STATISCHER PRÜFBERICHT FÜR CARPORT WING TYP 80

2023-09

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STRUCTURE DESIGN ASSESSMENT REPORT

Title	Carport Wing		
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1. Basic Information

1.1 Project Overview

TÜV Rheinland (hereafter refers to the **TR**) was entrusted by ETS Dienstleistungs- und Handels GmbH (hereafter refers to the **client**) as the third party to perform a structure design assessment regarding Carport Wing (hereafter refers to the **object**).

The structure design calculation and assessment are for the main body calculation of the object.

1.2 Principle Specifications

1) EN 1990:2002 *Eurocode - Basis of structural design;*
2) EN 1991-1-1:2002 *Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight and imposed loads for buildings;*
3) EN 1991-1-3:2003 *Eurocode 1 - Actions on structures - Part 1-3: General actions - Snow loads;*
4) EN 1991-1-4:2005 *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions;*
5) EN 1993-1-1:2005+A1:2014 *Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings;*
6) EN 1999-1-1:2007+A1:2009+A2:2013 *Eurocode 9: Design of aluminum structures - Part 1-1: General structural rules;*
7) *3D Model & Design description 2022.07;*
8) *Parts list & Drawings 2022.07.*

1.3 Structure Overview

According to the data provided by client, the external contour dimension of the cantilevered shed carport structure is 4.70m (length) x2.40m (width) x2.10m (column height). The top of the object is an inclined structure with an inclination of 6°. The overall stressed frame structure of the object structure is composed of two 90.0mm x200.0mm x2.2/3.5mm rectangular pipe columns and two 68.0mm x 150.0mm x2.0mm cantilever beams. The columns and cantilever beams are connected by built-in corner pieces. Except that the connecting corner pieces are steel material, the other frame structure parts are all aluminum alloy material.

Table 1-1 Dimension parameter of each component

Component	Material	Width(mm)	Height(mm)	Thickness(mm)
Column	6082-T5	90.0	200.0	3.5/2.2
Cantilever beam	6082-T5	68.0	150.0	2.0
Top cross beam	6082-T5	38.0	46.0	1.0
Beam-column corner piece	Q235	-	-	4.0

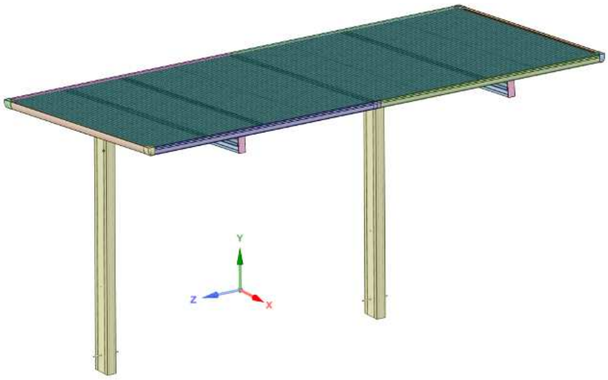

Figure 1-1 Overall design diagram of the object

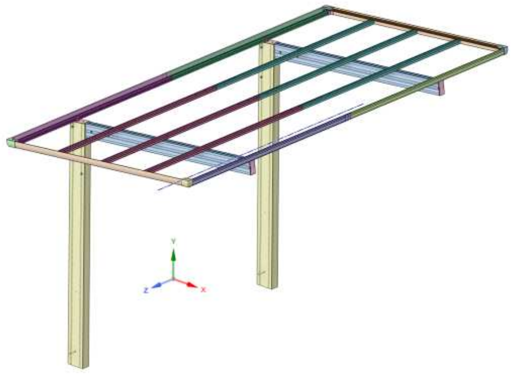

Figure 1-2 Framework diagram of the object

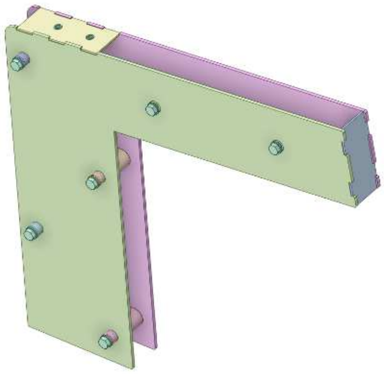

Figure 1-3 Beam-column stiffening corner piece

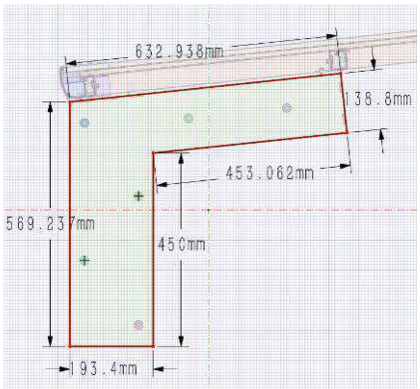

Figure 1-4 Dimension drawing of stiffening corner piece

1.4 Material and Performance

The material mechanical parameters of steel structure framework of the object are shown as follows.

Table 1-2 Material mechanical parameters

Materials	Elastic modulus (E) N/mm^2	Poisson's ratio (υ)	Density (ρ) Kg/m^3	Yield strength MPa
6082-T5	70,000	0.3	2,700	230
Steel material (Q235)	210,000	0.3	7,850	235

1.5 Load Value

For this object, the loads for consideration mainly include:

1) Wind load:

According to the information provided by client, the designed wind speed is 30.0m/s.

Referring to Clause 7.7 of EN 1991-1-4 (Wind load calculation method of rectangular section members), the value of wind load applied on the object is shown in Table 1-3~1-6.

