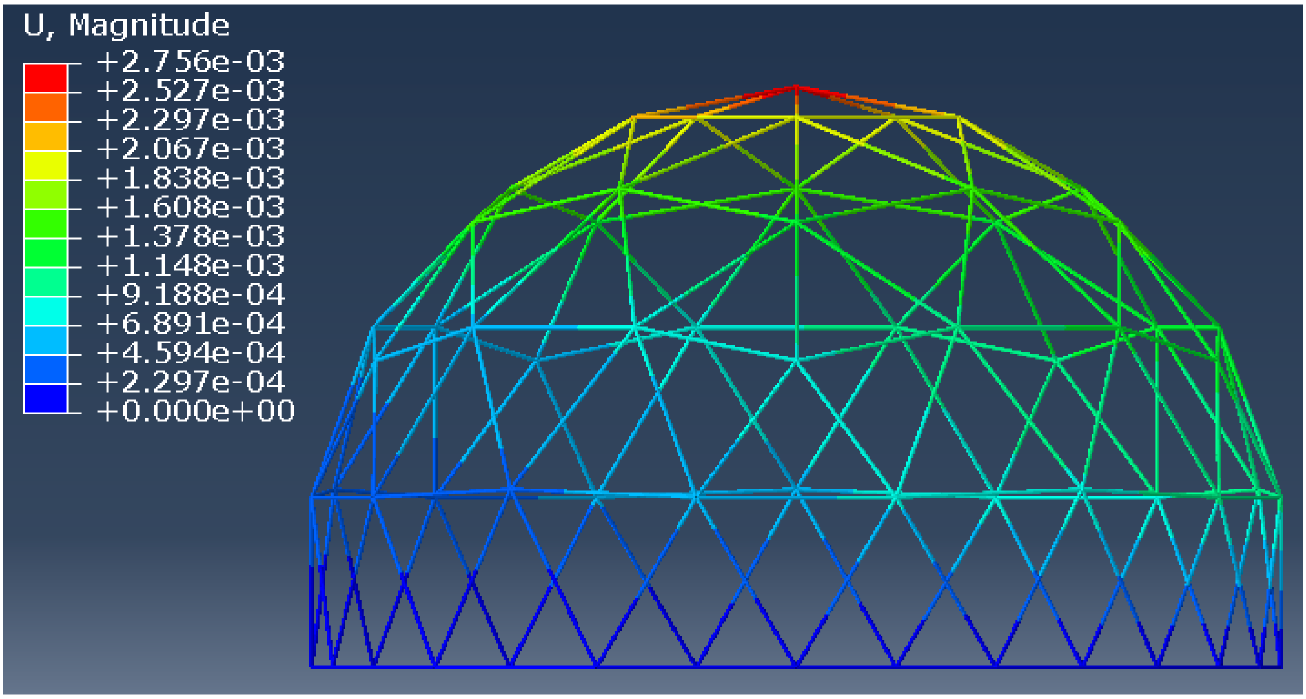
- **Load case 2(wind load only)**





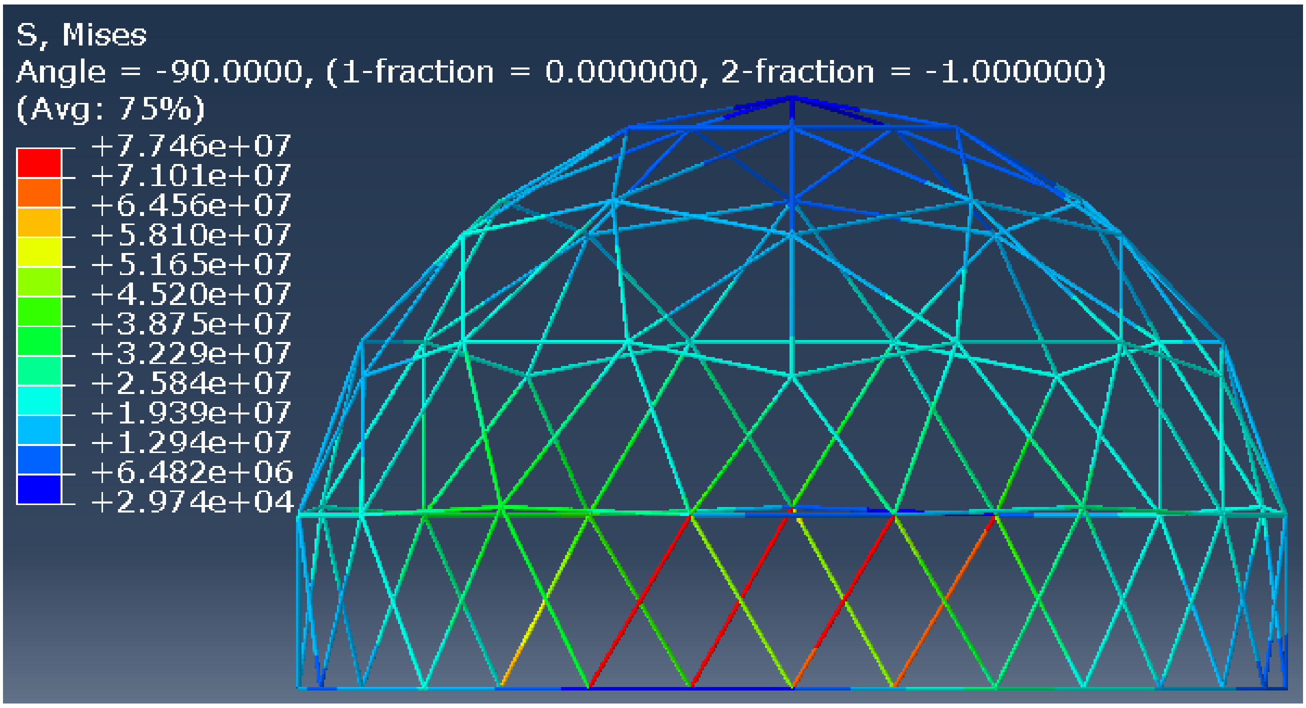
-Load case 3(1.5 S+0.4W**)**

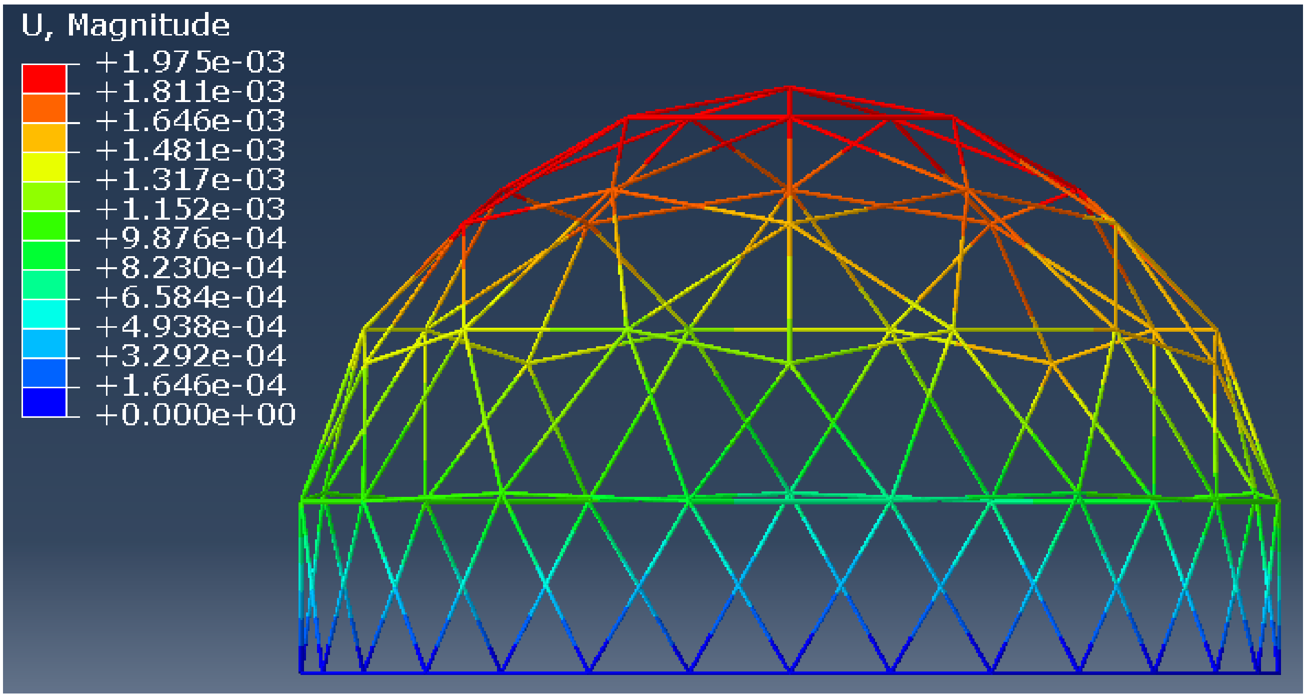




-Load case 4(1.4 W+0.5S**)**

DELUXE DOME





From the above figures, we know maximum Von Mises stress and maximum displacement happens in the load case 4(1.4 W+0.5S).

This maximum Von Mises stress 77.46MPa is smaller than the yield strength of the struts material $F_y = 235Mpa$. So, this structure is safe. Maximum displacement is 2.75 mm.

SAFE for tube size 32mm x 2mm

DELUXE DOME

Connection design

Plate thickness (t) = 4mm

plate width (b) = 38mm

Gross Area (A_g) =152 mm^2

Net Area (A_e) = 100 mm^2

Clear distance (L_c) = 14.3mm

Material Properties

$F_y = 235 Mpa$, $F_u = 370 Mpa$, $F_n = 415 Mpa$,

Bolt Size: M14

Diameter=12 mm,

Bolt Area= 113 mm^2 ,

Bolt Size: M12

Diameter=10mm,

Bolt Area= 78.5 mm^2 ,

A - Design strength of plate

- Tensile Yielding:

  $P_n / \Omega_t = \left(F_y \times A_g\right) / \Omega_t$ Ω_t =1.111 (LRFD)

  P_n / Ω_t =32.15KN

- Tensile Rupture

  $P_n / \Omega_t = \left(F_u \times A_e\right) / \Omega_t$ Ω_t =1.33(LRFD)

