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STUDY ON THE STRUCTURAL PERFORMANCE OF CURTAIN WALL GLASS AND CABLES ACTING TOGETHER

ShenShen Zhu[1,2], Dan Zhao[1,2], ZhiCheng Bai[1,2*], Xu Zhang[1,2], ZhenJie Tan[1,2]
[1]*China Construction Fourth Engineering Bureau Co., Ltd., Guangzhou 510000, Guangdong, China.*
[2]*China Construction Fourth Engineering Bureau Sixth Construction Co., Ltd., Hefei 230000, Anhui, China.*
Corresponding Author: ZhiCheng Bai, Email: 19822660870@163.com

Abstract: Based on the finite element analysis method, this paper systematically studies the effects of parameters such as glass thickness, cable diameter, cable pretension force and glass segmentation size on the static and vibration performance of the curtain wall structure. Research results show that glass segmentation size has the most significant impact on structural performance, and rational division of glass panel size is of great significance for optimizing structural performance. This study provides a theoretical basis and practical reference for the design and optimization of curtain wall structures in large-scale convention and exhibition centers.
Keywords: Cable-type glass curtain wall; Static performance; Vibration performance; Finite element analysis; Hangzhou convention and exhibition center

1 INTRODUCTION

With the acceleration of urbanization, the structural design of curtain walls in high-rise buildings and large public buildings has become increasingly complex. Cable-type glass curtain walls have become an important choice for modern architecture due to their light weight, high light transmittance and beautiful shape[1,2] . The Hangzhou Convention and Exhibition Center project is located in Nanyang Street, Xiaoshan District, Hangzhou City, Zhejiang Province. As the core area of Hangzhou Airport Economic Demonstration Zone, its curtain wall design must not only meet functional requirements, but also reflect Hangzhou's profound landscape cultural heritage. However, the cable-type glass curtain wall shows obvious flexibility under external effects such as wind load, and the performance of the curtain wall structure will change, showing strong geometric nonlinearity [3,4]. Therefore, in-depth analysis of the static and vibration performance of cable-type glass curtain walls under different parameter conditions is of great significance for optimizing design and ensuring structural safety.

2 PROJECT OVERVIEW

The Hangzhou Convention and Exhibition Center project is located in Nanyang Street, Xiaoshan District, Hangzhou City, Zhejiang Province. It is located on the bank of the Qiantang River, close to the outlet of the Qiantang River, and has a strategic location. As the core area of Hangzhou Airport Economic Demonstration Zone, this project aims to build a convention and exhibition complex that integrates the airport cover, Hangzhou city image window and complete facilities in the Yangtze River Delta region. The Hangzhou Convention and Exhibition Center will not only become an important airport convention and exhibition base in the country, but also serve as an important platform for opening up to the outside world, promoting regional economic development and international exchanges.

3 STATIC PERFORMANCE OF CURTAIN WALL GLASS AND CABLES WHEN COMBINED

The cable-type glass curtain wall structure is a geometric nonlinear problem among the three nonlinearities. Among them, the cable is a typical flexible support member, which has a large displacement and a small strain under the action of load. On the other hand, the cable cannot always be in the same state. It may be stretched or it may be in a relaxed state without any force.

3.1 Derivation of Nonlinear Theory of Curtain Wall Structure

The continuum method is used in the static nonlinear derivation of the cable-type glass curtain wall, and the cable structure of the cable-type glass curtain wall is assumed to be a continuous orthotropic film that is only stretched to a certain extent.

The following assumptions are made for single-layer cables:

(a) The cable structure is treated to a certain extent as a continuous orthotropic film under tension only.

(b) The curtain wall structural system has displacement outside the facade and displacement within the facade, and the displacement within the facade is much larger than the displacement outside the facade, so the displacement within the facade can generally be ignored.

The displacement curve distribution expression of the curtain wall structure under uniform load is assumed to be:

$$\sin\left[\pi\frac{x}{L_x}\right]\sin\left[\pi\frac{z}{L_z}\right] \quad (1)$$

Assuming ω_c is the displacement in the span of the cable curtain wall structure under uniform load, the displacement at any point can be obtained based on the assumption of the above formula:

$$\omega = \omega_c\sin\left[\pi\frac{x}{L_x}\right]\sin\left[\pi\frac{z}{L_z}\right] \quad (2)$$

Under the uniform load of Q_0, the static balance equation of any point on the curtain wall structural system is:

$$(\overline{H_x}+\overline{h_x})\frac{\partial^2\omega}{\partial z^2}+(\overline{H_z}+\overline{h_z})\frac{\partial^2\omega}{\partial z^2}=-Q_0 \quad (3)$$

In the formula, $\overline{H_x}$ -the component of the initial tensile force of the cable structure per unit width in the x direction; $\overline{H_z}$-the component of the initial tensile force of the cable structure per unit width in the z direction; $\overline{h_x}$- the internal force of the cable per unit length and width when the uniform load is applied from the initial position The horizontal component of the incremental value in the x direction; $\overline{h_z}$- the horizontal component of the incremental value of the internal force of the cable within the unit length and width from the initial position to the uniform load in the z direction.

in,

$$\overline{h_x} = EA_x\Delta L_x/L_x \quad (4)$$

$$\overline{h_z} = EA_z\Delta L_z/L_z \quad (5)$$

In the above formula, E - the elastic modulus of the cable; A_x - the initial cross-sectional area of the cable within the unit width in the x direction; A_z - the initial cross-sectional area of the cable within the unit width in the x direction.