Table 1-3 Single inclined roof wind pressure load value

Parameter name	Parameter	Value
Structural coefficient	$c_s c_d$	1
Roof angle (°)	α	6
Component force coefficient	c_f	0.7
Basic wind velocity (m/s)	v_b	30.0
Air density (kg/m^3)	ρ	1.25
Basic wind pressure (N/m^2)	$q_b = 0.5 \cdot \rho \cdot v_b^2$	562.5
Terrain category	-	I
Exposure factor	c_e	2
Peak wind pressure (N/m^2)	$q_p = c_e \cdot q_b$	1125.0
Reference area (m^2)	A_{ref}	11.2
Roof wind load (N)	$F_w = c_s \cdot c_d \cdot c_f \cdot q_p \cdot A_{ref} \cdot \mathrm{Sin}(\alpha)$	**920.3**

Table 1-4 Roof wind load friction load value

Parameter name	Parameter	Value
Structural coefficient	$c_s c_d$	1
Roof angle (°)	α	0
Friction coefficient	c_f	0.02
Basic wind velocity (m/s)	v_b	30.0
Air density (kg/m^3)	ρ	1.25
Basic wind pressure (N/m^2)	$q_b = 0.5 \cdot \rho \cdot v_b^2$	562.5
Terrain category	-	I
Exposure factor	c_e	2
Peak wind pressure (N/m^2)	$q_p = c_e \cdot q_b$	1125.0
Reference area (m^2)	A_{ref}	11.2
Roof wind load windward load (N)	$F_w = 2 \cdot c_s \cdot c_d \cdot c_f \cdot q_p \cdot A_{ref}$	**504.0**

Table 1-5 Y-direction each column wind load value

Parameter name	Parameter	Value
Section width (m)	b	0.09
Length (m)	l	2.10
Structural coefficient	$c_s c_d$	1
Component force coefficient	$c_{f.0}$	2.1
Section reduction factor	Ψ_r	1
Section reduction factor	Ψ_λ	1
Component force coefficient	$c_f = c_{f.0} \cdot \psi_r \cdot \psi_\lambda$	2.1
Basic wind velocity (m/s)	v_b	30.0
Air density (kg/m^3)	ρ	1.25
Basic wind pressure (N/m^2)	$q_b = 0.5 \cdot \rho \cdot v_b^2$	562.5
Terrain category	-	I
Exposure factor	c_e	2
Peak wind pressure (N/m^2)	$q_p = c_e \cdot q_b$	1125.0
Reference area (m^2)	A_{ref}	0.2
Wind load (N)	$F_w = c_s \cdot c_d \cdot c_f \cdot q_p \cdot A_{ref}$	**446.5**

Table 1-6 X-direction each column wind load value

Parameter name	Parameter	Value
Section width (m)	b	0.20
Length (m)	l	2.10
Structural coefficient	$c_s c_d$	1
Component force coefficient	$c_{f,0}$	2.1
Section reduction factor	Ψ_r	1
Section reduction factor	Ψ_λ	1
Component force coefficient	$c_f = c_{f,0} \cdot \psi_r \cdot \psi_\lambda$	2.1
Basic wind velocity (m/s)	v_b	30.0
Air density (kg/m^3)	ρ	1.25
Basic wind pressure (N/m^2)	$q_b = 0.5 \cdot \rho \cdot v_b^2$	562.5
Terrain category	-	I
Exposure factor	c_e	2
Peak wind pressure (N/m^2)	$q_p = c_e \cdot q_b$	1125.0
Reference area (m^2)	A_{ref}	0.4
Wind load (N)	$F_w = c_s \cdot c_d \cdot c_f \cdot q_p \cdot A_{ref}$	**992.3**

2) Snow load:

According to the information provided by client, the snow load is 1.03kN/m^2.

3) Self weight and decorative plate:

According to the data provided by client, the self weight and decorative plate load shall be loaded by 1.5 times of the self weight of the framework.

1.6 Loading Conditions and Combinations

When calculating the structure of the object, the loads are combined according to Eurocode, and the main load combination conditions are as follows:

Table 1-7 Loading conditions and combinations

No	Name		Type	Self weight of structure	Self weight of roof	Snow load	Wind load WX	Wind load WY
1	gLCB1	Active	Added	1.35	1.35	1.5		
2	gLCB2	Active	Added	1.35	1.35		1.5	
3	gLCB3	Active	Added	1.35	1.35			1.5
4	gLCB4	Active	Added	1.35	1.35		-1.5	
5	gLCB5	Active	Added	1.35	1.35			-1.5
6	gLCB6	Active	Added	1.35	1.35	1.05	1.5	
7	gLCB7	Active	Added	1.35	1.35	1.05		1.5
8	gLCB8	Active	Added	1.35	1.35	1.05	-1.5	
9	gLCB9	Active	Added	1.35	1.35	1.05		-1.5
10	gLCB10	Active	Added	1.35	1.35	1.5	0.9	
11	gLCB11	Active	Added	1.35	1.35	1.5		0.9
12	gLCB12	Active	Added	1.35	1.35	1.5	-0.9	
13	gLCB13	Active	Added	1.35	1.35	1.5		-0.9

2. Establishment of Model

Because of the complexity of such object structure, it will be inefficient to perform the calculation by integral entity finite element calculation, so the calculation analysis is performed with the finite element software - Midas GEN.

2.1 Unit Selection

During overall structure analysis, each member of the structure is simulated by beam elements.

2.2 Boundary and Constraints

Since the column of the final assembled structure is embedded into the ground, and the embedded depth is 0.5m, so the lower part of the column is calculated as the fixed connection.