  P_n / Ω_t =27.82KN

B. Bearing Strength of Bolts

R_n / Ω (1.5* $L_c * t * F_u$)/ Ω (Ω =1.33)

R_n / Ω = 23.9KN (M14, M12),

R_n / Ω (3.0*Bolt Diameter*Thickness* F_u)/ Ω

R_n / Ω = 40.06KN (M14), R_n / Ω = 33.4KN (M12)

C. Shear Strength of Bolts

$R_n / \Omega = \left(F_n \times A_b\right) / \Omega$

R_n / Ω =35.2KN (M14), R_n / Ω =24.4KN (M12)

Design Strength=23.9KN > Max Load as per=6.1KN

D. Bearing Strength of Anchor Bolts

R_n / Ω (1.5* $L_c * t * F_u$)/ Ω (Ω =1.33)

R_n / Ω = 23.9KN (M14, M12),

R_n / Ω (3.0*Bolt Diameter*Thickness* F_u)/ Ω

R_n / Ω = 40.06KN (M14), R_n / Ω = 33.4KN (M12)

E. Shear Strength of Anchor Bolts

$$R_n / \Omega = \left(F_n \times A_b \right) / \Omega$$

R_n / Ω =35.2KN (M14), R_n / Ω =24.4KN (M12)

Design Strength=23.9KN > Max Load as per=12.6KN

SAFE for M12 and M14(Bolt and Anchor Bolt)

FEA result 4 (200mph, 120psf)

Basic wind parameters

Basic wind speed.

Basic wind speed is based on peak gust speed averaged over a short time interval of about 3 seconds and corresponds to 10m height above the mean ground level in an open terrain (Category II).

$$V_b = 200mph = 89.4m/s$$

Design wind speed.

