Design of a Glass Geodesic Dome

1. Introduction

This project describes the procedure for designing a geodesic dome. The unique features of this project are the design and stress analysis of Glass and Aluminum using the relevant Eurocodes. The modeling of wind pressure is complicated due to the curved nature of the dome. To get accurate modeling of the wind pressures Computational Fluid Dynamics (CFD) is used. An actual design of a hemispherical dome with a radius of 5 m is demonstrated in this blog article.

This blog article consists of the following:

1. Specifications of a hemispherical dome
2. Eurocodes used for the design of the Aluminum Frame and Glass Panels
3. Section and Material Definition
4. Wind Simulations and Other Loads
5. Stress Analysis of the Aluminum Frame and Glass Panels
6. Code check for Aluminum and Glass Panels

In my previous blog article [https://structureplugins.xyz/polyhedra/] I have provided information on how to define a hemispherical dome.

2. Specifications of a Hemispherical Dome

Before a structural analysis is performed the primary characteristic of the dome should be defined. In the present case I have specified the following:

1. The base platonic solid shall be an Icosahedron.
2. The radius of the circumsphere shall be 5m.
3. The frequency shall be 6V.
4. The triangulation shall be Class I
5. The dome shall be a perfect hemisphere.

Once I have specified the above characteristics, I will be able to draw the preliminary shape. The shape of the Icosahedron is generated in Stella-4D [Hyperlink]

The details are shown in Figure 1.

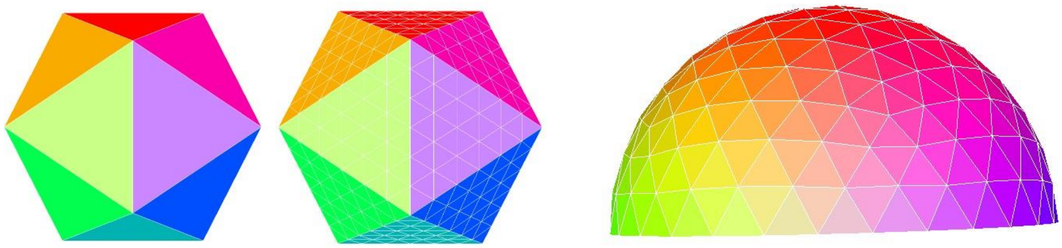

Figure 1: Specifications of the hemispherical dome

The edges of the hemisphere will now form the ribs of the hemisphere, and the triangular faces will form the glass panes.

The model is exported in DXF format, with one layer for the ribs and the other layer for the glass panes (see Figure 2).

The dxf. file is further processed in RFEM-6. Figure 2, shows the 5 m radius dome. The size of the model of a human model of height 1.70 m is included to give a perspective on the size of the dome.

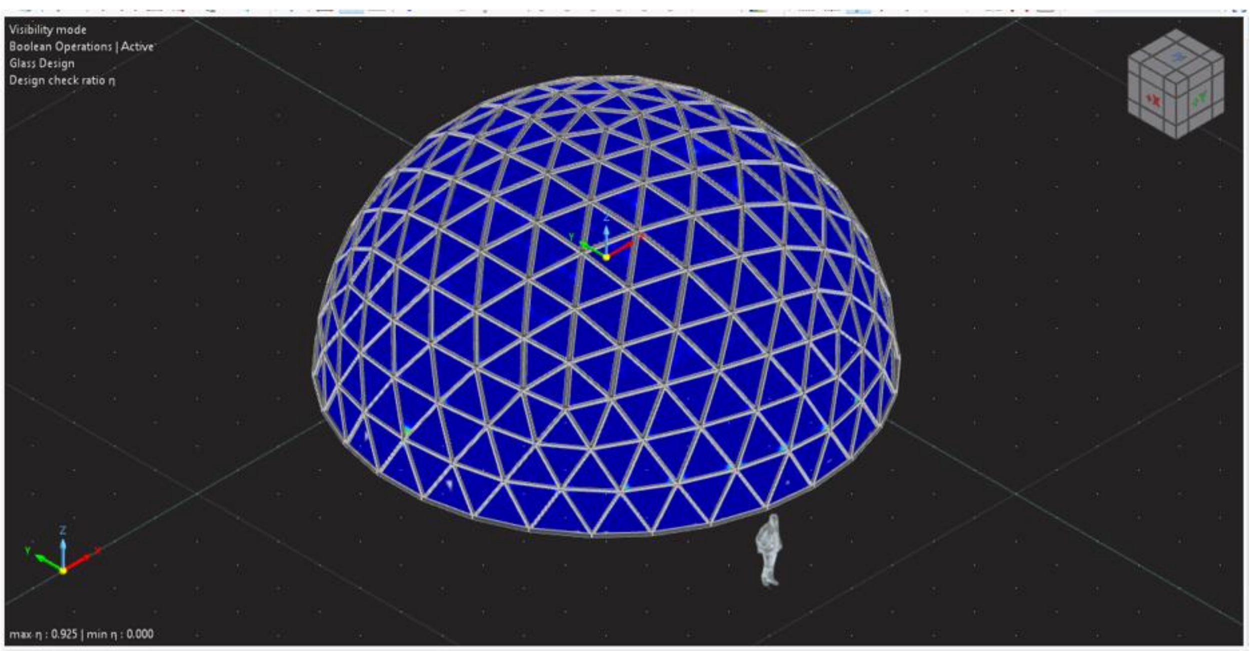

Figure 2: Five (5) m radius dome with a human model of 1.7 m height.

3. Eurocodes for Design of Aluminum and Glass

The basic standard group used is the EN 1991 with the national Annex CEN | 2015-09. The design of Aluminum structures is performed as per EN 1999 with national Annex CN | 2013-12. The glass design is as per DIN 18008 Edition DIN 18008-2020-05. The design codes help to define the following:

1. Permitted materials for Glass and Aluminum.
2. Ultimate Strength and Serviceability Criteria.
3. Code Checks that are required to be performed.

4. Section and Material Definition

4.1 Aluminum Section and Material Properties

The section used in this analysis is a non-standard section specifically configures to form a groove to accommodate the glass panel (8 mm thick) and to be aesthetically pleasing. The section also satisfies the strength and serviceability requirements. The angle of 184 degrees is selected to accommodate the die-hederal angle of approximately 172 degrees. The angle of 184 degrees is obtained as follows (180 – 172)/2 +180 = 184. The cross-section properties are shown in Figure 3. The material grade used is ***“6061M-T6, T6510, T6511-B221 (Extrusion)”.***

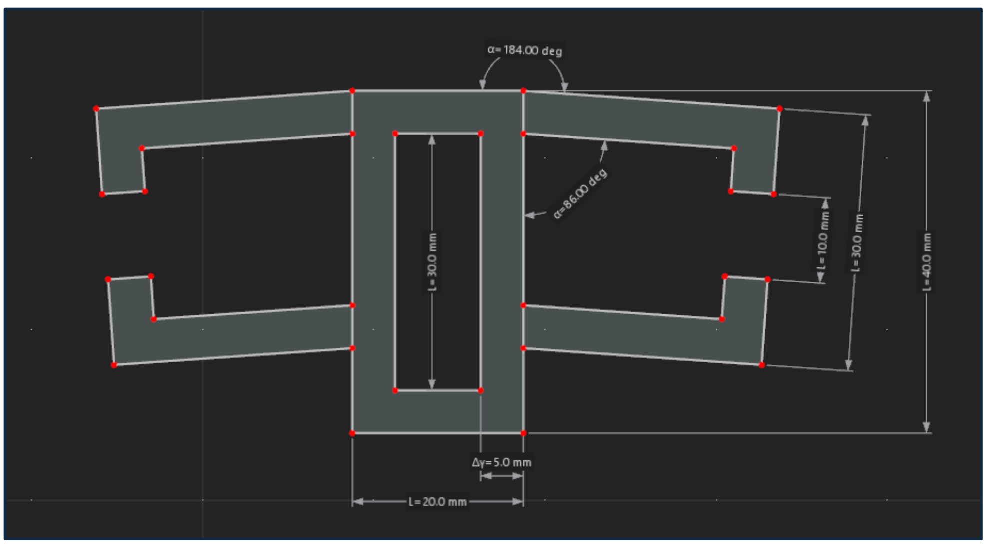

Figure 3: Aluminum cross-section

The section properties are shown in Table 1.

Table 1: Section Properties

	Description	Symbol	Value	Unit
1	**Geometry**			
2	Depth	h	40.0	mm
3	Width	b	79.9	mm
4				
5	**Sectional Area**			
6	Sectional area	A	11.79	cm2
7	Geometric sectional area	Ageom	11.79	cm2
9	**Bending**			
10	Location of centroidal axis in y-direction	ey	-39.9	mm
11	Location of centroidal axis in z-direction	ez	-17.6	mm
12	Area moment of inertia about y-axis	Iy	18.69	cm4
13	Area moment of inertia about z-axis	Iz	54.35	cm4
21	Elastic section modulus about y-axis	Wy,max	10.61	cm3
23	Elastic section modulus about z-axis	Wz	13.61	cm3
24				
25	**Shear**			
26	Shear area in y-direction	Ay	2.37	cm2
27	Shear area in z-direction	Az	2.37	cm2
50	**Other**			
51	Weight	G	3.2	kg/m
52	Surface area per unit length	Am	0.392	m2/m
53	Volume	V	1179.02	cm3/m
54	Section factor	Am/V	332.106	1/m

The material properties of the aluminum section are shown in Table 2.

