Rack Structural Calculation Report

Project Name: XXX Rack Structural Calculation Report

Client: XXX

Inspection type: Commission

Date: 2025.1.18

Inspected by： Shanghai Wesafe Rack Safety Inspection Technology Co., Ltd

Designed by		Date	
Checked by		Date	

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Client	Project address: Greece Corresponding address: Zip code: Manager: Mobile: E-mail:

目录

1 Basis

Reference standard	[1]BS EN 15512:2020+A1-2022. Steel static storage systems-Adjustable pallet racking systems-Principles for structural design. [2]BS EN 16681:2016. Steel static storage systems-Adjustable pallet racking systems-Principles for seismic design. [3] EN 1998-1:2004. Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings.
Results	Through calculation, the rack structural meets the standard requirements.
Suggestion	It’s suggested to establish three different inspection hierarchies for storage racks: (1) Instant inspection. Once problems are found in daily use, need to reported to the nominated Person Responsible for Rcking Safety who is responsible for carrying out a preliminary inspection and taking action where necessary. (2) Regular inspection. Person Responsible for Racking Safety should conduct regular inspection and make documented action points for any serious damage. Person Responsible for Racking Safety should conduct regular maintaince, such as FLT operator training, warehouse stuff safety awareness training and bolts tightening and rust removing. (3) Professional inspection. At least once a year professional inspection of the whole racking system, carried out by a qualified testing organization.

2 Assumption

（1）The frequency of discharge and unloading is low, without considering the fatigue effect.

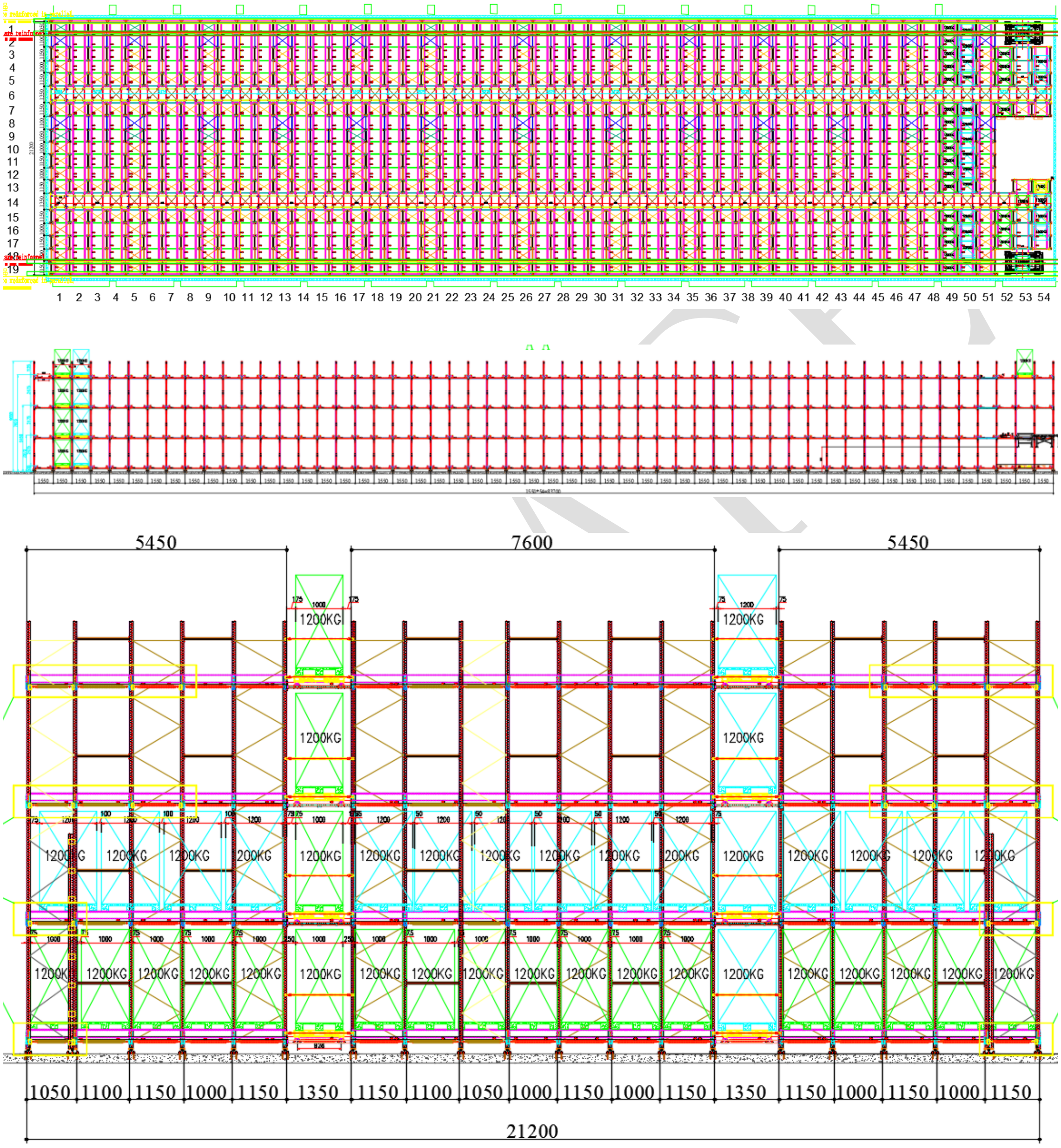
（2） The floor where the racks are located can be regarded as rigid floor, and the floor will not produce deformation that causes additional force on the racks.

（3）Storage management can ensure that the full load rate of the racks does not exceed the specified values in the table below.

（4）The equivalent section characteristics required for upright verification are replaced by the minimum net section characteristics.

3 System

The rack layout and component section drawings are subject to the CAD file provided by the client.



Rack structural layout plan

4 Material protperties

4.1 Steel

Steel properties

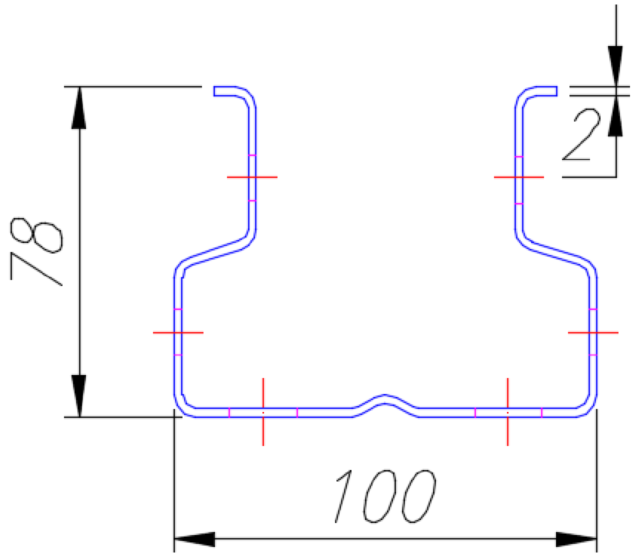
Modulus of elasticity	E	=	206000N/mm^2
Shear modulus	G	=	79231N/mm^2
Density	ρ	=	7850kg/m^3
Q235	f_y	=	235N/mm^2
	f_u	=	370N/mm^2
Q355	f_y	=	355N/mm^2
	f_u	=	470N/mm^2

4.2 Material safety factor

γ_{M0}=1.1，γ_{M2}=1.25。

5 Properties of the components and connections

5.1 Ordinary position Upright-100*78*2.0

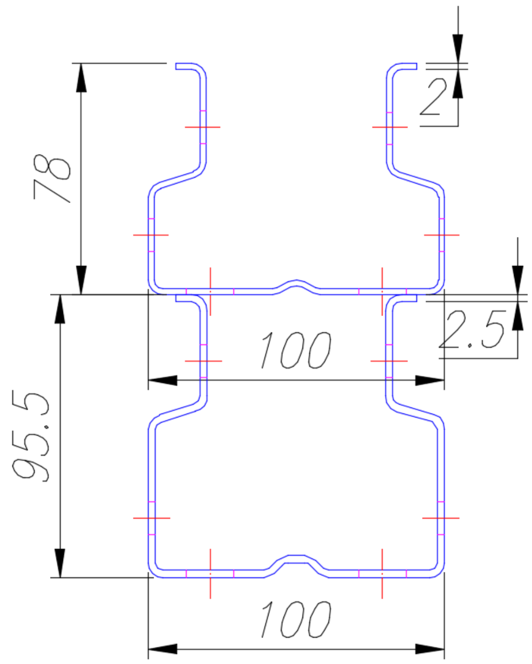


Upright section

Upright section properties

Name	Value	Instructions
fy	355.000	Yield strength of steel (N/mm^2)
E	206000.000	Modulus of elasticity (N/mm^2)
G	79231.000	Shear modulus (N/mm^2)
Aeq	477.000	Equivalent area (mm^2)
Aeff	462.000	Effective area (mm^2)
Iy,eq	648273.000	The moment of inertia about the Y-axis (axis of symmetry) (mm^4)
Iz,eq	338897.000	The moment of inertia about the Z-axis (mm^4)
It,eq	571.000	Free torsion constant (mm^4)
Iw,eq	905667167.000	Warping torsion constant (mm^6)
y0,eq	68.220	Centroid cut centroid distance (mm)
Wy,eff	13343.000	Effective section modulus around the Y-axis (mm^3)
Wz,eff,min	6407.000	Lesser effective section modulus around the Z-axis (mm^3)
Wz,eff,max	10625.000	Larger effective section modulus around the Z-axis (mm^3)

5.2 Strengthen position upright-100*78*2.0+100*96*2.5

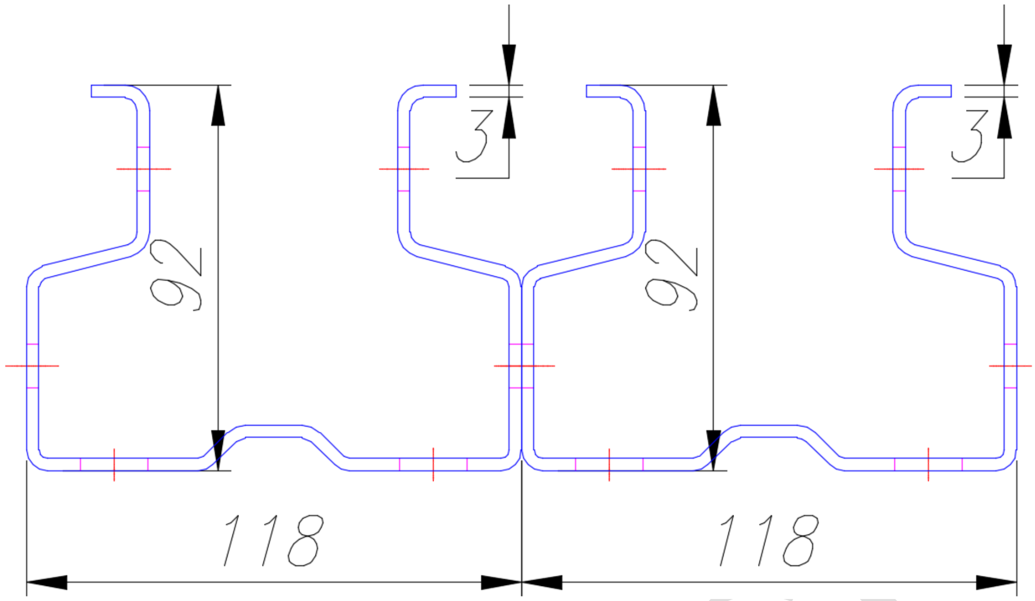


Upright section

Upright section properties

Name	Value	Instructions
fy	355.000	Yield strength of steel (N/mm²)
E	206000.000	Modulus of elasticity (N/mm²)
G	79231.000	Shear modulus (N/mm²)
Aeq	1299.000	Equivalent area (mm²)
Aeff	1126.635	Effective area (mm²)
Iy,eq	1809806.000	The moment of inertia about the Y-axis (axis of symmetry) (mm⁴)
Iz,eq	3534267.000	The moment of inertia about the Z-axis (mm⁴)
It,eq	1505184.000	Free torsion constant (mm⁴)
Iw,eq	905667167	Warping torsion constant (mm⁶)
y0,eq	72.680	Centroid cut centroid distance (mm)
Wy,eff	31193.82	Effective section modulus around the Y-axis (mm³)
Wz,eff,min	31713.332	Lesser effective section modulus around the Z-axis (mm³)
Wz,eff,max	39431.776	Larger effective section modulus around the Z-axis (mm³)

