Modal Analysis of the CCTV Headquarters Based on ANSYS Workbench

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Abstract. CCTV headquarters was selected as the research object in this paper. The building is located in the sandstorm area of Beijing and is plagued by wind and sand all year round. In order to verify the stability of the building under various vibration conditions, ANSYS simulation software was used to analyse the internal deformation of the building under different vibrate frequency and concluded that the cantilever beam was the weakest component of the building, and the vertical deformation of the structure is greater than the horizontal deformation of the structure. Some practical improvement can be adapted to reinforce the structure, like increasing the number of support trusses, improving the integrity of the roof system, or adding new support structures.

Keywords: Building Integrity; Modal Analysis; Structural Deformation; Seismic Resistance; CCTV Headquarters; Structural Weakness; Natural Disaster Resistance; Finite Element Model.

1 Introduction

1.1 Background

The structure was created by renowned architect Rem Koolhaas and his Dutch architectural firm, Office for Metropolitan Architecture (OMA). The state-owned television network in China, China Central Television (CCTV), has its headquarters in the CCTV Headquarters, which was finished in 2012.The building was selected by Time magazine as one of the top ten architectural wonders of 2007. [1]The structure, which consists of a loop of connected horizontal and vertical pieces, is renowned for its avant-garde and unique aesthetic. Traditional ideas about skyscraper architecture are challenged by this innovative architectural style. [2] The north annex building is 159 meters high, the main

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building is 30 floors, and the podium is 5 floors. Construction started on October 21, 2004, and was fully completed and put into use on May 16, 2012. [3]

1.2 Architectural details

The skyscraper has a looped shape that is frequently referred to as a "twisting doughnut" or "continuous loop", and it gives Beijing's skyline a striking and unmistakable appearance. It is made up of two leaning towers that are connected by a loop-shaped, 75-meter-long cantilevered portion. Offices, TV studios, production facilities, and public areas are all housed within the towers. [5] Due to the irregular design of the CCTV headquarters building, the force of each part of the building is very different, and these diamond-shaped blocks have become a tool for adjusting the force.[6]The surface of the CCTV headquarters building is composed of a glass curtain wall with irregular geometric patterns, which has a huge visual impact. The glass curtain wall not only has the advantages of light weight and convenient construction, but also its reflective performance can organically combine the building with the surrounding scenery.[2,3]

1.3 Previous research

The main difficulty faced during the designing process was how to support distribute the weigh the suspending cantilevered section. [7] Due to its architectural forms like the continuous rings, sloping towers, and the cantilevered cantilevers, the complexity of the structure increases, and the structure becomes unstable. Beijing is considered to be located in an earthquake zone, which explains the instability of the site, causing loads to be redistributed, thus requiring the structure to provide sufficient strength and stiffness. This analysis is repeated until the results are combined, and the strength of all structures is within the allowed capacity range.

Load transfer is mainly carried out through the inclined truss structure, which helps the building resist buckling loads and makes the entire system a continuous pipe. As a result of this structural design, the amount of steel used is reduced by 20% compared to the traditional steel structural design.[8] In addition, this diagonal structure minimizes structural damage to skyscrapers and has a better ability to distribute loads than a moment frame, meaning that partial damage does not lead to overall damage to the building. To verify the CCTV Headquarters' performance under both conventional and extreme conditions in the region, modal analysis of the structure was done based on Ansys software.

2 Methology

2.1 Modal conduct

In the step of simulation, the modal analysis method in ANSYS software is mainly applied. As an "inverse problem" analysis method, modal analysis is based on experiments, using a combination of experimental and theoretical methods to deal with vibration problems in engineering. [9] In ANSYS, modal analysis needs to do the following main parts:

a. Adjust the necessary parameter data of the model material.

b. After adjusting the appropriate size, divide the grid structure of the model.

c. Apply boundary conditions to the model (or select fixed support).

d. Conduct ANSYS solution to the model according to all previous conditions and known information.

e. Find the desired data result and export the corresponding change process chart.