Table 2: Material Properties

	Description	Symbol	Value	Unit
1	**Basic Properties**			
2	Modulus of elasticity	E	70000.0	N/mm2
3	Shear modulus	G	26000.0	N/mm2
4	Poisson's ratio	ν	0.330	--
5	Mass density	ρ	2700.00	kg/m3
6	Specific weight	γ	27.00	kN/m3
7	Coefficient of thermal expansion	α	0.000023	1/°C

The cross-section dimensions of the bottom rim are shown in Figure 4. The material properties are the same as ***"6061M-T6, T6510, T6511-B221 (Extrusion)".***

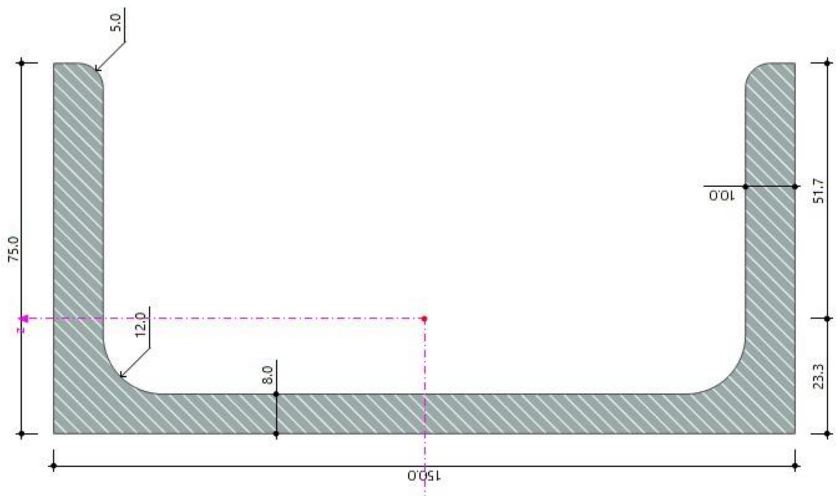

Figure 4: Channel section showing dimensions.

4.2 Glass Panel Section and Material Properties

The glass cross-section used in this design has a thickness of 7 mm. It is 3 layered, with two thermally toughened 3.0 mm thick float glass sandwiching a 1 mm thick Poly Vinyl Butyral (PVB) layer. PVB is a tough plastic resin that is used in between two panes of glass to bond them together. The cross-section dimensions are shown in Figure 5.

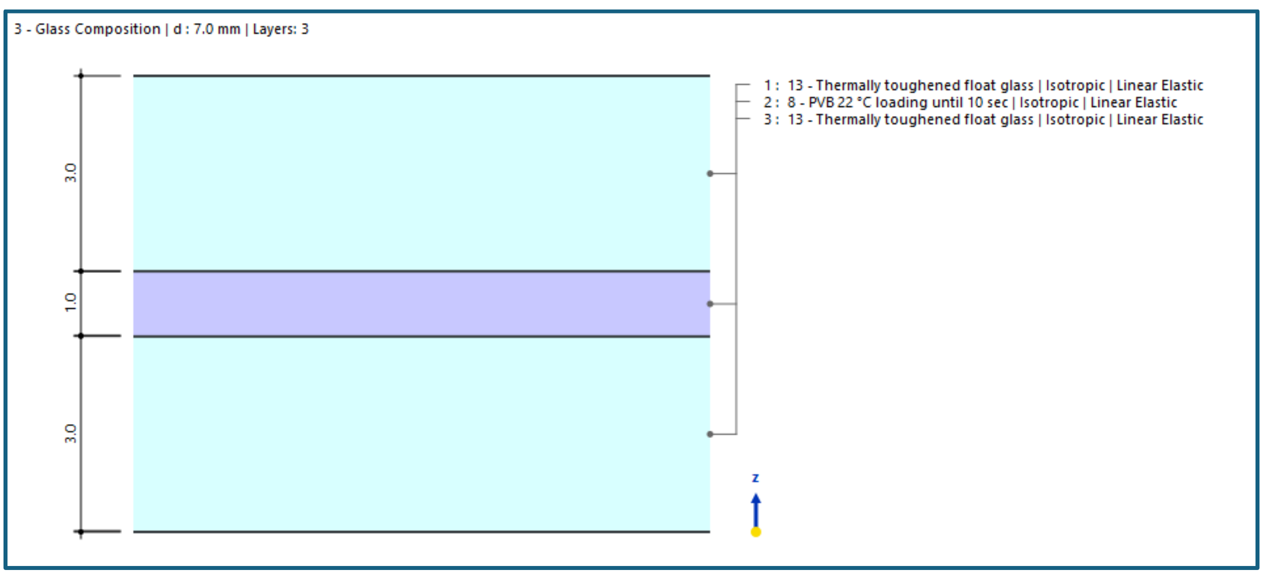

Figure 5: Cross-section dimensions of the glass panel.

The material properties of the glass panel are provided in

Table 3: Material Properties of the glass panel

	Description	Symbol	Value	Unit
1	**Basic Properties**			
2	**Modulus of elasticity**	**E**	**70000.0**	**N/mm2**
3	**Shear modulus**	**G**	**28455.3**	**N/mm2**
4	**Poisson's ratio**	**ν**	**0.230**	**--**
5	**Mass density**	**ρ**	**2500.00**	**kg/m3**
6	**Specific weight**	**γ**	**25.00**	**kN/m3**
7	**Coefficient of thermal expansion**	**α**	**0.000009**	**1/°C**
8				
9	**Strengths**			
10	**Characteristic bending strength**	**fgk**	**120.000**	**N/mm2**
11				
12	**Other Properties**			
13	**Thermal conductivity**	**λ**	**1.000**	**W·m-1·K-1**
14				
15	**Additional Information**			
16	**Glass type**		**Thermally toughened glass**	

The glass panel is modelled as laminated glass without shear coupling. The finite element analysis is performed using 2-dimensional plat theory.

5. Loads on the Geodesic Dome

The loads acting on the geodesic dome apart from the wind loads are summarized in Table 4.

Table 4: Basic Load Cases.

Load Case No.	Description	Fx (KN)	Fy (KN)	Fz (KN)	Action
LC1	Dead Load	0.00	0.0	-43.89	Permanent
LC2	Wind load	0.37		1.51	Wind
LC3	Rain Load (Column of 1 inch or 25.4 mm column of water (-0.25 KN/m^2.)	0.00	0.00	-38.93	Permanent
LC4	Roof Load (Roof Load Category H) - -0.40 KN/m^2.	0.00	0.00	-62.70	Permanent

5.1 Design Situations

A design situation defines the Limit Sates (Ultimate and Serviceability) to be checked. The corresponding load combinations are determined by the corresponding code of design. The limit state rules, or design strengths are analyzed in design situations. The "Design situation type" determines the specification according to which the load cases are combined in the superposition. The options are aligned with the standard

All design situations in the model are listed in this table of the design add-on. Here, you can decide whether and in what way a certain design situation should be taken into account. For the definition of the limit states in DIN 18008 | 2020-5 refer to Figure 6 and Figure 7.

DIN 18008 | 2020-05
ULS (STR/GEO) - Permanent and transient - Eq. 6.10

$$\sum_{j\geq 1} \gamma_{G,j} E_{Gk,j} + \gamma_P E_{Pk} + \gamma_{Q,1} E_{Qk,1} + \sum_{i>1} \gamma_{Q,i} \psi_{0,i} E_{Qk,i}$$

$\gamma_{G,j}$: Partial factor for permanent actions
$E_{Gk,j}$: Permanent actions
γ_P : Partial factor for prestress actions
E_{Pk} : Prestressing action
$\gamma_{Q,1}$: Partial factor for leading variable action
$E_{Qk,1}$: Leading variable action
$\gamma_{Q,i}$: Partial factor for non-leading variable actions
$\psi_{0,i}$: Coefficient for combination value
$E_{Qk,i}$: Other variable actions

Figure 6: Load Combination design for Ultimate Limit State.

DIN 18008 | 2020-05
SLS - Characteristic

$$\sum_{j\geq 1} E_{Gk,j} + E_{Pk} + E_{Qk,1} + \sum_{i>1} \psi_{0,i} E_{Qk,i}$$

$E_{Gk,j}$: Permanent actions
E_{Pk} : Pre-stressing action
$E_{Qk,1}$: Leading variable action
$\psi_{0,i}$: Coefficient for combination value
$E_{Qk,i}$: Other variable actions

Figure 7: Load Combination design for Serviceability Limit State.

The basic Load Cases and associated magnitudes are provided in Table 4. The Action Combinations are shown in the screenshot in Figure 8.

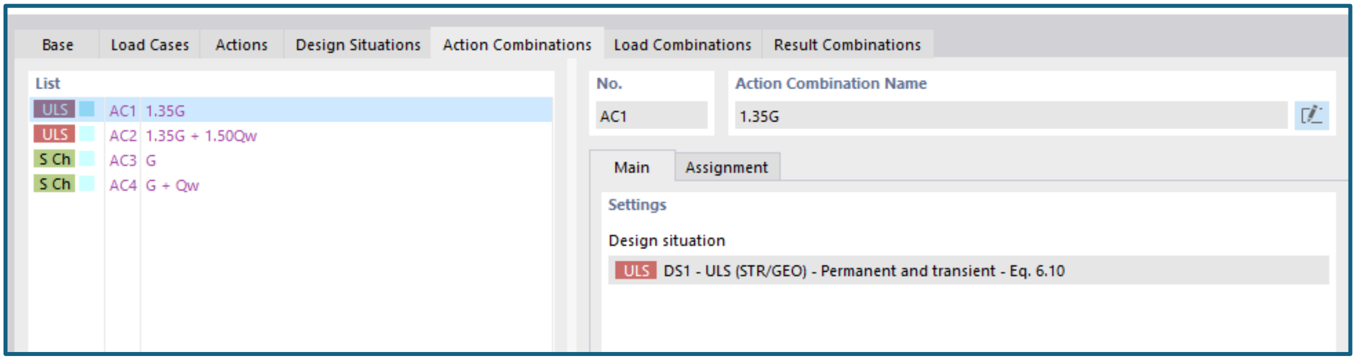

Figure 8: List of Actions

The load combinations for each design situation are shown in the screenshot in Figure 9.

