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Research on Seismic Performance of Large Span Steel Structure

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Abstract

The structure of the studio has the characteristics of large span, large clearance height and large hanging load. Based on the mechanical advantages of steel structure, large-span steel structure has been widely used in this kind of building. Due to the geometric characteristics of the structure and the distribution characteristics of roof load, the influence of horizontal seismic action and vertical seismic action on the mechanical properties of the structure is difficult to ignore. In this paper, the seismic performance of large-span studio steel structure is deeply studied based on the actual engineering.

Keywords

Horizontal Earthquake; Vertical Earthquake; Seismic Design Method; Coupled Earthquake.

1. Introduction

With the rapid rise of China's economy and the continuous pursuit of cultural and artistic works, the film and television industry has achieved unprecedented development. In order to reduce the shooting cost and improve the level of film and television production, the demand for studios and film and television shooting bases is increasingly strong, and many large-span studios came into being. The studio is the most important production base for shooting interior scenes in film studios. In the early days, the studio was just a "big shed" with only a ceiling and scaffolding, and all sides were empty. The name of "studio" in China came from this. Because of various film and television shooting needs, the studio needs a large indoor space, and its structural form needs to adopt the structural system of large span and large space; Due to the requirements of various indoor scenery, the roof truss structure must have a large bearing capacity, and the structure needs to bear a large hanging load in normal use. It can be seen that the studio structure is different from the ordinary long-span structure, which requires not only a large span and indoor clearance height, but also the roof structure with the ability to bear a large hanging load, so the mechanical properties of this kind of structure are also different from the ordinary long-span structure.

Due to the superior mechanical properties of steel, the roof structure of modern studio structure usually adopts large-span steel structure system, such as grid structure, steel pipe truss structure and steel truss structure, and its vertical bearing columns generally choose reinforced concrete columns, steel pipe concrete columns and steel columns with large section size. Because the typical characteristics of this kind of structure are: large roof hanging load, large indoor clearance height and span, the impact of earthquake on it will be very obvious.

2. Development Status of Large Span Steel Structure Space Structure at Home

In China, Wei Jun and others [1] found that the scheme of truss combined with thin concrete roof slab and truss plus chord full cloth support can significantly enhance the stiffness of the roof in its plane for different roof structure forms and truss structures under different horizontal support conditions.

These two structural designs effectively reduce the maximum displacement of the top of the structure, and reduce the displacement difference between the points, which proves their safety and reliability, and also shows their economic feasibility. Zhouchangdong et al. [2] took the hybrid structure of a large-scale studio as the research object, built a nonlinear finite element analysis model using the finite element soft SAP2000, and focused on the effect of improving the structural performance by configuring viscous dampers in the braced frame under horizontal earthquake. The influence of different numbers and parameters of dampers on the seismic mitigation effect under the conditions of fortification intensity earthquake and rare earthquake is studied and compared. The results show that the appropriate arrangement of viscous dampers can significantly reduce the displacement at the top of the column and the foundation shear, so as to enhance the seismic capacity of braced frames. Ding Dayi [3] made a systematic analysis on the selection of large-span steel structures, proposed a selection method based on structural performance, and determined their performance and design basis under normal working conditions through the study of the mechanical performance of key structures such as transfer joints and pin shaft joints, which provided an important reference for the design of complex steel structures. Lihaifeng et al. [4] conducted finite element simulation on 85 box steel column members, studied the effect of repeated horizontal loads, and found that the web width thickness ratio was the key parameter to determine the seismic performance of the members. The research pointed out that with the increase of the web width thickness ratio, the stiffness, bearing capacity and ductility of the members showed a downward trend. Based on the simulation results, the fitting relationship between the shear force at the top of the column and the displacement ductility coefficient was proposed, which provided theoretical support for the seismic performance evaluation of the structure. Jiyingying [5] took a large natatorium in Xi'an as the engineering background, respectively used Midas Gen and 3D3S to establish the finite element model of steel roof and integral hybrid structure, carried out the comparative analysis of dynamic characteristics, and systematically evaluated its wind resistance and seismic performance, providing an important case basis for the analysis and design of similar structures. Hu Lili [6] compared and analyzed the hysteretic characteristics, deformation capacity, energy consumption characteristics and seismic performance of pure steel frame, steel plate deep beam filled steel frame, reinforced concrete deep beam filled steel frame and composite deep beam filled steel frame through low cycle repeated load test, and revealed the influence of different filling forms on the seismic capacity of the structure. Shi Xiang [7] established a three-dimensional space model for the staggered truss structure system, compared the response difference between the bottom shear method and the mode decomposition response spectrum method under horizontal seismic action, and corrected the additional horizontal seismic action, verifying the applicability and accuracy of different calculation methods. Guocaihong [8] carried out elastic-plastic dynamic response analysis of 30 m-span spatial steel tube arch truss structures with different rise span ratios under strong earthquakes, and discussed the influence mechanism of rise span ratio parameters on its dynamic response performance.