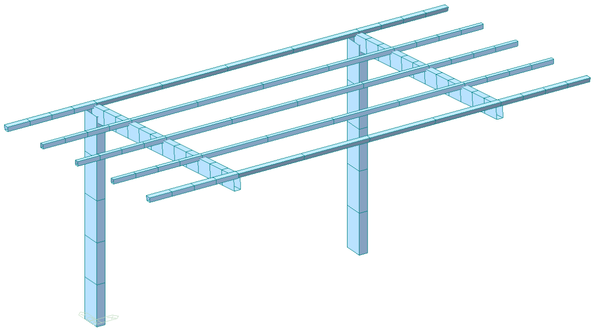

Figure 2-1 Overall structural framework diagram

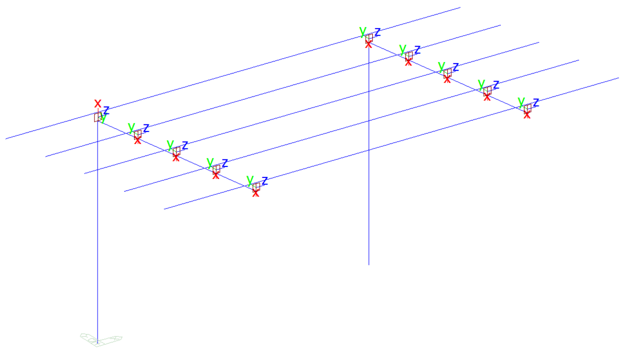

Figure 2-2 Connection diagram of cantilever and cross beam

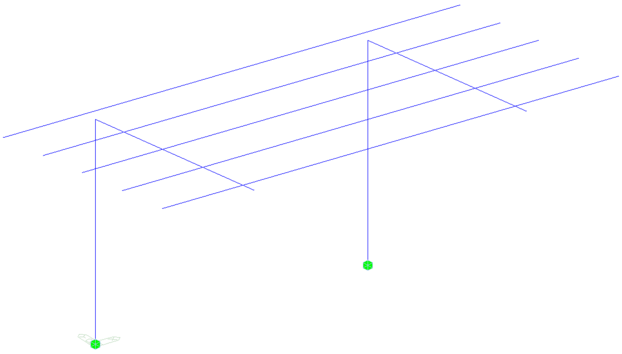

Figure 2-3 Diagram of column bottom fixation

3. Stress Analysis of Integral Structure

As the framework of the object structure is the main stress component, the beam element is mainly used to simulate the stress of the framework during stress analysis of the structure.

3.1 Introduction of Finite Element Model and Load Application of Structure

During the service of the object, external live loads mainly include wind load and snow load. Because the object may be subjected to wind loads from all directions, which can be divided into X-direction wind load and Y-direction wind load. The application methods of wind load and snow load are shown in Figure 3-1~3-3.

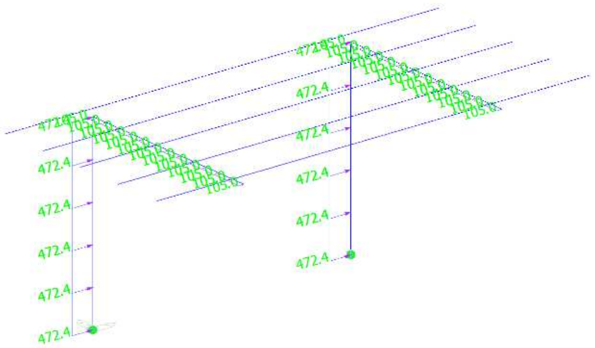

Figure 3-1 WX Wind load

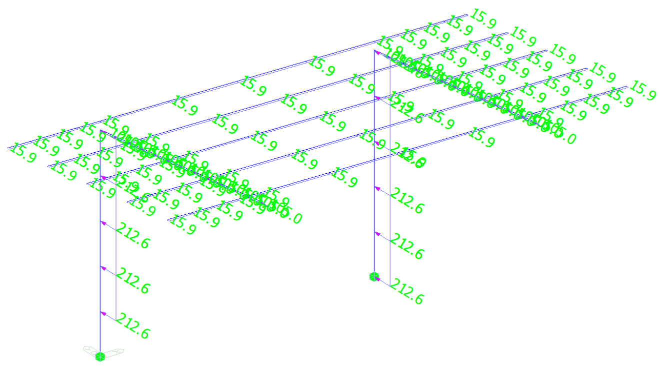

Figure 3-2 WY Wind load

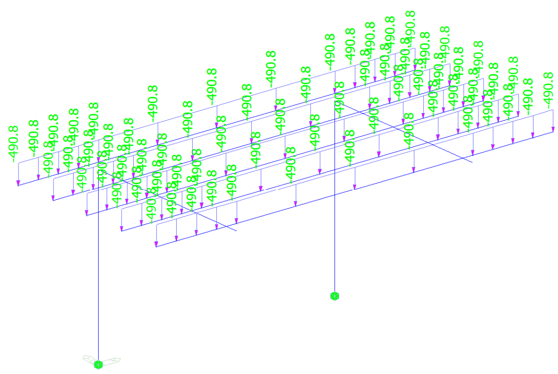

Figure 3-3 Snow load

3.2 Stress Analysis under Ultimate Load Bearing Capacity Condition at Service Stage

When analyzing the structure, the stress condition of the structure can be divided into ultimate load bearing capacity condition and ultimate normal service condition, which correspond to the displacement control of the structure and the stress control of structural materials respectively.

This structure is a single-layer assembled structure. So under ultimate normal service condition, when the displacement of the structure is large, it will not affect the service of the structure. Therefore, for this object structure, only analysis calculation of ultimate load bearing capacity condition is carried out.

In order to analyse the most unfavorable stress condition of structure under ultimate load bearing capacity conditions, this section analyses the stress envelope diagram of the structure under ultimate load bearing capacity conditions, and also the stress of the structure under individual load bearing capacity conditions.

