

Steel structure design and analysis of a modern extreme sports center

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Abstract. A modern extreme sports center consists of a three-story main structure and ancillary structures. The overall architectural shape is simple and elegant. In order to ensure that the center has the high strength, earthquake resistance, corrosion resistance and other characteristics required for extreme sports venues, while taking into account comfort and aesthetics, the building structure adopts a steel frame structure system. This article uses the PKPM2021-V2.1.1.1 version software to conduct an overall calculation and analysis of this steel structure project, and checks the floor displacement calculated by the elastic method under the action of wind load or frequent earthquake standard values. The results show that the vertical structure of this structure is The deformation of the axial members meets the requirements of the code; the displacement ratio and inter-story displacement ratio of the structure under the action of specified horizontal seismic forces considering the influence of accidental eccentricity are checked, and the results show that the structure does not belong to torsional irregularity; the overturning resistance of the structure is checked and The shear-to-weight ratio was calculated and the results showed that the stability of the structure met the specification requirements. It can be seen from the above calculation and analysis that this structure can meet the specification requirements under various working conditions, and the structural design is safe and reliable.

Keywords: steel structure; performance-based seismic design; multi-scale analysis; design analysis.

1. Project Overview

A modern extreme sports center is located in Nanjing, Jiangsu Province. It is a comprehensive modern extreme sports building targeting young and middle-aged people. It provides venues and related services for surrounding residents to engage in rock climbing, roller skating, skateboarding, billiards, taekwondo, yoga and other sports.

The entire building is divided into the main part and the auxiliary part with the seismic joint as the boundary. This study mainly discusses the structure-related contents of the main part. The main building of this project has three floors above ground, and the structural form is a steel frame structure. The main building is 29m long and 29m wide. The height of each floor is 4.2m. The calculated height of the first floor is 4.8m, and the building height is about 12.6m; the main body and the total construction area of the auxiliary part is 4147m², and the building base area is 1382m².

The column grid of the main structure is 4×4. The horizontal column grid is arranged based on the depth of the house. The distance between columns is 9.6m and the total axis size is 28.8m. The longitudinal column grid is arranged based on the bay of the house. The distance between columns is 9.6m, the total axis size is 28.8m. In order to ensure the bending load-bearing capacity in the weak axis direction, the frame column section is HM500×500×20×25, and the steel grade is Q345B. The cross-sections of transverse frame beams, longitudinal frame beams, and secondary beams are HN700×300×13×24, and the steel grade is Q345B. The combined floor adopts YX-75-230-690 profiled steel plate, and the steel grade is Q235. Due to the stress characteristics of profiled steel plates, floor panels and corridor panels are all one-way panels, and roof panels are similar [1].

The staircase adopts a double-running parallel beam staircase, and the foundation adopts an independent foundation under the column. The foundation is a natural foundation, and the clay layer

is selected as the bearing layer. The elevation of the top surface of the foundation is -0.600m, and the elevation of the bottom surface of the foundation is -3.000m.

According to the design requirements [2], the design reference period and service life of structure of this project are 50 years, and the durability life is 100 years. Engineering geological data are shown in Table 1 [3].

Table 1. Geological data

Soil layer name	The average thickness (m)	f_{ak} (kN/m ²)	natural moisture content ω (%)	Severe γ (kN/m ³)	Compression factor α (mm ² /N)	Compression modulus E_s (N/mm ²)	void ratio e	Shear wave speed V_s (m/s)
1.Topsoil	0.89	70	—	—	—	—	—	140
2.Silt soil	2.51	140	36.1	18.3	0.19	10.3	0.949	250
3.Clay	1.95	160	29.6	19.4	0.11	15.0	0.776	280
4.Silt sand	2.36	180	29.1	19.4	0.12	15.0	0.763	520

Note: Thickness of site covering layer 48m.

2. Design conditions and loads

2.1 Design conditions.

Design life: 50 years [4]; Safety grade of building structure: Level 1; Seismic fortification category: Category C; Earthquake resistance level: Level 3.

2.2 Analysis on consumption of prefabricated buildings.

This project is a steel frame structure load-bearing system. The walls only play the role of filling and partitioning. The walls are not load-bearing. Therefore, the weight of the walls is converted into line loads and acts on the beams (inter-beam loads). The remaining constant loads and live loads are input according to the design requirements [5].

