IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

The research of suspen-dome structure

To cite this article: Shengyuan Gong 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **242** 012050

IOP Conf. Series: Materials Science and Engineering **242** (2017) 012050 doi:10.1088/1757-899X/242/1/012050

The research of suspen-dome structure

Shengyuan Gong[1, a)]

[1] College of civil and safety engineering, Dalian Jiaotong University, Dalian 116028, China

[a)]arrow1994@foxmail.com

Abstract. After overcoming the shortcomings of single-layer latticed shell and cable dome structure, the suspen-dome was developed by inheriting the advantages of them, and it was recognized and applied as a new type of prestressed force large span space structure. Based on the analysis of the background and mechanical principle, the researches of suspen-dome are reviewed, including form-finding analysis, the analysis of static force and stability, the dynamic behaviors and the earthquake resistant behavior, the analysis of prestressing force and optimization design, and the research status of the design of the fir-resistant performance etc. This thesis summarizes the methods of various researches, being a reference for further structural performance research and structural engineering application.

1. Introduction

With the improvement of society and of the economy, the demand of large span space structure has seen a drastically increase. The single-layer latticed shell has graceful mould, proven technique, and advantageous construction technique, therefore it was used extensively in small and medium sized span project. However, the structure is very sensitive to the initial imperfection, which makes its stability become the governing factor; the double layer shell overcomes the shortcomings of the weakness of the shell, being no longer sensitive to the initial imperfection, but it possesses dense rod pieces. With the enlargement of the span, the dead load will lead to larger tensile force in the surrounding ring beams. As a result, the usage of iron and project cost are higher. The newer cable dome structure vastly influences the non-cable structural component because of the cable in the system, the cost is high and the construction is difficult.

To solve the problems in the large span space structures mentioned above, professor Mamoru Kawaguchi [1] in Hosei University in Japan put forward the idea of suspen-dome structure system in 1993, it includes the superior single latticed shell and the lower whole stretch-draw part, the whole stretch-draw part includes vertical stay bars, radial pull rods and circumferential lassoes.

The suspen-dome fused the advantages of the single latticed shell structures and the dome structure as one of the newly composite structures. On the one hand, it brings the whole stretch-draw part into the lower single latticed shell structure, which improves the stability of the single latticed shell structure; On the other hand, it reduces the difficulties of the design, analysis, and construction because the upper lasso of the cable dome was replaced by the single latticed shell structure. Since the idea of suspen-dome was proposed, it has been applied to a dozen of large projects at home and abroad, such as the Beijing Olympic badminton gymnasium in 2008, the gymnasium of Anhui University, the dome of Mitsuoka in Japan, and the gymnasium of Dalian, which displays the application prospect of it.

IOP Conf. Series: Materials Science and Engineering **242** (2017) 012050 doi:10.1088/1757-899X/242/1/012050

2. The research development of the suspen-dome structure

2.1 Static and Buckling Analysis

After Professor Mamoru Kawaguchi [1] put forward the idea of suspen-dome structure, he made a series of theoretical analysis and experimental research of the system. Model tests on a small-scale suspen-dome with a diameter of 3.0m and a rise of 0.45 m have also been carried out [1], in which the load-carrying capacity of stability and the rigidity were proved to be increased greatly compared with the single-layer dome. Finite element (FE) analysis results also showed good agreement with results from experiments. A design example that is used is a suspen-dome structure, of which span and rise are 200 and 30 m, respectively [2]. The static response of them on the pretension cables were compared. Here is the conclusion of the experiment and the finite element analysis: The internal force of radial bars in suspen-dome structure is only half of the single-layer latticed shell, the outer ring commutator bars also have significant force reductions, however the force of inner ring bars have little difference.

The stability of it was showed thorough the research of the literature [3-5], and they drew the following conclusions: (1) The buckling strength of the suspen-dome structure and it sensibility to the initial imperfection is superior to the relative single-layer latticed shell structure; (2) Prestressed force, the length of the stay bars and the sections of the lassoes have a great influence on the stability of the structure. The material nonlinearity was motioned in the literature [6] and the cable-strut joint structure have a larger influence on the global stability of the suspen-dome structure. The research of the literature [7] showed that the construction deviation probabilistic method can perfectly illustrate the impact on the stability of the suspen-dome structure of the initial geometric imperfections. The experiment [8] shows that the ultimate load under half-span load was obviously inferior to that under the full-span load.