2.2 Simulation overview

Simulation technology has been relatively mature, its main purpose is to use computer programs to simulate the real changes of the model. The general process is to adjust the density and other parameters of the model, divide the grid and apply certain boundary conditions to simulate the real scene.

2.3 Adjust parameters

The model is assumed that the whole model is a homogeneous solid and composed of structural steel. Recalculated density and the specific calculation formula is as follows:

$$Density = \frac{1.4 \times 10^{8}\ kg}{1.5663 \times 10^{6}\ m^{3}}$$

In the above formula, the volume of the model is supported based on ANSYS data. The total mass of CCTV Tower is 140,000 tons. [5] Other relevant data of materials are shown in Table 1.

Table 1. Material Properties in ANSYS setting.

Properties	
Material	Structural Steel
Density	$89.383\ kg/m^3$
Young's Modulus	$2 \times 10^{11}\ Pa$
Poisson's Ratio	0.3

2.4 Mesh generation

Discretization is the basis of the finite element approach。The number of classes and shapes of the unit must be determined according to the actual situation of the structure, size, and arrangement. [8] For this model, tetrahedral form is used to divide the grid, and the effect diagrams after division are shown in Figure 1, Figure 2 and Figure 3.

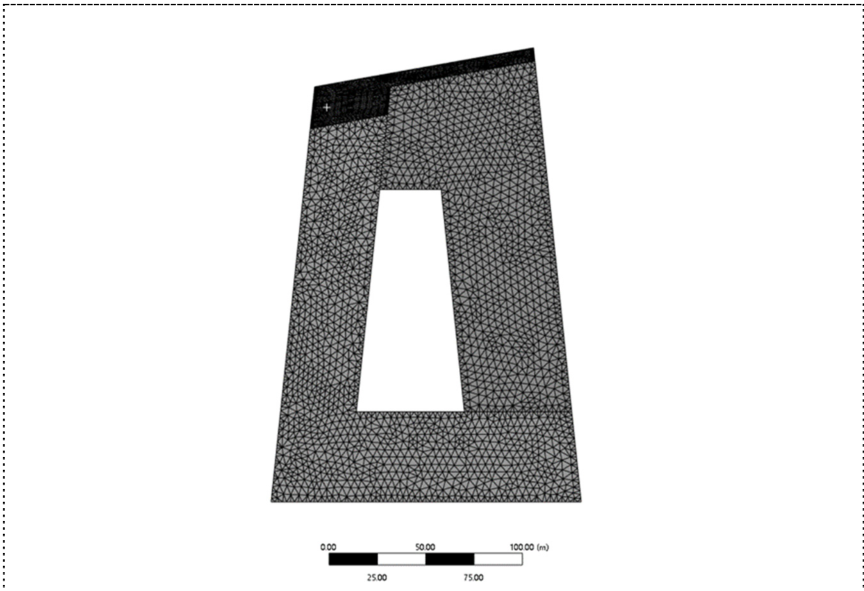

Fig. 1. Front View of the Model Mesh Result with Grid Size of 2\.