When the cable section moves from the initial position to the position where a uniform load is applied, the extension part of the cable can be expressed as:

$$\Delta L_x=\frac{1}{2}\int_0^{L_x}\left(\frac{\partial y}{\partial x}\right)^2 dx=\omega_c^2\sin^2\left(\frac{\pi z}{L_z}\right)/(4L_x) \quad (6)$$

$$\Delta L_x=\frac{1}{2}\int_0^{L_z}\left(\frac{\partial y}{\partial z}\right)^2 dz=\omega_c^2\sin^2\left(\frac{\pi z}{Lx}\right)/(4L_z) \quad (7)$$

Substitute equations (4) and (7) into equation (3) and simplify to get:

$$\overline{H}_x\frac{\partial^2\omega}{\partial x^2}+\overline{H}_z\frac{\partial^2\omega}{\partial z^2}+EA_x\frac{\pi^2\omega_c^2}{4L_x^2}\sin^2\left(\frac{\pi z}{L_z}\right)\frac{\partial^2\omega}{\partial x^2}+EA_z\frac{\pi^2\omega_c^2}{4L_z^2}\sin^2\left(\frac{\pi x}{L_x}\right)\frac{\partial^2\omega}{\partial z^2}=-Q_0 \quad (8)$$

By integrating and simplifying the above equation (8), the overall static balance equation of the structure can be obtained as:

$$\left(\frac{\overline{H_x}}{L_x^2}+\frac{\overline{H_z}}{L_z^2}\right)\omega_c+\left(EA_c\frac{\pi^2}{6L_x^4}+EA_z\frac{\pi^2}{6L_z^4}\right)\omega_c^3=\frac{Q_0}{4} \quad (9)$$

Initial stress stiffness of structure:

$$a=\left(\frac{\overline{H}_x}{L_x^2}+\frac{\overline{H}_z}{L_z^2}\right) \quad (10)$$

Structural nonlinear stiffness:

$$b=\left(EA_x\frac{\pi^2}{6L_x^4}+EA_z\frac{\pi^2}{6L_z^4}\right)\omega_c^3 \quad (11)$$

It can be seen from Equation (10) that the initial stiffness of the cable segment is generally determined by the initial prestress applied to the cable. It can be seen from Equation (11) that the nonlinear stiffness of the cable structure is jointly determined by the linear stiffness and displacement.

Let the nonlinear coefficient be (the ratio of nonlinear stiffness to initial stress stiffness), and the expression is:

$$\lambda=\frac{b}{a}=\frac{\left(EA_x\frac{\pi^2}{6L_x^4}+EA_z\frac{\pi^2}{6L_z^4}\right)\omega_c^2}{\left(\frac{\overline{H_x}}{L_x^2}+\frac{\overline{H_z}}{L_z^2}\right)} \quad (12)$$

For intuitive expression, assuming $A_x=A_z, H_x=H_z, L_x=L_z, \alpha=\frac{H_x}{EA_x}$, then formula (12) can be simplified to:

$$\lambda=\frac{\pi^2\omega_c^2}{6\alpha L_x^2} \quad (13)$$

It can be seen from the above formula that λ in addition to being affected by α, it is also affected by the dimensionless deflection of the structure $\frac{\omega_c^2}{L_x^2}$. At that time, when $\frac{\omega_c}{L_x}<\frac{1}{250}$, geometric nonlinearity could be ignored; at that time, when $\frac{\omega_c}{L_x} = \frac{1}{150}$, the impact of structural nonlinearity on the cable curtain wall needed to be considered.

3.2 Establishment of Finite Element Model

When establishing the finite element model of a single-layer cable curtain wall structure, the loads considered include the self-weight of the cable, the self-weight of the glass, the self-weight of the connectors, as well as wind load and earthquake load. The material selection covers cables, glass and stainless steel claws, etc., and the parameter settings are simulated according to different situations. Glass panel thickness range is 8–18mm, longitudinal cable diameter is 10.8–30.5mm, using 100 series connecting claws. The elastic modulus of the cable is 1.35×10^5MPa, that of glass is 0.72×10^5MPa, and that of the stainless steel claw is 2.06×10^5MPa. The Poisson ratios are 0.3 for the connecting claws and steel cables, and 0.2 for the glass panels; the linear expansion coefficients are 1.2×10^{-5} and 0.9×10^{-5}. The gravity density of the prestressed cables and claws is 78.5KN/m³ and the glass panel is 25.6KN/m³. Through the above parameters, the model can accurately simulate the stress and deformation of the curtain wall structure, providing a basis for optimal design.

3.3 Effects of Changes in Various Parameters on the Static Performance of Cable Glass Curtain Walls

The effects of glass thickness, cable diameter, pretension force and glass segmentation size on the static performance and vibration performance of the curtain wall structure were studied respectively. By comparing key indicators such as glass internal force, stress, cable stress and deflection, node displacement and natural frequency under different parameter conditions, the impact of each parameter on the overall structural performance is evaluated.

