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Seismic Research on Large-span Spatial Structures

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Abstract

This paper reviews the progress of seismic research on large-span spatial structures, summarizes and analyzes the research status of seismic resistance of large-span spatial structures at home and abroad, and the seismic response analysis methods suitable for performance-based seismic design of large-span spatial structures. It is found that the current domestic and foreign scholars ' research on the vibration control of large-span spatial structures mainly focuses on the reticulated shell structure. Whether the dynamic response characteristics of the grid structure and the reticulated shell structure are the same, the seismic response and other issues need to be further studied. It is still necessary to further develop a simple and efficient seismic response analysis method for long-span spatial structures.

Keywords

Large-span Spatial Structure; Seismic Reflection Analysis; Seismic Response Analysis Method.

1. Foreword

With the improvement of production and social living standards, people's demand for spatial structures has been increasing in recent years. Due to the reasonable force distribution, good integrity and stability, high spatial stiffness, good seismic performance, and beautiful appearance of spatial structures, they have been widely used in the construction of public venues such as large-span factories, hangars, sports venues, exhibition centers, and opera houses. Usually, large-span spaces have the function of undertaking important social, economic, political and other activities, and are often used as temporary resettlement points and rescue sites for disaster stricken people in the event of earthquakes. Therefore, ensuring the safety of the structure and the continuity of its functional use is of great significance for public buildings with large-span spatial structures after earthquakes.

The key to achieving satisfactory seismic design of large-span spatial structures lies in two aspects: correct seismic response analysis and corresponding seismic design. Among them, the appropriateness of the seismic response analysis method used is a fundamental and crucial issue, as well as a prerequisite for correct design. At present, research on seismic response analysis methods for large-span spatial structures at home and abroad is significantly lagging behind engineering applications. With the gradual promotion of performance-based seismic design in building structures, the above-mentioned lagging phenomenon has become increasingly apparent.

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2. Research Status

2.1 Domestic Research Status

Wang Jingqin [1] used the time history analysis method to analyze the seismic response of two types of large-span space truss structures under multi-point input and consistent input, and studied the seismic response characteristics of space structures with and without SMA composite rubber bearings under multi-point input. The results show that after installing SMA composite rubber bearings, the seismic response of most members of the spatial grid structure is significantly reduced, achieving the effect of energy dissipation and seismic reduction.

He Fanglong et al. [2] defined the stress state at a certain moment in the seismic process when the structural displacement suddenly increases due to small changes in seismic action as the critical load of dynamic instability of the structure, and pointed out that its essence is motion instability in the sense of Lyapunov.

Luo Xiaolong et al. used the time history analysis method to analyze the seismic response of a certain ultra long steel roof under multi-dimensional and multi-point inputs considering the traveling wave effect. They investigated the influence of multi-dimensional and multi-point inputs on the base shear force, torsional effect, and internal force of components of the structure, and explored the relationship between structural seismic response rules and seismic wave propagation speed.

Liu Yi et al. [4] studied the seismic response of pile soil lattice shell structures under oblique incidence of seismic waves. When considering pile soil interaction, real soil was used as the constraint medium for piles and finite element modeling was performed.

Yang Benxue [5] conducted seismic response analysis of a steel canopy structure under multi-point input, and studied the influence of multi-point seismic input on the large-span spatial truss structure. The degree of influence is related to multiple factors such as the type, size, and direction of seismic waves.

Ding Yang et al. [6] conducted a non-stationary random seismic response analysis of the roof steel structure of the Tianjin Olympic Center Sports Stadium under three-way orthogonal seismic excitation at multiple points. Using the wavefront method, the superposition of the element stiffness matrix and the elimination of unknown variables in the equation system were alternated and completed simultaneously, thereby simplifying the calculation process.

Bai Fenglong [7] conducted seismic response analysis on several typical large-span structures, including large-span bridge structures, transmission tower line systems, and spatial steel structures, under multi-point excitations. He analyzed the nonlinear response of large-span structures under spatial seismic changes in uneven sites and conducted detailed numerical simulations.

Dong Shilin et al. [8] used pole elements to simulate grid structures, beam elements to simulate columns, and springs to replace supporting columns in a bridge type industrial factory building. They analyzed them using a finite element method combining the two elements. The study showed that it is unreasonable and uneconomical to only consider the upper truss without considering the collaborative work of the upper and lower structures.

Li Huafeng et al. [9] conducted dynamic elastic-plastic analysis of several typical large-span spatial structures under seismic action using ABAQUS finite element analysis software. The analysis shows that in the seismic elastic-plastic response analysis of structures with large spans, three-dimensional seismic effects should be considered, and the seismic performance of supporting systems and components near supports should be ensured.

