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Modal analysis of Shanghai world financial center based on using ANSYS

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Abstract. This study delves into the resonance phenomena within the complex structure of the Shanghai Global Financial Center. By utilizing ANSYS simulations, we can accurately predict the vibration patterns and magnitudes exhibited by the building under various conditions. These resonance phenomena have the potential to significantly impact the building's stability, occupant comfort, and overall structural integrity. This research conducts a thorough analysis of the self-resonance conditions of the Shanghai Global Financial Center through the application of ANSYS software. The study successfully identifies resonance frequencies and provides a deeper understanding of resonance mechanisms. These findings offer valuable insights for comprehending and mitigating resonance-related issues. Moreover, they hold great significance for the design and engineering of super-tall skyscrapers, offering essential guidance to ensure their safety and performance. AMSS_0403rchitects and engineers can use this knowledge to optimize the design and construction of such impressive structures, ultimately contributing to the advancement of tall building technology. Enze Li and Zhe Yu are dedicated to data collection, Bowen You and Yizhao Wang specialize in modeling and data recording and analysis, while Zhijie Shen and Enze Li are responsible for carefully crafting and refining the paper.

Keywords: in-depth analysis, self-resonance conditions, Shanghai Global Financial Center

1. Introduction

Skyscrapers, such as the Shanghai World Financial Center, are not only buildings with significant practical value but also symbols of urban culture and economics [1]. They become landmarks of cities, attracting tourists and commercial investments, contributing to prosperity and vitality. However, behind these magnificent structures lie various engineering challenges, one of which is the impact of resonance

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phenomena on them. With the increase of the height of super high-rise buildings, the structural characteristics of low frequency, light weight and small damping become more and more prominent, and the risk of vortex-induced resonance under the action of strong winds becomes more and more serious [2].

When the frequency of the driving force approaches the natural frequency of the object, the amplitude of the forced vibration increases, a phenomenon called resonance [3]. For skyscrapers, this means that under specific conditions, such as strong winds or earthquakes, the building may experience unstable vibrations, which could pose a threat to its safety and structural integrity. For instance, the dramatic Tacoma Narrows Bridge disaster of 1940 is still very much in the public eye today [4]. Therefore, understanding and controlling resonance phenomena is crucial for the design and construction of skyscrapers.

To delve deeper into this issue, we will use ANSYS software for simulation analysis. ANSYS(analysis system) is a large CAE general finite element analysis software integrating structure, heat, fluid, electromagnetic, and acoustics [5]. ANSYS 8.0 is the latest version of large general-purpose finite element software developed by ANSYS. This software is the only computer-aided engineering (CAE) design analysis software that has passed ISO9001 quality certification in FEM(Finite Element Method) analysis so far [6]. The designed structure can be model analysis using Finite element analysis codes ANSYS, and the results will effectively estimate the vibration specific of structure in order to optimize structure design [7]. Through this numerical simulation method, we can accurately predict the vibration modes and amplitudes of buildings in various scenarios. This allows us to determine the resonance frequencies, which are the frequencies at which external forces match the natural frequencies of the building—a key factor in preventing resonance phenomena.

The purpose of this research is to provide robust support for the design and engineering practices of skyscrapers. By understanding the mechanisms of resonance, we can develop more effective design strategies to reduce the risk of resonance. Additionally, we can offer recommendations for structural modifications to enhance the building’s resistance to resonance.

The significance of this study extends beyond ensuring the safety of skyscrapers. It also contributes to the sustainable development of cities and the advancement of architectural engineering. The rise of skyscrapers has become a prominent symbol of modern urban development, adding to the aesthetics of cities and contributing to economic growth and cultural vibrancy. Therefore, ensuring the stability and safety of these magnificent structures is of paramount importance, and this is what drives our in-depth investigation of resonance phenomena.