3.3.1 Glass thickness

In order to analyze the impact of glass thickness on the overall structure, the glass panel thickness values are 8mm, 10mm, 12mm, 14mm, 16mm and 18mm respectively. The diameter of the prestressed cable is 22mm, the segmented size of the glass plate is 4m×2.5m, and the prestressed force value of the steel cable is 160kN. The maximum internal force, maximum stress, maximum stress of the cable, maximum deflection of the cable and maximum node displacement of the glass panel are obtained when the thickness of the glass panel changes. See the table 1 below for details.

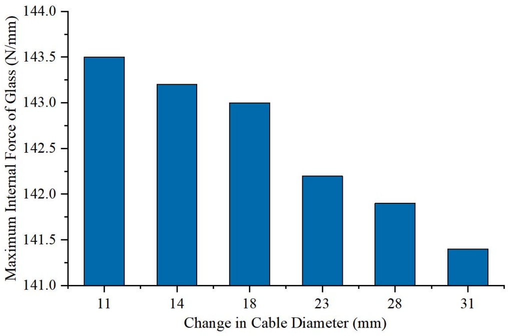
Table 1 Structural Performance under Changes in Glass Panel Thickness

Glass thickness (mm)	Maximum internal force of glass (N/mm)	Maximum stress of glass (MPa)	Maximum stress of longitudinal cable (MPa)	Maximum displacement of node (mm)	Maximum deflection of longitudinal cable (mm)
8	126	65	405	28	24
10	133	59	406	26	24
12	142	55	407	24	23
14	151	52	408	23	23
16	159	50	409	23	22
18	164	49	409	22	22

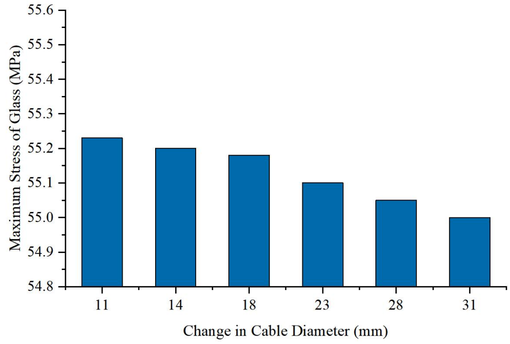
As the thickness of the glass panel increases, the performance of the structural system undergoes the following changes: the maximum internal force of the glass increases significantly, showing a nearly linear growth; the maximum stress of the glass is inversely proportional to the thickness, and the increase in thickness causes the cross-sectional area to increase, thereby reducing the stress; longitudinal The maximum stress of the cable increased slightly, but the change was not obvious, indicating that the increase in glass thickness increased the self-weight, and the vertical load borne by the longitudinal cable under wind load increased slightly; the maximum displacement of the nodes and the maximum deflection of the longitudinal cable both decreased, which was due to the increase in thickness. Structural stiffness reduces flexibility, thereby reducing displacement and deflection; it can be seen from these results that increasing the thickness of the glass panel helps to improve the load-bearing capacity and stability of the structure, but has a limited impact on the longitudinal cable stress.

3.3.2 Cable diameter

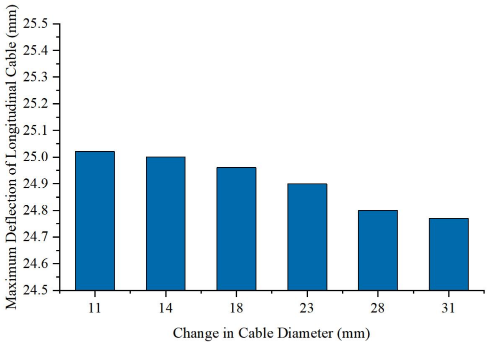
In order to analyze the influence of the cable diameter on the overall structure, the wind load was taken as 1kN/m^2 when establishing the model, the cable diameters were 10.8mm, 14mm, 18.2mm, 22.5mm, 28mm, 30.5mm, the glass thickness was 12mm, and the glass segmentation size was 4m×2.5m. The maximum internal force of the glass, the maximum stress, the maximum node displacement, and the maximum deflection of the longitudinal cable when the cable diameter changes are obtained respectively. See the figure 1 below for details.



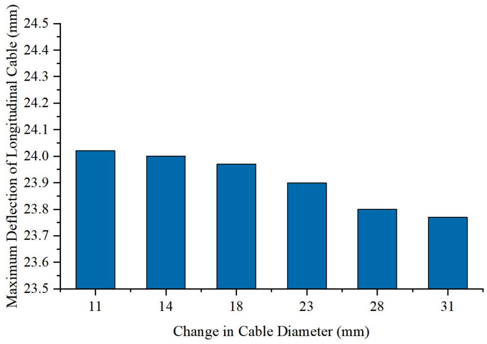
(a) The Change in the Cable Diameter Corresponds to the Maximum Internal Force of the Glass



(b) The Change in the Cable Diameter Corresponds to the Maximum Stress in the Glass