Zhou Quanzhi et al. [10] analyzed the response of the Laoshan Bicycle Pavilion under frequent and rare earthquakes, considering the multidimensional nature of earthquake motion, and studied the impact of seismic traveling wave effects on the structure. They concluded that the traveling wave effect has a significant impact on large-span spatial structures and should be taken into consideration in design.

On the basis of the threshold method for mode selection, Wang Lei et al. [11] further proposed the tangent stiffness separation method based on the nonlinear dynamic finite element method. By combining the tangent stiffness separation method and the threshold method theory, the nonlinear modal method can be further derived, which has good computational accuracy and high solving efficiency.

Wu Xingwen studied the large-scale spatial structure of a subway station in a certain city, focusing on the circular island spatial structure, stations with two different subway lines, and facilities in the surrounding commercial area. Through ABAQUS finite element simulation and time history analysis, the horizontal displacement and overall internal force of the structure were obtained.

You Xinhong et al. studied the application of seismic bearings in large-span spatial structures. By studying different types of seismic bearings in different buildings, the results showed that seismic bearings are widely used in large-span structures due to their advantages of simple structure, low cost, material savings, and simple installation. By continuously improving and optimizing the bearing structure system, the development of the construction industry can be promoted.

Gaoyang uses the response displacement method to calculate the mechanical properties of the structure based on the calculated soil vibration as the seismic motion. By controlling key factors such as the axial compression ratio of the central column and the bearing capacity of the wall, it ensures that the components can work normally under seismic action and reduces the impact of seismic action on the building. Meanwhile, using the reactive displacement method, a model is established with soil deformation as the load to calculate the shear force, horizontal displacement, and inertial force of the structure.

2.2 Foreign Research Present Situation

Li et al. [12] observed local and global dynamic instability based on vibration table tests of two Goersk lattice shells, and provided time history curves of component stress and node displacement, respectively. They also provided criteria for determining dynamic instability of lattice shell structures.

The summarized seismic performance objective matrix of large-span roof structures provided by Tatemichi et al. [13] can be used to obtain the different structural response performance parameters corresponding to the finely divided seismic performance objectives through the table.

Soyluk et al. [14] conducted traveling wave analysis and random vibration analysis on the Jindo Bridge in South Korea. The analysis results showed that the apparent wave velocity had a significant impact on the structural response, and the consistent input random analysis method may have underestimated the structural response.

Takeuchi [15] used the fully quadratic combination method (CQC method) in the response spectrum method to study the seismic response of domes with supporting structures. The maximum horizontal and vertical acceleration distribution of the dome was described by mathematical expressions considering the influence of lower supporting structures, and the amplification coefficients of the arch structure, cylindrical mesh shell, and circular dome under different stiffness of supporting structures were analyzed.

The load related Ritz vector method proposed and developed by Wilson et al. [16] adopts appropriate Ritz vector generation rules. By using a small number of Ritz vectors, the displacement shape of the structure under earthquake action can be accurately expressed, thereby significantly reducing the order of the structural dynamic equation.

Hrerdia Zavoni et al. [17] transformed the dynamic response analysis of the entire multi-point support structure into a set of oscillators of a single degree of freedom mode under a series of single point excitations, thus avoiding some complex calculations of multi-point input problems.

The studies of Fajar et al. [18] have shown that using the Pushover method to estimate the response of structures under predetermined seismic intensity levels is a good method for predicting the seismic elastic-plastic response of regular structures. It should be noted that this method cannot provide indepth and detailed analysis of structural dynamic response, damping, seismic characteristics, and structural stiffness degradation.

3. Conclusion

On the one hand, current research on vibration control of large-span space structures by domestic and foreign scholars mainly focuses on grid shell structures. However, although both grid structure and grid shell structure are large-span space grid structures, further research is needed on whether their dynamic response characteristics are the same and seismic response. However, the existing research results on grid shell still have significant inspiration for the vibration control research of grid structure.

On the other hand, in the context of seismic design with performance as the main factor, further development is needed for seismic response analysis methods applicable to large-span spatial structures. At present, the popular research direction of response analysis methods for large-span spatial structures under earthquake action mainly reflects the randomness issues of materials, damage, etc. in the calculation model. When analyzing, the uncertainty of earthquake action and the response results of nonlinear effects are considered simultaneously. Scholars and engineering designers at home and abroad have mastered many seismic response laws of spatial structures based on existing calculation methods. Some scholars have also comprehensively analyzed mature seismic response methods and proposed new analysis methods. However, the existing calculation and design methods still cannot meet the needs of practical engineering applications, and further development of more efficient and simple seismic response analysis methods for large-span spatial structures is needed

In the exploration of seismic response analysis methods for space structures in the future, attention should be paid to the needs of practical engineering and practical solutions to problems in practical engineering. In the research process, attention should be paid to the coordination of theoretical analysis, numerical calculation, structural measurement, and model testing, and to the coordination and unity of the complexity, accuracy, and simplicity of analysis methods.

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