During the analysis of the structural framework, since the overlapping length of the corner piece and the cantilever beam and the column is close to 0.5m, the load at the connection between the column and the cantilever beam is born by the stiffening corner piece under the actual load, so the range of 0.4m at the connection position between the column and the cantilever beam is not considered for analysing.

Stress envelope of structure under each ultimate load bearing capacity condition is shown in Figure 3-4. According to the analysis of the envelope diagram, under ultimate load bearing capacity condition, maximum compressive stress of the structure is 202.8MPa, maximum tensile stress is 201.4MPa. Both stresses are lower than material yield strength of 230.0MPa. So material yield failure will not happen, which meets the design requirements of code.

Stress envelope of column under each ultimate load bearing capacity condition is shown in Figure 3-5. According to the analysis of the envelope diagram, under ultimate load bearing capacity condition, maximum compressive stress of the column is 164.8MPa, maximum tensile stress is 151.6MPa. Both stresses are lower than material yield strength of 230.0MPa. So material yield failure will not happen, which meets the design requirements of code.

Stress envelopes of cantilever beam under each ultimate load bearing capacity condition are shown in Figure 3-6. According to the analysis of the envelope diagram, under ultimate load bearing capacity condition, maximum compressive stress of cantilever beam is 202.8MPa, maximum tensile stress is 201.4MPa. Both stresses are lower than material yield strength of 230.0MPa. So material yield failure will not happen, which meets the design requirements of code.

Stress envelopes of cross beam under each ultimate load bearing capacity condition are shown in Figure 3-7. According to the analysis of the envelope diagram, under ultimate load bearing capacity condition, maximum compressive stress of cross beam is 167.7MPa, maximum tensile stress is 167.7MPa. Both stresses are lower than material yield strength of 230.0MPa. So material yield failure will not happen, which meets the design requirements of code.

Structural stress diagram under each load bearing capacity condition of gLCB1 ~ gLCB13 is shown in Figure 3-8~3-20. And Table 3-1 shows the statistics of maximum compressive and tensile stress of structure under each ultimate load bearing capacity condition of gLCB1 ~ gLCB13. According to these statistical data, the most unfavorable load conditions of structure are gLCB10 and gLCB12, and load combination of stress is 1.35 (constant load) + 1.50 (snow load) ± 0.90WX (wind load). Therefore, the most unfavorable stress of the structure is the under these two load conditions.

In summary, under ultimate load bearing capacity condition, material yield failure will not happen at the column (maximum stress 164.8MPa), cantilever beam (maximum stress 202.8MPa) and cross beam (maximum stress 167.7MPa) of frame structure. So the structure under ultimate load bearing capacity condition meets the design requirements of code.

Table 3-1 Maximum stresses of structure under each load bearing capacity conditions

No	Name	Beam & Column	
		Maximum compressive stress MPa	Minimum tensile stress MPa
1	gLCB1	195.8	159.5
2	gLCB2	62.0	56.4
3	gLCB3	16.7	11.3
4	gLCB4	62.0	5.6
5	gLCB5	34.5	15.2
6	gLCB6	152.7	113.3
7	gLCB7	140.2	122.4
8	gLCB8	152.7	113.3
9	gLCB9	122.4	142.0
10	gLCB10	202.8	159.5
11	gLCB11	159.3	167.7
12	gLCB12	202.8	159.5
13	gLCB13	196.4	167.7

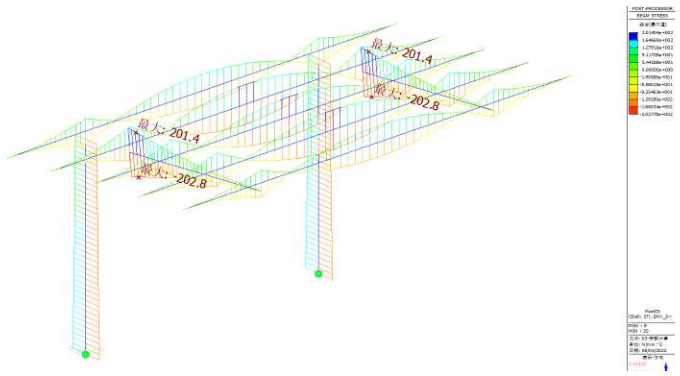

Figure 3-4 Stress envelope diagram of frame structure under ultimate load bearing capacity condition (-202.8 ~ 201.4MPa)

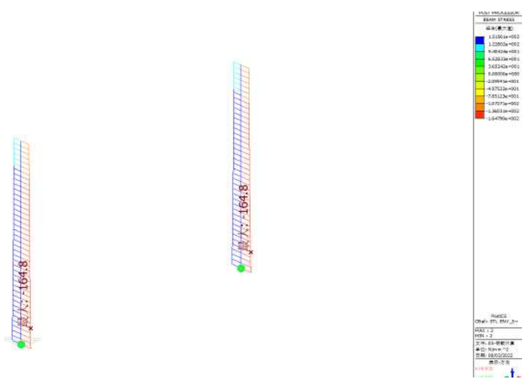

Figure 3-5 Stress envelope diagram of column under ultimate load bearing capacity condition (-164.8 ~ 151.6MPa)

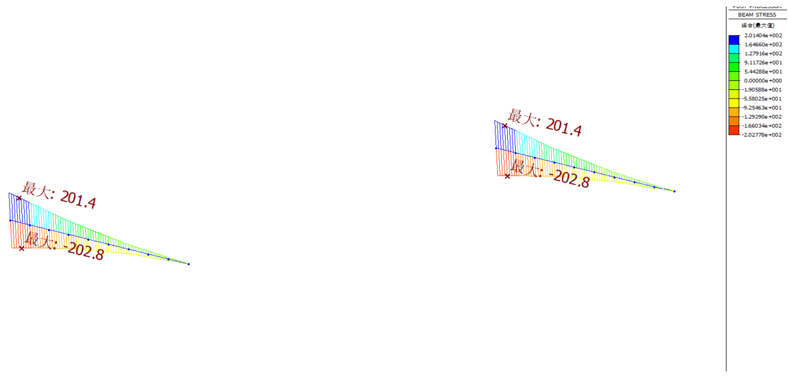

Figure 3-6 Stress envelope diagram of cantilever beam under ultimate load bearing capacity condition (-202.8 ~ 201.4MPa)