(c) The Change in Cable Diameter Corresponds to the Maximum Node Displacement



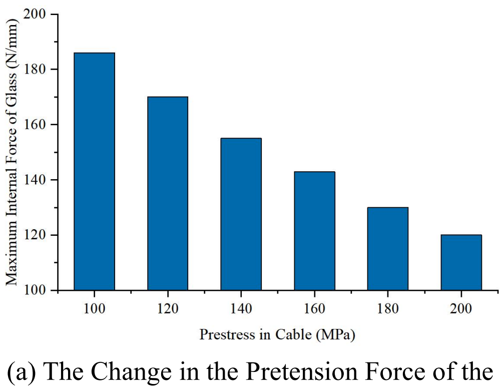
(d) The Change in Cable Diameter Corresponds to the Maximum Deflection of the Longitudinal Cable

Figure 1 Structural Performance under Changes in Cable Diameter

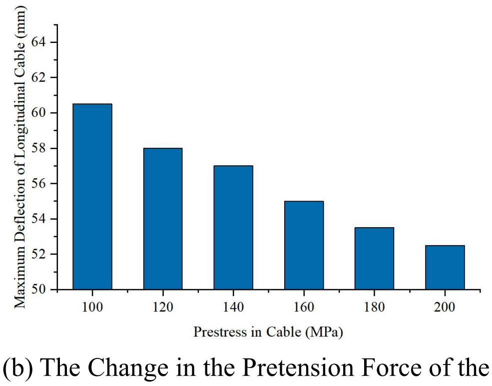
The results show that the increase in cable diameter causes a decrease in all performance indicators of the structure. Combined with the change in slope, the cable diameter has a significant impact on the internal force of the glass, but has a small impact on glass stress, node displacement, and cable deflection.

3.3.3 Longitudinal cable pretension force

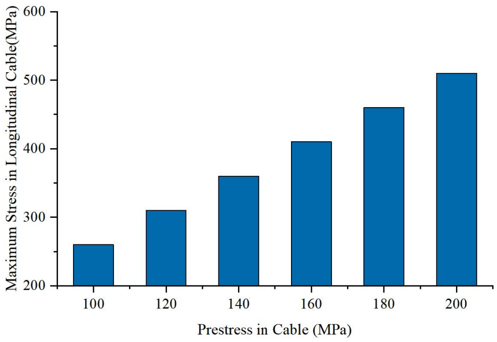
In order to analyze the influence of the longitudinal cable pre-tension force on the overall structure, the pre-tension force applied to the cables is 100kN, 120kN, 140kN, 160kN, 180kN, 200kN, the glass thickness is 12mm, the glass segmentation size is 4m×2.5m, and the cable diameter is 22mm. The maximum internal force of the glass, the maximum stress, the maximum stress of the longitudinal cable, the maximum displacement of the nodes, and the maximum deflection of the longitudinal cable under the change of the longitudinal cable pretension force are obtained respectively. See the figure 2 below for details.



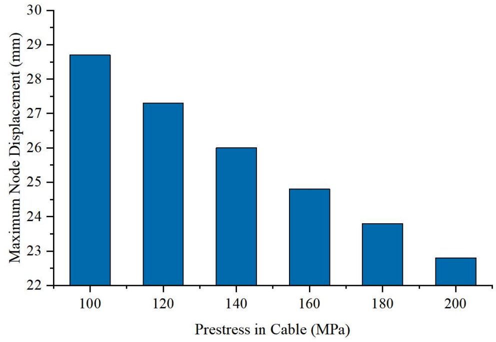
(a) The Change in the Pretension Force of the Longitudinal Cable Corresponds to the Maximum Internal Force of the Glass



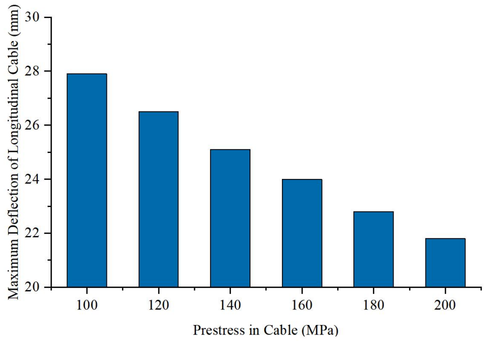
(b) The Change in the Pretension Force of the Longitudinal Cable Corresponds to the Maximum Stress of the Glass



(c) The Change in the Longitudinal Cable Pretension Force Corresponds to the Maximum Stress of the Longitudinal Cable



(d) The Change in the Longitudinal Cable Pretension Force Corresponds to the Maximum Node Displacement



(e) The change in Pretension Force of the Longitudinal Cable Corresponds to the Maximum Deflection of the Longitudinal Cable

Figure 2 Structural Performance under Changes in Longitudinal Cable Pretension Force

From the above analysis, it can be seen that as the longitudinal cable pretension force increases, the internal force of the glass panel decreases and the change is more obvious; the stress reduction trend of the glass panel is relatively small, indicating that the structural system is strengthened as the longitudinal cable pretension force increases. overall stiffness. In addition, the maximum stress of the longitudinal cable rises linearly and with a large amplitude, indicating that the change in the prestress of the longitudinal cable has a greater impact on the longitudinal cable; the maximum deflection of the longitudinal cable is greatly reduced, basically forming a linear relationship. At the same time, the maximum node displacement of the structure also decreased significantly, indicating that the maximum node displacement of the structural system is greatly affected by the cable prestress.