Dead load: The self-weight of the structure is automatically calculated by the program based on the cross-section size. The steel structure beam and column components adopt a density of 78.5kN/m³.

Standard value of roof permanent load: 4.915kN/m².

Standard value of floor permanent load: 3.925kN/m².

Live load: The standard value of the live load acting on the structure is 0.5kN/m² on the roof that is not accessible to people, the standard value of the live load evenly distributed on the floor is 3.0kN/m², the standard value of the live load evenly distributed on the corridor and stairs is 2.0kN/m², and it is being calculated. Unfavorable placement of live loads is considered.

Wind load: basic wind pressure $\omega_0=0.40\text{kN/m}^2$ (100-year return period). The ground roughness is Category C, and the wind load type coefficient is taken based on the wind tunnel test report.

Snow load: basic snow pressure 0.65kN/m² (100-year return period). This project has a flat roof, and the snow distribution coefficient $\mu_r=1.0$. Therefore, for the structure of this project, the snow load is not a controlled load condition, and it is not calculated and combined during the structural calculation.

Seismic effects: When calculating the response spectrum, the seismic parameters used are shown in Table 2 [6]. Consider bidirectional earthquake and vertical earthquake effects [7].

Table 2 Seismic information parameters

Basic fortification intensity	7 (0.1g)	Fortification earthquake grouping	Group 1
α_{max}	0.08	Characteristic period	0.35s
Site category	Category II	Damping ratio	$\xi_L=0.04$

3. Natural vibration period

This project uses PKPM2021-V2.1.1.1 version software to conduct overall calculation and analysis of this steel structure project. The calculation model is shown in Fig 1.

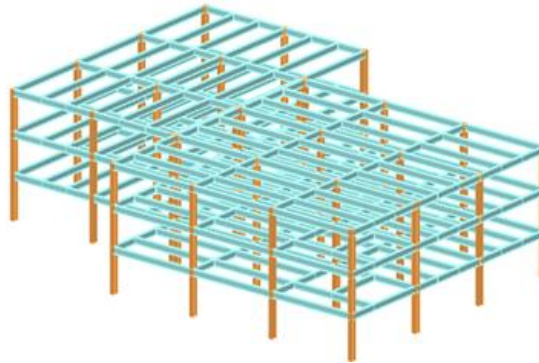


Fig 1 Isometric view of the structural layout of the extreme sports center

3.1 Design conditions.

Through the eigenvalue analysis under the action of (1.0×constant +0.5×active), the natural vibration period and mode shape can be obtained. Period and mode shape are important parameters for structural dynamic analysis [8], as shown in Table 3.

Table 3 Structural period and vibration direction

Vibration model	Period (s)	Direction angle (degrees)	type	Torsional vibration component	X side vibration component	Y side vibration component	Total side vibration component
1	0.9040	0.04	<i>X</i>	0%	100%	0%	100%
2	0.6715	90.53	<i>T</i>	58%	0%	42%	42%
3	0.6436	89.69	<i>Y</i>	42%	0%	58%	58%
4	0.2947	0.02	<i>X</i>	0%	100%	0%	100%
5	0.2071	90.61	<i>T</i>	77%	0%	23%	23%
6	0.1988	89.85	<i>Y</i>	23%	0%	77%	77%
7	0.1800	0.02	<i>X</i>	0%	100%	0%	100%
8	0.1183	91.15	<i>T</i>	90%	0%	10%	10%
9	0.1119	89.90	<i>Y</i>	10%	0%	90%	90%

3.2 Deformation check.

According to regulations [9], under the action of wind load or frequent earthquake standard values, the ratio of the maximum horizontal displacement between floors calculated by the elastic method to the floor height should not be greater than 1/250. The maximum inter-story displacement and maximum displacement angle of this structure under all working conditions are as follows:

The maximum floor displacement of the whole building under the action of the *X*-direction earthquake is 10.73mm, the maximum inter-story displacement is 5.04mm, and the maximum inter-story elastic displacement angle is 1/952<1/250, which meets the elastic inter-story displacement angle limit of the steel structure. requirements.