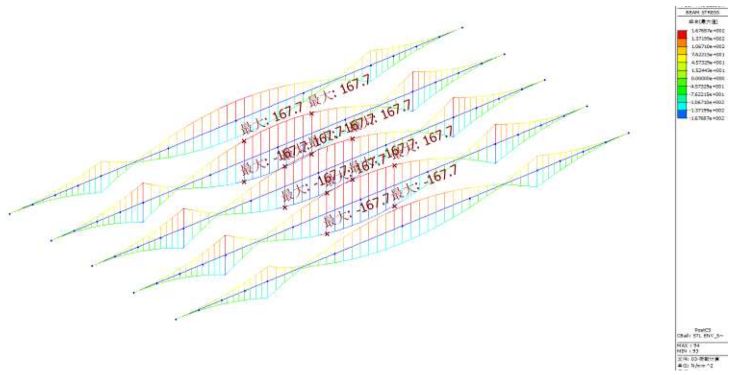

Figure 3-7 Stress envelope diagram of cross beam under ultimate load bearing capacity condition (-167.7 ~ 167.7MPa)

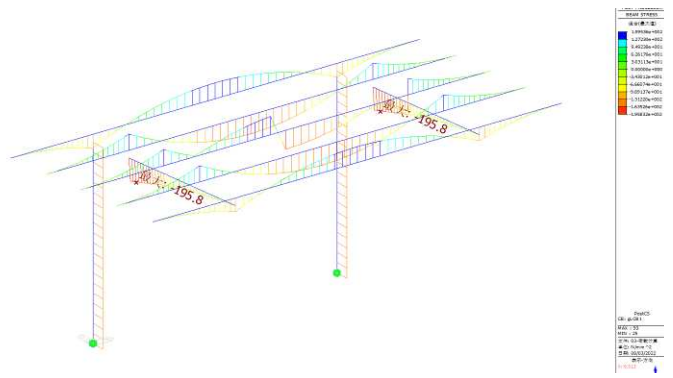

Figure 3-8 Structural stress under gLCB1 load condition (-195.8 ~ 159.5MPa)

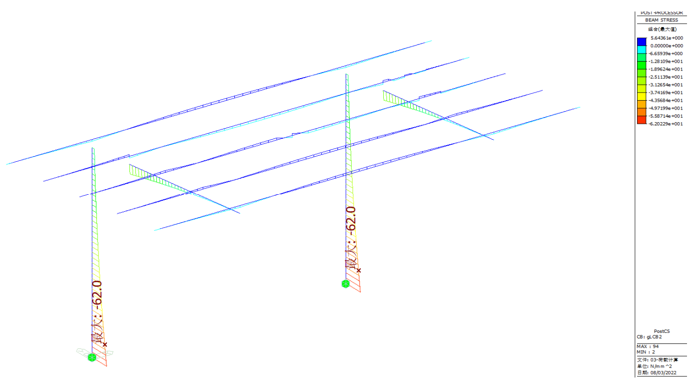

Figure 3-9 Structural stress under gLCB2 load condition (-62.0 ~ 56.4MPa)

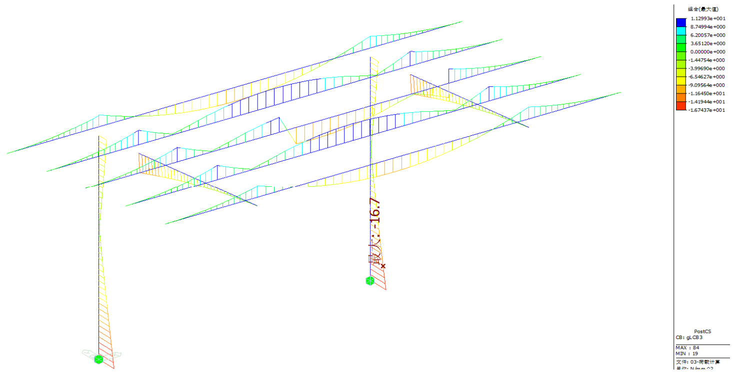

Figure 3-10 Structural stress under gLCB3 load condition (-16.7 ~ 11.3MPa)

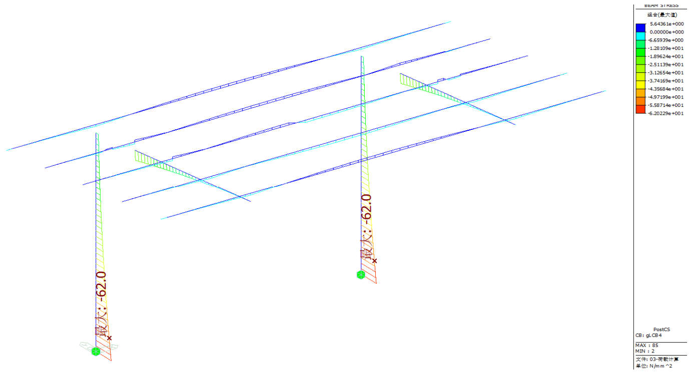

Figure 3-11 Structural stress under gLCB4 load condition (-62.0 ~ 5.6MPa)