3.3.4 Glass division size

Under the condition that the load on the cable curtain wall structure remains unchanged, the reaction of the static performance of the cable curtain wall structure is studied by changing the segmentation size of the glass panels. The division dimensions of the glass panels are 7.5m×2.5m, 6m×2.5m, 4m×2.5m, 2.5m×1.2m, 1.8m×1.2m, 1.5m×1.2m respectively; the longitudinal cable pretension force is 160kN; the longitudinal cable diameter Take 22mm; the glass panel thickness takes 16mm. The maximum internal force of the glass, the maximum stress, the maximum stress of the longitudinal cable, the maximum displacement of the nodes, and the maximum deflection of the longitudinal cable are obtained when the split size of the glass panel changes. See the table 2 below for details.

Table 2 Structural Performance under Changes in Glass Segmentation Size

Glass segmentation size (mm)	Maximum internal force of glass (N/mm)	Maximum stress of glass (MPa)	Maximum stress of longitudinal cable (MPa)	Maximum displacement of node (mm)	Maximum deflection of longitudinal cable (mm)
7.5m×2.5m	186	60	412	29	31
6m×2.5m	159	58	408	28	28
4m×2.5m	142	56	406	25	26
2.5m×1.2m	106	55	403	21	22
1.8m×1.2m	90	54	402	20	18
1.5m×1.2m	79	52	402	19	16

It can be seen from the above table 2 that changes in the size of the glass partitions have a greater impact on the overall performance of the structure. The smaller the segmentation size, the maximum internal force and maximum stress of the glass decrease, and the magnitude of the decrease is larger. This is because after the segmentation size is reduced, the film tensile force of the entire structure becomes smaller, while the bending stiffness of the single glass becomes larger, which also shows that the film force effect is greater than the single glass effect. The maximum stress of the cable decreases with the decrease of glass size division, but the decreasing trend is slow. In addition, the maximum node displacement also decreases with the reduction of the segmentation size, by about 40%, which shows that the overall stiffness of the structure increases significantly and the flexibility decreases after the segmentation size of the glass panel decreases. In addition, the maximum deflection of the longitudinal cable also decreases to a great extent with the reduction of the glass segment size, and the maximum deflection decreases by about 47%. Based on the above analysis results, the segmentation size of the glass should be reasonably deepened in the actual application of the cable curtain wall.

In summary, when curtain wall glass and cables work together, changes in structural parameters will affect the overall performance. Specifically: the size of the glass segment is proportional to the maximum internal force of the cable curtain wall system; the thickness of the glass significantly affects the maximum stress of the structure; the cable pretension force mainly determines the maximum stress of the longitudinal cable; the maximum deflection of the longitudinal cable is determined by the glass segment Determined by size, the two are directly proportional. Therefore, when designing and constructing a cable-stayed glass curtain wall with a fixed span, the split dimensions of the glass panels should be reasonably divided to ensure structural performance.

4 VIBRATION PERFORMANCE OF CURTAIN WALL GLASS AND CABLES WHEN COMBINED

Next, we will mainly analyze the natural frequency and vibration shape characteristics of the cable-stayed glass curtain wall structure, so as to obtain the changes in vibration performance of the structure itself. The key parameters to consider include: glass panel thickness, longitudinal cable pretension force, longitudinal cable diameter and glass panel segmentation size, so as to comprehensively analyze the impact of each parameter on the self-vibration characteristics of the cable glass curtain wall structural system, in order to provide a theoretical basis for practical applications.

4.1 Finite Element Analysis Theory of self-Vibration Characteristics of Curtain Wall Structure

When deriving the vibration equation of the cable curtain wall structure system, considering that the damping effect has a very small effect on its self-vibration characteristics, it can be ignored during analysis. The free vibration equation without considering the effect of damping on the cable curtain wall structure system can be obtained:

$$[M]\{\ddot{\mu}\} + [K]\{\mu\} = \{0\} \quad (14)$$

Where, $[M]$ —mass matrix of the cable curtain wall structure; $[K]$ —stiffness matrix in the tangential direction when the cable curtain wall is in static equilibrium; $\{\mu\}$ —displacement vector of the structure; $\{\ddot{\mu}\}$ —acceleration vector of the structure system.

In the calculation and analysis process, assuming that the cable glass curtain wall structure system is a simple harmonic vibration, we can get:

$$\{\mu\} = \{\phi\}\sin(\omega t + \theta) \quad (15)$$

$$\{\ddot{\mu}\} =- \omega^2\{\phi\}\sin(\omega t + \theta) \quad (16)$$

Where, $\{\phi\}$ —mode vector of the cable curtain wall structure; θ —initial phase; ω —circular frequency of self-vibration.