$$V_z = 76m/s$$

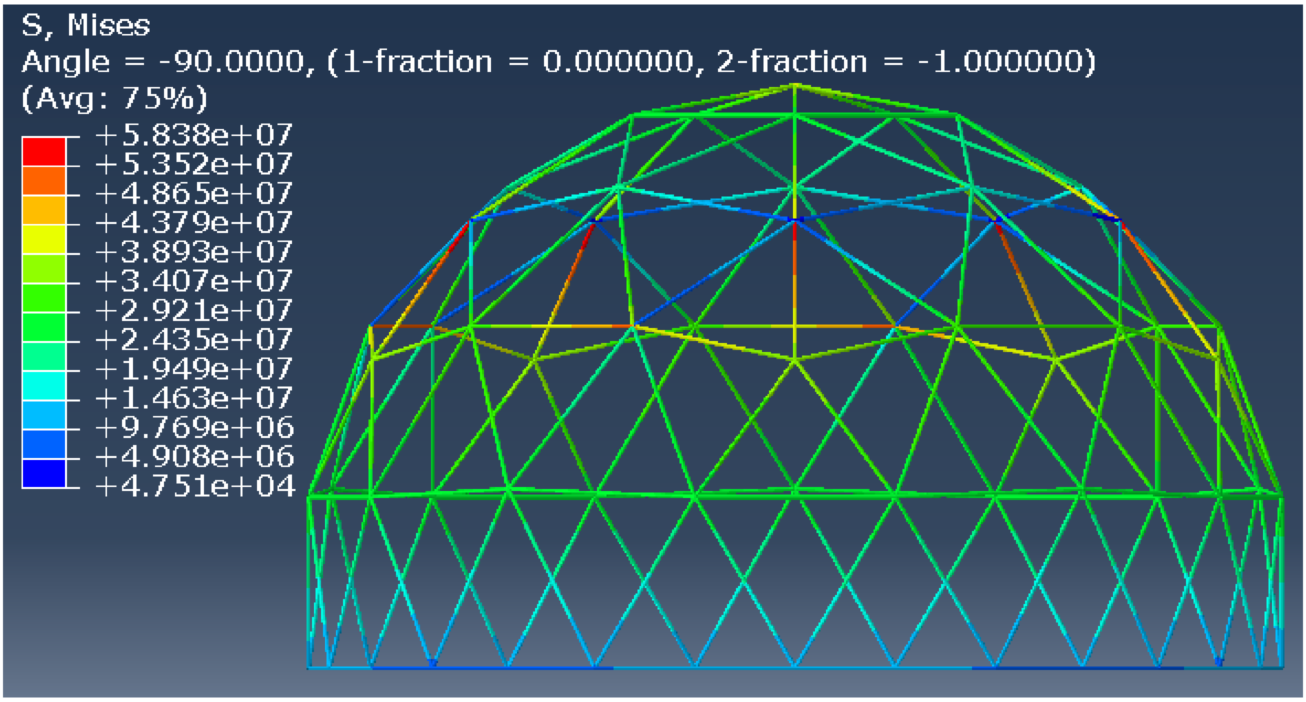
Design wind pressure

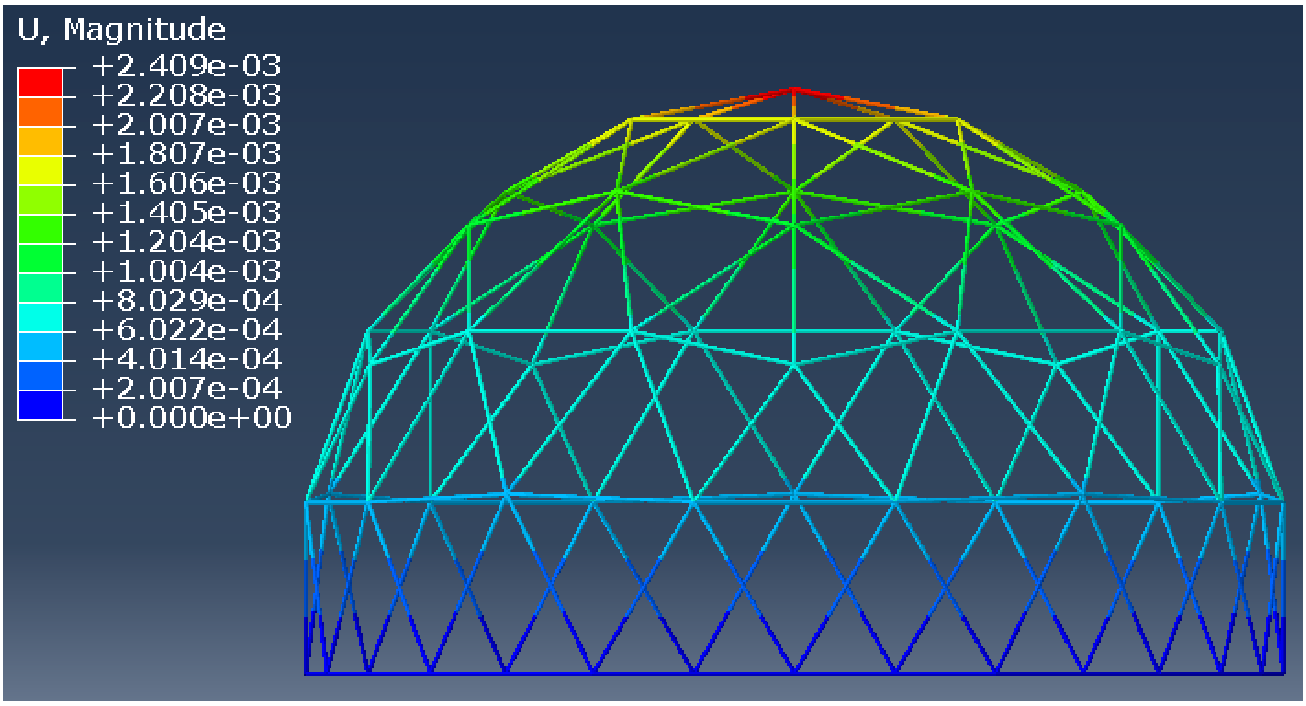
$$p_d = 3.465Kpa$$

Tube Strut Size

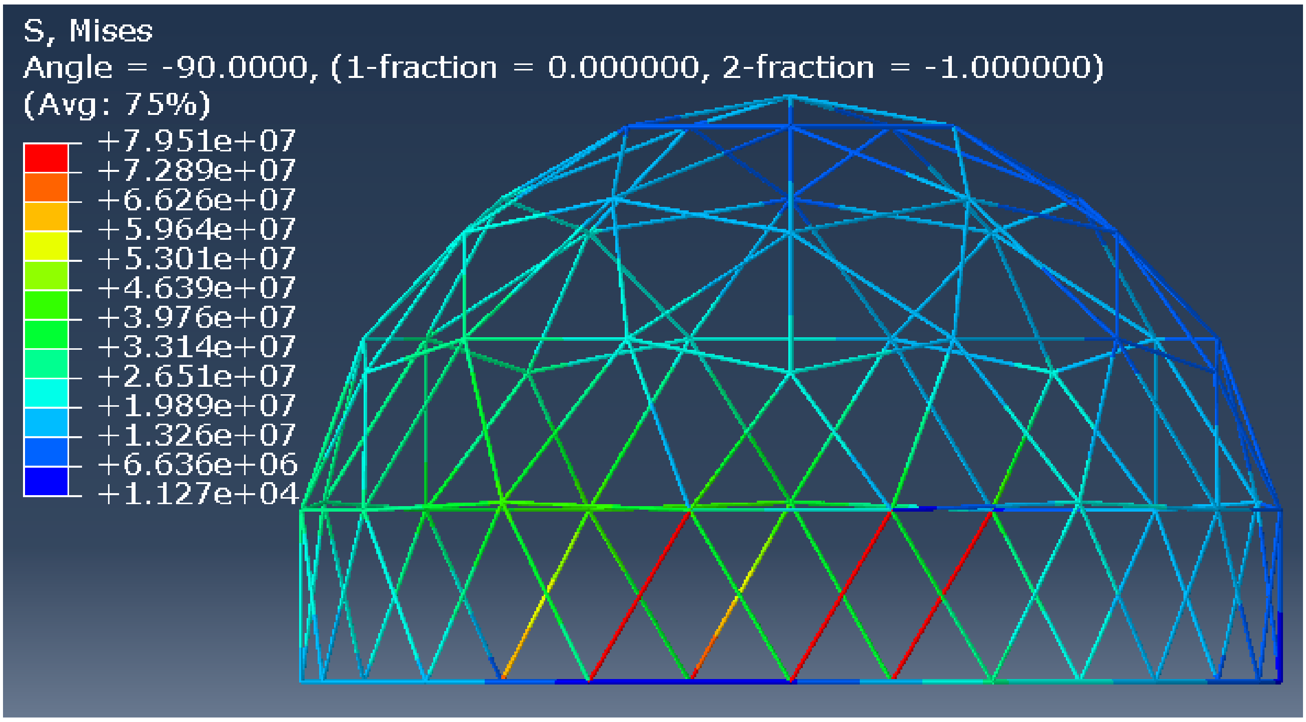
32mm x 2.0mm

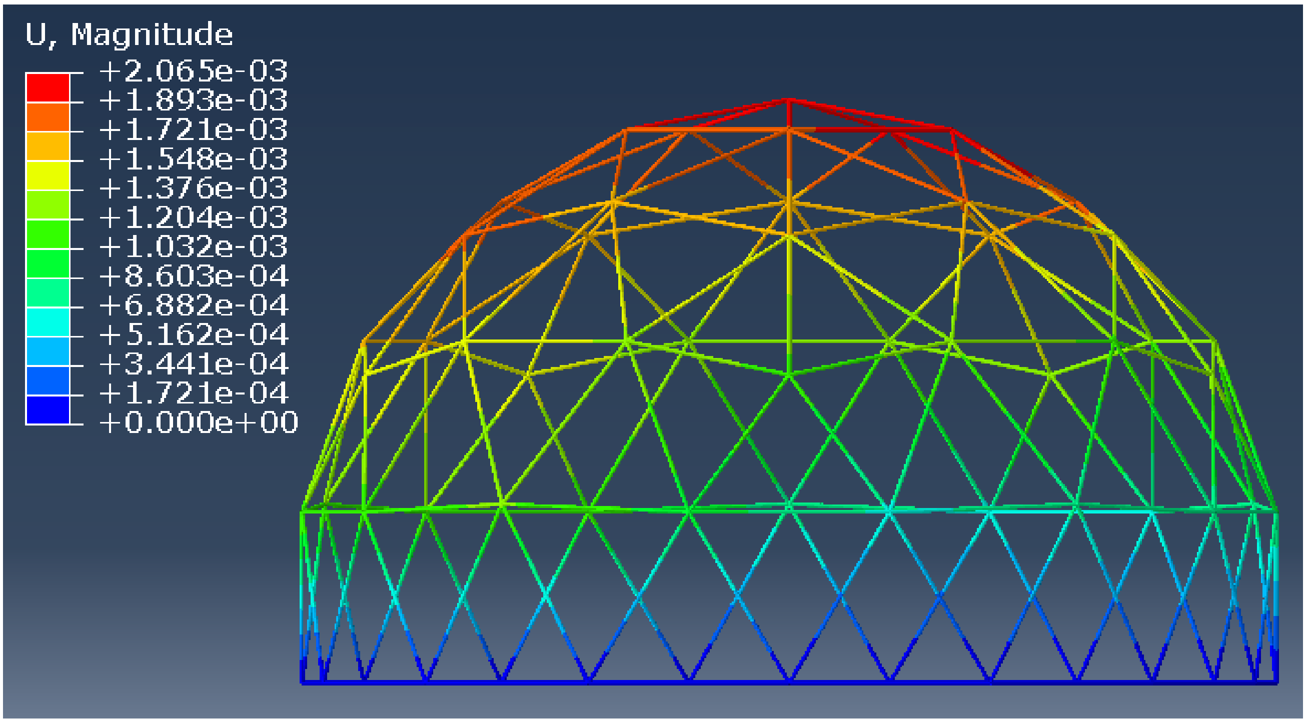
-**Load case 1(snow load only)**



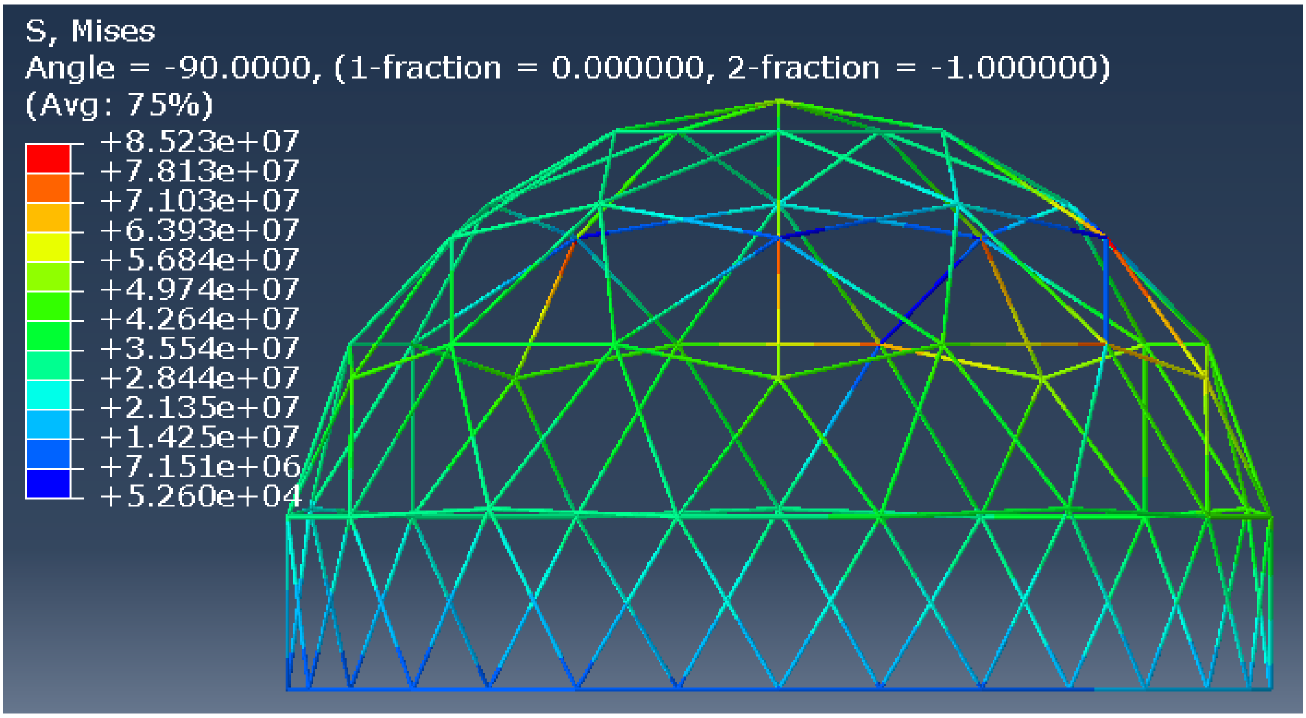


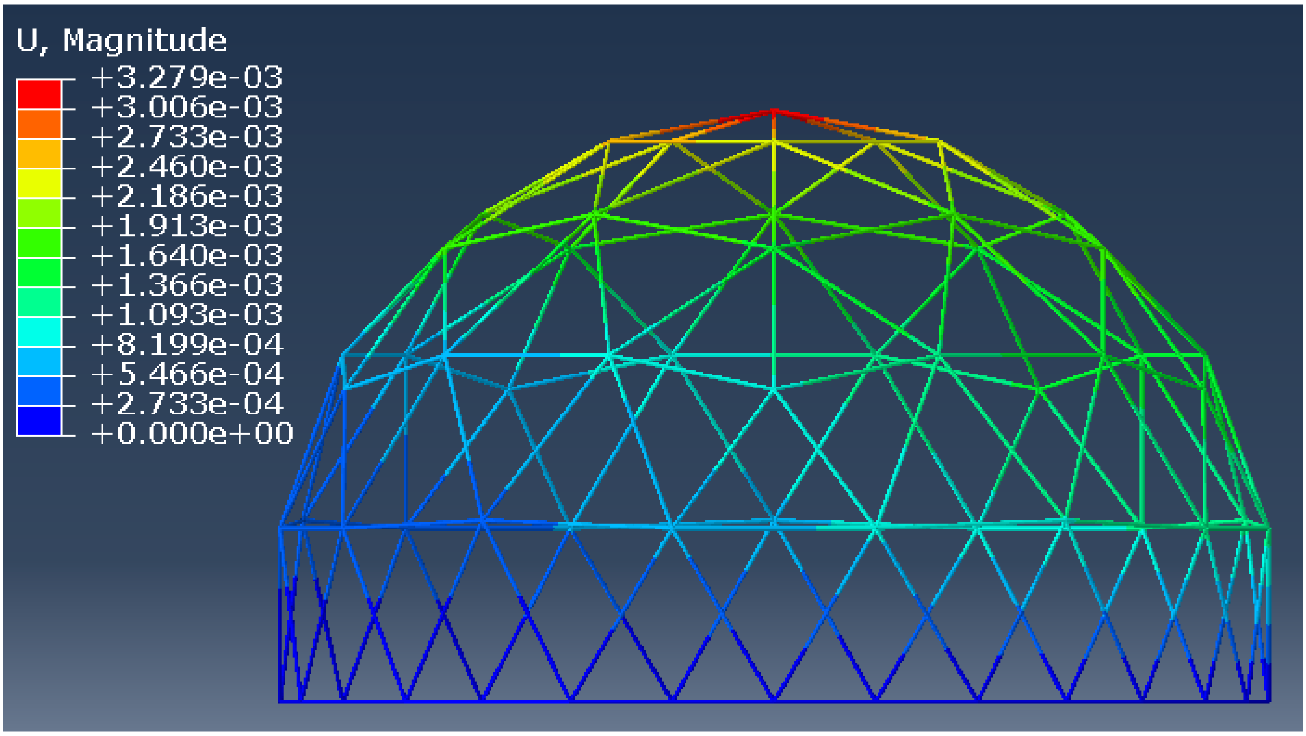
- **Load case 2(wind load only)**



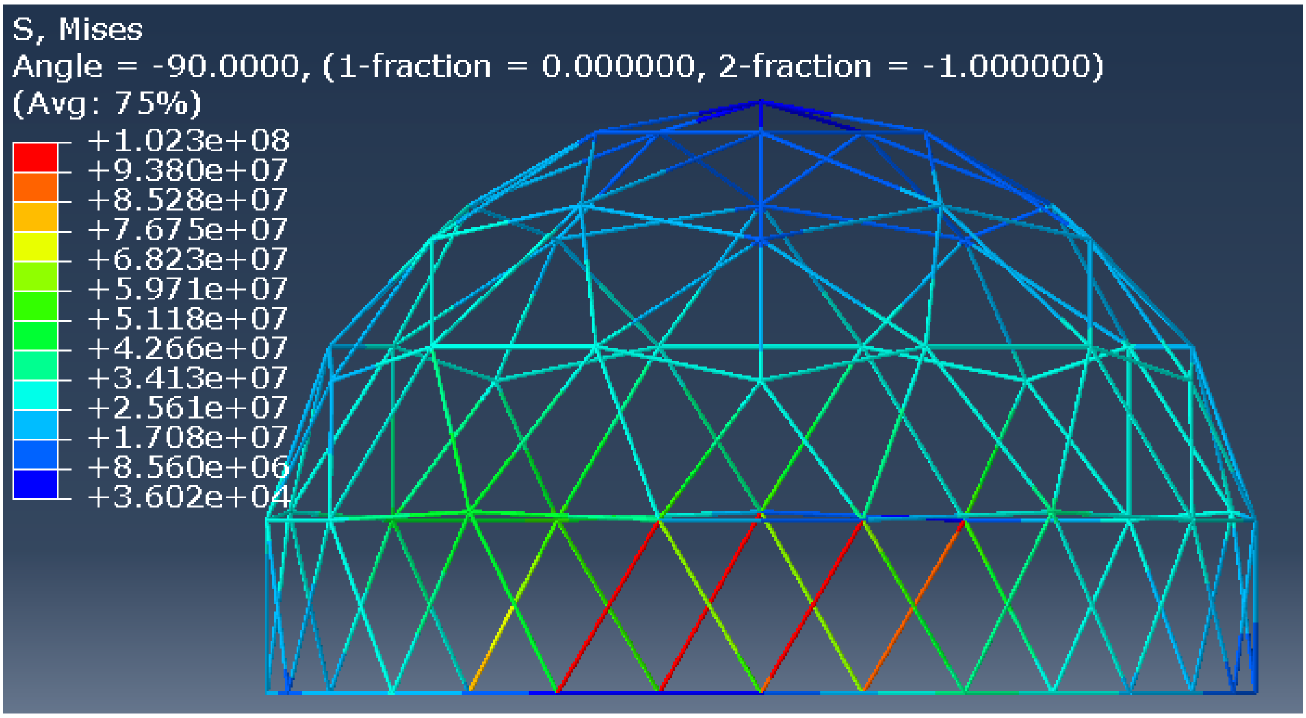


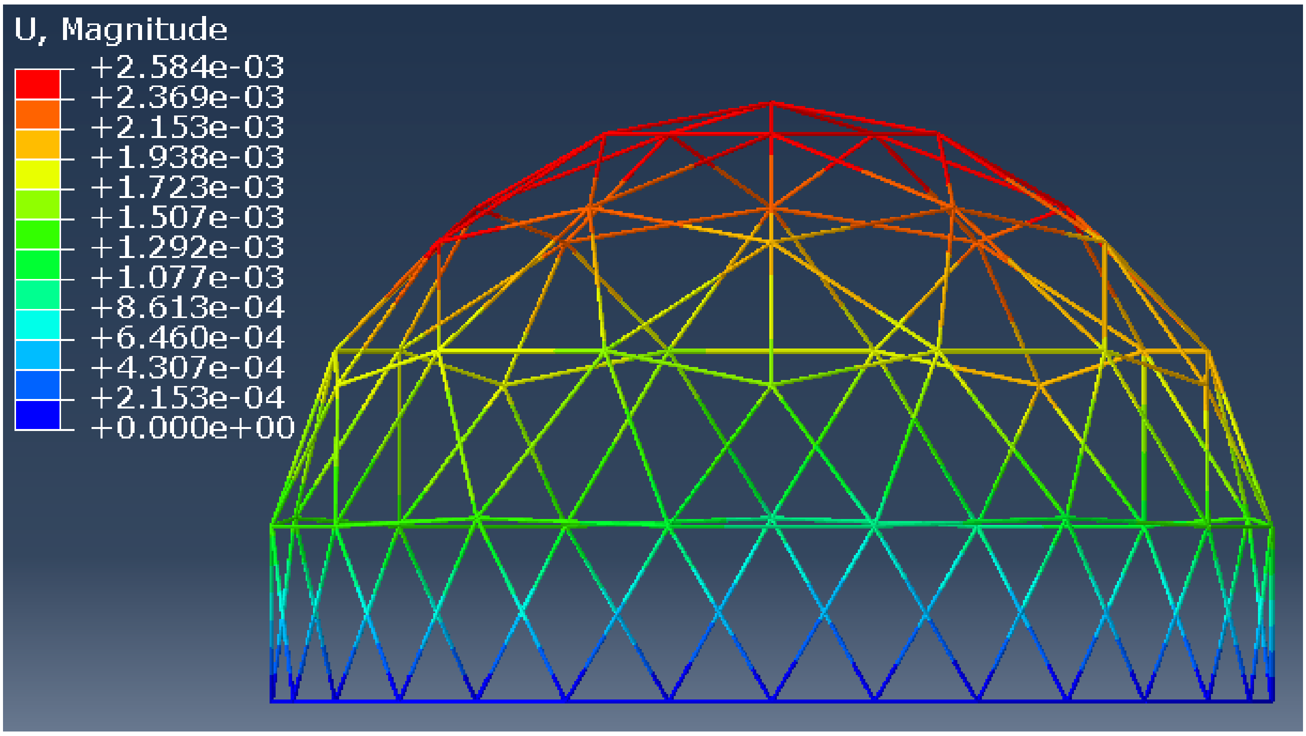
-Load case 3(1.5 S+0.4W**)**





-Load case 4(1.4 W+0.5S**)**





From the above figures, we know maximum Von Mises stress and maximum displacement happens in the load case 4 (1.4W+0.5S).