Niuxiaolin [9] took the roof structure of a large exhibition hall as the research subject, and used SAP2000 finite element analysis software to deeply study its vertical seismic performance. Through detailed numerical simulation and analysis, it revealed the response characteristics of the structure and its components under vertical seismic action. Based on these research results, the overall seismic performance of the roof structure is comprehensively and effectively evaluated. Wangjiaqi [10] took a 3-story cold storage structure in a 7-degree fortification area as the research object, designed a large-span structure combining prestressed slab column and seismic wall by using yjk software, and then conducted dynamic time history and static loading analysis by ABAQUS to study the structural response under vertical seismic action. Zhang Siqi [11] focused on the vertical ground motion in the near-field earthquake, found that the vertical earthquake had a significant impact on the displacement of the suspension structure and the axial force of the suspender, and pointed out that the role of the vertical earthquake should not be ignored in the incremental dynamic analysis, especially in the near fault area. Wangjingyu [12] proposed a simplified calculation method of vertical seismic internal force based on the mechanical characteristics of grid structure. Based on the systematic study of the

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distribution of dynamic internal force coefficient and equivalent seismic action coefficient, it provided a theoretical basis for the seismic design of grid structure. Zhouchangdong et al. [13] took a typical long-span studio hybrid structure as the research object, established the nonlinear finite element analysis model of the structure by using SAP2000 finite element software, compared and analyzed the column top displacement, base shear force, internal force of grid members and various indicators of structural elastic-plastic development of the original structure and damping structure under the action of three-dimensional earthquake, and discussed the feasibility and effectiveness of using viscous dampers for damping control of the overall structure of the studio. Zhu duo'e et al. [14] studied a large-span space steel truss with a roof planting with a rise to span ratio of 1/15 and a span of 60 meters, and evaluated the dynamic characteristics and seismic performance of the structure using Midas Gen software. Zhang naidao [15] conducted a detailed dynamic response analysis by inputting 6 different vertical acceleration response spectrum curves for 9 different span space truss roofs, and obtained relevant research conclusions based on this.

Zeng Xianfang [16] studied that the dynamic internal force coefficient of components under vertical seismic action gradually increases from the bottom to the top of the floor. Although the vertical seismic responses caused by three different seismic waves are different, the vertical seismic responses of the two structural types are not different, and the deflection of the frame supported supporting beam meets the specification requirements. Liufeng et al. [17] conducted a two-way multi-point seismic response analysis considering the traveling wave effect for the capital airport T3a terminal building, and found that the torsional effect of the structure under multi-point input was significantly enhanced, indicating that the traditional single point input method may underestimate the structural response. Shen Shungao [18] and others further applied the time history analysis method to two large maintenance buildings, Xi'an aircraft assembly plant and Beijing A380 hangar, and verified the importance of multi-point input seismic response analysis considering the traveling wave effect. Nieqingqing [19] constructed the seismic performance evaluation index system of large-span spatial steel structures and demonstrated the applicability of performance-based evaluation method. Mawenna [20] used SAP2000 finite element model to analyze the seismic response of a large-span steel arch structure of a university gymnasium in the elastic stage. The research shows that the structure shows excellent seismic performance, which provides valuable reference for the design and analysis of similar structures in the future. Yang Muwang [21-23] and others proposed a new method called push-down, which is specially used for the vertical static elasto-plastic calculation of long-span rigid spatial structures. This method is especially suitable for the structure whose first mode is vertical deformation, and can effectively evaluate its seismic performance. Yaofenghui [24] conducted modal analysis on the model, studied the influence of span change on structural vibration mode characteristics and natural vibration period, and emphasized the importance of vertical seismic action through response spectrum method. It further uses the seismic time history analysis method to discuss the vertical response characteristics of the structure under different seismic intensity levels, and verifies the significant effect of seismic intensity on the seismic response of the structure. Sunweiping [25] carried out dynamic elastoplastic analysis on the three center circular steel tube arch truss structure with a span of 180m and a rise to span ratio of 0.2, revealed the failure mechanism and failure mode of the structure under rare earthquake conditions, and summarized the evolution trend of the structural seismic performance enhanced with the increase of steel strength. Qin Meizhu [26] took the composite space steel pipe arch truss with a span of 110 m in a practical project as the research object, and systematically analyzed the dynamic response characteristics of this kind of structure under seismic load by using ANSYS finite element software and comprehensively considering geometric nonlinearity and material nonlinearity. Lihaiwang [27,28] focused on the dynamic behavior of a single steel tube spatial arch truss under vertical seismic load, studied its response law under different seismic intensity levels, and pointed out that the displacement and internal force response of the structure showed a trend of nonlinear growth with the increase of peak seismic acceleration. Zhouchangdong et al. [29] selected the structure of a large-scale studio as the research object, built three different models through SAP2000 software: fixed hinge support roof truss model, equivalent

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elastic support model and overall structure model, and conducted a comparative analysis of its static and dynamic characteristics, in order to evaluate the influence of the lower support structure on the mechanical characteristics of the upper roof truss. It is found that there is a significant difference in the stress between the fixed hinge bearing model and the overall structure model. When only static load and vertical seismic action are considered, the simplified equivalent elastic bearing model can replace the overall structure model for analysis.