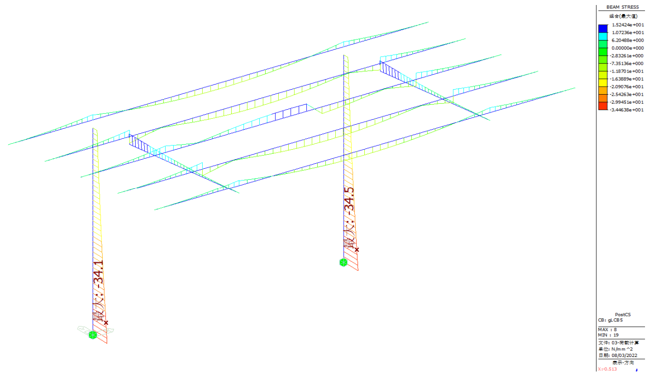

Figure 3-12 Structural stress under gLCB5 load condition (-34.5 ~ 15.2MPa)

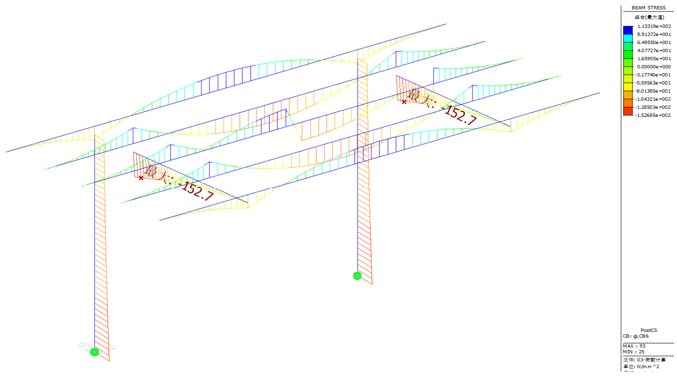

Figure 3-13 Structural stress under gLCB6 load condition (-152.7 ~ 113.3MPa)

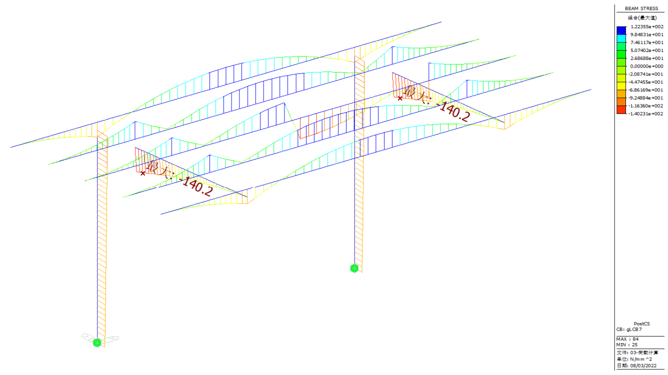

Figure 3-14 Structural stress under gLCB7 load condition (-140.2 ~ 122.4MPa)

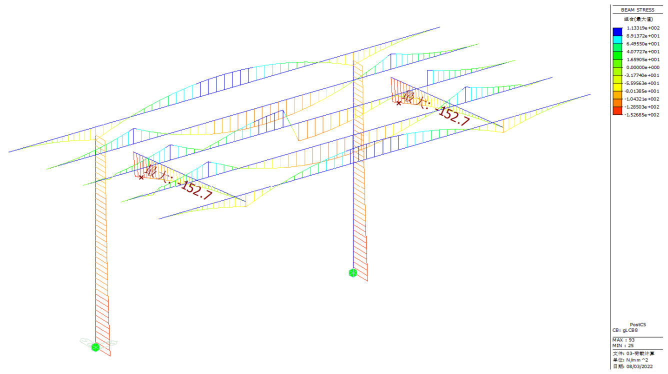

Figure 3-15 Structural stress under gLCB8 load condition (-152.7 ~ 113.3MPa)

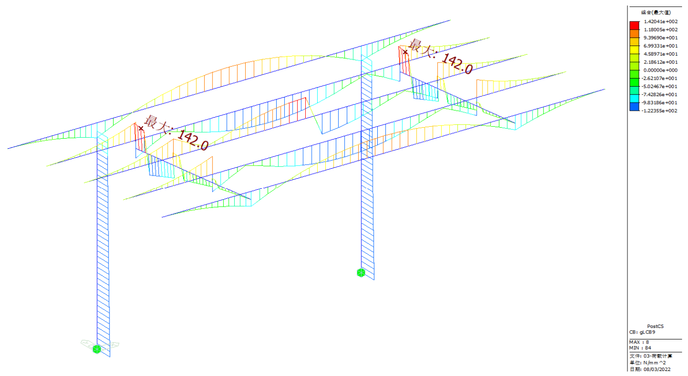

Figure 3-16 Structural stress under gLCB9 load condition (-122.4 ~ 142.0MPa)

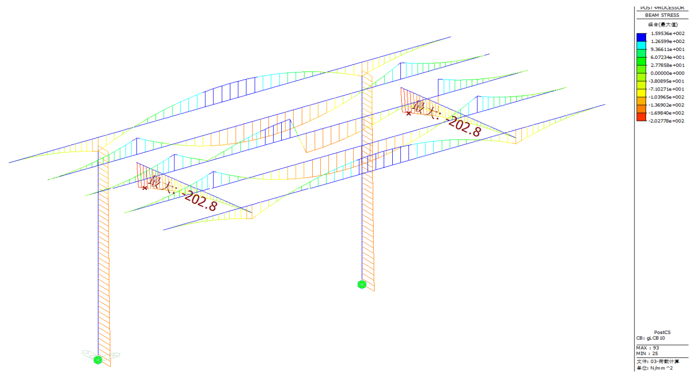

Figure 3-17 Structural stress under gLCB10 load condition (-202.8 ~ 159.5MPa)