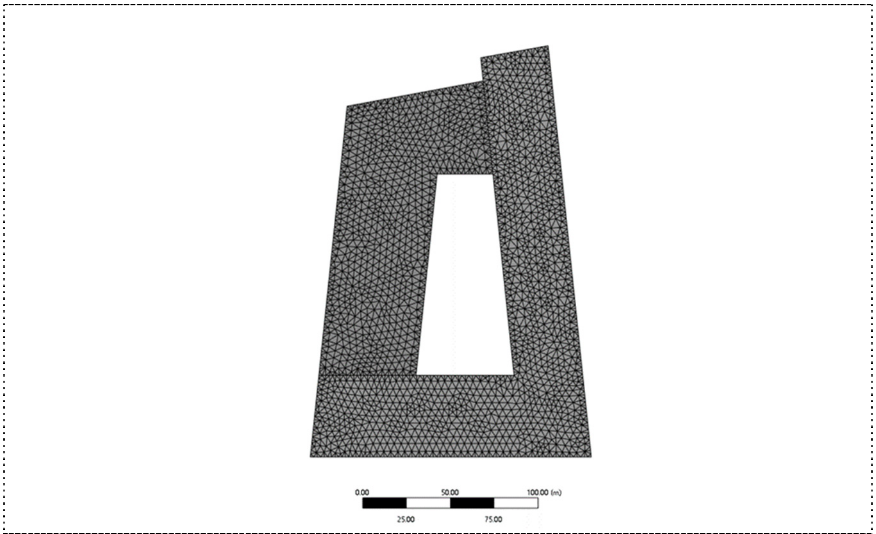

Fig. 2. Side View of the Model Mesh Result with Grid Size of 2m.

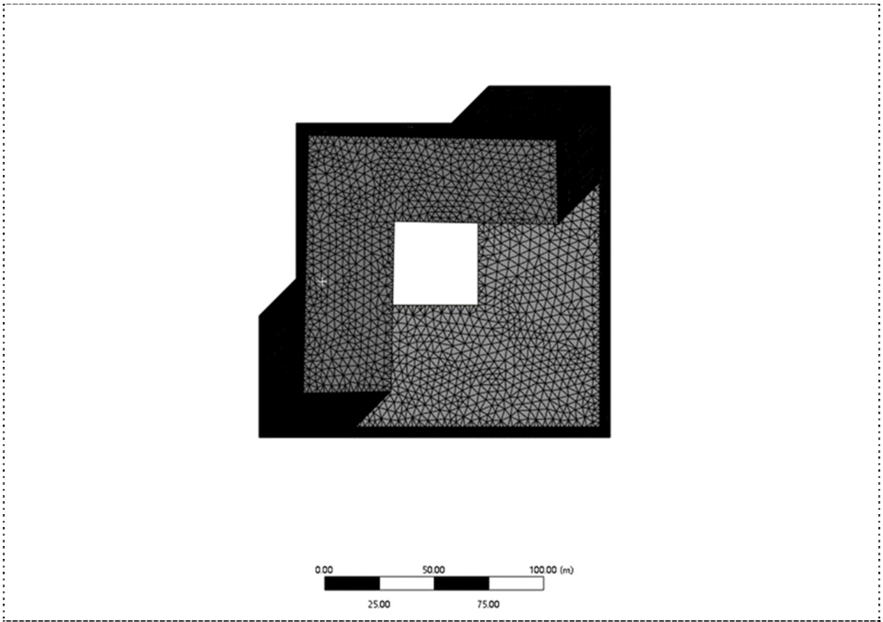

Fig. 3. Top View of the Model Mesh Result with Grid Size of 2m.

The basic frequencies of model vibration and deformation are different under different mesh sizes. By calculating the grid of 10m, 7m, 5m, 3m, 2.5m and 2m, the fundamental frequency of the model vibration is basically stable at 2m, as shown in Figure 4. Finally, a tetrahedron with a side length of 2m is selected for grid division.