5.3 Back bracing position upright-118*91*3.0+118*91*3.0

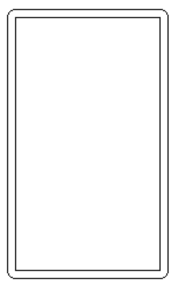


Upright section

Upright section properties

Name	Value	Instructions
fy	355.000	Yield strength of steel (N/mm^2)
E	206000.000	Modulus of elasticity (N/mm^2)
G	79231.000	Shear modulus (N/mm^2)
Aeq	2020.000	Equivalent area (mm^2)
Aeff	1798.629	Effective area (mm^2)
Iy,eq	10612237.000	The moment of inertia about the Y-axis (axis of symmetry) (mm^4)
Iz,eq	1850595.000	The moment of inertia about the Z-axis (mm^4)
It,eq	7833.000	Free torsion constant (mm^4)
Iw,eq	1811334334	Warping torsion constant (mm^6)
y0,eq	68.220	Centroid cut centroid distance (mm)
Wy,eff	79028.642	Effective section modulus around the Y-axis (mm^3)
Wz,eff,min	332644.850	Lesser effective section modulus around the Z-axis (mm^3)
Wz,eff,max	44202.922	Larger effective section modulus around the Z-axis (mm^3)

5.4 Beam 1-100*50*1.5

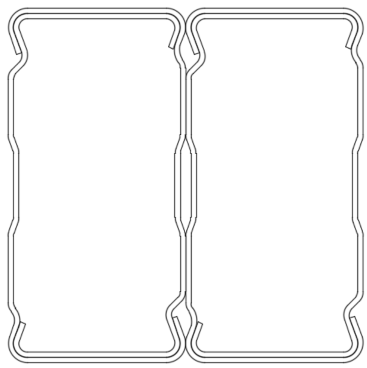


Beam section

Beam section properties

Name	Value	Instructions
MRd,y	3687062.000	Strong axial moment bearing capacity (Nmm)
MRd,z	2546524.000	Weak axial moment bearing capacity (Nmm)

5.5 Beam 2-100*50*1.5*2

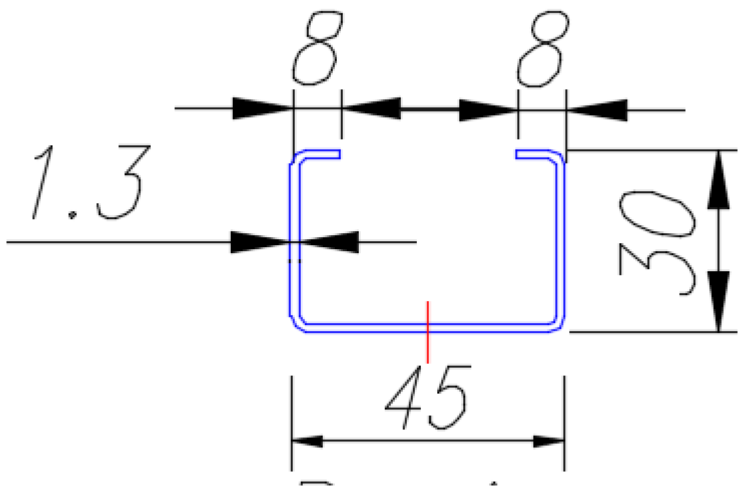


Beam section

Beam section properties

Name	Value	Instructions
MRd,y	12591327.000	Strong axial moment bearing capacity (Nmm)
MRd,z	8139434.000	Weak axial moment bearing capacity (Nmm)

5.6 Bracing C45*30*8*1.3

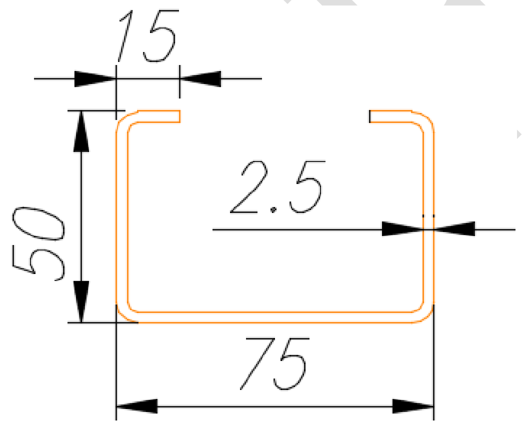


Bracing section

Bracing section properties

Name	Value	Instructions
fy	235.000	Yield strength of steel (N/mm^2)
fu	370.000	Tensile strength of steel (N/mm^2)
E	206000.000	Modulus of elasticity (N/mm^2)
G	79231.000	Shear modulus (N/mm^2)
An	132.000	Minimum net sectional area (mm^2)
A	146.000	Total sectional area (mm^2)
Aeff	132.000	Effective area (mm^2)
Iy	48868.000	The moment of inertia about the Y-axis (axis of symmetry) (mm^4)
Iz	17789.000	The moment of inertia about the Z-axis (mm^4)
It	82.000	Free torsion constant (mm^4)
Iw	8195996.000	Warping torsion constant (mm^6)
y0	25.560	Centroid cut centroid distance (mm)
Wz,eff	914.000	Lesser effective section modulus around the Z-axis (mm^3)

5.7 Back bracing C75*50*15*2.5



Back bracing section

Back bracing section properties

Name	Value	Instructions
fu	350.000	Tensile strength of steel (N/mm^2)
An	442.000	Minimum net sectional area (mm^2)

5.8 Beam end connector

Beam end connector properties

Properties	kNm/rad
K_b	150

5.9 Upright foot joint

Upright foot joint properties

Properties	kNm/rad
K_{C-2}	147
K_{C-3}	0

5.10 Upright frame

5.10.1 Looseness of beam-upright

Φ_l=1.0x10^{-3}rad。

5.10.2 Stiffness reduction

The stiffness of the upright brace is reduced to 5% in accordance with BS EN 15512 Section 9.2.3.4.

9.2.3.4 Upright frames

For upright frame design, in addition to 9.2.3.1, the shear flexibility of the bracing system including the flexibility of the connections between the uprights and the bracing members shall be considered. This shall be determined by test according to A.2.4. Where the height to width ratio of the frames is less than 10 and the racking is not subjected to lateral crane, wind or seismic loads, this test is not required and the reduction in transverse stiffness may be accounted for by reducing the axial stiffness of the bracing members of the upright frame to 5 % of the unreduced value. This reduction includes also the effect of looseness that therefore need not to be considered as initial out-of-plumb.

6 Load and action

6.1 Dead load D

In the finite element model, the software automatically generates the dead load of the rack member.

6.2 Unit loads PL

The pallet load is placed on the shuttle rail and can be regarded as a uniform load along the rail:

5450mm shuttle rail: q1=1200x10.0x5/2/5450= 5.505N /mm;

7600mm shuttle rail: q2=1200x10.0x7/2/7600=5.526 N/mm.

6.2.1 Rate of loads

Down-aisle direction seismic: 80%, cross-aisle direction seismic: 100%;

Others: 100%

6.3 Placement load

6.3.1 Horizontal placement load

Rack height 9050mm,

Down-aisle: 2 Qph=0.5kN ,Qph=0.25kN, Every layer of beams;

Cross-aisle: Qph=0.25kN, acting on the top beam beam-upright connector.

6.3.2 Vertical placement load HPL

25% of the load of a single pallet, placed in the most unfavorable position (in the middle of a single beam span);

HPL-V=1200x10.0x25%=3000 N

6.4 Global imperfections ϕ

6.4.1 Down-aisle direction

Ultimate limit state:

$\Phi_0=3/2x1/350=0.0043$

$\alpha_h=1$

$n_{da}=52$

$\alpha_{da}=(0.5(1+1/52))^{0.5}=0.714$

$\Phi_{l,BEC}=0.001$

$\Phi_0\alpha_h\alpha_{da}=0.0043x1x0.714=0.0031>1/500$

$\Phi_{ULS}=0.0031+0.001=0.0041$

Serviceability limit state:

$\Phi_{SLS}=1/350+0.001=0.0039$

6.4.2 Cross-aisle direction

Ultimate limit state:

$\Phi_0=3/2x1/350=0.0043$

$\alpha_h=1$

$n_{ca}=10$

$\alpha_{ca}=(0.5(1+1/10))^{0.5}=0.742$

$\Phi_{l,fr}=1/1000=0.001$

$\Phi_0\alpha_h\alpha_{da}=0.0043x1x0.742=0.0032$

$\Phi_{ULS}=0.0032+0.001=0.0042>1/500$

Serviceability limit state:

$\Phi_{SLS}=1/350+1/1000=0.0039$

6.5 Accidental horizontal impact load

Down-aisle: 1.25kN, acting on the upright 300mm from the ground;

Cross-aisle: 2.50kN, acting on the upright 400mm from the ground.

6.6 Horizontal seismic load Eq

The project is located in Greece and is calculated according to the following seismic information as specified by the client:

Table 3.2: Values of the parameters describing the recommended Type 1 elastic response spectra

Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1,0	0,15	0,4	2,0
B	1,2	0,15	0,5	2,0
C	1,15	0,20	0,6	2,0
D	1,35	0,20	0,8	2,0
E	1,4	0,15	0,5	2,0

(4)P For the horizontal components of the seismic action the design spectrum, $S_d(T)$, shall be defined by the following expressions:

$$0 \le T \le T_B : S_d(T) = a_g \cdot S \cdot \left[\frac{2}{3} + \frac{T}{T_B} \cdot \left(\frac{2,5}{q} - \frac{2}{3} \right) \right] \tag{3.13}$$

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EN 1998-1:2004 (E)

$$T_B \le T \le T_C : \; S_d(T) = a_g \cdot S \cdot \frac{2,5}{q} \tag{3.14}$$

$$T_C \le T \le T_D : S_d(T) \begin{cases} = a_g \cdot S \cdot \dfrac{2,5}{q} \cdot \left[\dfrac{T_C}{T} \right] \\ \ge \beta \cdot a_g \end{cases} \tag{3.15}$$

$$T_D \le T : \quad S_d(T) \begin{cases} = a_g \cdot S \cdot \dfrac{2,5}{q} \cdot \left[\dfrac{T_C T_D}{T^2} \right] \\ \ge \beta \cdot a_g \end{cases} \tag{3.16}$$

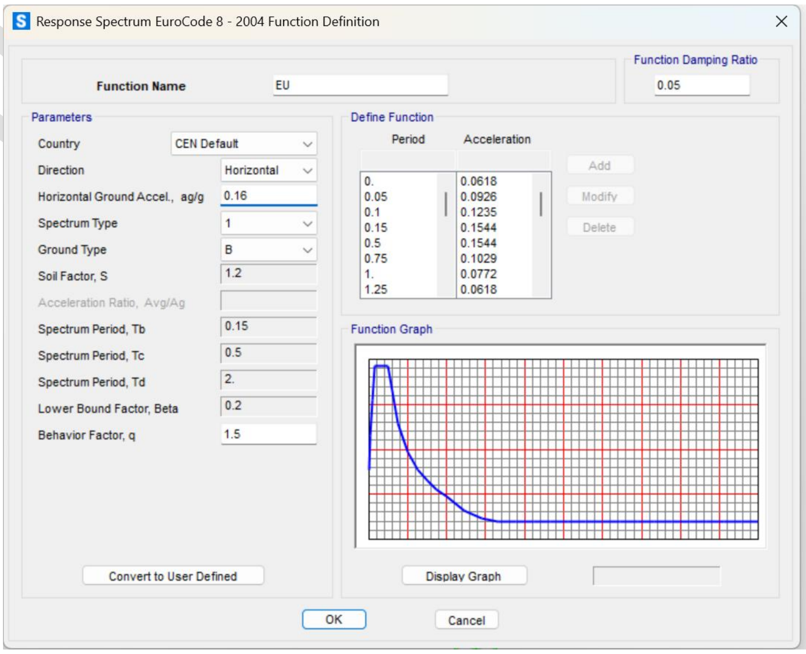
where

a_g, S, T_C and T_D are as defined in **3.2.2.2**;

$S_d(T)$ is the design spectrum;

q is the behaviour factor;

β is the lower bound factor for the horizontal design spectrum.