This maximum Von Mises stress 102.3MPa is smaller than the yield strength of the struts material $F_y = 235Mpa$. So, this structure is safe. Maximum displacement is 3.3mm.

SAFE for strut size 32mm x 2mm

Connection design

We should review the connection design, taking into account only load case 3 (1.5s + 0.4w).

Plate thickness (t) = 4mm plate width (b) = 38mm

Gross Area (A_g) =152 mm^2 Net Area (A_e) = 100 mm^2

Clear distance (L_c) = 14.3mm

Material Properties

$F_y = 235 Mpa$, $F_u = 370 Mpa$, $F_n = 415 Mpa$,

Bolt Size: M14

Diameter=12 mm,

Bolt Area= 113 mm^2,

Bolt Size: M12

Diameter=10mm,

Bolt Area= 78.5 mm^2,

A - Design strength of plate

- Tensile Yielding:

  $P_n / \Omega_t = \left(F_y \times A_g\right) / \Omega_t$ Ω_t =1.111 (LRFD)

  P_n / Ω_t =32.15KN

- Tensile Rupture

  $P_n / \Omega_t = \left(F_u \times A_e\right) / \Omega_t$ Ω_t =1.33(LRFD)

  P_n / Ω_t =27.82KN

B. Bearing Strength of Bolts

R_n / Ω (1.5* $L_c * t * F_u$)/ Ω (Ω =1.33)

R_n / Ω = 23.9KN (M14, M12),

R_n / Ω (3.0*Bolt Diameter*Thickness* F_u)/ Ω

R_n / Ω = 40.06KN (M14), R_n / Ω = 33.4KN (M12)

C. Shear Strength of Bolts

$R_n / \Omega = \left(F_n \times A_b\right) / \Omega$

R_n / Ω =35.2KN (M14), R_n / Ω =24.4KN (M12)

<u>Design Strength=23.9KN > Max Load as per=7.33KN</u>

D. Bearing Strength of Anchor Bolts

R_n / Ω (1.5* $L_c * t * F_u$)/ Ω (Ω =1.33)

R_n / Ω = 23.9KN (M14, M12),