In summary, this research aims to explore the impact of resonance phenomena on skyscrapers by using ANSYS software for simulation analysis. By accurately predicting resonance frequencies and vibration patterns, we can provide strong support for engineering practices, ensuring the stability and safety of these remarkable structures while promoting sustainable urban development and the continuous advancement of architectural engineering. This study represents a significant contribution to scientific research and technological innovation in modern society, laying a solid foundation for the future development of human society.

2. Structure and Parameters of Shanghai World Financial Center

2.1. Model Building Using ANSYS SpaceClaim

In the present research, the ANSYS is used as a tool to model and simulate Shanghai World Financial Center, to observe the variation in its vibrational characteristics. The model of building is designed in ANSYS SpaceClaim and it is updated to ANSYS workbench for analysis. After updating the model file, the tools in ANSYS mesh have added constraints to the model, and the whole structure is divided into grids using FEM, and then the frequency pattern is solved. After changing the size of the grid and solving it several times, you can obtain six modal values of different sizes of the grid, after comparing the grid size with the smallest error within the allowable range of calculation.

The specific steps of model making are as follows:

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1. Use the Sketch mode function of ANSYS SpaceClaim to draw a sketch of the building base as Fig 1 and stretch to a predetermined height using the Pull function as Fig 2.

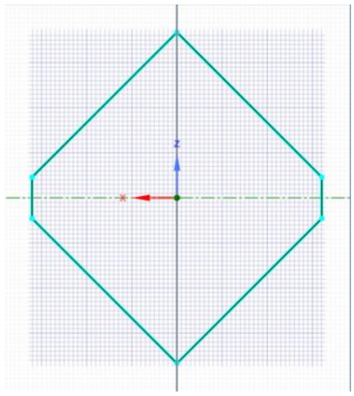

Figure 1. Sketch of building base

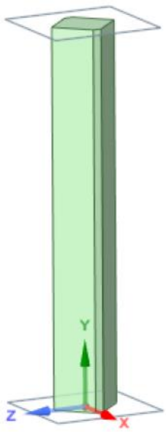

Figure 2. Geometry after Pull

2.Draw the side outline sketch of building according to the structure information as Fig 3.

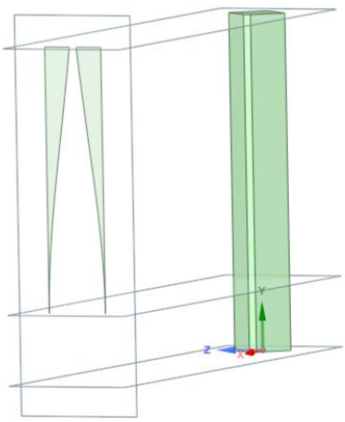

Figure 3. Sketch of the side outline

3.Cut off the excess part of the geometry using the Pull function as Fig 4.

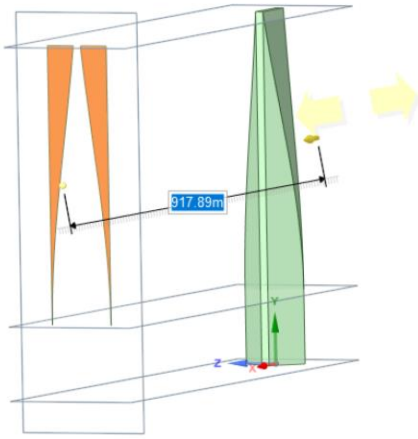

Figure 4. Geometry after first cutting

4. Similarly, cut off the square area of the upper part of the geometry as Fig5.

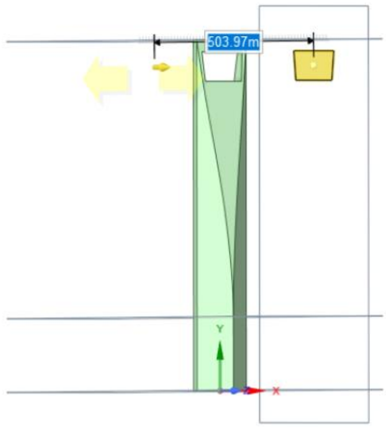

Figure 5. Geometry after second cutting

5.Complete the modeling as Fig 6.