According to the information provided by the client, it can be seen from Table 1 of BS EN 16681 that the structural importance factor γ1=0.67;

Table 1 — Importance factors for racks

Importance Class	Description	Importance factor γ_I	
		30 years design life	50 years design life
I	Warehouses with fully automated storage operations	0,67	0,8
II	Standard warehouse conditions, including picking areas	0,84	1,0
III	Any kind of rack with random public access for private customer	N/A	1,2
IV	Hazardous product storage *(Hazardous products storage is subject to the approval of National Authorities)* Strategic facilities	N/A	1,4

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BS EN 16681:2016
EN 16681:2016 (E)

The default value of conventional warehouse racks shall be 30 years for Class I and II, and 50 years for clad rack buildings.

According to the relevant content of Section 7.5 of BS EN 16681, the seismic response spectrum is modified: down-aisle KD=1.0x0.8=0.8, transverse KD=0.9x0.8= 0.72. The finite element model of the structure shows that the natural period T_{down}=1.023s and the T_{cross}=1.393s.

7.5.1 General

The seismic design of racks shall be performed using the following modified design spectrum:

$$S_{d,\mathrm{mod}} = K_D \times S_d(T) \tag{7}$$

where

$S_d(T)$ is the reference design spectrum defined in EN 1998-1

E_{D1} and E_{D3} are the design spectrum modification factors, with $E_{D1} \cdot E_{D3} \geq 0,4$

$$K_D = 1 - P_{E,prod} / P_E \times (1 - E_{D1} \times E_{D3}) \tag{8}$$

where:

P_E is the total weight of the rack in the seismic design situation (including dead weight, permanent weight, live load in the seismic situation and the stored product weight);

$P_{E,prod}$ is the total product weight stored on the rack, in the seismic design situation.

$K_D = E_{D1} \times E_{D3}$ can be assumed when $P_{E,prod}$ is greater or equal to 90 % of P_E.

a) E_{D1} is affected by the following parameters:

1) intensity of the seismic action;

2) number of load levels, total mass and flexibility of the racking structure, expressed by the period of vibration (dominant period in the direction considered);

3) maximum horizontal force that can be transmitted by the unit load to the beams, expressed in terms of the unit load-beam friction coefficient;

$$E_{D1} = \max\left[0,4;\mu_S/S_e\left(T_1\right)+0,2\right] \leq 1,0 \tag{9}$$

where

μ_S is the reference value of the unit load-beam friction coefficient given in 7.5.3

T_1 is the fundamental period of vibration of the racking structure in the considered direction (the period with highest modal participating mass in the considered direction)

$S_e(T_1)$ is the ordinate of the elastic spectrum defined in EN 1998-1 (normalized by g) with the viscous damping as defined in 6.2.

When unit loads are restrained on the beams by means of any special system (for example materials increasing the friction between pallet and beam), E_{D1} = 1,0.

b) E_{D3} is a reduction coefficient of the seismic action.

The value of E_{D3} is 0,80

The elastic spectrum defined in EN 1998-1 is as follows.

3.2.2.2 Horizontal elastic response spectrum

(1)P For the horizontal components of the seismic action, the elastic response spectrum $S_e(T)$ is defined by the following expressions (see Figure. 3.1):

$$0 \leq T \leq T_B : S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 2,5 - 1)\right] \tag{3.2}$$

$$T_B \leq T \leq T_C : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \tag{3.3}$$

$$T_C \leq T \leq T_D : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5\left[\frac{T_C}{T}\right] \tag{3.4}$$

$$T_D \leq T \leq 4\text{s} : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5\left[\frac{T_C T_D}{T^2}\right] \tag{3.5}$$

7 Laod combinations

7.1 Global analysis

Load combinations

Group-1：ULS with only PL	
G1-LC01	1.3D+1.40PL+ImpX
G1-LC02	1.3D+1.40PL+ImpY
Group-2：ULS with PL+PHL	
G2-LC01	1.3D+1.26PL+1.26PHL-X+ImpX
G2-LC02	1.3D+1.26PL+1.26PHL-X+ImpY
Group-3：ULS with PL+A	
G3-LC01	1.0D+1.0PL+1.0AX+ImpX
G3-LC02	1.0D+1.0PL+1.0AY+ImpY
Group-4：ULS with PL+EQ	
G4-LC01	1.0D+0.8PL+1.0EqX+0.3EqY
G4-LC02	1.0D+0.8PL+1.0EqY+0.3EqX
Group-5：SLS with only PL	
G5-LC01	1.0D+1.0PL+ImpX
G5-LC02	1.0D+1.0PL+ImpY
Group-6：SLS with PL+PHL	
G6-LC01	1.0D+0.9PL+0.9PHL-X+ImpX
G6-LC02	1.0D+0.9PL+0.9PHL-X+ImpY

Where,

ULS: Ultimate limit state

SLS: Serviceability limit state

ImpX: Global imperfection in down-aisle direction

ImpY: Global imperfection in cross-aisle direction

HPL-X: Horizontal placement in down-aisle direction

HPL-Y: Horizontal placement in cross-aisle direction

Eq: Horizontal seismic actions

A: Accidental horizontal impact load

8 Global analysis

8.1 Software information

The structural computing software used in this calculation is SAP2000. SAP2000 is a rich and powerful finite element computing software, such as modeling function, editing function, analysis function, load function, custom function and design function.

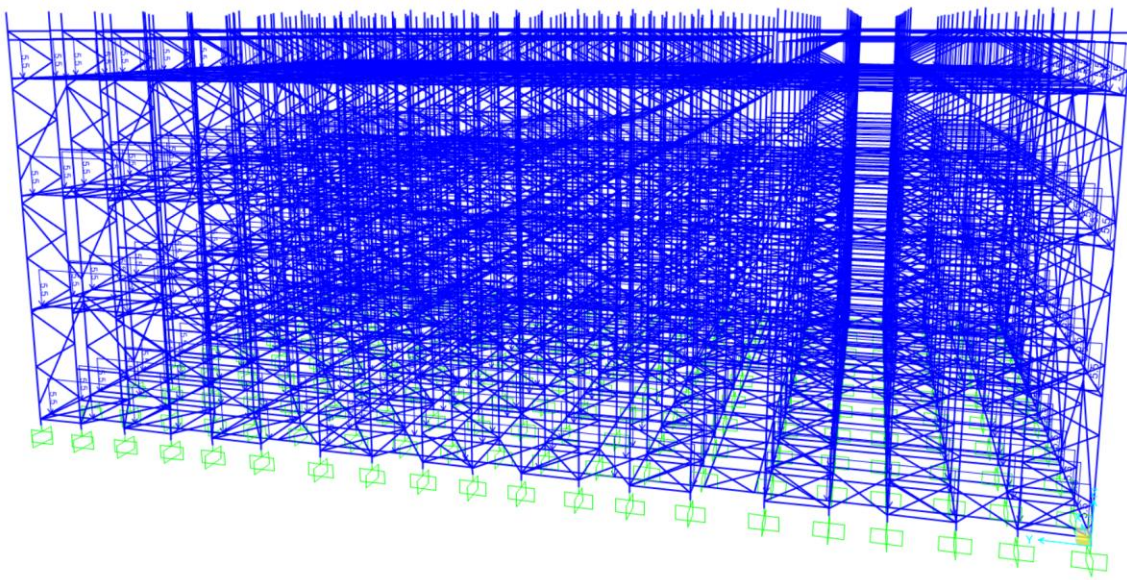
8.2 Finite element modal

The finite element model is established according to the drawings provided by the entruster, as shown in the figure below. The end release of the component, stiffness of the node and other characteristics should be considered in the model, which will not be discussed here. The storage unit load needs to consider the unfavorable load arrangement, as shown in the following figure. Other load models are not discussed here.

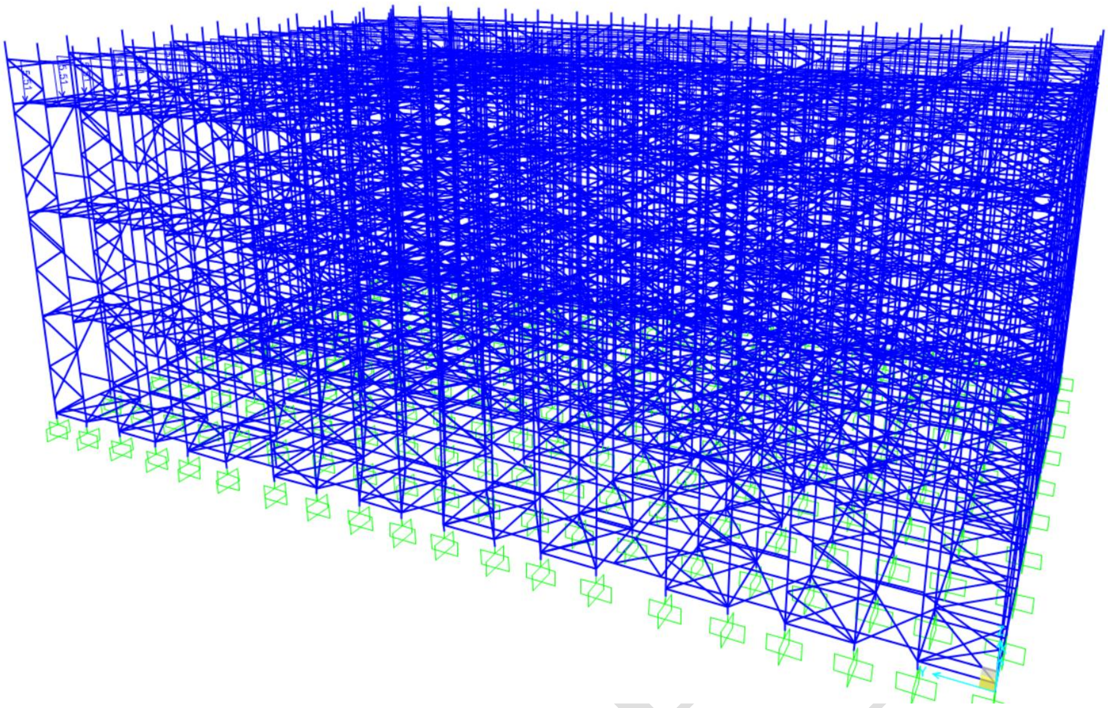
The horizontal distance between upright and beam center:

$e=d_{beam}/2-\ y_{s,upright}=50/2-29.34=-4.34mm<0.25d_u=0.25x100=25mm$;

The eccentricity can be negligible.