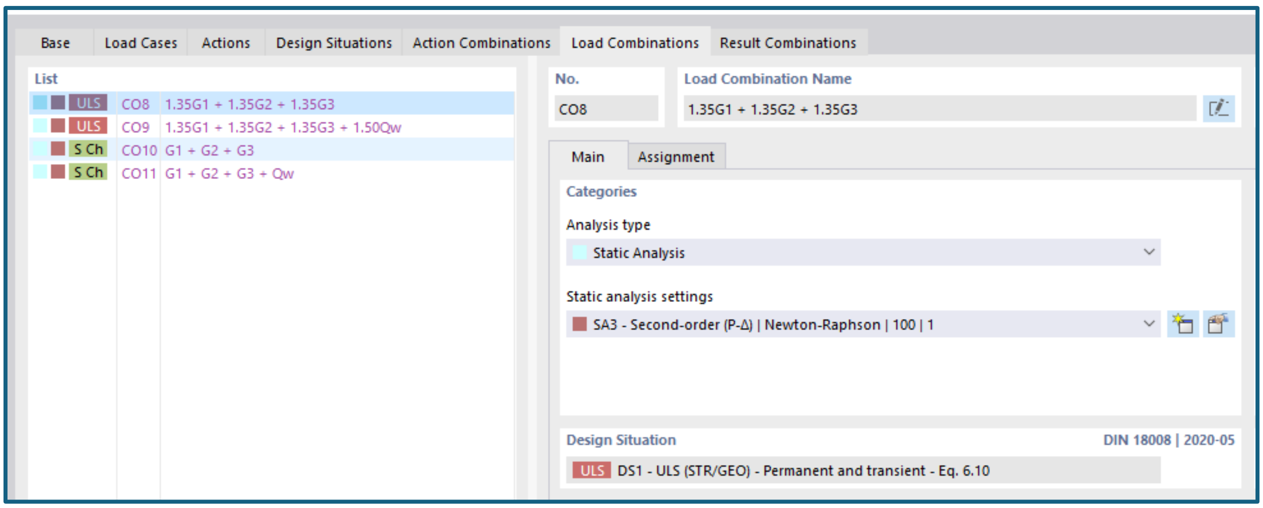

Figure 9: Load combinations for each design situation

5.2 Simulation of Wind Loads

An advanced method using Computation Fluid Dynamics (CFD) is used to simulate the wind pressure on the glass dome. Wind loads on to a curved structure are difficult to model, because as the wind provide profile moves along a curved surface the direction vectors of wind velocity change. CFD models the wind pressures more accurately than traditional means. Figure 10 shows the wind profile used for this project. Since the dome is symmetrical only in the direction of loading (along the global X-axis is used

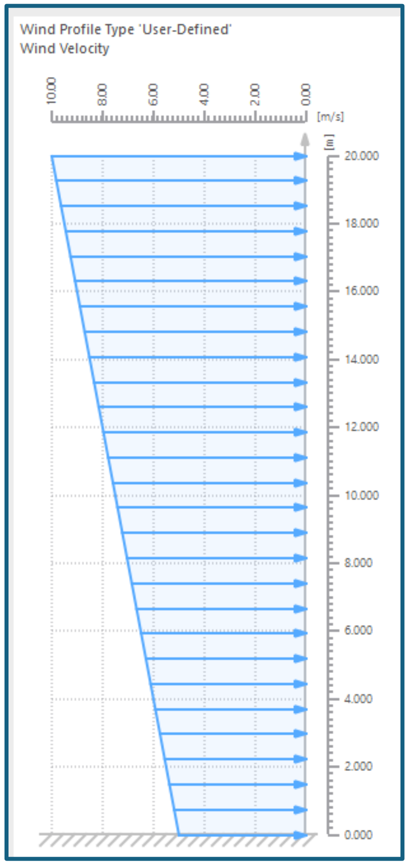

Figure 10: Wind Profile used in analysis

The wind tunnel generated is shown in Figure 11.

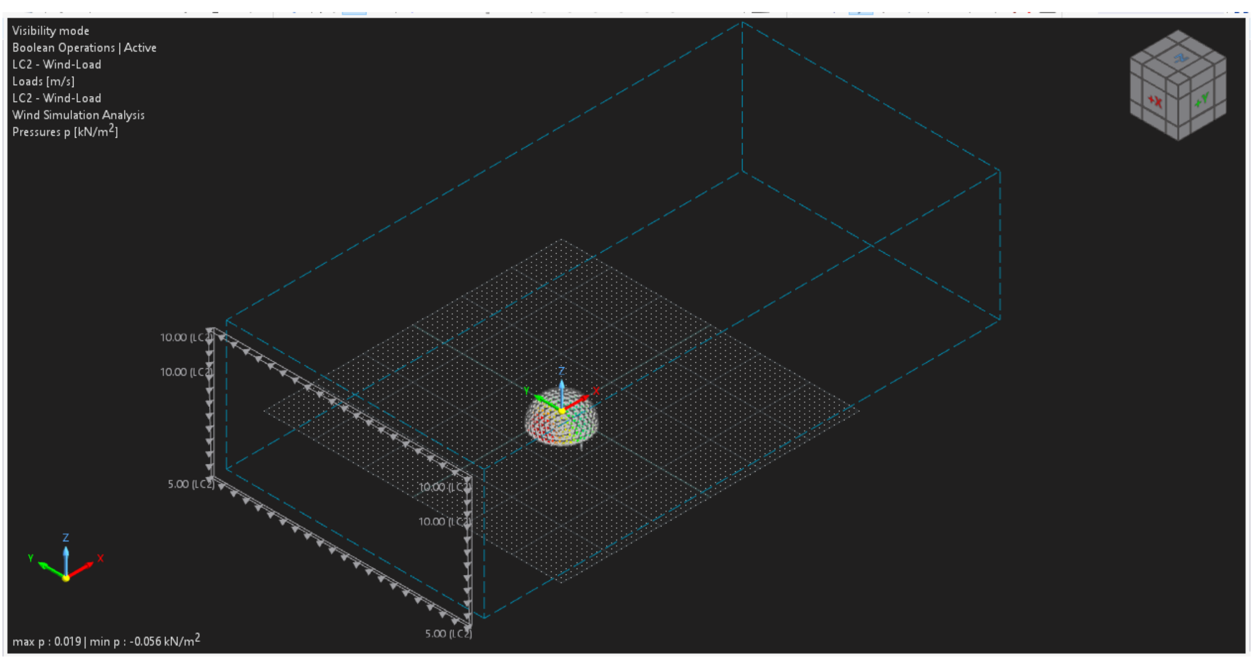

Figure 11: Wind tunnel generated to model wind pressure and velocity.

The wind pressure distribution is shown in Figure 12 and Figure 13.

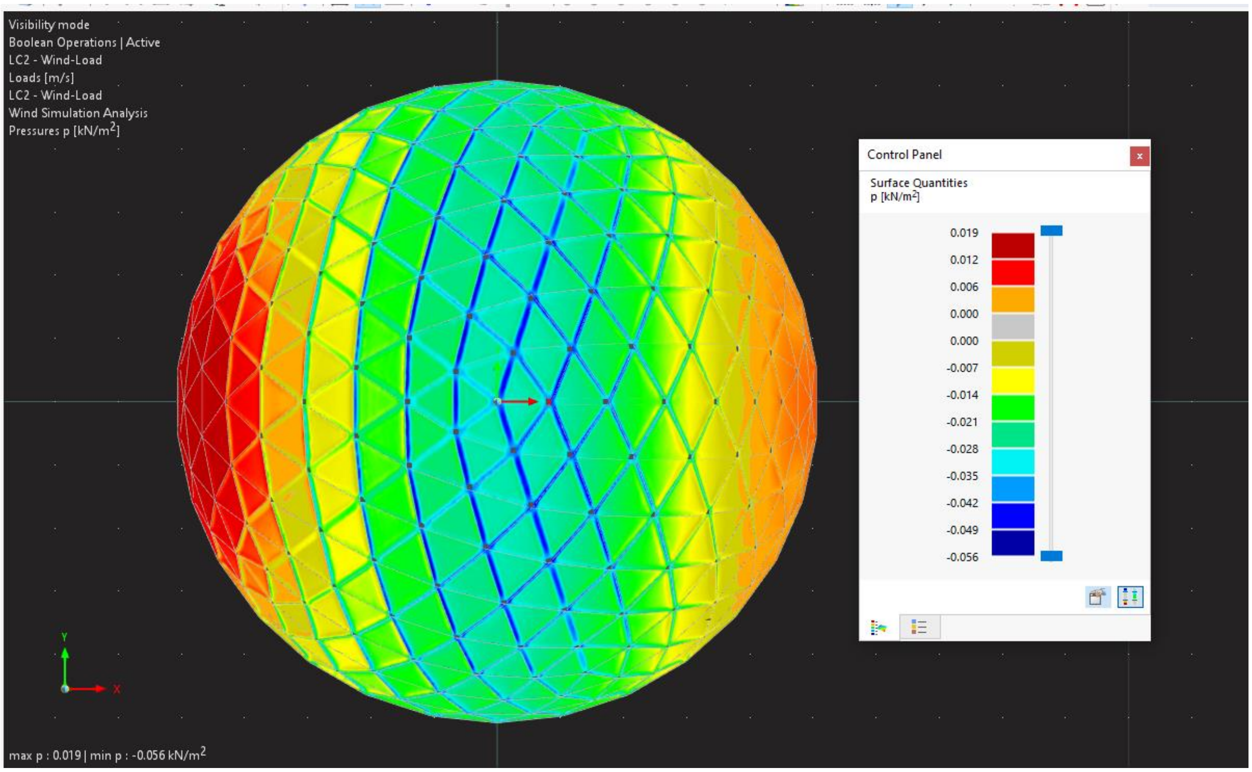

Figure 12: Wind pressure distribution top view.