R_n / Ω (3.0*Bolt Diameter*Thickness* F_u)/ Ω

R_n / Ω = 40.06KN (M14), R_n / Ω = 33.4KN (M12)

E. Shear Strength of Anchor Bolts

$$R_n / \Omega = \left(F_n \times A_b\right) / \Omega$$

R_n / Ω =35.2KN (M14), R_n / Ω =24.4KN (M12)

Design Strength=23.9KN > Max Load as per=16.65 KN

SAFE for M12 and M14(Bolt and Anchor Bolt)

CONCLUSION:

We found that 6m diameter geodesic dome with 32mm×2.0mm Round Tube Strut Size can withstand wind of 200mph and snow load of 120psf.

Table.1

Tube size	Maximum wind speed(mph)	Maximum snow load (psf)	Yield strength of tube (MPa)	Maximum Stress (MPa)	Maximum displacement (mm)	
32mm x 2mm	125	60	235	43.12	1.7	Safe
32mm x 2mm	150	80	235	57.16	2.23	Safe
32mm x 2mm	175	100	235	77.46	2.75	Safe
32mm x 2mm	200	120	235	102.3	3.3	Safe

Table.2

Maximum wind speed(mph)	Maximum snow load (psf)	Design strength of plate(kN)	Design strength of Bolt (kN)	Max load in connection node(kN)	Design strength of Anchor bolt(kN)	Max load in connection node(kN)	
125	60	27.82	23.9	3.68	23.9	6.23	Safe
150	80	27.82	23.9	4.89	23.9	9.13	Safe
175	100	27.82	23.9	6.1	23.9	12.6	Safe
200	120	27.82	23.9	7.33	23.9	16.65	Safe

References:

1. Literature:
   a. Based on 2015 National Building Code of Canada (NBCC) Current Edition
   b. Steel Construction Manual, CISC Current Edition
   c. COMBINED PROBABILITIES OF PEAK WIND AND SNOW LOAD EVENTS, 2016
2. Software:
   Abaqus