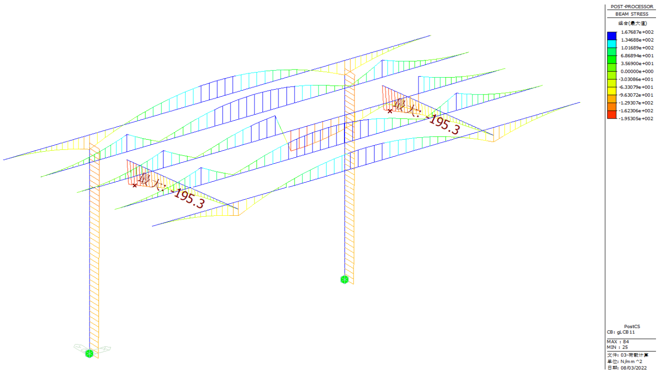

Figure 3-18 Structural stress under gLCB11 load condition (-195.3 ~ 167.7MPa)

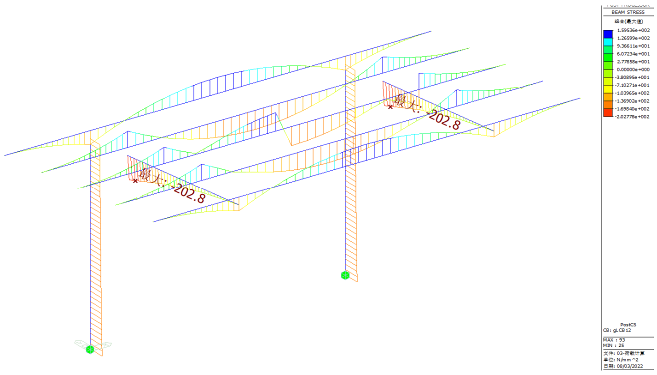

Figure 3-19 Structural stress under gLCB12 load condition (-202.8 ~ 159.5MPa)

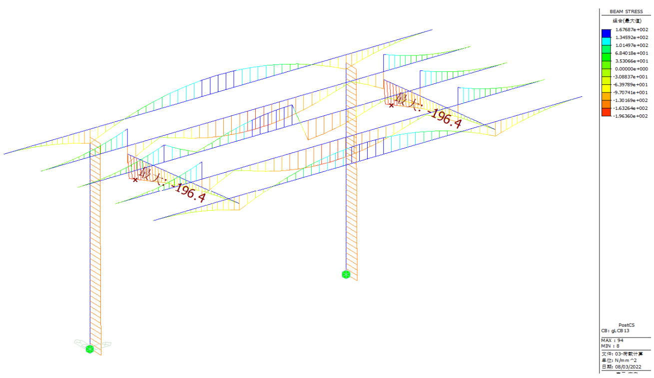

Figure 3-20 Structural stress under gLCB13 load condition (-196.4 ~ 167.7MPa)

3.3 Chapter Summary

After overall calculation and analysis on the object structure by Midas GEN, main results and conclusions are shown as follows:

1) Under ultimate load bearing capacity condition, maximum compressive stress of the structure with member system unit is 202.8MPa, maximum tensile stress is 201.4MPa, and both stresses are lower material yield strength of 230.0MPa. So material yield failure will not happen, which meets the design requirements of code.
2) Under ultimate load bearing capacity condition, the most unfavorable load combination conditions of structure are gLCB10 and gLCB12. The corresponding load combination is 1.35 (constant load) + 1.50 (snow load) ± 0.90WX (wind load).

3) Under ultimate load bearing capacity condition, material yield failure will not happen at the column (maximum stress 164.8MPa), cantilever beam (maximum stress 202.8MPa) and cross beam (maximum stress 167.7MPa) of frame structure. So the structure under ultimate load bearing capacity condition meets the design requirements of code.

4. Stress Analysis of Local Structure

For this structure, the local area with complicated stress is the beam-column connecting corner piece, whose main stress is to transfer the bending moment at the root of the cantilever beam to the column. Therefore, in this section, the local stress of the connecting corner piece is analyzed by solid finite element.

4.1 Finite Element Model and Load Application of Corner Piece Structure

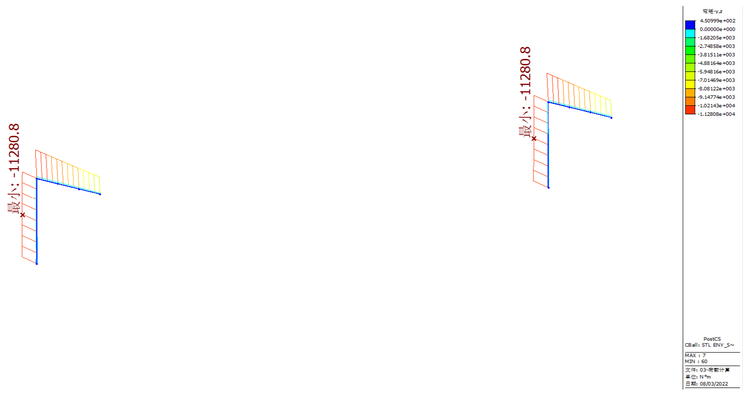

Figure 4-1 Bending moment envelope of corner piece under ultimate load bearing capacity condition (11280Nm)

Figure 4-2 Diagram of corner piece finite element model

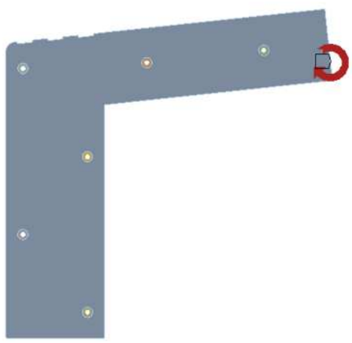

Figure 4-3 Diagram of load application

4.2 Calculation Results of Corner Piece Structure

According to the calculation results of Figure 4-5~4-7, under ultimate load bearing capacity condition, the maximum principal tensile stress of the corner piece is 221.6MPa, the maximum principal compressive stress is 261.7MPa, and the maximum Mises stress is 229.3MPa. The maximum principal compressive stress is higher than the material yield strength of 235.0MPa. So the corner piece will yield locally, and the yield position is at the lower angle of the corner piece. According to Figure 4-8, the maximum plastic strain at the stress concentration area of the corner piece is 0.0024, which is lower than the allowable material value of 0.1, so failure will not happen at the corner piece.