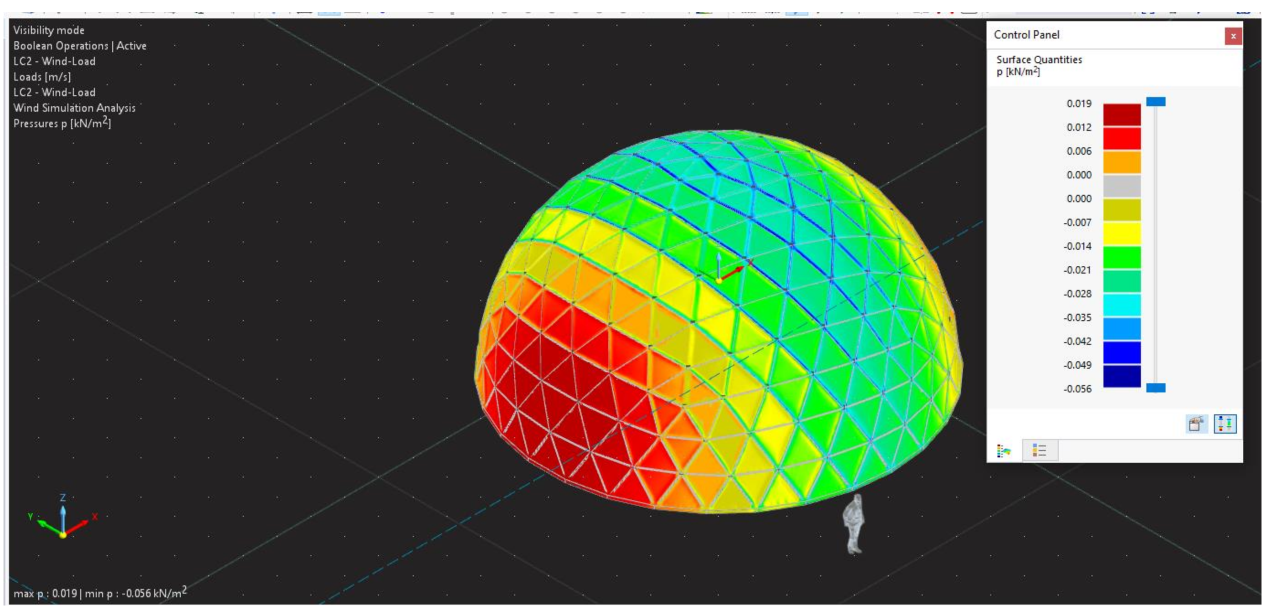

Figure 13: Wind pressure isometric view.

The pressure and velocity distribution are shown in Figure 14, Figure 15 and Figure 16.