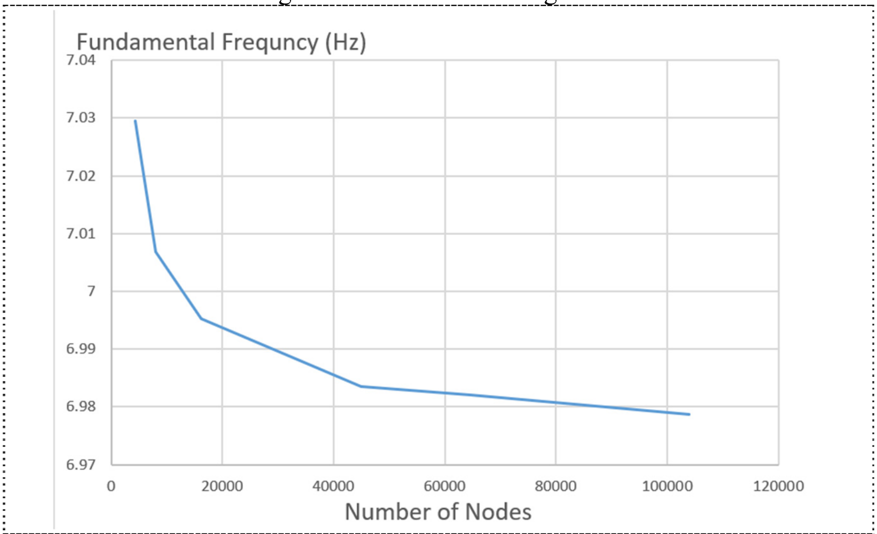

Fig. 4. Result of Mesh Independence Study.

2.5 Boundary conditions

This study mainly studies the above-ground part of the building, so the boundary conditions are therefore applied to the fixed support surface of the above-ground part (lower side) of the building model, as shown in Figure 5.

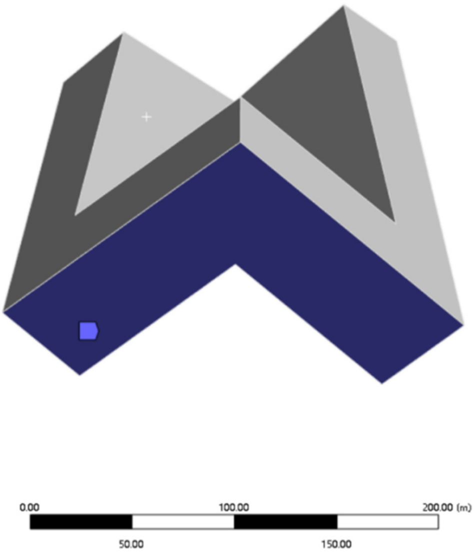

Fig. 5. Fix Support of the Simulation Model.

3 Results

The modal analysis of CCTV Tower model is carried out as shown in Table 2 and Figure 6.

Table 2. Frequency Calculation Results of the Modal Analysis.

Mode Number	Frequency (Hz)
1	6.9787
2	12.556
3	16.456
4	32.184
5	33.97
6	45.585

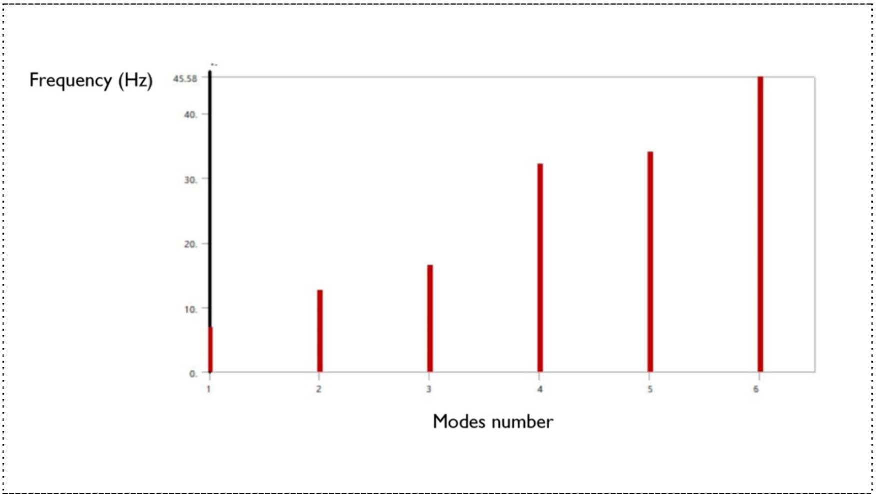

Fig. 6. Frequency Output of ANSYS Modal Analysis.