Full finite element modal-full load



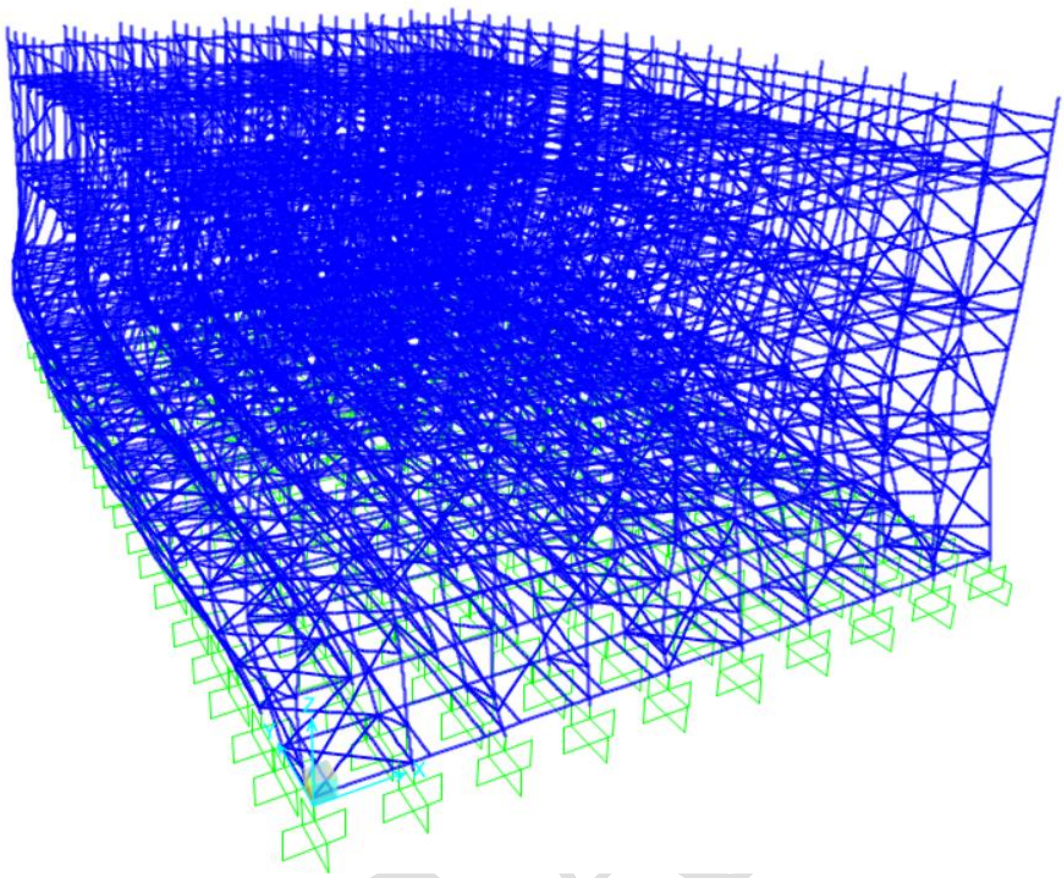
Structural finite element model - top level only

8.3 Buckling analysis

Firstly, the elastic buckling analysis was carried out, and the load condition was considered as 1.3D+1.4 PL(Full).

The first global l buckling mode is shown in the figure below, and the corresponding buckling coefficient is 2.0<7.355<10.0, which meets the requirements of EN standard.

Besides, because 3.333<7.355<10.0, the second-order effects should be indirectly considered in the global analysis.



Global buckling mode

8.4 Analytical method

-Linear elasticity of material

-Consider the global imperfection

-The seismic is calculated by mode decomposition response spectrum method

-Preset P-Δ effect

9 Component check

9.1 Ordinary position Upright-100*78*2.0

All 100*78*2.0 uprights were checked, and the internal force of the most unfavorable upright section was shown in the figure below. The detailed calculation process is shown in the table below.

Internal diagram of member

Component check table

ID	4347	
Laod combinations	1.3D+1.4L+1.4ULS-X-1	
Name	Value	Unit
fy	355.000	N/mm^2
γ M0	1.100	
E	206000.000	N/mm^2
G	79231.000	N/mm^2
Aeq	477.000	mm^2
Aeff	462.000	mm^2
Iy,eq	648273.000	mm^4

Iz,eq	338897.000	mm^4
It,eq	571.000	mm^4
Iw,eq	905667167.000	mm^6
y0,eq	68.220	mm
Wy,eff	13343.000	mm^3
Wz,eff,min	6407.000	mm^3
Wz,eff,max	10625.000	mm^3
Ly	2475.000	mm
Lz	1200.000	mm
Lt	1200.000	mm
Ky	1.000	
Kz	1.000	
Kt	0.700	
α y	0.340	
α z	0.340	
α LT	0.340	
Nc,Rd	149100.000	N
My,Rd	4306150.000	Nmm
Mz,Rd,min	2067713.636	Nmm
Mz,Rd,max	3428977.273	Nmm
iy	36.865	mm
iz	26.655	mm
i0	81.997	mm
λ y	67.136	
Ncr,y	215166.420	N
λ y,rel	0.873	
Φ y	0.996	
χ y	0.678	
Nby,Rd	101157.357	N
λ z	45.020	
Ncr,z	478489.264	N
λ z,rel	0.585	
Φ z	0.737	
χ z	0.844	
Nbz,Rd	125883.325	N
β	0.308	
Ncr,T	394862.279	N
Ncr,TF	150739.078	N
λ TF,rel	1.043	
Φ TF	1.187	
χ TF	0.570	
NFT,Rd	84977.876	N
λ T,rel	0.644	
Φ T	0.783	
χ T	0.814	
NT,Rd	121383.706	N
N	53207.862	N
My	4904.431	Nmm
Mz	85653.529	Nmm

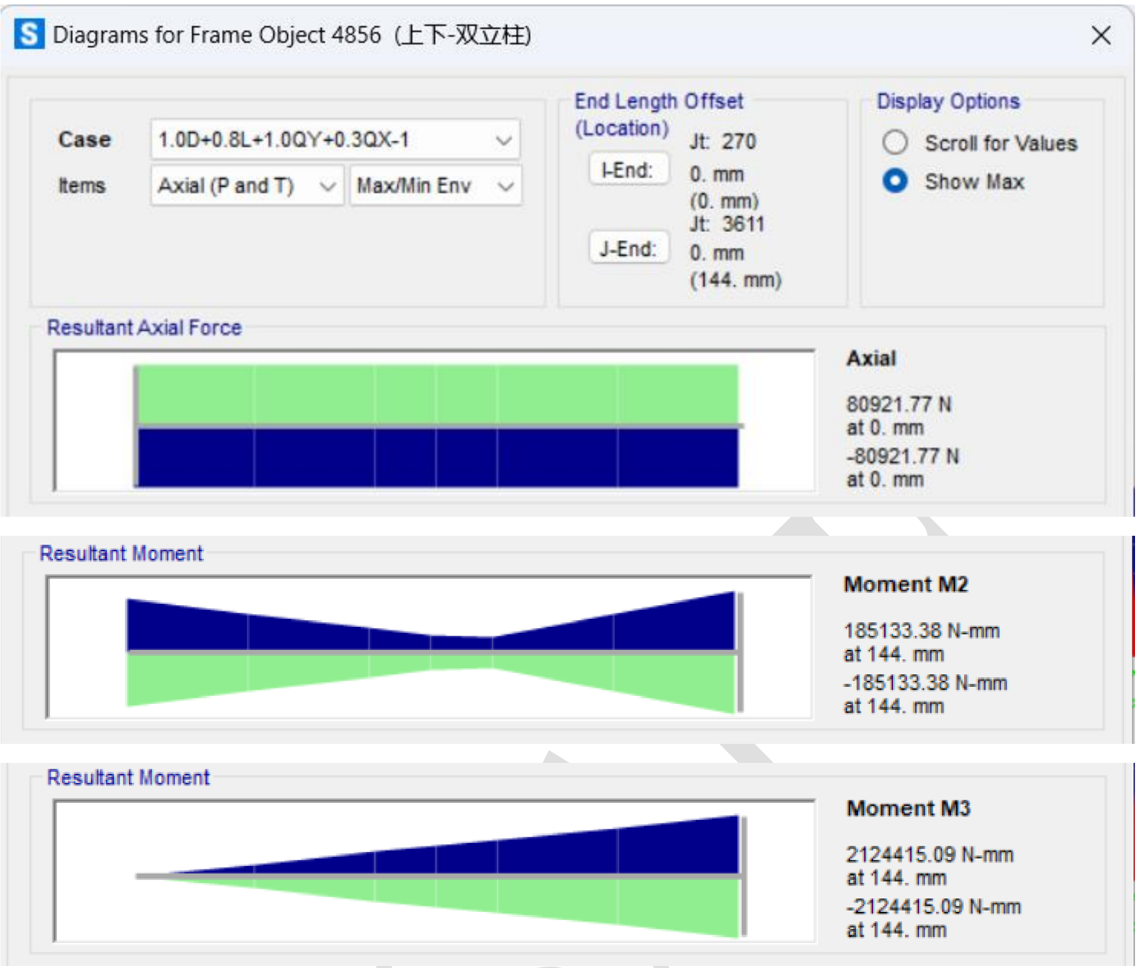
α β δ y	0.850	
α β δ z	0.850	
(NEd/ χ Nc,Rd) α y	0.672	
（My,Ed/ χ LTMy,Rd) β y	0.003	
(Mz,Ed/Mz,Rd) δ y	0.067	
DCR1	0.742	
(NEd/ χ zNc,Rd) α z	0.481	
（My,Ed/ χ LTMy,Rd) β z	0.003	
(Mz,Ed/Mz,Rd) δ z	0.067	
DCR2	0.551	
Laod combinations	1.0D+0.8L+1.0QX+0.3QY-1	
Name	Value	Unit
fy	355.000	N/mm^2
γ M0	1.100	
E	206000.000	N/mm^2
G	79231.000	N/mm^2
Aeq	477.000	mm^2
Aeff	462.000	mm^2
Iy,eq	648273.000	mm^4
Iz,eq	338897.000	mm^4
It,eq	571.000	mm^4
Iw,eq	905667167.000	mm^6
y0,eq	68.220	mm
Wy,eff	13343.000	mm^3
Wz,eff,min	6407.000	mm^3
Wz,eff,max	10625.000	mm^3
Ly	2475.000	mm
Lz	1200.000	mm
Lt	1200.000	mm
Ky	1.000	
Kz	1.000	
Kt	0.700	
α y	0.340	
α z	0.340	
α LT	0.340	
Nc,Rd	149100.000	N
My,Rd	4306150.000	Nmm
Mz,Rd,min	2067713.636	Nmm
Mz,Rd,max	3428977.273	Nmm
iy	36.865	mm
iz	26.655	mm
i0	81.997	mm
λ y	67.136	
Ncr,y	215166.420	N
λ y,rel	0.873	
Φ y	0.996	
χ y	0.678	
Nby,Rd	101157.357	N
λ z	45.020	
Ncr,z	478489.264	N

λz,rel	0.585	
Φz	0.737	
χz	0.844	
Nbz,Rd	125883.325	N
β	0.308	
Ncr,T	394862.279	N
Ncr,TF	150739.078	N
λTF,rel	1.043	
ΦTF	1.187	
χTF	0.570	
NFT,Rd	84977.876	N
λT,rel	0.644	
ΦT	0.783	
χT	0.814	
NT,Rd	121383.706	N
N	59214.266	N
My	197978.321	Nmm
Mz	316353.008	Nmm
α β δy	0.850	
α β δz	0.850	
(NEd/χNc,Rd)αy	0.736	
（My,Ed/χLTMy,Rd)βy	0.073	
(Mz,Ed/Mz,Rd)δy	0.203	
DCR1	1.011	
(NEd/χzNc,Rd)αz	0.527	
（My,Ed/χLTMy,Rd)βz	0.073	
(Mz,Ed/Mz,Rd)δz	0.203	
DCR2	0.802	

By calculation, the maximum stress ratio of the upright under the most unfavorable static condition DCR=0.742 < 1.0; Under the most unfavorable seismic conditions, the maximum stress ratio DCR=1.011 >1.0, but the overlimit ratio is small. It can be considered to meet the bearing requirements.

9.2 Strengthen position upright-100*78*2.0+100*96*2.5

All 100*78*2.0+100*96*2.5 uprights were checked, and the internal force of the most unfavorable upright section was shown in the figure below. The detailed calculation process is shown in the table below.