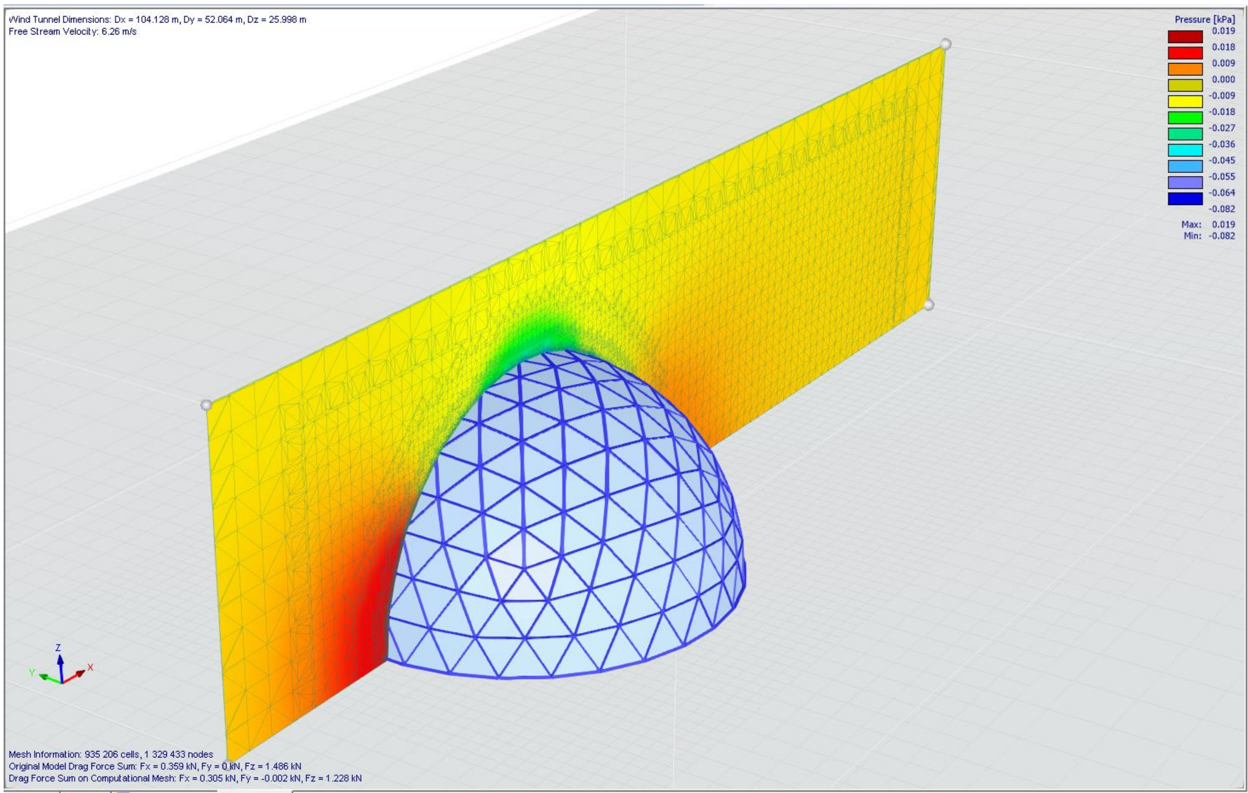

Figure 14: Pressure distribution in the XZ plane

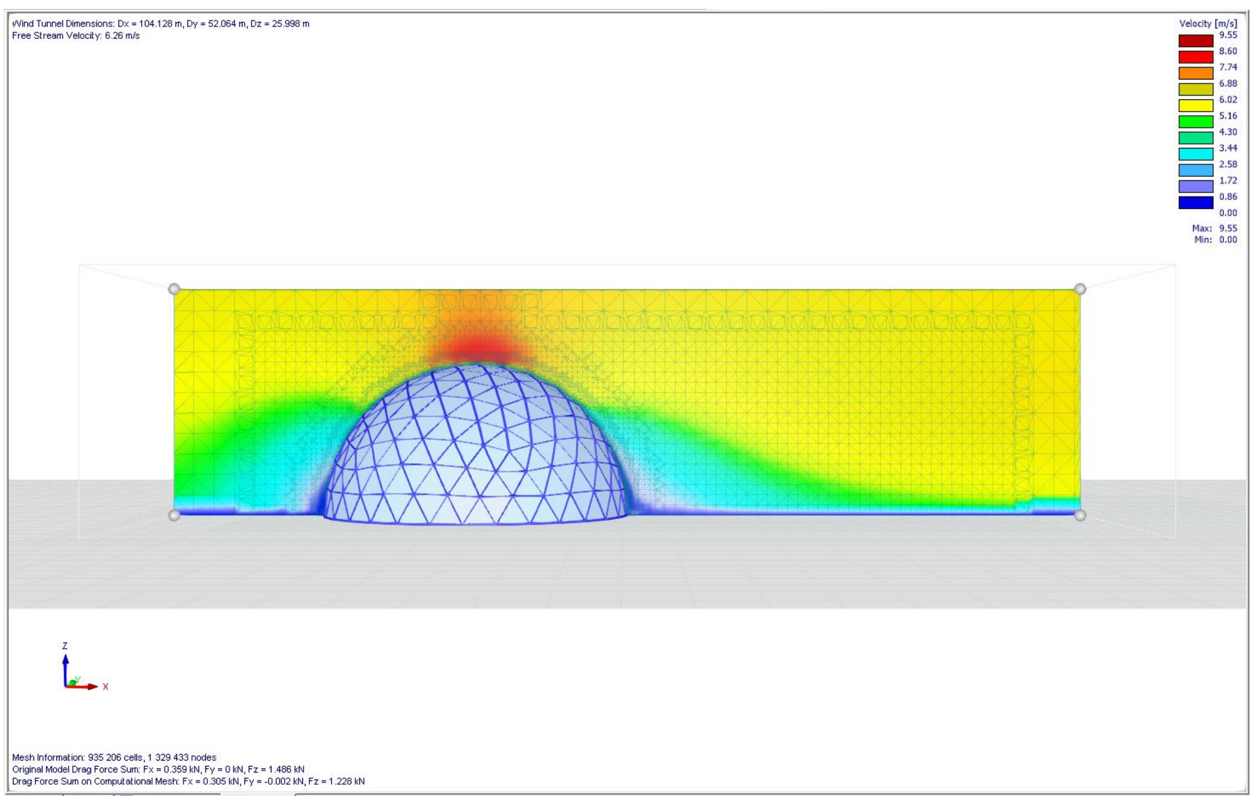

Figure 15: Velocity distribution in the XZ plane

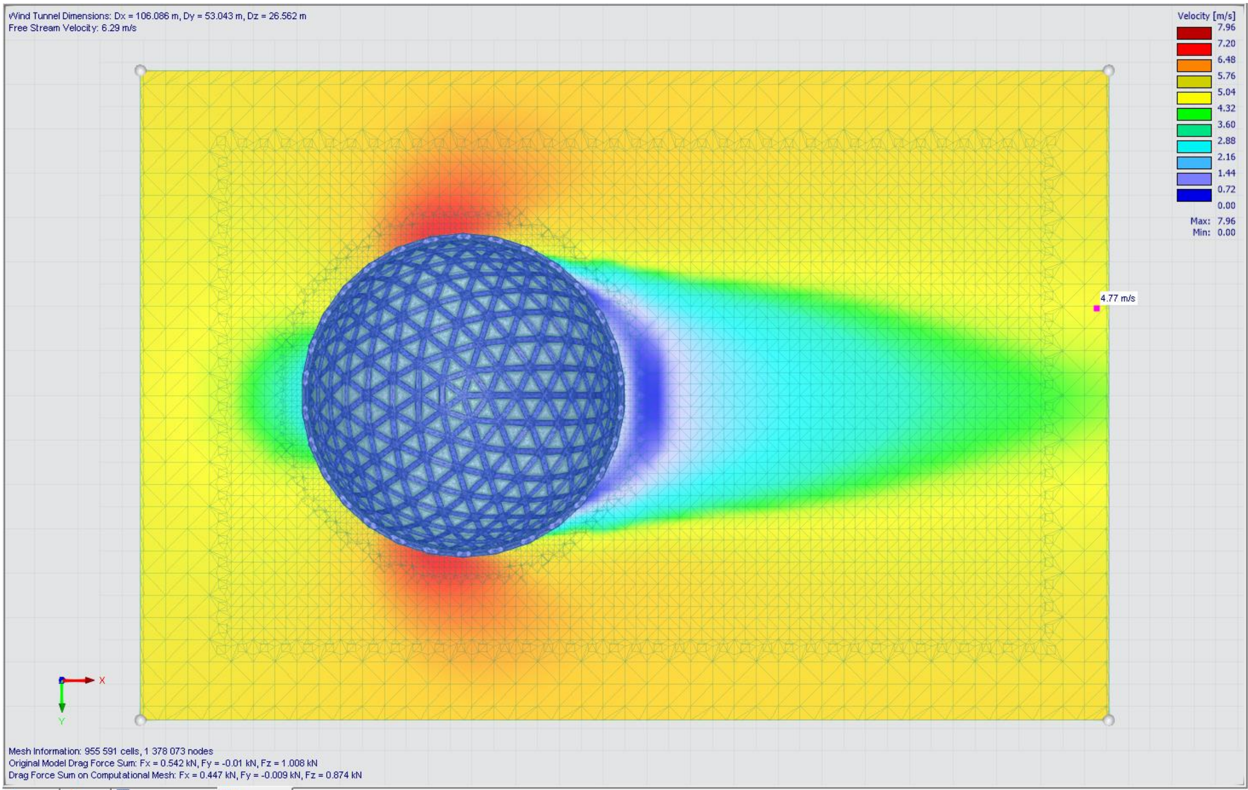

Figure 16: Velocity distribution in the XZ plane

6. Structural Analysis Results

The results from the global analysis are presented first followed by specific results for Glass and Aluminum

6.1 Global Analysis Results

The result for the load combination C09, which represents all 4 basic load cases acting simultaneously and with the highest load combination factors, is presented below.

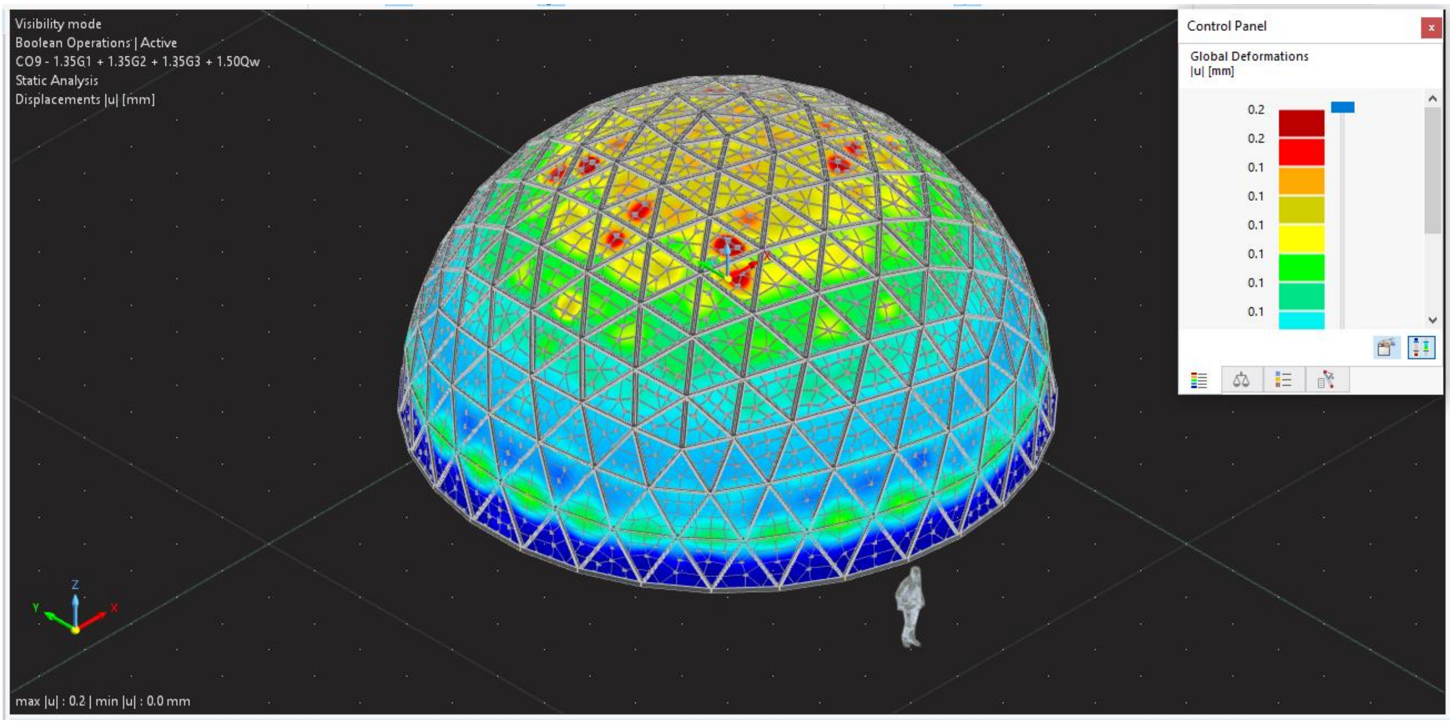

Figure 17: Global displacement distribution

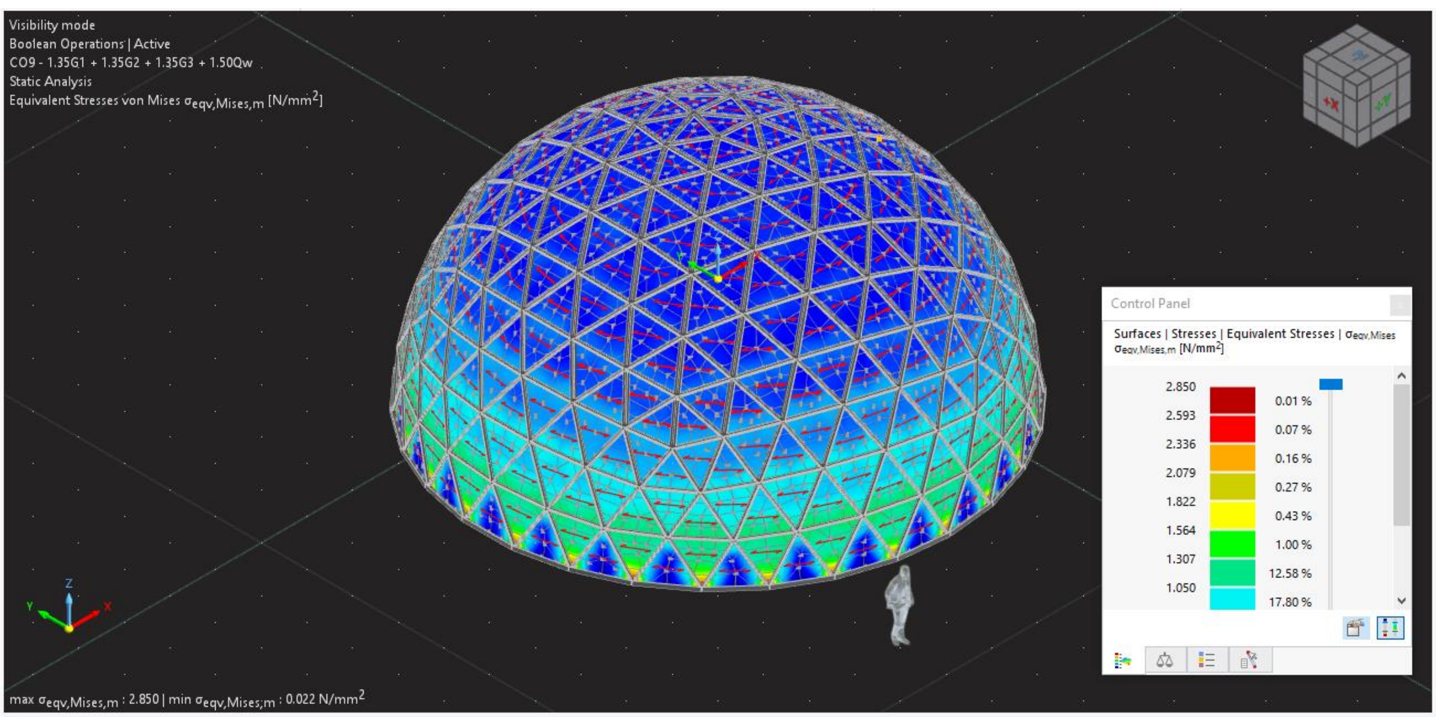

Figure 18: Von-misses stress distribution

6.2 Analysis of Aluminum Sections

Figure 19 shows the stress distribution on the aluminum frame. The code check as per EN 1999 – CEN | 2013-12 for the aluminum member indicated by an orange arrow is presented in Table 5.