The vibration frequency and vibration form of order 1~6 of free modal analysis is solved. The frequency calculation results are shown in the table below. Figure 7-12 shows the vibration modes of order from 1 to 6.

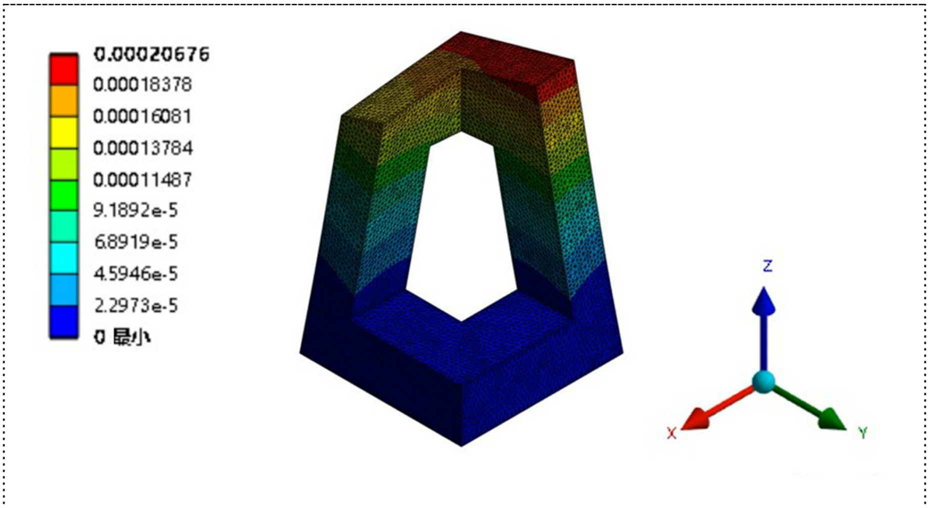

Fig. 7. Total Deformation of the Modal under Frequency of Mode 1.

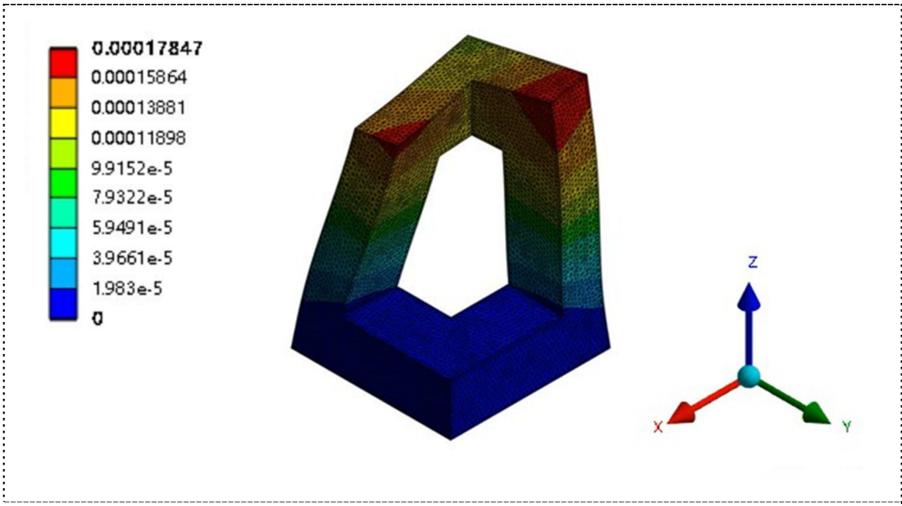

Fig. 8. Total Deformation of the Modal under Frequency of Mode 2.