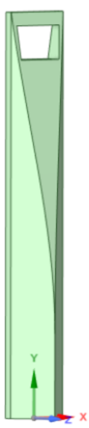

Figure 6. The model of building

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2.2. Modal Analysis of Shanghai World Financial Center

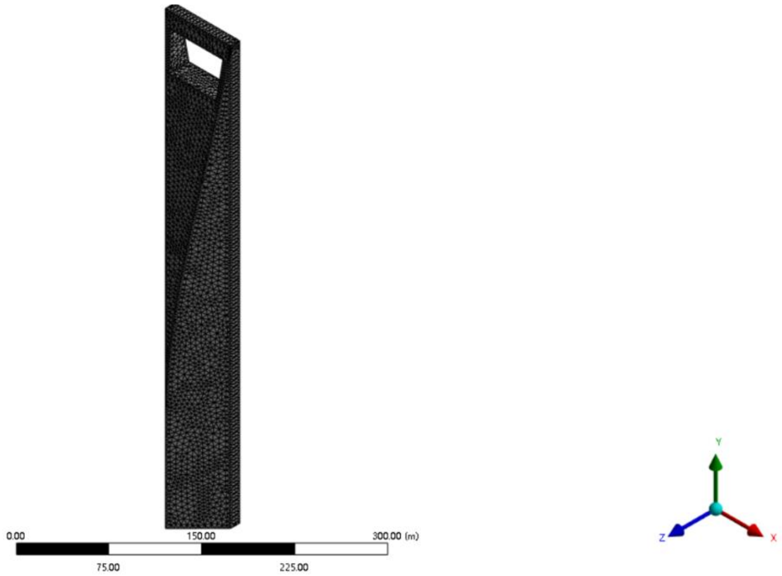

Figure 7. The grid model

Table 1. Cell size, node, and frequency of the model grid

Mesh Size	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Nodes	89435	37581	23464	14479	10395	7901	6506	5535	4804
Elements	51515	21135	13024	7797	5506	4110	3334	2841	2426
Frequency(Hz)	2.1441	2.1442	2.1443	2.1444	2.1445	2.1446	2.1448	2.1448	2.145

Table 2. Cell size, node, and frequency of the model grid

Mesh Size	2.1	2.25	2.3	2.5	2.52	2.53	2.55	2.6	2.7
Nodes	77566	37581	64646	55994	54022	53128	52946	51950	47989
Elements	44705	38088	36936	31928	30767	30135	30086	29564	27194
Frequency(Hz)	2.1441	2.1441	2.1441	2.1441	2.1441	2.1442	2.1442	2.1442	2.1452

Through the application of ANSYS software, we set different Mesh Sizes to obtain the different finite element models. The bottom of the model is fixed. When we set the Mesh Size is 2.5, we get this model. As shown in the figure 7.

It can be seen from Table 1 and Table 2 that the Frequency will vary due to the mesh size. The most important thing we need to do is to find the critical point of the line chart in Nodes and Frequency.