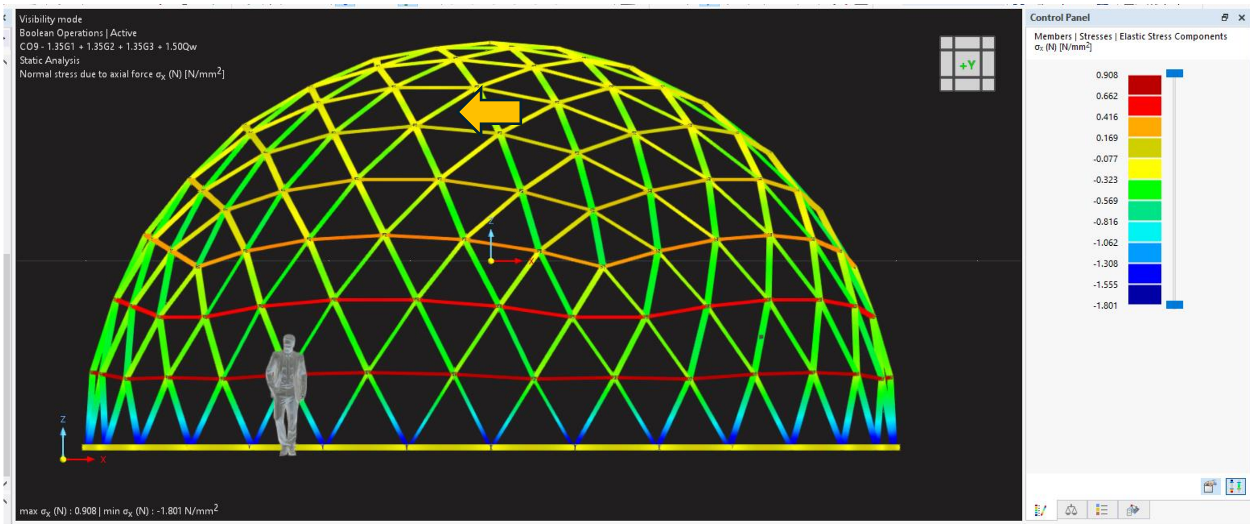

Figure 19: Stress distribution of the Aluminum frame

Table 5: Code check for various identified member in Figure 19

Section Properties | RSECTION BoxExtrudedSection					
Design Internal Forces					
Design axial force	NEd	-0.18	kN		Negligible
Design shear force	Vy,Ed	0.02	kN		Negligible
Design shear force	Vz,Ed	0.02	kN		Negligible
Design torsional moment	TEd	0.00	kNm		Negligible
Design bending moment	My,Ed	0.00	kNm		Negligible
Design bending moment	Mz,Ed	0.00	kNm		Negligible
Design Check Values					
Design compressive force	Nc,Ed	0.18	kN		
Design shear force	Vy,Ed	0.02	kN		
Design shear force	Vz,Ed	0.02	kN		
Design torsional moment	TEd	0.00	kNm		
Design bending moment	My,Ed	0.00	kNm		
Design bending moment	Mz,Ed	0.00	kNm		
Design torsion shear stress	τt,Ed	-0.133	N/mm2		
Area of gross section	Ag	11.79	cm2		
Shear area	Av,y	2.37	cm2		6.2.6(2)
Shear area	Av,z	2.37	cm2		6.2.6(2)
Plastic section modulus of gross section	Wpl,y	13.80	cm3		
Plastic section modulus of gross section	Wpl,z	21.05	cm3		
Elastic section modulus of gross section	Wel,y	8.34	cm3		
Elastic section modulus of gross section	Wel,z	13.61	cm3		
Characteristic value of 0,2% proof strength	fo	240.000	N/mm2		3.2.1(1)
Partial factor	γM1	1.10	--		6.1.3(1)
Design axial force resistance	No,Rd	257.241	kN		6.2.4, Eq. 6.22
Design shear resistance	Vy,Rd	29.854	kN		6.2.6(2), Eq. 6.29
Design shear resistance	Vz,Rd	29.892	kN		6.2.6(2), Eq. 6.29
Shape factor	αy	1.653	--		6.2.9
Design resistance for bending to general yielding	Mo,y,Rd	3.01	kNm		6.2.5.1, Eq. 6.25
Shape factor	αz	1.546	--		6.2.9
Design resistance for bending to general yielding	Mo,z,Rd	4.59	kNm		6.2.5.1, Eq. 6.25
Limit value of negligible compression	ηNc,lim	0.001	--		
Limit value of negligible shear in y-axis	ηVy,lim	0.001	--		
Limit value of negligible shear in z-axis	ηVz,lim	0.001	--		
Limit value of negligible torsion	ητt,lim	0.010	--		
Limit value of negligible bending about y-axis	ηMy,lim	0.001	--		
Limit value of negligible bending about z-axis	ηMz,lim	0.001	--		
Design component for compression	ηNc	0.001	--		6.2.4
Design component for shear in y-axis	ηVy	0.001	--		6.2.6
Design component for shear in z-axis	ηVz	0.001	--		6.2.6
Design component for torsion	ητt	0.001	--		6.2.7
Design component for bending about y-axis	ηMy	0.001	--		6.2.5
Design component for bending about z-axis	ηMz	0.001	--		6.2.5

More details of the code check calculations are provided in Appendix 1.

6.3 Analysis of Glass Panels

The stress distribution in the glass panels is shown in Figure 20 and Figure 21. The glass panel with the highest stress is shown in Figure 22 with code checks presented in Table 6, Table 7 and screenshot in Figure 25: Design calculations performed on the glass panelFigure 25.

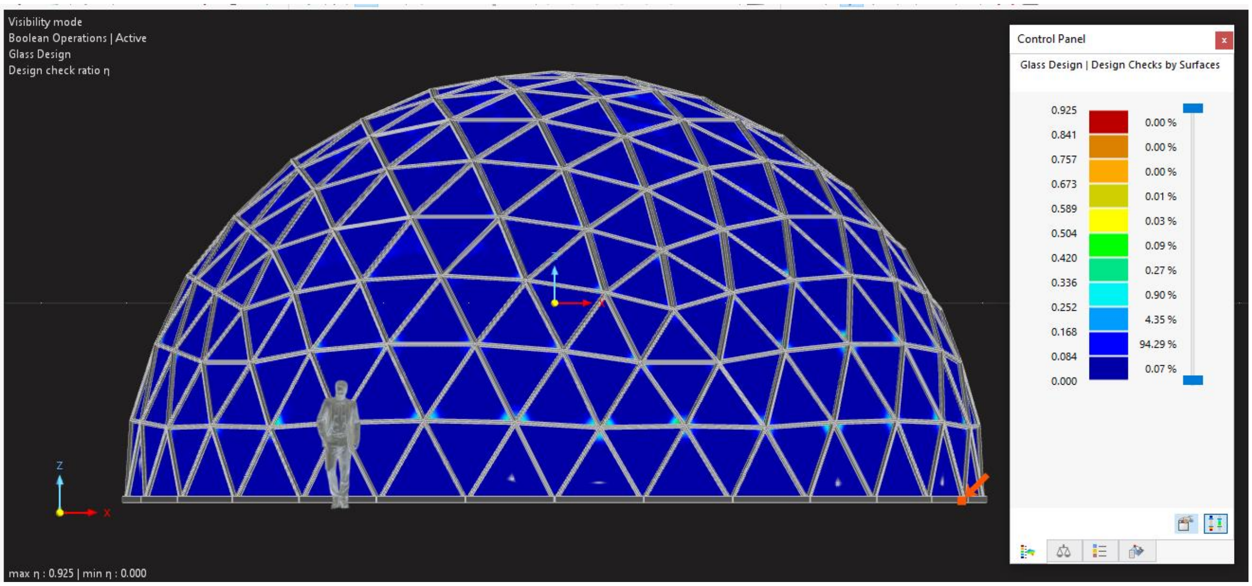

Figure 20: Stress distribution of the Glass Panels (view from Y direction)

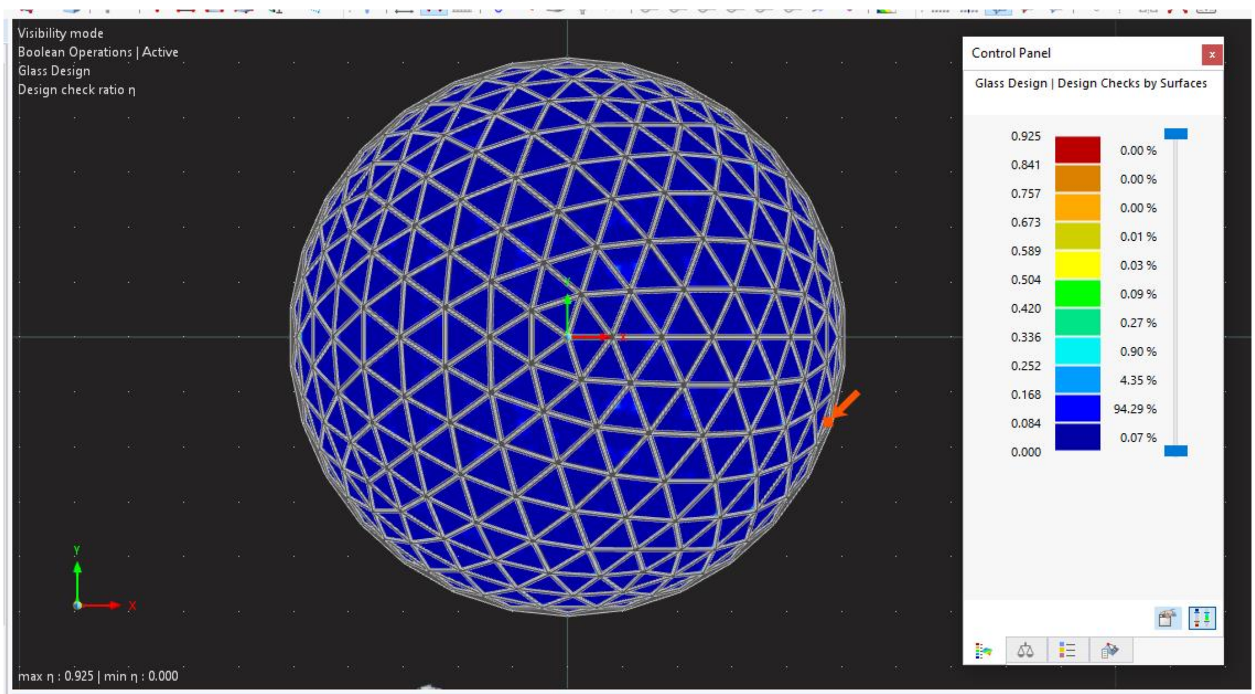

Figure 21: Stress distribution of the Glass Panels (Top View)