Substituting equations (15) and (16) into (14), we get:

$$[K]\{\phi\}\sin(\omega t+\theta)-\omega^2[M]\{\phi\}\sin(\omega t+\theta)=\{0\} \quad (17)$$

Simplifying the above equations, we get:

$$([K]-\omega^2[M])\{\phi\} = \{0\} \quad (18)$$

Furthermore, we can get the natural frequency equation of the cable curtain wall structure:

$$|[K] - \omega^2[M]| = 0 \quad (19)$$

The subspace iteration method can make the assumed vibration mode and fundamental frequency relatively accurate, so that the actual vibration mode is closer to the assumption. The subspace iteration method is a combination of the Rayleigh-Ritz method and the iteration method for solving low-order frequencies. The basic calculation steps of this method are as follows:

Given q n-dimensional vectors:

$$\left|\{X\}_1^0\{X\}_2^0\ldots\{X\}_q^0\right| = \{X\}_{n\times q}^0 \quad (20)$$

Based on previous experience, q min 2s, s 8 , where s represents the frequency and vibration mode of the s-order.

Second iteration:

Using the q vectors obtained by the above inverse iteration as the assumed vibration mode, the Rayleigh-Ritz method is

$$[K]_{n\times n}[\overline{X}]_{n\times q}^{(K+1)} = [m]_{n\times n}[X]_{n\times q}^{(K)} \quad (21)$$

applied to solve the first q frequencies and vibration modes:

$$[K]_{q\times q}^* = [\bar{X}]_{q\times n}^{(K+1)T}[K]_{n\times n}[\bar{X}]_{q\times n}^{(K+1)} \quad (22)$$

$$[m]^{*}_{q\times q} = [\overline{X}]^{(K+1)T}_{q\times n}[m]_{n\times n}[\overline{X}]^{(K+1)}_{q\times n} \quad (23)$$

$$[K]^{*}_{q\times q}A_{q\times 1} = p^{2}[m]_{n\times n}A_{q\times 1} \quad (24)$$

Where, $[K]$—stiffness matrix; $[m]$—mass matrix; A—combined coefficient vector.
Repeat equations (8)-(11) until the accuracy meets the requirements.

4.2 Finite Element Calculation Model Establishment

The materials and properties used for modeling are shown in the following table 3.

Table 3 Sections and Material Properties of cable Curtain Wall Structure System

Components	Thickness or diameter	Elastic modulus （N/mm²）	Density （kN/m³）	Poisson's ratio	Linear expansion coefficient
Glass panels	8mm、10mm、12mm、14mm、16mm、18mm	0.72×10^{5}	25.6	0.2	1.0×10^{-5}
Cables	10.8mm、14mm、18.2mm、22mm、28mm、30.5mm	1.35×10^{5}	78.5	0.3	1.2×10^{-5}
Glass panel segmentation dimensions	7.5m×2.5m、6m×2.5m、4m×2.5m、2.5m×1.2m、1.8m×1.2m、1.5m×1.2m	/	/	/	/

The appropriate model parameter values are selected through verification. The thickness of the glass panel is 12mm, the pre-tension of the cable is 160kN, the plate segmentation size of the glass plate is set to 4m×2.5m, the cross-sectional diameter of the steel cable is 22.5mm, and the calculated size of the curtain wall structure is 16m×10m. The first 25 vibration modes and corresponding frequency values of the structure are shown in the table 4 below.

Table 4 Simulation Values of the First 25 Frequencies of the Cable-Stayed Glass Curtain Wall Structure

Order	Frequency (Hz)	Order	Frequency (Hz)	Order	Frequency (Hz)	Order	Frequency (Hz)	Order	Frequency (Hz)
1	5.8	6	13.0	11	14.9	16	20.4	21	33.7
2	8.3	7	13.7	12	16.0	17	20.7	22	34.0
3	9.8	8	14.3	13	17.0	18	23.6	23	38.8
4	10.8	9	14.7	14	17.7	19	26.0	24	46.9
5	11.3	10	14.8	15	18.0	20	30.2	25	51.2

4.3 Effect of Parameter Changes on Vibration Performance of Cable Glass Curtain Wall

4.3.1 Glass Thickness

In order to study the effect of glass thickness change on the self-vibration characteristics of cable glass curtain wall structure system, the glass thickness is 8mm, 10mm, 12mm, 14mm, 16mm, 18mm respectively; the glass plate segmentation size is 4m×2.5m, the longitudinal cable diameter is 22mm; the longitudinal cable pre-tension is 160kN. Numerical models are established to analyze the changes of the first 12 natural frequencies of the curtain wall under the condition of glass thickness change, see the table 5 and figure 3 below for details.

Table 5 The First 12 Frequencies of the Cable-Stayed Glass Curtain Wall Structure (Glass Panel Thickness Changes)

Degree	Glass panel thickness(mm)					
	8	10	12	14	16	18
1	6.5	6.1	5.8	5.6	5.4	5.2
2	8.7	8.5	8.3	8.1	7.9	7.8
3	9.9	9.9	9.8	9.6	9.6	9.5
4	10.2	10.8	10.8	10.9	10.9	11.0
5	10.4	11.3	11.3	11.4	11.4	11.5
6	10.8	12.1	13.0	13.6	13.9	14.3
7	10.9	12.9	13.7	13.6	14.1	14.6
8	11.5	12.9	14.4	14.2	14.6	15.2
9	11.6	13.2	14.7	15.5	16.1	16.8
10	12.1	13.9	14.8	16.3	17.5	17.7
11	12.4	14.0	14.9	17.1	18.2	18.8
12	12.5	14.6	16.0	17.2	18.3	19.2