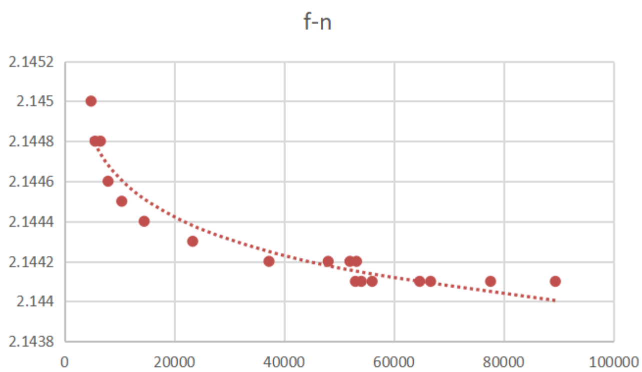

Figure 8. Grid analysis curve for cell size and frequency

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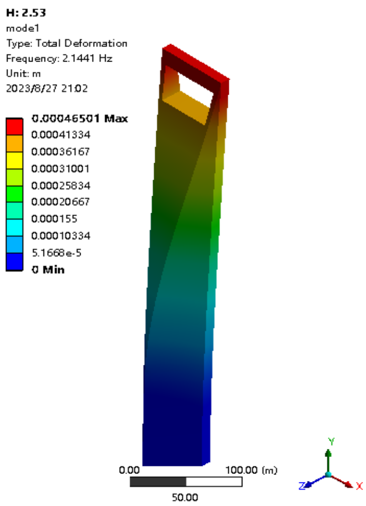
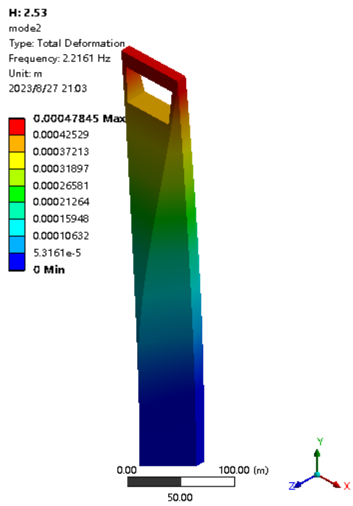
See through the line chart (figure 7). The Frequency decreases with the increase of the Nodes. Between 40,000 and 60,000 Nodes. The Frequency fluctuates and goes down. It indicates that the value of the part point should be obtained in this range, and we obtain the relatively accurate critical point through this fluctuation change. The more accurate definite critical boundary node is selected according to the Mesh Size. And we obtain the 6 models of the critical model by setting the Mesh Size.

3. Analysis of Result

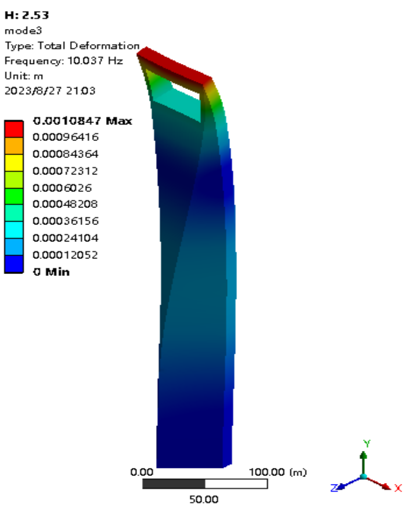
The model analysis of the Shanghai World Financial Center is carried out, and the 1-6 order frequencies and modes of the free model analysis are solved. The calculated results of natural frequencies are shown in Table 1 and Table 2. We set different mesh sizes to obtain different frequencies. Figure 9 shows the 1,2,3,4,5,6 order vibration modes of the Shanghai World Financial Center.