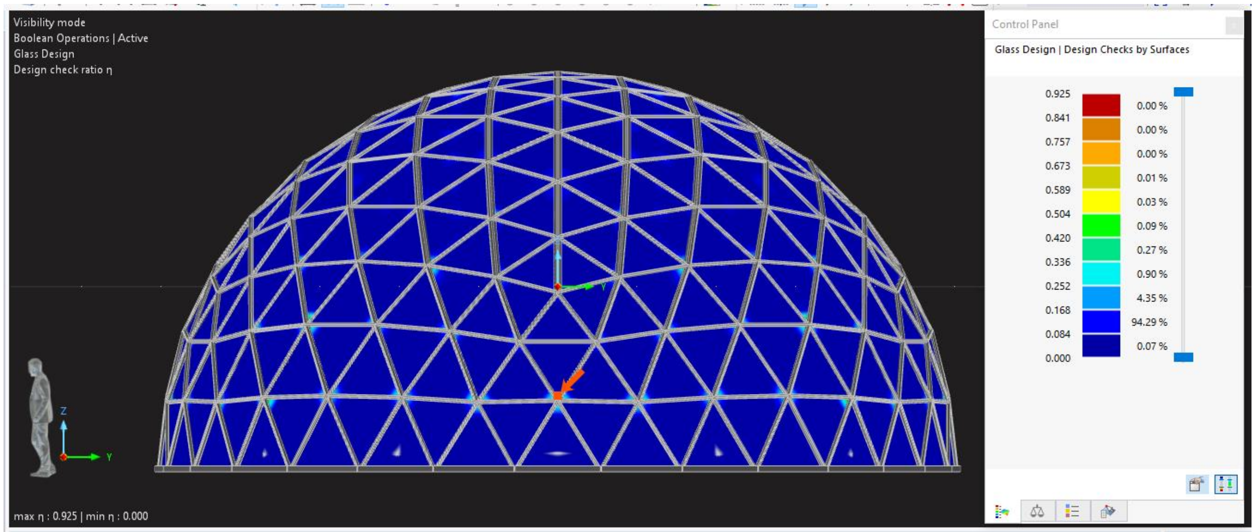

Figure 22: Governing Glass Panel Stresses (indicated by orange arrow).

Table 6: Code check of glass panel as per DIN 18008 | 2020-05.

Material Properties | Thermally toughened float glass | DIN 18008-1:2020-05					
Basic properties					
Modulus of elasticity	E	70000.0	N/mm2		
Shear modulus	G	28455.3	N/mm2		
Poisson's ratio	ν	0.230	--		
Mass density	ρ	2500.00	kg/m3		
Specific weight	γ	25.00	kN/m3		
Coefficient of thermal expansion	α	0.000009	1/°C		
Strengths					
Characteristic bending strength	fgk	120.000	N/mm2		
Other properties					
Thermal conductivity	λ	1.000	W·m-1·K-1		
Additional information					
Glass type		Thermally toughened glass			
Thickness Properties					
Thickness of surface	d	7.0	mm		
Shear coupling between layers		Inactive			
Layer Properties					
Glass type		Thermally toughened glass			
Thickness of layer	t	3.0	mm		
Design Stresses of Glass Surface					
Normal stress in direction of principal axis 1	σ1	81.386	N/mm2		
Design Check Values					
Design bending strength					
Normal stress in direction of principal axis 1	σ1	81.386	N/mm2		
Design bending strength	σRd	88.000	N/mm2		[1], 8.3.6, Eq. 2
Design check ratio	η	0.925	--	≤ 1	[1], 8.3.3, Eq. 1
References					
[1] DIN 18008-1:2020-05					

Table 7: Different Code Checks as per DIN 18008 | 2020-05, performed on the Glass Panel.

Design Check Details | Design Checks in Location

Layer No.	Layer Side	Design Check Ratio η [--]	Design Check Type	
1	Top	0.000 ✓	UL0100.00	Ultimate Limit State | Negligible stresses
1	Middle	0.009 ✓	UL1100.00	Ultimate Limit State | Principal stress σ_1 | Without shear coupling between layers
1	Bottom	0.925 ✓	UL1100.00	Ultimate Limit State | Principal stress σ_1 | Without shear coupling between layers
3	Top	0.000 ✓	UL0100.00	Ultimate Limit State | Negligible stresses
3	Middle	0.009 ✓	UL1100.00	Ultimate Limit State | Principal stress σ_1 | Without shear coupling between layers
3	Bottom	0.925 ✓	UL1100.00	Ultimate Limit State | Principal stress σ_1 | Without shear coupling between layers

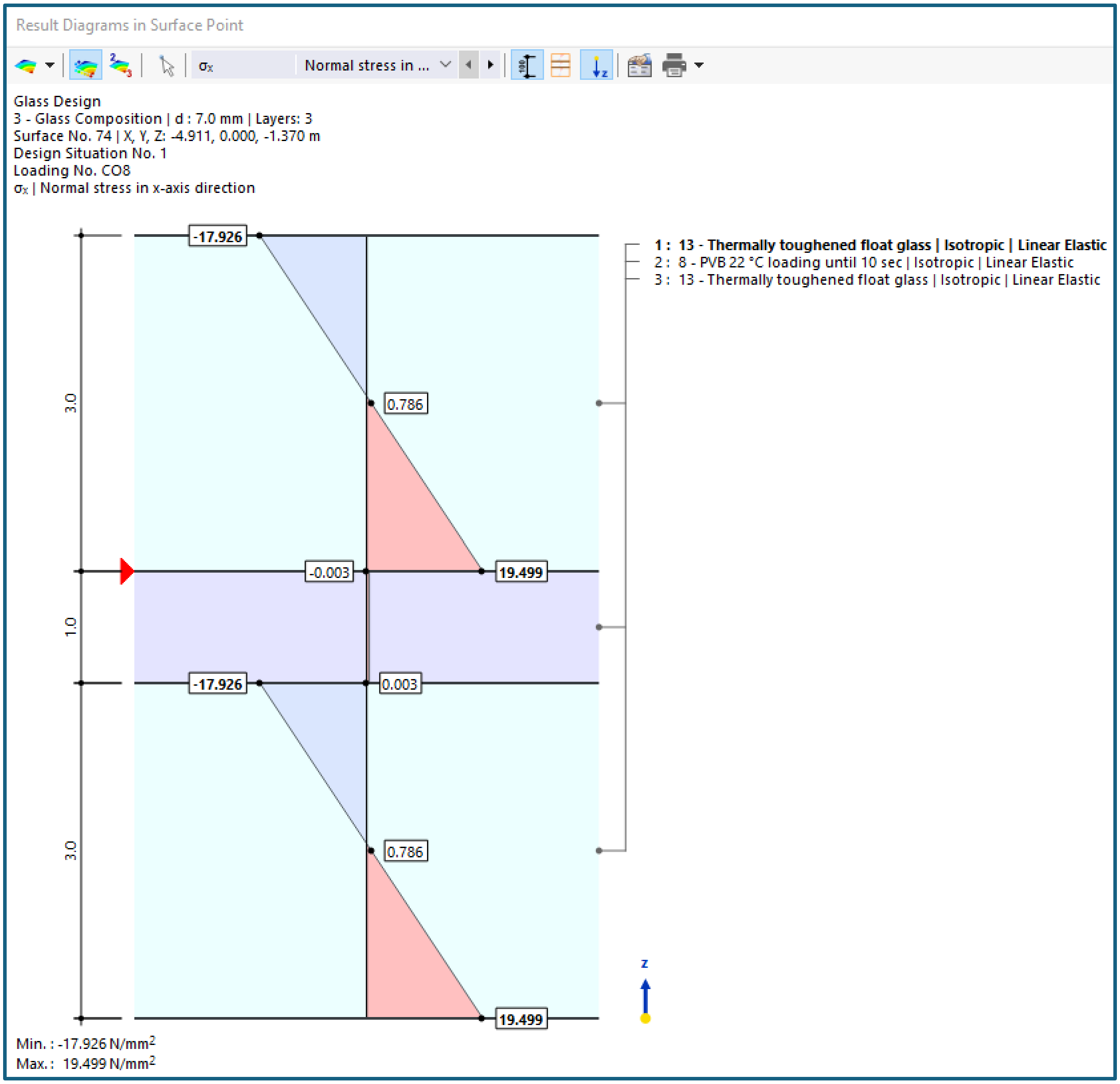

Figure 23: Stress distribution in the indicated glass panel.