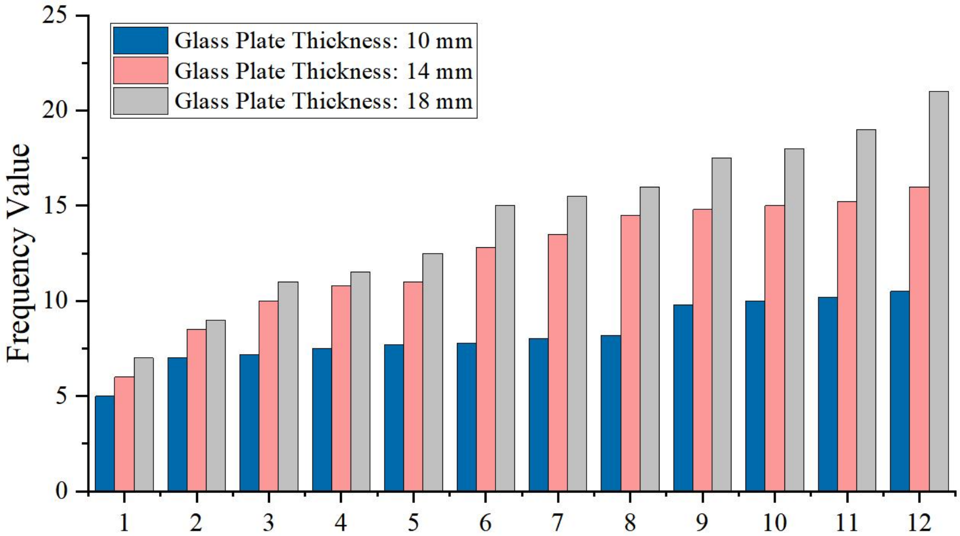


Figure 3 Changes in the Natural Frequency of the Cable Curtain Wall Structure (Changes In Glass Panel Thickness)

From the table and figure 3 above, it can be seen that with the increase in the thickness of the glass panel of the cable curtain wall structure system, its natural frequency increases to a certain extent, and the first three frequencies of the structure decrease with the increase in the thickness of the glass plate, while the frequencies above the third order increase with the increase in the thickness of the glass plate. This shows that increasing the thickness of the glass plate can increase the high-order frequency of the structure, but will reduce the low-order frequency of the structure.

4.3.2 Longitudinal cable diameter

In order to study the influence of the change in the longitudinal cable diameter on the natural vibration characteristics of the cable glass curtain wall structure system, the longitudinal cable diameters are 10.8mm, 14mm, 18.2mm, 22mm, 28mm, and 30.5mm respectively; the glass panel thickness is 12mm; the glass panel segmentation size is 4m×2.5m; the longitudinal cable pre-tension is 160kN. Numerical models are established to analyze the changes in the first 12 natural frequencies of the curtain wall when the longitudinal cable diameter changes, as shown in the table 6 below.

Table 6 The First 12 Frequencies of the Cable Glass Curtain Wall Structure (Change In Longitudinal Cable Diameter)

Order	Cable diameter change (mm)					
	10.8	14	18.2	22	28	30.5
1	5.6	5.7	5.8	5.9	5.9	5.9
2	8.1	8.2	8.3	8.4	8.4	8.5
3	9.5	9.6	9.8	9.9	9.9	10.0
4	10.7	10.7	10.9	10.9	11.0	11.1
5	11.1	11.2	11.4	11.5	11.5	11.6
6	12.9	12.9	13.0	13.1	13.1	13.1
7	13.1	13.2	13.7	13.8	13.7	13.5
8	13.5	13.6	14.1	14.7	13.9	13.9
9	14.6	14.7	14.7	14.8	14.7	14.8
10	14.7	14.7	14.8	14.9	14.9	14.9
11	14.9	14.9	14.9	16.1	15.0	15.0
12	15.9	15.9	16.0	16.1	16.1	16.1

From the above analysis, we can see that as the diameter of the longitudinal cable increases, the vibration frequency of the structure itself also increases. This means that the increase in the cross-sectional area of the cable can increase the structural stiffness, but the increase is limited, which means that the longitudinal cable diameter has little effect on the natural vibration performance of the structure.

4.3.3 Longitudinal cable pretension

In order to study the influence of longitudinal cable pretension on the natural vibration characteristics of the cable-stayed glass curtain wall structure system, the longitudinal cable pretension was 100kN, 120kN, 140kN, 160kN, 180kN, and 200kN respectively; the glass panel thickness was 12mm; the glass panel segmentation size was 4m×2.5m; and the longitudinal cable diameter was 22mm. Numerical models were established to analyze the changes in the first 12 natural frequencies of the curtain wall under the condition of longitudinal cable pretension changes, as shown in the following table 7 and figure 4.