Internal diagram of member

Component check table

ID	4856	
Laod combinations	1.3D+1.4L+1.4ULS-X-1	
Name	Value	Unit
fy	355.000	N/mm^2
γ M0	1.100	
E	206000.000	N/mm^2
G	79231.000	N/mm^2
Aeq	1299.000	mm^2
Aeff	1126.635	mm^2
Iy,eq	1809806.000	mm^4
Iz,eq	3534267.000	mm^4
It,eq	1505184.000	mm^4
Iw,eq	905667167.000	mm^6
y0,eq	72.680	mm
Wy,eff	31193.82	mm^3
Wz,eff,min	31713.332	mm^3
Wz,eff,max	39431.776	mm^3
Ly	144.000	mm
Lz	1200.000	mm
Lt	1200.000	mm

Ky	1.000	
Kz	1.000	
Kt	0.700	
α y	0.340	
α z	0.340	
α LT	0.340	
Nc,Rd	363596	N
My,Rd	10067000	Nmm
Mz,Rd,min	10235000	Nmm
Mz,Rd,max	12726000	Nmm
iy	37.326	mm
iz	52.161	mm
i0	96.935	mm
λ y	3.858	
Ncr,y	177449183.455	N
λ y,rel	0.047	
Φ y	0.475	
χ y	1.000	
Nby,Rd	363600	N
λ z	23.006	
Ncr,z	4990037.729	N
λ z,rel	0.283	
Φ z	0.554	
χ z	0.970	
Nbz,Rd	352790	N
β	0.438	
Ncr,T	12969530	N
Ncr,TF	12442110	N
λ TF,rel	0.179	
Φ TF	0.513	
χ TF	1.000	
NFT,Rd	363600	N
λ T,rel	0.176	
Φ T	0.511	
χ T	1.000	
NT,Rd	363600	N
N	57614.776	N
My	3898.610	Nmm
Mz	250468.052	Nmm
α β δ y	1.000	
α β δ z	0.970	
(NEd/ χ Nc,Rd) α y	0.158	
（My,Ed/ χ LTMy,Rd) β y	0.000	
(Mz,Ed/Mz,Rd) δ y	0.024	
DCR1	0.183	
(NEd/ χ zNc,Rd) α z	0.172	
（My,Ed/ χ LTMy,Rd) β z	0.000	
(Mz,Ed/Mz,Rd) δ z	0.027	

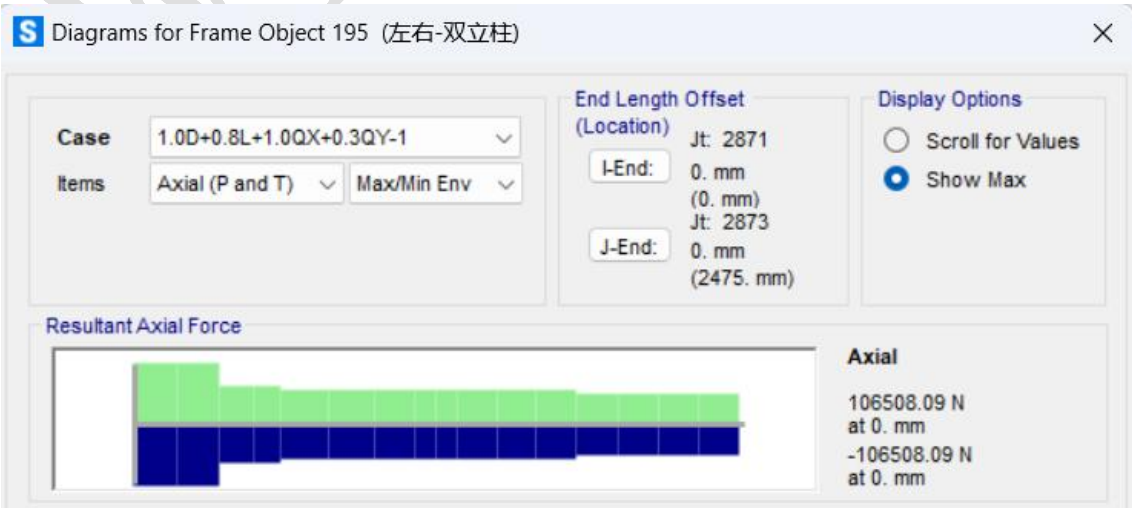
DCR2	0.200	
Laod combinations	1.0D+0.8L+1.0QX+0.3QY-1	
Name	Value	Unit
fy	355.000	N/mm^2
γ M0	1.100	
E	206000.000	N/mm^2
G	79231.000	N/mm^2
Aeq	1299.000	mm^2
Aeff	1126.635	mm^2
Iy,eq	1809806.000	mm^4
Iz,eq	3534267.000	mm^4
It,eq	1505184.000	mm^4
Iw,eq	905667167.000	mm^6
y0,eq	72.680	mm
Wy,eff	31193.82	mm^3
Wz,eff,min	31713.332	mm^3
Wz,eff,max	39431.776	mm^3
Ly	144.000	mm
Lz	1200.000	mm
Lt	1200.000	mm
Ky	1.000	
Kz	1.000	
Kt	0.700	
α y	0.340	
α z	0.340	
α LT	0.340	
Nc,Rd	363596	N
My,Rd	10067000	Nmm
Mz,Rd,min	10235000	Nmm
Mz,Rd,max	12726000	Nmm
iy	37.326	mm
iz	52.161	mm
i0	96.935	mm
λ y	3.858	
Ncr,y	177449183.455	N
λ y,rel	0.047	
Φ y	0.475	
χ y	1.000	
Nby,Rd	363600	N
λ z	23.006	
Ncr,z	4990037.729	N
λ z,rel	0.283	
Φ z	0.554	
χ z	0.970	
Nbz,Rd	352790	N
β	0.438	
Ncr,T	12969530	N
Ncr,TF	12442110	N
λ TF,rel	0.179	
Φ TF	0.513	

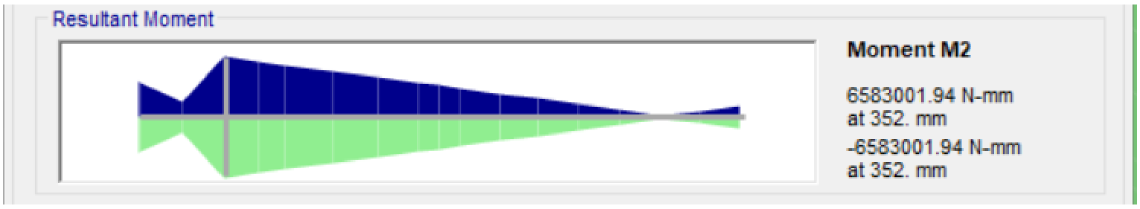
χTF	1.000	
NFT,Rd	363600	N
λT,rel	0.176	
ΦT	0.511	
χT	1.000	
NT,Rd	363600	N
N	80921.787	N
My	185132.685	Nmm
Mz	2124414.978	Nmm
αβδy	1.000	
αβδz	0.970	
(NEd/χNc,Rd)αy	0.223	
(My,Ed/χLTMy,Rd)βy	0.018	
(Mz,Ed/Mz,Rd)δy	0.208	
DCR1	0.449	
(NEd/χzNc,Rd)αz	0.240	
(My,Ed/χLTMy,Rd)βz	0.021	
(Mz,Ed/Mz,Rd)δz	0.218	
DCR2	0.478	

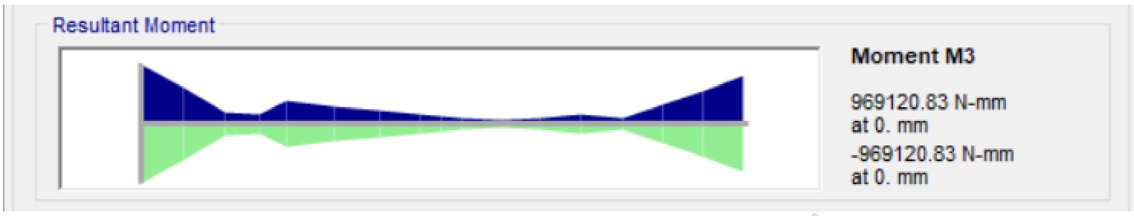
By calculation, the maximum stress ratio of the upright under the most unfavorable static condition DCR=0.200 < 1.0; Under the most unfavorable seismic conditions, the maximum stress ratio DCR=0.478 <1.0, meet the bearing requirements.

9.3 Back bracing position upright-118*91*3.0+118*91*3.0

All 118*91*3.0+118*91*3.0 uprights were checked, and the internal force of the most unfavorable upright section was shown in the figure below. The detailed calculation process is shown in the table below.







Internal diagram of member

Component check table

ID	195	
Laod combinations	1.3D+1.4L+1.4ULS-X-1	
Name	Value	Unit
fy	355.000	N/mm^2
γ M0	1.100	
E	206000.000	N/mm^2
G	79231.000	N/mm^2
Aeq	2020.000	mm^2
Aeff	1798.629	mm^2
Iy,eq	10612237.000	mm^4
Iz,eq	1850595.000	mm^4
It,eq	7833.000	mm^4
Iw,eq	1.81E+09	mm^6
y0,eq	68.220	mm
Wy,eff	79028.642	mm^3
Wz,eff,min	332644.85	mm^3
Wz,eff,max	44202.922	mm^3
Ly	2475.000	mm
Lz	1200.000	mm
Lt	1200.000	mm
Ky	1.000	
Kz	1.000	
Kt	0.700	
α y	0.340	
α z	0.340	
α LT	0.340	
Nc,Rd	580467	N
My,Rd	25505000	Nmm
Mz,Rd,min	107354000	Nmm
Mz,Rd,max	14265000	Nmm
iy	72.482	mm
iz	30.268	mm
i0	104.037	mm
λ y	34.147	
Ncr,y	3522276.941	N

λ y,rel	0.426	
Φ y	0.629	
χ y	0.916	
Nby,Rd	531540	N
λ z	39.646	
Ncr,z	2612858.302	N
λ z,rel	0.494	
Φ z	0.672	
χ z	0.887	
Nbz,Rd	514710	N
β	0.570	
Ncr,T	539540	N
Ncr,TF	503440	N
λ TF,rel	1.126	
Φ TF	1.292	
χ TF	0.520	
NFT,Rd	301700	N
λ T,rel	1.088	
Φ T	1.243	
χ T	0.543	
NT,Rd	314910	N
N	23021.427	N
My	647201.634	Nmm
Mz	75135.945	Nmm
α β δ y	0.850	
α β δ z	0.887	
(NEd/ χ Nc,Rd) α y	0.112	
（My,Ed/ χ LTMy,Rd) β y	0.044	
(Mz,Ed/Mz,Rd) δ y	0.002	
DCR1	0.158	
(NEd/ χ zNc,Rd) α z	0.064	
（My,Ed/ χ LTMy,Rd) β z	0.038	
(Mz,Ed/Mz,Rd) δ z	0.002	
DCR2	0.104	
Laod combinations	1.0D+0.8L+1.0QX+0.3QY-1	
Name	Value	Unit
fy	355.000	N/mm^2
γ M0	1.100	
E	206000.000	N/mm^2
G	79231.000	N/mm^2
Aeq	2020.000	mm^2
Aeff	1798.629	mm^2
Iy,eq	10612237.000	mm^4
Iz,eq	1850595.000	mm^4
It,eq	7833.000	mm^4
Iw,eq	1.81E+09	mm^6
y0,eq	68.220	mm
Wy,eff	79028.642	mm^3
Wz,eff,min	332644.85	mm^3