2.2 Dynamic and Seismic Behavior Analysis

Chen Zhihua [5] used the finite element software ANSYS to analyze the self-vibration characteristics of the suspen-dome structure. He analyzed the impact of the loads, rise, span, external-prestressing loop cable, bearing restraint on the structure’s self-vibration, he gave a proposal value to the structural design as well; The time-history method was used to analyze the suspen-dome structure’s response to the earthquake, and the influence of the parameters like the prestressing force, rise span ratio to its response. And followed are the conclusions: The frequency spectrum of the suspen-dome structure is intensive; the structure have a complicated vibration; the first few frequencies have an apparently enlargement than the single latticed shell structure, but their vibration modes have little differences; The suspen-dome structure’s respond to the horizontal wave is obviously larger than the vertical wave, and the internal force is reduced the single latticed shell structure; and it conducted a consistent conclusion with the theoretical analysis through pulsating excitation and impact excitation in exiting actual projects. Li Meng [9] did a research about the dynamic performance of the suspen-dome structure under the geological process, the results indicate that: when a structural seismic analysis was conducted, the role of multi-dimensional earthquake should be considered; Border suspen-dome structure has a larger seismic coefficient and a stronger the structure boundary is needed. Li Li [10] researched the self-vibration of the suspen-dome structure through changing many kinds of parameters, and she concluded the distribution law of the seismic internal force, seismic coefficient of the suspdome structure elements. Then, she gave the recommend values for structural design as well. Zhang Ailin [11] made following conclusion through the dynamic experiment of the Olympic badminton gym: the frequency of the suspen-dome structure is intensive-the period is long; the vibration centered on the vertical direction; the symmetric form and the asymmetric form take the major parts of the vibration, and the structural damping is between 0.02 and 0.03. Tian Shixuan [12] established the structure failure load of cellular automata (CA) model based on energy balance equation for structural energy response analysis and the incremental dynamic analysis conclusion of the suspen-dome structure under the ground motion.

2.3 Prestressing Force Analysis

The mechanical principle of the suspen-dome structure is enhancing the single latticed shell structure through bringing in prestressing force to bear the lower tensegrity structure to improve its capacity. Therefore, the design of the lower tensegrity structure is of vital importance in structure designing. At present, the designing principle of prestressing force is minimizing the peak values of the supports and the latticed shell members. Professor Mamoru Kawaguchi [1] took the method of trial and error, and the successive approximation method to design the party dome. These methods are simple in concept, but they are lacking in efficiency and effect. Chen Zhihua [13] put forward the simplex algorithm of the prestressed cable support system based on the mechanical balance principle. This method is convenient, but its precision is not high. Zhang Mingshan [14] used the genetic algorithm to conduct a secondary majorization of the suspen-dome structure. This method takes a single-target genetic algorithm, which means only one target can be optimized every time. When the secondary majorization is being conducted, the first level optimization structure has already changed, so this method cannot guarantee the accuracy of the majorization. After that, Zhang Mingshan [14] used the local analysis method to confirm the initial prestressing force distribution of the suspen-dome structure based on the balance matrix theory. The simplified calculation is the simplest method of the above with low construction cost, however its accuracy is the lowest as well. On the contrary, the genetic algorithm method is the most complicated method, but it has the highest accuracy and a wide application. In practical engineering, engineers can select these methods based on physical condition.

2.4 Fire Resistance and Temperature Analysis

In the aspect of the fire resistance design of the suspen-dome structure, Huang Wenqin [15] simulated the unitary fire-resistant performance of the suspen-dome structure under large enclosure fire using software ANSYS. He analyzed the structure behavior and its failure mechanism under fire. Then the sensitive of parameters like temperature field distribution, load ratio, and geometry and boundary conditions were analyzed by numerical simulation, and the critical temperature of the structure under fire was obtained. Based on this, the evaluation method of the fire resistance conditions of the suspen-dome structure was put forward.