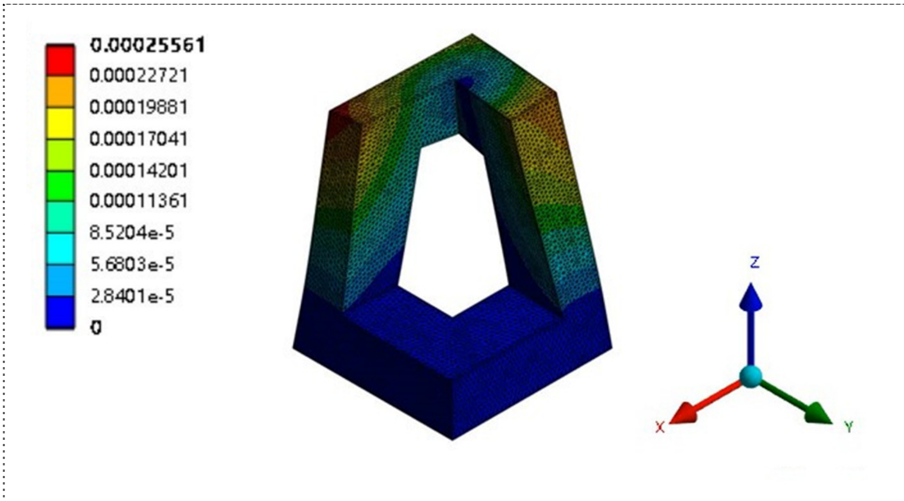

Fig. 9. Total Deformation of the Modal under Frequency of Mode 3.

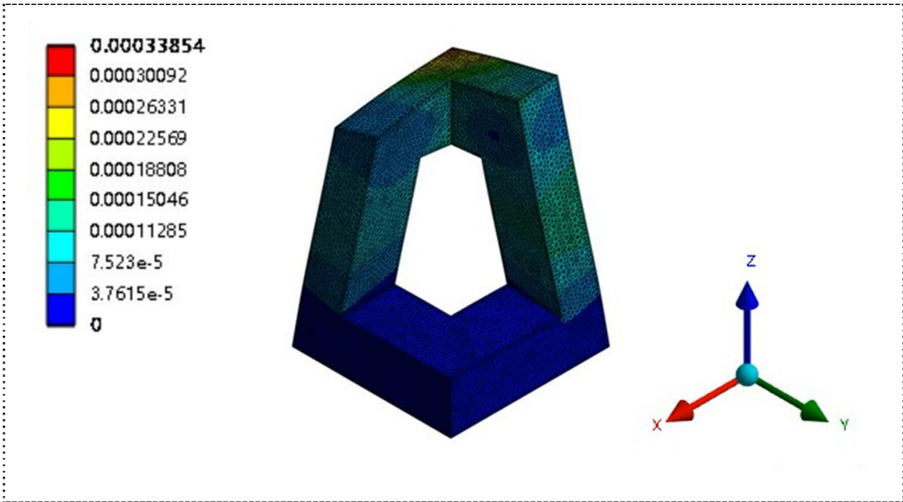

Fig. 10. Total Deformation of the Modal under Frequency of Mode 4.

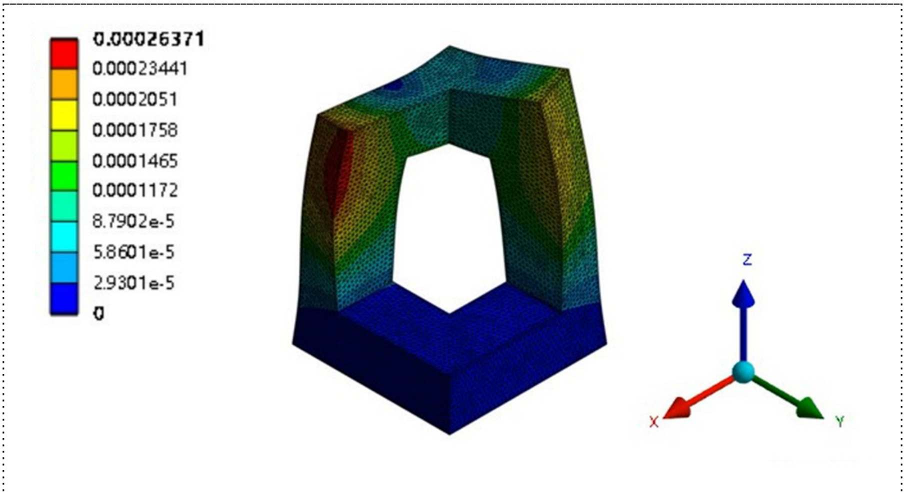

Fig. 11. Total Deformation of the Modal under Frequency of Mode 5.