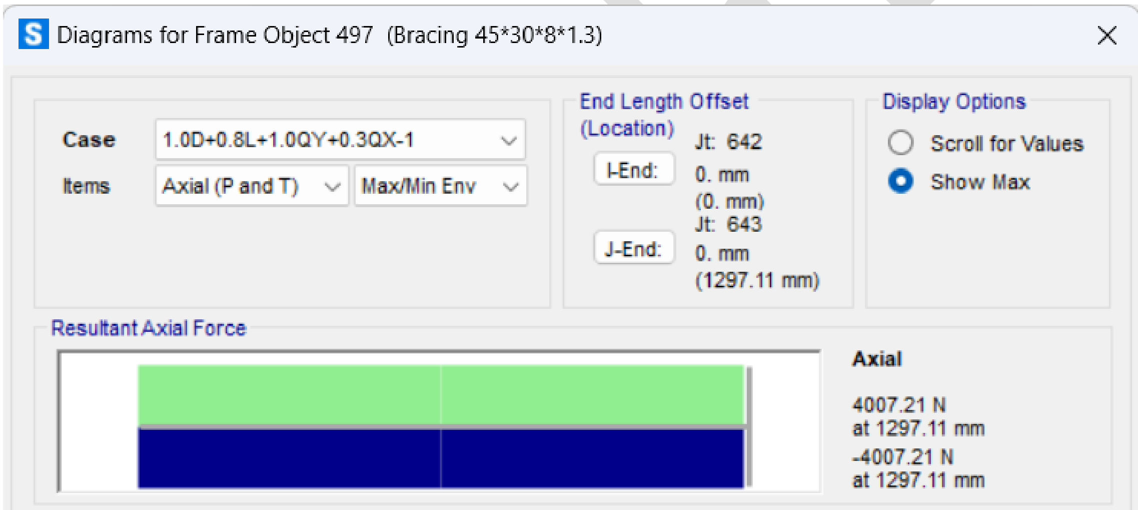
Wz,eff,max	44202.922	mm^3
Ly	2475.000	mm
Lz	1200.000	mm
Lt	1200.000	mm
Ky	1.000	
Kz	1.000	
Kt	0.700	
α y	0.340	
α z	0.340	
α LT	0.340	
Nc,Rd	580467	N
My,Rd	25505000	Nmm
Mz,Rd,min	107354000	Nmm
Mz,Rd,max	14265000	Nmm
iy	72.482	mm
iz	30.268	mm
i0	104.037	mm
λ y	34.147	
Ncr,y	3522276.941	N
λ y,rel	0.426	
Φ y	0.629	
χ y	0.916	
Nby,Rd	531540	N
λ z	39.646	
Ncr,z	2612858.302	N
λ z,rel	0.494	
Φ z	0.672	
χ z	0.887	
Nbz,Rd	514710	N
β	0.570	
Ncr,T	539540	N
Ncr,TF	503440	N
λ TF,rel	1.126	
Φ TF	1.292	
χ TF	0.520	
NFT,Rd	301700	N
λ T,rel	1.088	
Φ T	1.243	
χ T	0.543	
NT,Rd	314910	N
N	106508.091	N
My	6583002.277	Nmm
Mz	969120.713	Nmm
α β δ y	0.850	
α β δ z	0.887	
(NEd/ χ Nc,Rd) α y	0.413	
（My,Ed/ χ LTMy,Rd) β y	0.316	
(Mz,Ed/Mz,Rd) δ y	0.018	
DCR1	0.747	

(NEd/ χ zNc,Rd) α z	0.247	
（My,Ed/ χ LTMy,Rd) β z	0.301	
(Mz,Ed/Mz,Rd) δ z	0.015	
DCR2	0.564	

By calculation, the maximum stress ratio of the upright under the most unfavorable static condition DCR=0.158 < 1.0; Under the most unfavorable seismic conditions, the maximum stress ratio DCR=0.747 <1.0, meet the bearing requirements.

9.4 Bracing C45*30*8*1.3

All CC45*30*8*1.3 bracings were checked, and the internal force of the most unfavorable bracing section was shown in the figure below. The detailed calculation process is shown in the table below.



Internal diagram of member

Component check table

ID	497	
Laod combinations	1.3D+1.4L+1.4ULS-Y-1	
Name	Value	Unit
NEd	1314.440	N
fy	235.000	N/mm^2
fu	350.000	N/mm^2
γ M0	1.100	
γ M2	1.250	
E	206000.000	N/mm^2
G	79231.000	N/mm^2
An	132.000	mm^2
A	146.000	mm^2
Aeff	132.000	mm^2

Iy	48868.000	Mm^4
Iz	17789.000	mm^4
It	82.000	mm^4
Iw	8195996.000	mm^6
y0	25.560	mm
Wz,eff	914.000	mm^3
Ly	1297.112	mm
Lz	1297.112	mm
Lt	1297.112	mm
Ky	1.000	
Kz	1.000	
Kt	1.000	
α y	0.490	
α z	0.490	
α LT	0.490	
Nc,Rd	28200.000	N
Mz,Rd	195263.636	
iy	18.295	mm
iz	11.038	mm
i0	33.315	mm
λ y	70.899	
Ncr,y	59052.251	N
λ y,rel	0.725	
Φ y	0.891	
χ y	0.709	
Nby,Rd	20002.210	N
λ z	117.511	
Ncr,z	21496.286	N
λ z,rel	1.201	
Φ z	1.467	
χ z	0.433	
Nbz,Rd	12215.276	N
β	0.411	
Ncr,T	14777.437	N
Ncr,TF	12721.335	N
λ TF,rel	1.562	
Φ TF	2.053	
χ TF	0.295	
NFT,Rd	8330.187	N
λ T,rel	1.449	
Φ T	1.856	
χ T	0.332	
NT,Rd	9353.859	N
ey	0.000	mm
MRd.z.eff	270250.000	Nmm
η	1.065	
MEd.Z	0.000	Nmm
α y	0.850	
α z	0.850	
DCR1	0.420	

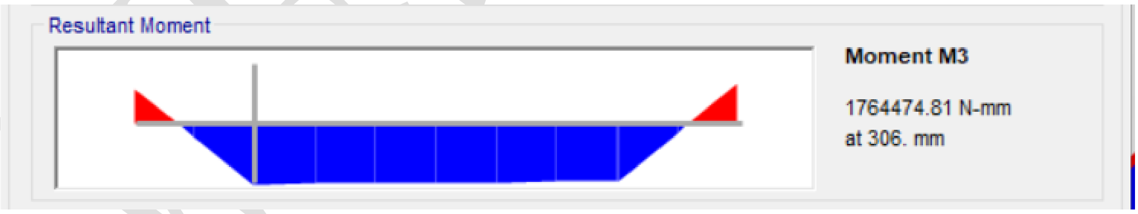
DCR2	0.303	
DCR3	0.081	
Laod combinations	1.0D+0.8L+1.0QY+0.3QX-1	
Name	Value	Unit
NEd	4007.211	N
fy	235.000	N/mm^2
fu	350.000	N/mm^2
γ M0	1.100	
γ M2	1.250	
E	206000.000	N/mm^2
G	79231.000	N/mm^2
An	132.000	mm^2
A	146.000	mm^2
Aeff	132.000	mm^2
Iy	48868.000	Mm^4
Iz	17789.000	mm^4
It	82.000	mm^4
Iw	8195996.000	mm^6
y0	25.560	mm
Wz,eff	914.000	mm^3
Ly	1297.112	mm
Lz	1297.112	mm
Lt	1297.112	mm
Ky	1.000	
Kz	1.000	
Kt	1.000	
α y	0.490	
α z	0.490	
α LT	0.490	
Nc,Rd	28200.000	N
Mz,Rd	195263.636	
iy	18.295	mm
iz	11.038	mm
i0	33.315	mm
λ y	70.899	
Ncr,y	59052.251	N
λ y,rel	0.725	
Φ y	0.891	
χ y	0.709	
Nby,Rd	20002.210	N
λ z	117.511	
Ncr,z	21496.286	N
λ z,rel	1.201	
Φ z	1.467	
χ z	0.433	
Nbz,Rd	12215.276	N
β	0.411	
Ncr,T	14777.437	N
Ncr,TF	12721.335	N
λ TF,rel	1.562	

ΦTF	2.053	
χTF	0.295	
NFT,Rd	8330.187	N
λT,rel	1.449	
ΦT	1.856	
χT	0.332	
NT,Rd	9353.859	N
ey	0.000	mm
MRd.z.eff	270250.000	Nmm
η	1.229	
MEd.Z	0.000	Nmm
αy	0.850	
αz	0.850	
DCR1	0.537	
DCR2	0.388	
DCR3	0.108	

It is calculated that the maximum stress ratio DCR=0.420< 1.0 under the most unfavorable static condition. The maximum stress ratio DCR=0.537 <1.0 under the most unfavorable seismic conditions; Meet the load bearing requirements.

9.5 Beam 1-100*50*1.5

All 100*50*1.5 beams were checked, and the internal forces of the most unfavorable beams were shown in the figure below. The detailed calculation process is shown in the table below.



Internal diagram of member

Component check table

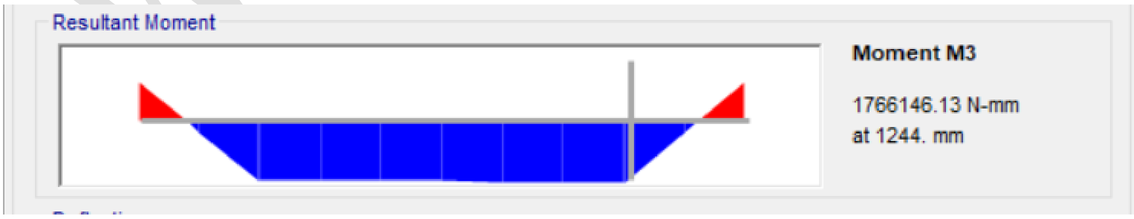
ID	2815	
Laod combinations	1.3D+1.4L+1.4ULS-X-1	
Name	Value	Unit
M3	1764475	Nmm
L	1550.000	mm
Qph	250	N
Qpv	3000	N
J	1	
Vq	1.400	
Vh	0.900	

n	1	
MEd,z	135625	Nmm
MEd,y+	1627500	Nmm
MRd,y	3687062	Nmm
MRd,z	2546524	Nmm
DCR	0.876	
Laod combinations	1.0D+0.8L+1.0QX+0.3QY-1	
Name	Value	Unit
M3	1206979	Nmm
L	1550	mm
Qph	250	N
Qpv	3000	N
J	1	
Vq	1.4	
Vh	0.9	
n	1	
MEd,z	135625	Nmm
MEd,y+	1627500	Nmm
MRd,y	3687062	Nmm
MRd,z	2546524	Nmm
DCR	0.740	

By calculation, the maximum stress ratio DCR of 100*50*1.5 beam under the most unfavorable static condition is 0.876<1.0; The maximum stress ratio DCR=0.740<1.0 under the most unfavorable seismic conditions; Meet bearing requirements.

9.6 Beam 2-100*50*1.5*2

All 100*50*1.5*2 beams were checked, and the internal forces of the most unfavorable beams were shown in the figure below. The detailed calculation process is shown in the table below.