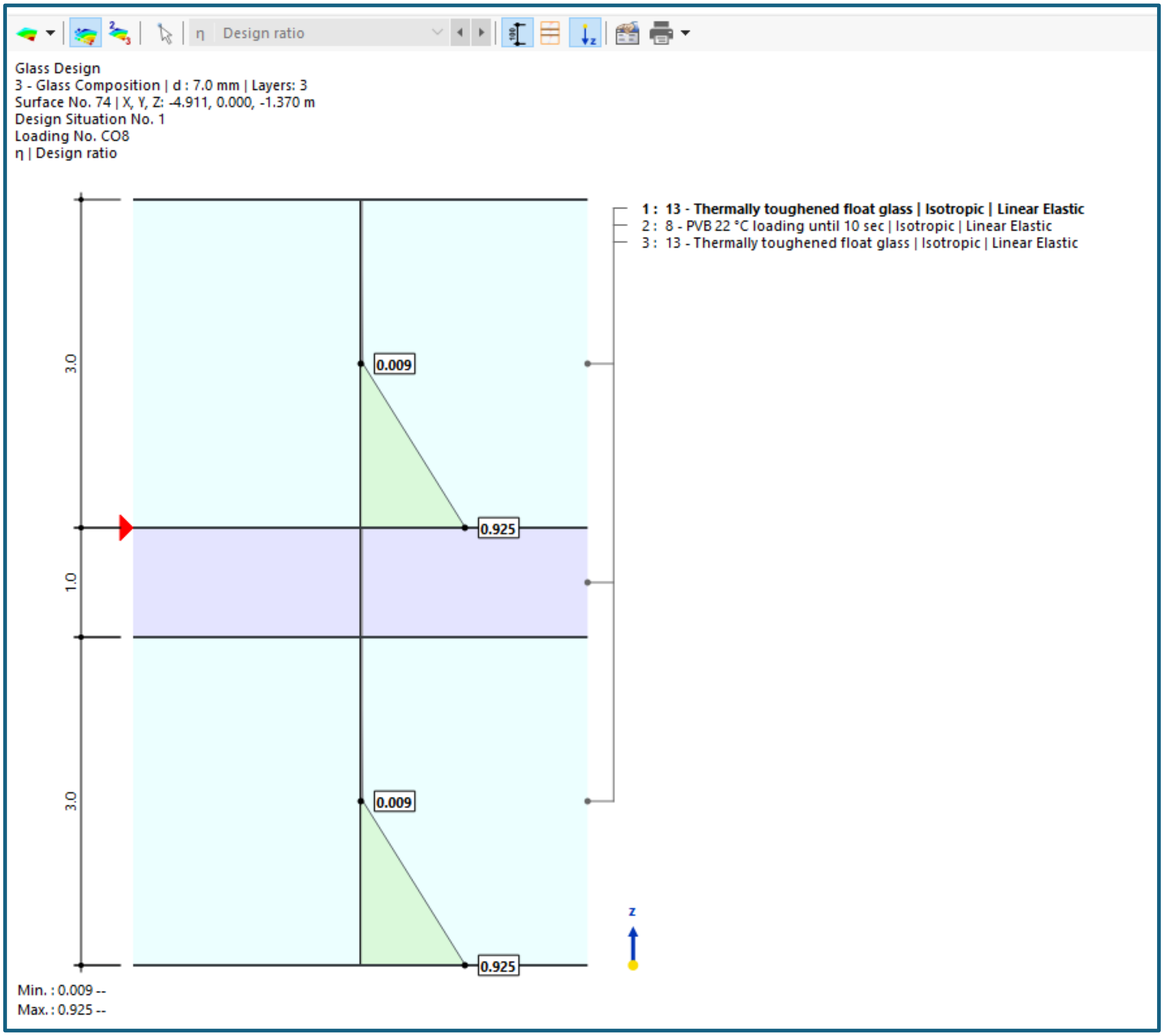

Figure 24: Design ratios on the indicated glass panel

Design Check UL1100 | DIN 18008 | 2020-05

Ultimate Limit State
Principal stress σ_1 | Without shear coupling between layers

$$\sigma_{Rd} = \frac{k_{LG} \cdot k_c \cdot f_k}{\gamma_M} = \frac{1.10 \cdot 1.00 \cdot 120.000\,N/mm^2}{1.50} = 88.000\,N/mm^2$$

[1], 8.3.6, Eq. 2

$$\eta = \frac{\sigma_1}{\sigma_{Rd}} = \frac{81.386\,N/mm^2}{88.000\,N/mm^2} = 0.925$$

[1], 8.3.3, Eq. 1

$$\eta = 0.925 \leq 1 \checkmark$$

σ_{Rd}	Design bending strength
k_{LG}	Factor for laminated glass
k_c	Construction factor
f_k	Characteristic bending strength
γ_M	Partial factor
σ_1	Normal stress in direction of principal axis 1

References:

[1] DIN 18008-1:2020-05

Figure 25: Design calculations performed on the glass panel

7. Conclusion

In this report I have shown how to design a real-life size 5 m radius hemispherical geodesic dome. This report shows how to

1. Specify the geometrical requirements of a hemispherical dome
2. How to define the loads
3. Use CFD to model wind loads
4. Perform design code checks for Glass and Aluminum sections

This is a practical example, which can be easily implemented in real life. If you would like to contact me regarding the design of hemispherical domes use the contact sheet on my website (https://www.structureplugins.com).

Appendix – I

Calculation for Code Check of the identified Aluminum Section

A

MEMBER NO. 209 | DS1 | CO9 | 0.114 M | SP0100

Aluminum Design

Design Check SP0100 | EN 1999 | CEN | 2013-12

Section Proof
Negligible internal forces

Compression:

$$N_{o,Rd} = A_g \cdot \frac{f_o}{\gamma_{M1}} = 11.79\,\text{cm}^2 \cdot \frac{240.000\,\text{N/mm}^2}{1.10} = 257.241\,\text{kN}$$ 6.2.4, Eq. 6.22

$$\eta_{Nc} = \frac{N_{c,Ed}}{N_{o,Rd}} = \frac{0.25\,\text{kN}}{257.241\,\text{kN}} = 0.001$$ 6.2.4

$\eta_{Nc} \leq \eta_{Nc,lim}$

$N_{c,Ed}$ is negligible.

Shear in y-axis:

$$V_{y,Rd} = A_{v,y} \cdot \frac{f_o}{\sqrt{3} \cdot \gamma_{M1}} = 2.37\,\text{cm}^2 \cdot \frac{240.000\,\text{N/mm}^2}{\sqrt{3} \cdot 1.10} = 29.854\,\text{kN}$$ 6.2.6(2), Eq. 6.29

$$\eta_{Vy} = \frac{V_{y,Ed}}{V_{y,Rd}} = \frac{0.03\,\text{kN}}{29.854\,\text{kN}} = 0.001$$ 6.2.6

$\eta_{Vy} \leq \eta_{Vy,lim}$

$V_{y,Ed}$ is negligible.

Shear in z-axis:

$$V_{z,Rd} = A_{v,z} \cdot \frac{f_o}{\sqrt{3} \cdot \gamma_{M1}} = 2.37\,\text{cm}^2 \cdot \frac{240.000\,\text{N/mm}^2}{\sqrt{3} \cdot 1.10} = 29.892\,\text{kN}$$ 6.2.6(2), Eq. 6.29

$$\eta_{Vz} = \frac{V_{z,Ed}}{V_{z,Rd}} = \frac{0.01\,\text{kN}}{29.892\,\text{kN}} = 0.000$$ 6.2.6

$\eta_{Vz} \leq \eta_{Vz,lim}$

$V_{z,Ed}$ is negligible.

Shear stress due to torsion:

$$\eta_{\tau t} = \frac{\sqrt{3} \cdot |\tau_{t,Ed}|}{\frac{f_o}{\gamma_{M1}}} = \frac{\sqrt{3} \cdot |-0.269\,\text{N/mm}^2|}{\frac{240.000\,\text{N/mm}^2}{1.10}} = 0.002$$ 6.2.7

$\eta_{\tau t} \leq \eta_{\tau t,lim}$

$\tau_{t,Ed}$ is negligible.

Bending about major y-axis:

A MEMBER NO. 209 | DS1 | CO9 | 0.114 M | SP0100 — Aluminum Design

$$\alpha_y = \frac{W_{pl,y}}{W_{el,y}} = \frac{13.80\,cm^3}{8.34\,cm^3} = 1.653$$ 6.2.9

$$M_{o,y,Rd} = \alpha_y \cdot W_{el,y} \cdot \frac{f_o}{\gamma_{M1}} = 1.653 \cdot 8.34\,cm^3 \cdot \frac{240.000\,N/mm^2}{1.10} = 3.01\,kNm$$ 6.2.5.1, Eq. 6.25

$$\eta_{My} = \frac{M_{y,Ed}}{M_{o,y,Rd}} = \frac{0.00\,kNm}{3.01\,kNm} = 0.000$$ 6.2.5

$\eta_{My} \leq \eta_{My,lim}$

$M_{y,Ed}$ is negligible.

Bending about minor z-axis:

$$\alpha_z = \frac{W_{pl,z}}{W_{el,z}} = \frac{21.05\,cm^3}{13.61\,cm^3} = 1.546$$ 6.2.9

$$M_{o,z,Rd} = \alpha_z \cdot W_{el,z} \cdot \frac{f_o}{\gamma_{M1}} = 1.546 \cdot 13.61\,cm^3 \cdot \frac{240.000\,N/mm^2}{1.10} = 4.59\,kNm$$ 6.2.5.1, Eq. 6.25

$$\eta_{Mz} = \frac{M_{z,Ed}}{M_{o,z,Rd}} = \frac{0.00\,kNm}{4.59\,kNm} = 0.001$$ 6.2.5

$\eta_{Mz} \leq \eta_{Mz,lim}$

$M_{z,Ed}$ is negligible.

All internal forces are negligible.

$\eta = 0.000 \leq 1$ ✓

$N_{o,Rd}$	Design axial force resistance
A_g	Area of gross section
f_o	Characteristic value of 0,2% proof strength
γ_{M1}	Partial factor
η_{Nc}	Design component for compression
$N_{c,Ed}$	Design compressive force
$\eta_{Nc,lim}$	Limit value of negligible compression
$V_{y,Rd}$	Design shear resistance
$A_{v,y}$	Shear area
η_{Vy}	Design component for shear in y-axis
$V_{y,Ed}$	Design shear force
$\eta_{Vy,lim}$	Limit value of negligible shear in y-axis
$V_{z,Rd}$	Design shear resistance
$A_{v,z}$	Shear area
η_{Vz}	Design component for shear in z-axis
$V_{z,Ed}$	Design shear force
$\eta_{Vz,lim}$	Limit value of negligible shear in z-axis

A MEMBER NO. 209 | DS1 | CO9 | 0.114 M | SP0100 — Aluminum Design

$\eta_{\tau t}$	Design component for torsion
$\tau_{t,Ed}$	Design torsion shear stress
$\eta_{\tau t,lim}$	Limit value of negligible torsion
α_y	Shape factor
$W_{pl,y}$	Plastic section modulus of gross section
$W_{el,y}$	Elastic section modulus of gross section
$M_{o,y,Rd}$	Design resistance for bending to general yielding
η_{My}	Design component for bending about y-axis
$M_{y,Ed}$	Design bending moment
$\eta_{My,lim}$	Limit value of negligible bending about y-axis
α_z	Shape factor
$W_{pl,z}$	Plastic section modulus of gross section
$W_{el,z}$	Elastic section modulus of gross section
$M_{o,z,Rd}$	Design resistance for bending to general yielding
η_{Mz}	Design component for bending about z-axis
$M_{z,Ed}$	Design bending moment
$\eta_{Mz,lim}$	Limit value of negligible bending about z-axis