In summary, under ultimate load bearing capacity condition, failure will not happen at the corner piece, and the corner pieces structure meets the design requirements of code.

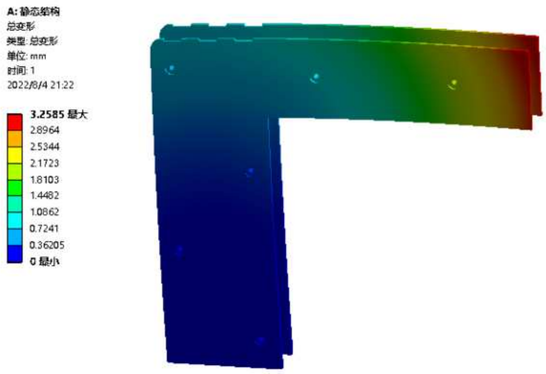

Figure 4-4 Diagram of corner piece diaplacement (3.26mm)

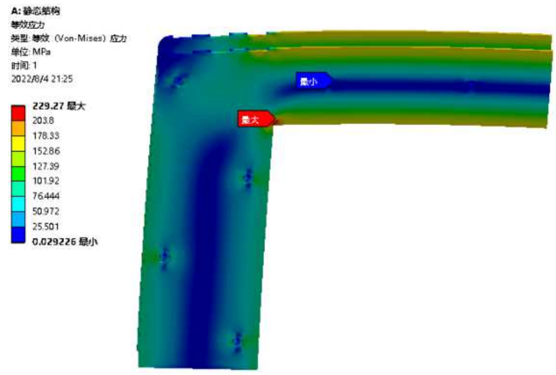

Figure 4-5 Mises stress (229.3MPa)

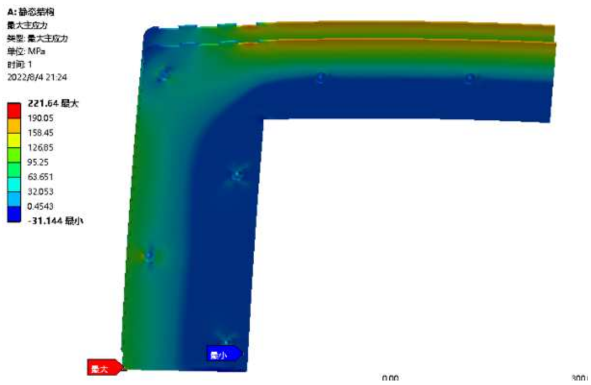

Figure 4-6 Principal tensile stress (221.6MPa)

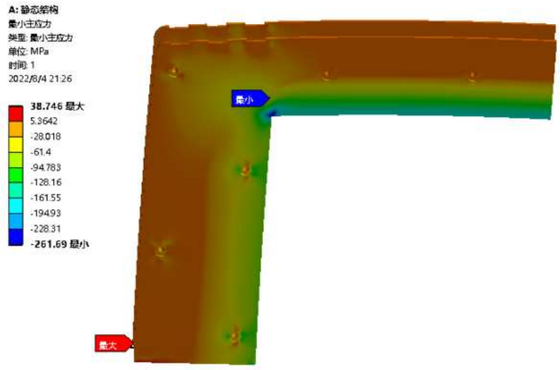

Figure 4-7 Principal compressive stress (261.7MPa)

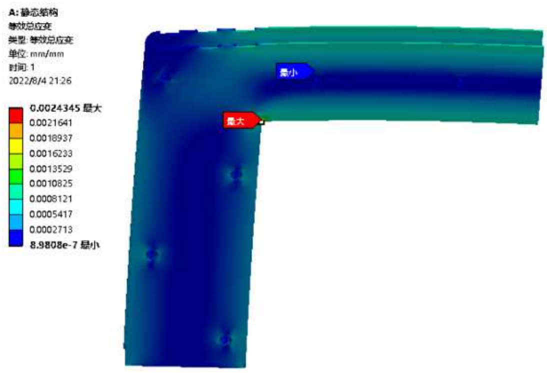

Figure 4-8 Diagram of equivalent plastic strain (0.0024)

5. Conclusions

Calculation results of overall and local structure framework by using Midas GEN and ANSYS software are shown as follows:

1) Under ultimate load bearing capacity condition, maximum compressive stress of the structure with member system unit is 202.8MPa, maximum tensile stress is 201.4MPa, and both stresses are lower material yield strength of 230.0MPa. So material yield failure will not happen, which meets the design requirements of code.
2) Under ultimate load bearing capacity condition, the most unfavorable load combination conditions of structure are gLCB10 and gLCB12. The corresponding load combination is 1.35 (constant load) + 1.50 (snow load) ± 0.90WX (wind load).
3) Under ultimate load bearing capacity condition, material yield failure will not happen at the column (maximum stress 164.8MPa), cantilever beam (maximum stress 202.8MPa) and cross beam (maximum stress 167.7MPa) of frame structure. So the structure under ultimate load bearing capacity condition meets the design requirements of code.
4) Through the local calculation of corner piece structure by solid finite element method, under ultimate load bearing capacity condition, failure will not happen at the corner piece, and the corner pieces structure meets the design requirements of code.

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