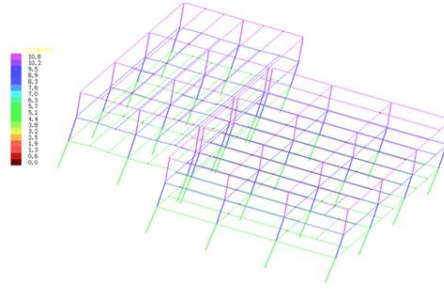


Fig 2 Displacement cloud diagram under *X*-direction earthquake action

The maximum floor displacement of the whole building under the action of *Y*-direction earthquake is 7.97mm, the maximum inter-story displacement is 3.19mm, and the maximum inter-story elastic displacement angle is $1/1379 < 1/250$, which meets the elastic inter-story displacement angle limit of steel structure requirements.

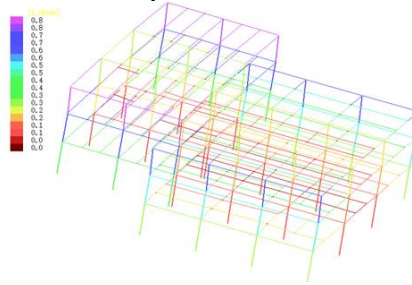


Fig 3 Displacement cloud diagram under *Y*-direction earthquake action

The maximum floor displacement of the whole building under the *Y*-direction wind load is 1.99mm, the maximum inter-story displacement is 0.82mm, and the maximum inter-story elastic displacement angle is $1/5674 < 1/250$, which meets the elastic inter-story displacement angle limit of the steel structure. value requirements.

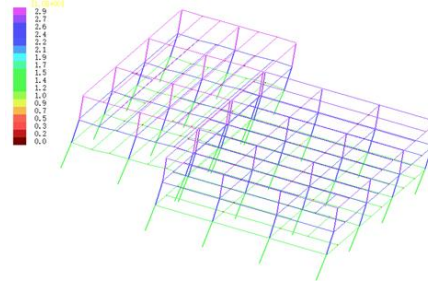


Fig 4 Displacement cloud diagram under the action of *X*-direction wind load

The maximum floor displacement of the whole building under the *Y*-direction wind load is 1.99mm, the maximum inter-story displacement is 0.82mm, and the maximum inter-story elastic displacement angle is $1/5674 < 1/250$, which meets the elastic inter-story displacement angle limit of the steel structure. value requirements.

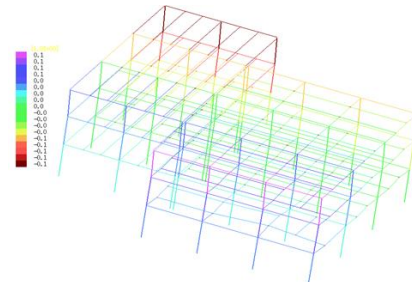


Fig 5 Displacement cloud diagram under *Y*-direction wind load

According to regulations [10], under the action of specified horizontal seismic forces taking into account the influence of accidental eccentricity, when the ratio of the elastic horizontal

displacement of the lateral force-resisting members at both ends of the floor or the maximum value of the inter-story displacement to the average value is greater than 1.2, torsion should be included in the calculation. Influence.

As shown in Table 4, the displacement ratio and inter-story displacement ratio under all working conditions are less than 1.2, so the structure does not belong to torsional irregularity.

Table 4 Structural displacement ratio and inter-story displacement ratio under accidental eccentric earthquakes

Working conditions	Layer number	Displacement ratio	interstory displacement ratio
X positive eccentric quiet vibration	3	1.07	1.07
	2	1.07	1.07
	1	1.06	1.06
X negative eccentric static shock	3	1.06	1.07
	2	1.06	1.07
	1	1.05	1.05
Y positive eccentric static vibration	3	1.24	1.23
	2	1.25	1.24
	1	1.25	1.25
Y negative eccentric static shock	3	1.13	1.13
	2	1.13	1.13
	1	1.13	1.13

3.3 Anti-overturning and stability check

The overall overturning calculation and stiffness-to-weight ratio calculation of the structure are directly related to the overall safety of the structure and are important overall indicators in structural design. In order to ensure that the structure will not overturn under load and control the stability of the structure, it is necessary to Carry out anti-overturning calculation and stiffness-to-weight ratio calculation.