Internal diagram of member

Component check table

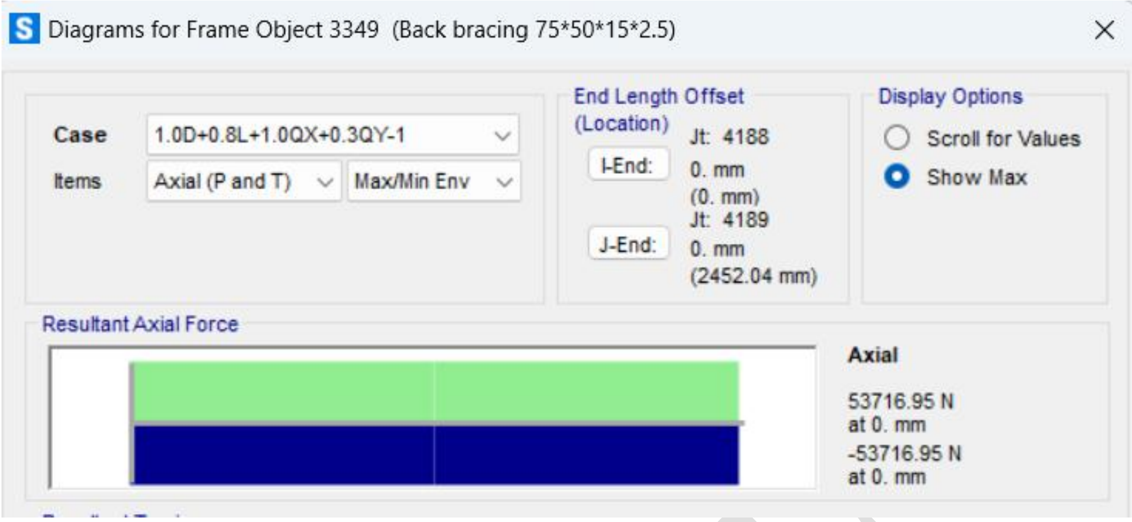
ID	2267	
Laod combinations	1.3D+1.4L+1.4ULS-X-1	
Name	Value	Unit
M3	1766146	Nmm
L	1550.000	mm

Qph	250	N
J	1	N
Vq	1.400	
Vh	0.900	
n	1	
MEd,z	135625	
MEd,y+	1627500	Nmm
MRd,y	12591327	Nmm
MRd,z	8139434	Nmm
DCR	0.258	
Laod combinations	1.0D+0.8L+1.0QX+0.3QY-1	
Name	Value	Unit
M3	1218416	Nmm
L	1550	mm
Qph	250	N
Qpv	3000	N
J	1	
Vq	1.4	
Vh	0.9	
n	1	
MEd,z	135625	Nmm
MEd,y+	1627500	Nmm
MRd,y	12591327	Nmm
MRd,z	8139434	Nmm
DCR	0.218	

By calculation, the maximum stress ratio DCR of 100*50*1.5*2 beam under the most unfavorable static condition is 0.258<1.0; The maximum stress ratio DCR=0.218<1.0 under the most unfavorable seismic conditions; Meet bearing requirements.

9.7 Back bracing C75*50*15*2.5

All the back bracings were checked, and the internal forces of the most unfavorable back bracings were shown in the figure below. The detailed calculation process is shown in the table below.



Internal diagram of member

According to the finite element model, the maximum axial tension of the back bracings is 53.716kN. Because the back bracings in the structure was cross-arranged, half of the tie rod will be compressed out of the work under the lateral load in actual use, so the axial tension of a single back bracings should be amplified by 1 times, and the maximum axial tension should be 53.716*2=107.432KN.

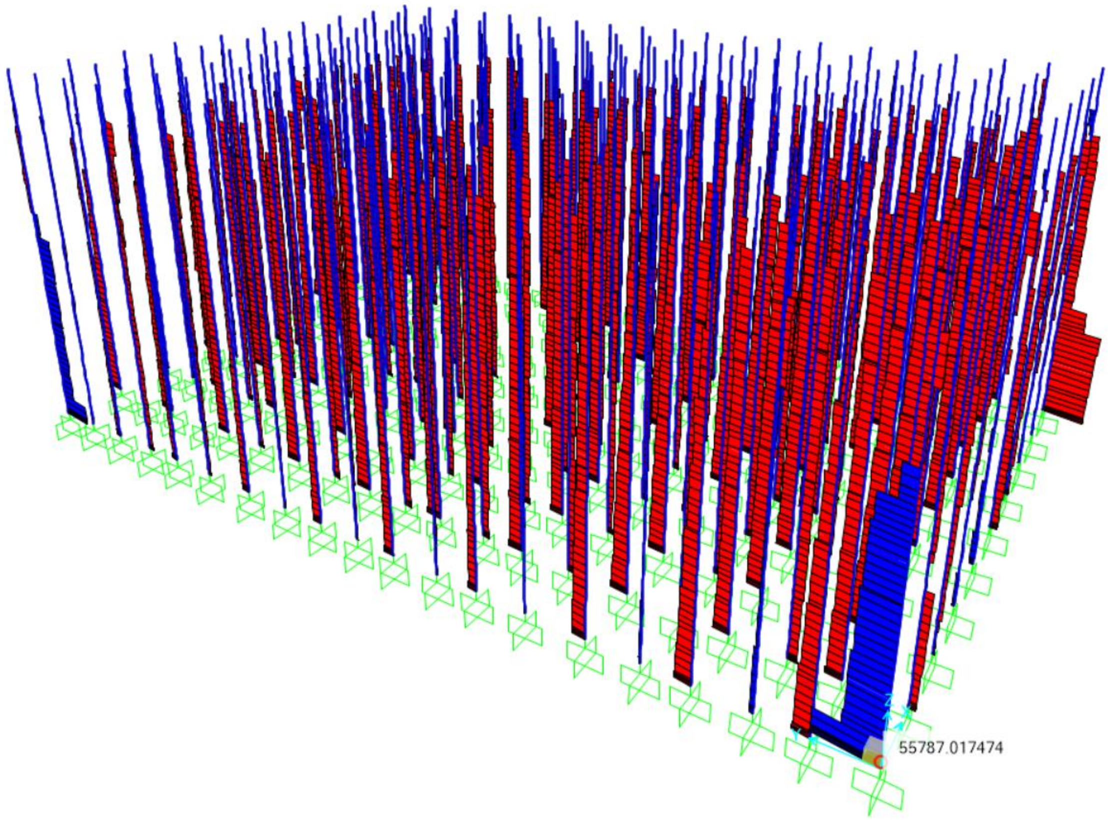
Component check table

ID	3349	
Laod combinations	1.3D+1.4L+1.4ULS-X-1	
Name	Value	Unit
fu	470	N/mm2
Nmax	2768	N
An	442	mm2
DCR	0.02	
Laod combinations	1.0D+0.8L+1.0QX+0.3QY-1	
Name	Value	Unit
fu	470	N/mm2
Nmax	107432	N
An	442	mm2
DCR	0.650	

It is calculated that the maximum stress ratio DCR=0.020<1.0 under the most unfavorable static condition. The maximum stress ratio DCR=0.650<1.0 under the most unfavorable seismic conditions; Meet bearing requirements

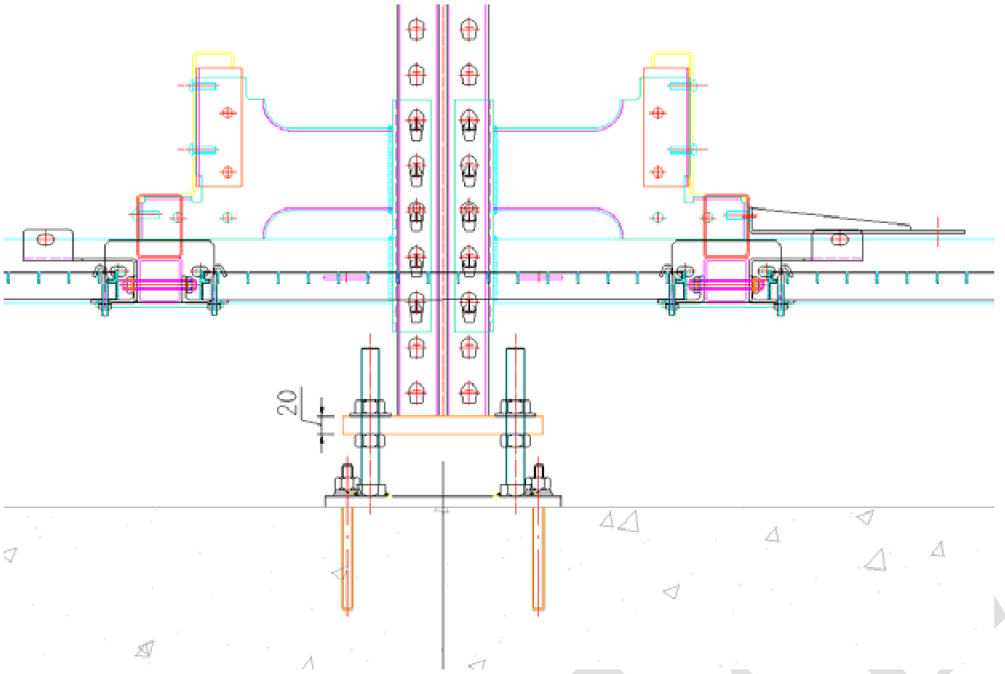
9.8 Upright foot joint

Under the overturning condition where only the top beam is loaded and all lower beam are unloaded, the axial tension/axial pressure on the column is shown in the figure below, where red is the axial pressure and blue is the axial tension:



Axial diagram of upright under overturning condition

According to the finite element model, the maximum pulling force appears at the entrance of the first longitudinal row under longitudinal seismic conditions, with the maximum axial tension/pressure=55.889KN and the maximum shear force =6.699KN; The maximum axial pressure/tension of the remaining positions of the two rows of reinforced columns =21.356KN and the maximum shear force =3.216KN; The maximum axial tension/pressure at the position of non-reinforced column=11.097KN, the maximum shear =0.910KN.



The size of the adjustable screw at the upright foot node is 2*8.8 M20; The anchor bolts at the longitudinal entrance are 2*M20 (5.8 grade) anchors; The remaining position of the strengthening upright is 2*M12 (5.8 grade); The position of the unreinforced upright is 2*M12(5.8 grade).

9.8.1 Compressive

2×20×20×3.14/4×400/1000=251.2KN>55.889KN, Meet the requirements.

9.8.2 Shear

2×20×20×3.14/4×320/1000=200.9KN>6.699KN, Meet the requirements.

9.8.3 Tension

The drawing force calculation table provided by the bolt supplier is as follows:

Design resistance

Anchor size			M8	M10	M12	M16	M20	M24	M27	M30
Seismic performance C1										
Tension $N_{Rd,seis}$	HAS-U 5.8	[kN]	-	16,0	22,5	27,3	43,3	59,4	-	-
	HAS-U 8.8		-	16,0	22,5	27,3	43,3	59,4	72,6	86,6
	HAS-U A4		-	16,0	22,5	27,3	43,3	59,4	72,6	86,6
	HAS-U HCR		-	16,0	22,5	27,3	43,3	59,4	-	-
Shear $V_{Rd,seis}$	HAS-U 5.8	[kN]	-	8,8	12,0	21,6	34,4	49,6	-	-
	HAS-U 8.8		-	12,8	19,2	35,2	55,2	79,2	103	126
	HAS-U A4		-	10,0	15,0	27,9	38,5	55,8	34,0	41,2
	HAS-U HCR		-	12,8	19,2	35,2	55,2	49,7	-	-
Seismic performance C2										
Tension $N_{Rd,seis}$	HAS-U 8.8		-	-	-	12,1	18,5	-	-	-
Shear $V_{Rd,seis}$	HAS-U 8.8		-	-	-	32,0	56,8	-	-	-

Bolt drawing force calculation table

Back bracing plane outermost upright foot

Drawing force check calculation: 2×43.3=86.6KN>55.889KN, OK;

Adjustable screw weld checking calculation:

$\beta_f * f_f^w * h_e * l_w$=1.22*280*0.7*6*(2*3.14*20-2*6)=162.984KN>55.889KN, OK;

Other position upright foot of the reinforcing upright

Drawing force check calculation: 2×22.5=45.0KN>21.356KN, OK;

Adjustable screw weld checking calculation:

$\beta_f * f_f^w * h_e * l_w$=1.22*280*0.7*6*(2*3.14*20-2*6)=162.984KN >21.356KN, OK;

Other position upright foots

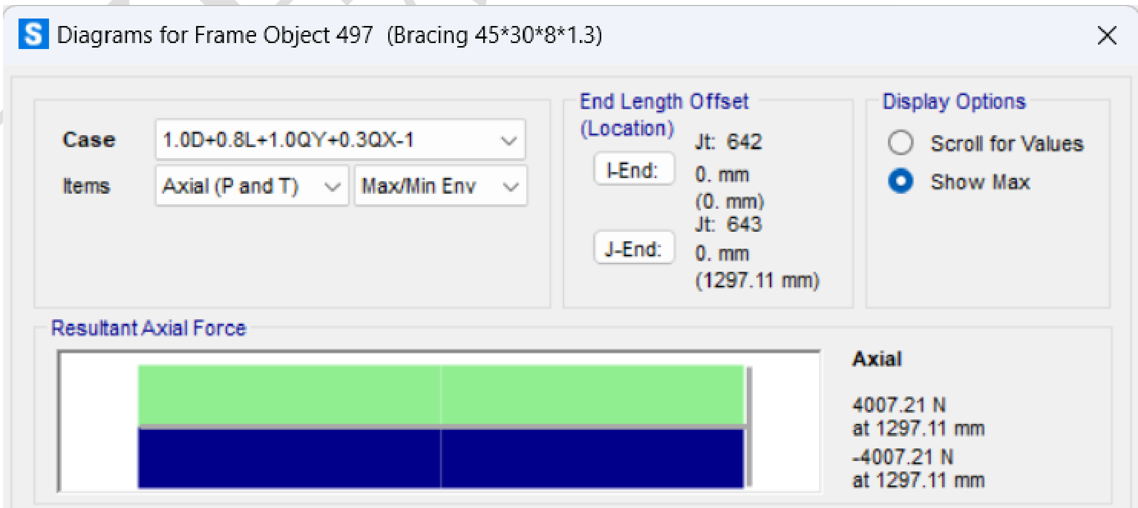
Drawing force check calculation: 2×22.5=45.0KN>11.097KN, OK;

Adjustable screw weld checking calculation:

$\beta_f * f_f^w * h_e * l_w$=1.22*280*0.7*6*(2*3.14*20-2*6)=162.984KN >11.097KN,OK.