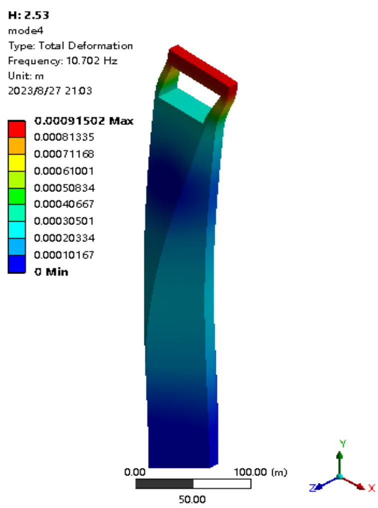
Model 1



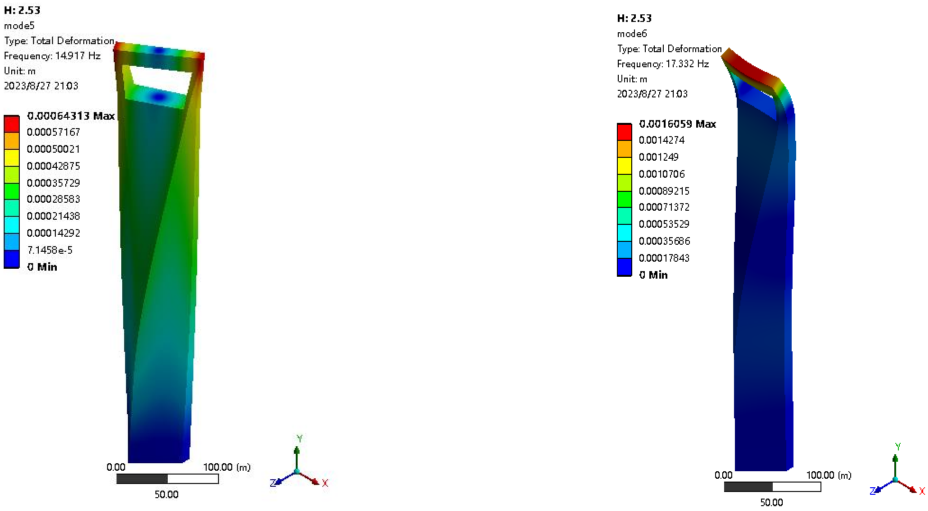
Model 2



Model 3



Model 4



Model 5 Model 6

Figure 9. Finite Model diagram of the natural frequency of Shanghai World Financial Center

In Figure 9 above, pictures from top left to bottom right are modes one through six.

Based on the calculation results, the first-order body and the top part of the fourth and sixth-order main vibration modes exhibit deformations along the X axes. Among them, the top section of the sixth-order main vibration mode experiences the largest deformation. The second-order body and the top part of the third-order main vibration mode display deformations along the Y axes. The primary deformation mode of the fifth-order main vibration mode is torsional deformation along the axis of symmetry.

4. Conclusion

Through this study, we have made significant progress in exploring the resonance potential of the Shanghai World Financial Center as a complex structure and accurately predicting the vibration modes and amplitudes of the building under different conditions through simulations using ANSYS software. From this study, we draw the following conclusions:

Frequency Decreases with Increasing Node Count: Under different grid sizes, we observed that the frequency decreases as the number of nodes increases, especially in the range of 40,000 to 60,000 nodes. Within this range, there is a fluctuation in frequency, leading to a decrease.

Significance of Grid Size: The choice of grid size is highly important in determining critical points. Different grid sizes can result in different locations of critical points, emphasizing the importance of carefully selecting grid parameters.

Obtaining Six Critical Models: By using different grid sizes, we obtained six critical models. This contributes to a more comprehensive understanding of the system's response and resonance behavior.

In summary, the data analysis emphasizes the importance of node count and grid size in finite element models and how these parameters can be used to determine critical properties of the system. These research findings hold significant implications for optimizing design and engineering applications.

4.1. Limitations

Despite achieving important outcomes in this study, there are some limitations. First, the accuracy of the model depends on the precise input of material properties, boundary conditions, and building parameters. Inaccurate input can lead to model inaccuracies. Secondly, this study only focuses on resonance phenomena and does not delve into other factors that may affect building performance. Finally, the behavior of building structures is influenced by various factors, including external factors such as weather conditions and earthquakes, which were not considered in this study.

4.2. Future Trends

Future research can further improve the accuracy of the model, including more precise material parameters and realistic engineering conditions. Additionally, more factors can be taken into account to comprehensively understand the performance of building structures. At the same time, research can be extended to other large-scale buildings to validate the universality of these findings. Finally, using advanced computational techniques and simulation methods, resonance phenomena can be more comprehensively studied to provide more accurate guidance for building engineering. These efforts will contribute to enhancing the structural safety and performance of large-scale buildings.

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