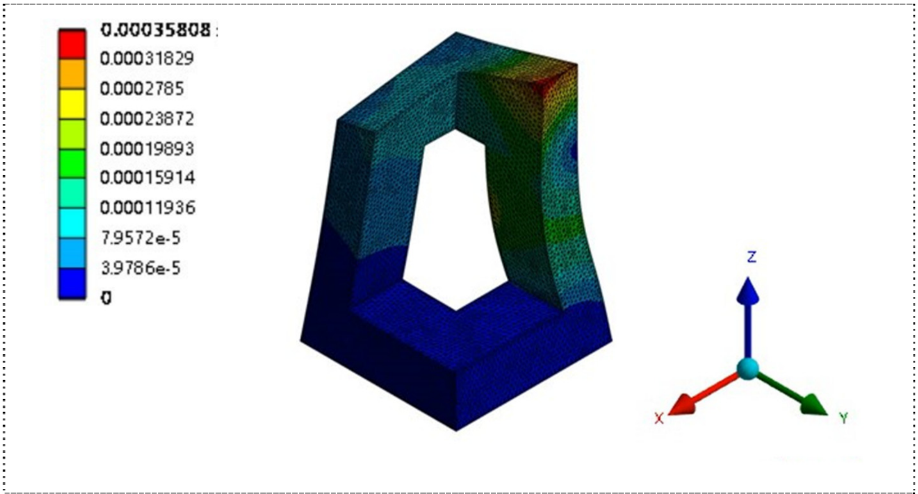

Fig. 12. Total Deformation of the Modal under Frequency of Mode 6.

By analyzing six different oscillations, we find that both mode 1 and mode 2 vibrate around axes in the X-Y plane. Mode3 is a twist around the Z axis. Mode4 and mode6 are different forms of extrusion deformation along the Z axis. Mode5 is an expansive vibration of the two parts of the building body. The specific vibration frequency and maximum deformation value are summarized in the Table 3.

Table 3. Comparative Hardness Data for Tested Metals (Lab Section Average).

Mode #	Frequency (Hz)	Maximum Normalized Deformation(m)	**Type of displacement**
1	6.9787	0.000206	**X-direction displacement**
2	12.556	0.00017847	**X-Y direction displacement**
3	16.456 Hz	0.00025561	**Z-axis torsion**
4	32.184 Hz	0.00033854	**Z direction displacement**
5	33.97 Hz	0.00026371	**Z-axis sway**
6	45.585 Hz	0.00031829	**Z direction displacement**

4 Conclusions

1. The cantilever is the weakest component of the building, which experiences the most severe deformation under different external vibration and load conditions.

2. The structural has larger deformation in vertical direction compared with horizontal deformation, which shows that the building has relatively low resistance of vertical displacement.
3. Using structural systems such as reinforced concrete or steel frames can be used as a solution to absorb and dissipate seismic forces.
4. Increasing the number of support trusses, columns, or beams can effectively distribute the load and decrease the possibility of potential collapses.
5. Increasing the integrity of roofing systems, strengthening the facade, and utilizing impact-resistant glass is practical to strengthen the construction of the building.
6. Adding new bracing, dampers, and anchors can increase the resistance of the structure to the specific forces produced by various natural calamities.

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Yichi Zhang and Chuning Yan contributed equally to this work and should be considered co-second authors.

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