According to regulations [10], under the combined action of the standard value of gravity load and horizontal load or the representative value of gravity load and the standard value of frequent horizontal earthquakes, for high-rise buildings with a height-to-width ratio not greater than 4, the area of zero stress zone between the bottom surface of the foundation and the foundation It should not exceed 15% of the base area of the foundation.

The anti-overturning calculation results of the structure are shown in Table 5.

Table 5 Anti-overturning calculation

Working conditions	Resistance to overturning moment $Mr(\text{kN}\cdot\text{m})$	Overturning moment $Mov(\text{kN}\cdot\text{m})$	Ratio Mr/Mov	zero stress zone (%)
E_X	7.53e+5	10481.66	71.88	0.00
E_Y	5.71e+5	12802.70	44.61	0.00
W_X	7.93e+5	2874.77	275.78	0.00
W_Y	6.01e+5	3536.84	169.85	0.00

The overall stability stiffness-to-weight ratio verification results of the structure are shown in Table 6. It can be seen from the table that the minimum stiffness-to-weight ratio of this structure is $24.1 \geq 5$, and it can pass the overall stability check of high steel regulations (6.1.7) [9].

Table 6 Calculation of stiffness-to-weight ratio of whole-layer buckling mode

Layer number	X-direction stiffness (kN·m)	Y-direction stiffness (kN·m)	Floor height (m)	X stiffness to weight ratio	Y stiffness to weight ratio
3	2.4e+5	3.5e+5	4.2	82.4	120.5
2	2.5e+5	4.0e+5	4.2	34.7	56.1
1	2.4e+5	4.8e+5	4.8	24.1	48.6

4. Conclusion

(1) From the analysis of the overall structural deformation calculation and structural vibration shape, the overall structural design is safe and reliable, and meets the corresponding national standards.

(2) Under the action of wind load or frequent earthquake standard values, the ratio of the maximum horizontal displacement between floors calculated by the elastic method to the floor height should not be greater than 1/250. The maximum inter-story displacement angle under all working conditions of the structure meets the specification requirements.

(3) Under the action of the specified horizontal seismic force taking into account the influence of accidental eccentricity, the maximum horizontal displacement and inter-story displacement of the vertical components of the floor should not be greater than 1.2 times the average value of the floor, and should not be greater than 1.5 times the average value of the floor. The displacement ratio and inter-story displacement ratio under all working conditions of this project are less than 1.2. The structure does not belong to torsion irregularity and meets the requirements of the specification.

(4) Under the combined action of the standard values of gravity load and horizontal load or the representative value of gravity load and the standard value of frequent horizontal earthquakes, the overturning resistance check calculation and stiffness-to-weight ratio check calculation results of the structure both meet the overall stability check of the structure, making the structure safe and reliable.

References

- [1] Steel structure design standard: GB 50017-2017 [S]. Beijing: China building industry press,2018.
- [2] Unified Standard for Reliability Design of Building Structures: GB 50068-2018 [S]. Beijing: China building industry press,2018.
- [3] Code for the design of building foundations: GB 50007-2011 [S]. Beijing: China Construction Industry Press, 2012.
- [4] General Specification for Engineering Structures: GB 55001-2021 [S]. Beijing: China Construction Industry Press, 2021.
- [5] Code for structural loading of buildings: GB 50009-2020 [S]. Beijing: China Construction Industry Press, 2020.
- [6] Standard for seismic defense classification of building projects: GB 50023-2008 [S]. Beijing: China Construction Industry Press, 2008.
- [7] Code for seismic design of buildings: GB 50011-2022 [S]. Beijing: China Construction Industry Press, 2022.
- [8] Xu Rui, Wen Desheng, Zhang Qiang, et al. Steel structure design of the central hall of Tianjin National Convention and Exhibition Center[J]. Building Science,2020,36(09): 36-41.DOI: 10.13614/j.cnki.11-1962/tu.2020.09.005.
- [9] Technical specification for steel structure of high-rise civil buildings: JGJ 99-2015 [S]. Beijing: China building industry press,2016.
- [10] Technical regulations for concrete structures for high-rise buildings: JGJ 3-2010 [S]. Beijing: China Construction Industry Press, 2011.