Table 7 The First 12 Frequencies of Cable-Stayed Glass Curtain Wall Structure (Change In Longitudinal Cable Pretension)

Degree	Cable pre-tension change(kN)					
	100	120	140	160	180	200
1	5.4	5.5	5.7	5.8	5.9	6.0
2	7.3	7.7	8.0	8.3	8.7	8.8
3	9.6	9.6	9.7	9.8	9.8	9.9
4	9.6	10.0	10.5	10.8	10.5	11.5
5	10.8	11.0	11.2	11.3	11.5	11.7
6	11.9	12.3	12.7	13.0	13.4	13.5
7	12.4	12.7	13.0	13.7	13.7	13.6
8	13.6	13.7	13.7	14.3	14.8	15.8
9	14.1	14.3	14.5	14.7	14.9	14.9
10	14.5	14.6	14.7	14.8	15.0	15.9
11	14.9	14.9	14.9	14.9	16.1	17.0
12	15.6	15.7	15.9	16.0	17.1	17.2

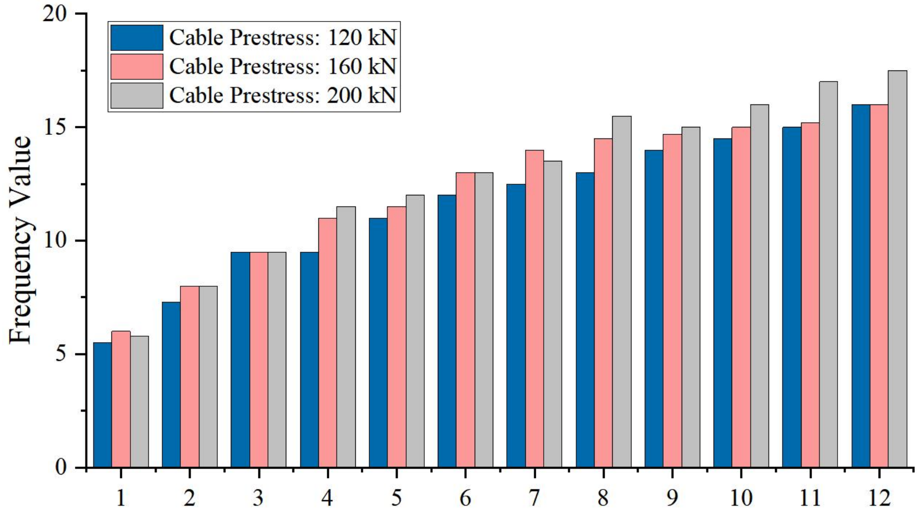


Figure 4 Changes in the Natural Frequency of the Cable Curtain Wall Structure (Changes in the Longitudinal Cable Pretension)

It can be found that the increase in the longitudinal cable pretension can increase the natural frequency of the structure, that is, it can increase the overall stiffness of the structure, and the changes in the high-order frequency and low-order frequency of the structure are not much different. In general, the change of the longitudinal cable pre-tension parameters has a certain degree of influence on the natural frequency of the cable curtain wall structure system, and it is relatively obvious.

4.3.4 Glass segmentation size

In order to study the influence of the change of glass segmentation size on the natural vibration characteristics of the cable glass curtain wall structure system, the glass segmentation size is 7.5m×2.5m, 6m×2.5m, 4m×2.5m, 2.5m×1.2m, 1.8m×1.2m, 1.5m×1.2m; glass panel thickness is 12mm; longitudinal cable diameter is 22mm; longitudinal cable pre-tension is 160kN. Numerical models are established to analyze the changes in the first 12 natural frequencies of the curtain wall when the glass segmentation size changes, as shown in the table 8 below.

Table 8 The First 12 Frequencies of the Cable-Stayed Glass Curtain Wall Structure (Glass Segmentation Size Changes)

Degree	Glass dividing size					
	7.5m×2.5m	6m×2.5m	4m×2.5m	2.5m×1.2m	1.8m×1.2m	1.5m×1.2m
1	5.0	7.1	5.8	6.3	6.6	6.8
2	6.7	9.3	8.3	8.8	9.0	9.2
3	7.2	10.6	9.8	11.0	11.6	12.1
4	7.5	11.6	10.8	11.8	12.0	12.2
5	7.8	12.1	11.3	12.7	13.1	13.6
6	7.8	12.9	13.0	14.8	15.2	15.4
7	8.3	13.1	13.7	14.9	15.4	15.8
8	8.5	13.4	14.4	15.5	16.3	16.9
9	9.7	14.0	14.7	16.7	17.4	18.0
10	9.9	14.6	14.8	17.8	18.5	18.9

11	10.3	15.2	14.9	18.4	19.2	19.8
12	10.4	15.7	16.0	20.4	21.3	21.9

As the size of the glass partition decreases, the natural frequency of the structural system increases, indicating that the stiffness of the structural system increases. At the same time, the change in glass segmentation size has less impact on the low-order frequencies of the cable curtain wall structure system than on the high-order frequencies.

5 CONCLUSION

Based on the Hangzhou Convention and Exhibition Center project, this study systematically studies the static and vibration performance of the cable-type glass curtain wall under different parameter conditions through finite element analysis. The results show that the glass segmentation size has the most significant effect on the structural performance, and the reasonable division of the glass panel size can effectively optimize the internal force distribution and vibration characteristics of the structure. In addition, the adjustment of glass thickness and cable pre-tension also has an important influence on the structural performance, but the economy and safety need to be comprehensively considered in the design. This study provides an important theoretical basis and practical reference for the optimization design of the curtain wall structure of large convention and exhibition centers.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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