Liu Hongbo [16] analyzed the construction processes of bearing frame-fastener type steel tube supporting frame, considered the influence of sliding friction and temperature change to the construction control theory. He also researched the influence of the solar radiation and structural behavior under temperature load, by using the temperature field numerical simulation method. Then he concluded that the environmental temperature changes under the tensioning construction stage of the suspen-dome structure had a great influence on the tensioning construction. He suggests that the influence of temperature change on the tensioning construction should be considered when designing the tension control values of the suspen-dome.

3 Conclusion

(1) The suspen-dome structure is kind of a highly efficient form of prestressed spatial structure. It possesses a superior static and dynamic performance, while its construction cost is low. The suspen-dome structure has already been applied in many large projects at home and abroad, and it has shown great superiority in many aspects.

(2) Current studies of the suspen-dome structure are mainly concentrated in the static, dynamic and stability analysis, prestressing force design and optimization design of the structure, etc.

(3) Researches on the fire resistance design and temperature analysis of the suspen-dome structure are relatively few, and further researches are needed.

References

[1] Mamoru Kawaguchi, Masaru Abe, Ikuo Tatemichi, et al. Design, tests and realization of “suspen-dome” system[J]. Journal of the IAAS, 1999, 40 (3):179-192.

[2] Mamoru Kawaguchi, Masaru Abe, Tatsuo Hatato, et al. Structural tests on the “suspen-dome” system[C]. Proceedings of IASS Symposium. Marid, Spain: IASS, 1994: 384-392.
[3] Cui Xiaoqiang, Guo Yanlin. Research of Elastic Limit Bearing Capacity of the Kiewitt Suspen-dome Structure [J]. Journal of Building Structures, 2003, 24(1): 74-79.
[4] Li Yongmei, Zhang Yigang. Stability and Static Analysis of Cable-Supported Lattice Shells [J]. International Journal of Space Structure, 2003, 9(1): 25-30.
[5] Chen Zhihua, Li Yang. Parameter analysis on stability of a suspen-dome [J]. International Journal of Space Structure, 2005, 20(2): 115-124.
[6] Ge Jiaqi, Zhang Guojun, Wang Shu, etc. The Overall Stability Analysis of the Suspen-dome Structure System of the Badminton Gymnasium for 2008 Olympic Games [J]. Journal of Building Structures, 2007, 28(6): 22-30.
[7] Liu Xuechun, Zhang Ailin, Ge Jiaqi, etc. Study on the influence of construction deviation random distribution on the integral stability of suspen-dome. [J]. Journal of Building Structures, 2007, 28(6): 76-82.
[8] Zhang Ailin, Liu Xuechun, Wang Dongmei, etc. Seismic Behaviors Study of the 2008 Olympic Games New Type Suspen-dome Structure [J]. Journal of Building Structures, 2007, 28(6): 58-67.
[9] Li Meng. Research of Static and Dynamic Performance of the Chord Dome Considering Supporting Structure [D]. Xi’an: Xi’an University of Architecture and Technology, 2010.
[10] Li Li. The Anti-Seismic Property Analysis of the Suspen-dome Structure [D]. Harbin: Harbin Institute of Technology. 2008.
[11] Zhang Ailin, Liu Xuechun, Wang Dongmei, etc. Seismic Behaviors Study of the 2008 Olympic Games New Type Suspen-dome Structure [J]. Journal of Building Structures, 2007, 28(6): 68-75.
[12] Tian Shixuan. Seismic Response Analysis of Suspen-dome Based on Energy Method [D] Harbin: Harbin Institute of Technology. 2013.
[13] Kang Wenjiang, Chen Zhihua, Heung-Fai Lam, et al. Analysis and design of the general and outmost-ring stiffed suspen-dome structures [J]. Engineering Structures, 2003, 25(13):1685-1695.
[14] Zhang Mingshan, Dong Shilin, Zhang Zhihong, Distribution of Initial Pre-stress and Stability Analysis of Suspen-dome [J]. International Journal of Space Structure, 2004, 10(2): 9-12.
[15] Huang Wenqin, Study of Numerical Analysis and Fire Resistance Conditions of the Suspen-dome Structure Under Fire [J]. 2013.
[16] Liu Hongbo, Study on the Construction Control Theory and Temperature Effect of Suspen-dome Structure [J]. 2011.