Yin Yue [30] introduced the concept of generalized mode participation mass to quantify the main motion direction of each mode in the vibration process of long-span spatial structures. By setting the proportional threshold between the sum of generalized mode participation mass and the total structure mass, the number of effective modes to be considered in the mode decomposition response spectrum method of long-span spatial structures was reasonably determined. Huang Xin [31] used different adjustment methods to adjust the typical seismic records as the input seismic wave of the time history analysis method. By comparing the results of these calculations with the results of the response spectrum method, it was found that the comprehensively adjusted seismic wave was more in line with the standard response spectrum based on seismology and site characteristics. Thus, it was concluded that the comprehensive adjustment method was suitable for the time history analysis of long-span spatial structures. Zhang Jiwei [32] based on the random vibration theory, proposed a seismic response analysis algorithm suitable for long-span spatial structures, discussed the influence of seismic field model and seismic spatial effect, and proposed an anti-seismic design method integrating spatial effect. Zhaochaoqun et al. [33] created a 75m truss string model with ANSYS finite element software, evaluated its dynamic performance, and obtained a variety of seismic performance parameters including natural frequency, hysteretic curve, skeleton curve, energy dissipation capacity and stiffness degradation. Zhangailin et al. [34] made a 1:10 scale model for the steel roof of zone C1 of Beijing new airport terminal building and carried out static and quasi-static experiments to study the overall seismic performance under the joint action of C-shaped columns and the upper roof structure. Based on the response spectrum method, Li Lu [35] studied the displacement difference between long-span and short-span nodes of the pipe truss roof of Suzhou railway station under various seismic combinations, aiming to identify potential vulnerable parts and evaluate the response capacity of the structure under extreme seismic conditions. Sunchangqing [36] took the building cover structure of the main station of Qingdao north railway station as an example, systematically analyzed its seismic response law under a variety of seismic combined loads with the help of finite element simulation method, and revealed some key dynamic characteristics of the structure through static analysis and time history analysis. Tang Lichun [37] selected the steel truss structure of a gymnasium roof as the research object and used the elasto-plastic dynamic time history analysis method to focus on the response mechanism of structural joints under earthquake and the potential damage risk of components. Wang Ying [38] used response spectrum method and dynamic time history method to evaluate the seismic performance of a science and technology museum building, compared the difference between Ritz method and eigenvector method in modal analysis, and summarized the response characteristics of the overall structure and key node components under various working conditions. Dingzijie [39] took the large-span steel structure pipe gallery with different connection modes as the object, selected three typical seismic waves, conducted time history analysis under three seismic intensities, and summarized the influence of connection modes on the seismic performance of the structure, providing a theoretical basis for the optimization of seismic design. Liyifan [40] took a suspen dome in a practical project as the research object and analyzed its seismic performance under multi-dimensional earthquake action; The influence of various damping control strategies on the structural damping effect and the corresponding optimization measures are deeply studied. Wang Jian [41] focused on the stability and health monitoring of spatial structures in service, proposed the mechanical criterion of structural instability based on catastrophe theory, deduced the calculation method of critical load and critical stress, and further constructed the evaluation system for judging the overall stability of spatial structures under external loads, providing theoretical support for the safety evaluation of structures in the whole life cycle. Wang Dasui [42] took the steel roof truss of the

Oriental Art Center as the research object, carried out the seismic performance analysis from the single model of the steel roof truss, the concrete shell, the top ring plate and the overall model of five independent regions, and discussed the change law of the structural response after integrating the five sub models into a unified whole, providing an optimization path for the seismic design of complex multifunctional buildings. Based on the large-span steel structure of the National Stadium, Qian Jiaru [43] systematically studied the seismic performance of the structure under rare earthquakes by using the rod end plastic hinge model and combining the static elastoplastic and dynamic elastoplastic analysis methods, and proposed design suggestions to improve the ductility and collapse resistance of the structure. Xiong Meng [44] took the large-span steel roof of Zhengzhou International Convention and Exhibition Center as an example, analyzed the seismic performance based on SAP2000 platform, quantified the safety redundancy of the structure under seismic load, and put forward some feasible suggestions for the seismic design of spatial steel truss. Tangxiaodi [45] studied the seismic response of large-span steel pipe truss roof structure. The results showed that the vibration frequency distribution of this kind of structure was dense, the dynamic characteristics were complex, and the high-order vibration mode had a significant impact on the overall response, which should be fully considered in the design.

3. Summary

At present, To sum up, domestic scholars' research on space truss structure started relatively early, and made corresponding achievements on the bearing capacity of truss intersecting joints, structural dynamic performance and a large number of research. However, the seismic design theory of long-span space structures under earthquake is still immature and needs to be improved. According to the actual project, the seismic performance of different types of structures is analyzed, and the failure mechanism of weak area components of various structures under different earthquakes is summarized, so as to design reasonable seismic mitigation measures. In addition, the seismic research methods of spatial structures should be further improved to ensure the accuracy of the calculation results while improving the calculation efficiency.

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