9.9 Bracing joint

The internal forces of the most unfavorable transverse bracing joints are shown in the figure below. The detailed calculation process is shown in the table below.



Internal diagram of member

Component check table

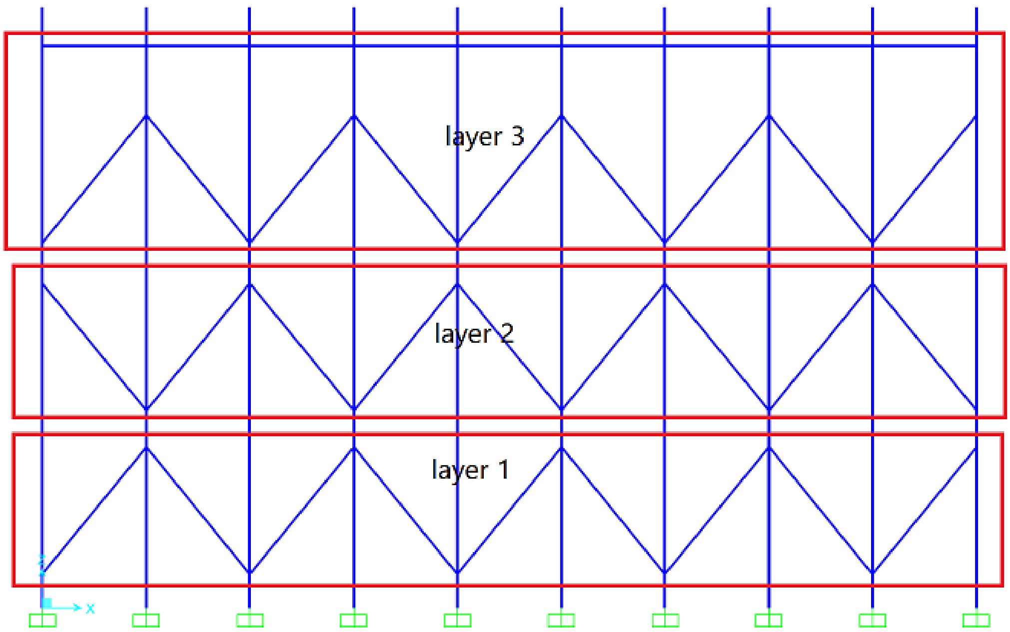
Name	Value	Unit

Sv	4007	N
Sc	4007	N
γ_{M2}	1.25	
nv	1	
e1	16	mm
d	10	mm
t	1.3	mm
fu	290	N/mm^2
ab	0.533333	
kt	1	
As	58	mm^2
fub	800	N/mm^2
Gd	8.8	
Co	0.6	
DCR1	0.180	
DCR2	0.996	

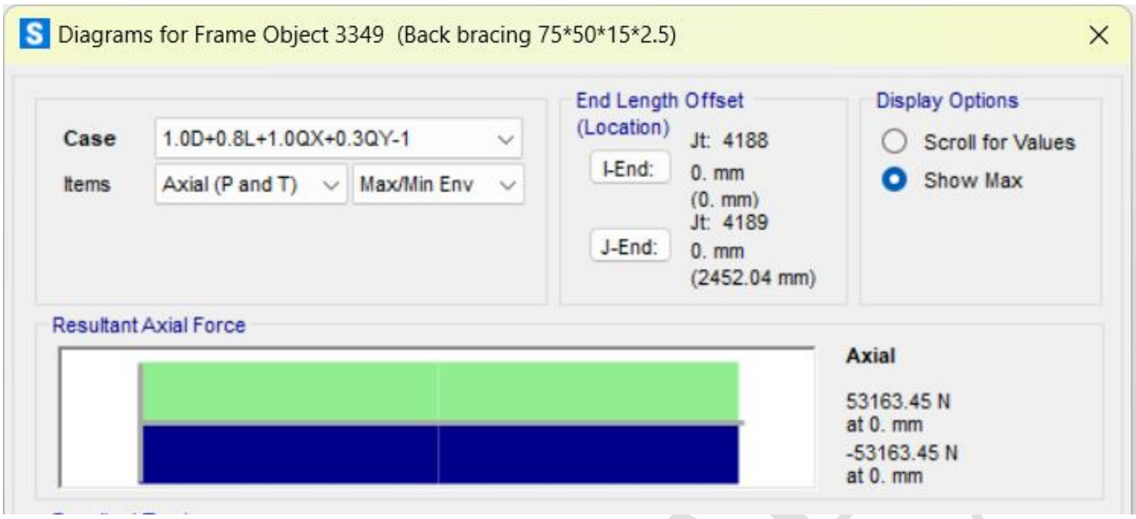
By calculation, the maximum stress ratio DCR=0.996<1.0 under the most unfavorable working conditions; Meet the load bearing requirements.

9.10 Back bracing joint

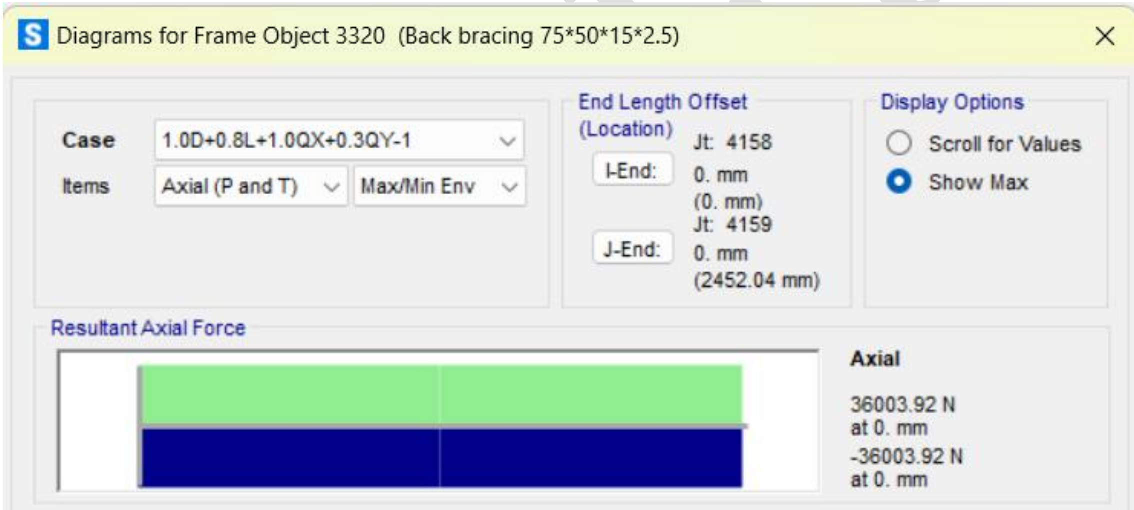
All the joint bolts of the back bracing were checked. The internal forces of the three-layer back bracing under the most unfavorable working conditions are shown in the figure below. The detailed calculation process is shown in the table below.



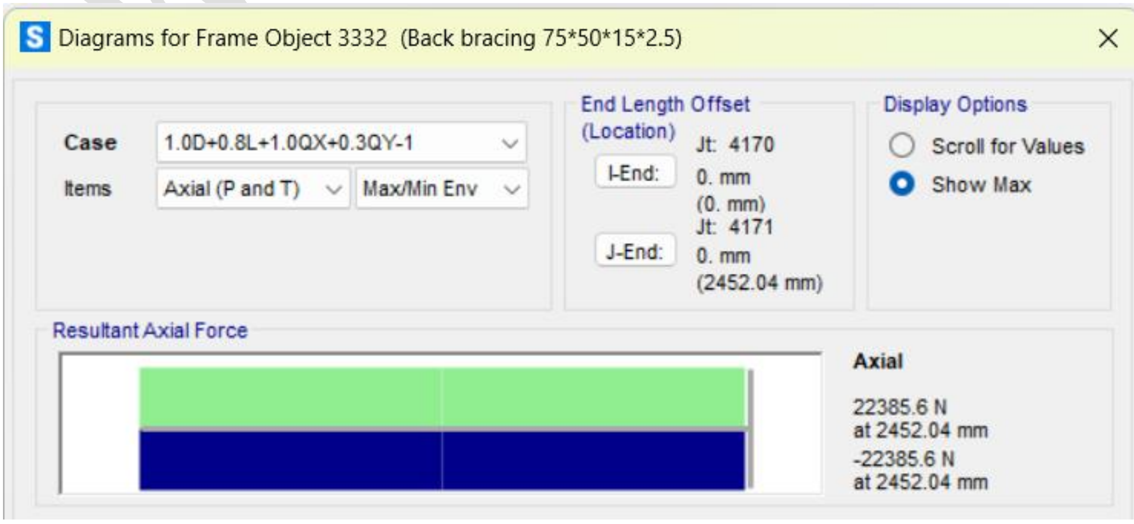
Layering diagram of back bracing



Layer 1 Internal force diagram



Layer 2 Internal force diagram



Layer 3 Internal force diagram

According to the finite element model, the maximum axial tension of the back bracing is shown in the figure above. Since the back bracing in the structure is cross-arranged, half of the tie rod will be compressed out of work under lateral load in actual use. Therefore, the axial tension of a single back tie rod should be amplified by 1 time, and the maximum axial tension should be as follows: N1=53.716*2=107.432KN、N2=36.004*2=72.008KN、N3=22.386*2=44.772KN.

9.10.1 Joint bolt

Component check table

Name	Layer 1	Layer 2	Layer 3	Unit
Sv	107432	72008	44772	N
Sc	107432	72008	44772	N
γ_{M2}	1.25	1.25	1.25	
nv	2	1	1	
e1	20	20	20	mm
d	16	18	14	mm
t	8	12	8	mm
fu	510	510	510	N/mm^2
ab	0.416667	0.37037	0.47619	
kt	1	1	1	
As	157	192	115	mm^2
fub	800	800	800	N/mm^2
Gd	8.8	8.8	8.8	
Co	0.6	0.6	0.6	
DCR1	0.891	0.977	1.014	
DCR2	0.987426	0.882451	0.823015	

According to the calculation, the maximum stress ratio DCR=1.014>1.0 under the most unfavorable working conditions; However, the over-limit ratio is small, which can be considered to meet the bearing requirements

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