The analysis of dynamic characteristics and wind-induced displacement response of space Beam String Structure

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Abstract: The Beam String Structure structural system, also called BSS, has the advantages of lighter dead weight and greater flexibility. The wind load is the main design control factor. The dynamic characteristics and wind-induced displacement response of BSS are studied by the finite element method. The roof structure of the stadium roof of the Fuzhou Olympic Sports Center is the engineering background. 1)The numerical model was built by ANSYS, by shape finding, determine the initial stress state of structural members such as external cables; 2)From the analysis of dynamic characteristics, the main mode of vibration is the vibration of cables; 3)The wind speed spectrum of MATLAB generation structure is obtained by AR method, the structural response of the structure under static wind load and fluctuating wind load is calculated. From the analysis result, considering the equivalent static wind load of BSS , the design of adverse wind is not safe, and the fluctuating wind load should be taken into account.

1 Introduction

BSS is a new type of spatial structure, it has been applied more and more widely in recent years [1-3]. The structure is mainly composed of a brace and a prestressed cable to lift the arch truss, it will cause the structure to produce the anti arch, also may reduce the vertical deflection in the use stage. The BSS shows a strong nonlinearity, and the structural design is generally controlled by stability rather than strength. The natural vibration period of the BSS is close to the predominant period of the natural wind, frequency dense, less damping, the structure more flexible, it belongs to wind sensitive structure. It is very important to consider the wind-induced vibration coefficient in the design, but the research on wind-induced vibration response of long-span BSS is less. The static wind and fluctuating wind loads on the BSS of the Fuzhou Olympic Sports Center Stadium are numerically simulated, finite element method is used to calculate and analyze, the dynamic characteristics and the structural displacement response under static wind load and fluctuating wind load are studied.

2 Numerical Investigation

2.1 Engineering Background

The reinforced concrete frame shear wall structure is adopted in the lower part of the Fuzhou Olympic Sports Center Stadium, the superstructure of the steel roof is composed of a quadrilateral ring, a string chord and a chord and a chord structure, and a plane primary and secondary truss structure, the steel wall is made of single-layer rhombus crossed grid structure. The plane primary and secondary truss structure in the competition area is distributed in all the roof structures outside the grandstand of the competition area, it can be divided into two kinds: radial truss and ring truss, the maximum span of radial truss is 35m; the maximum span of the X axis in the training area is 120m, the maximum span of Y axis truss is 73m. Fuzhou Strait Olympic Sports Center Stadium as shown in Figure 1.

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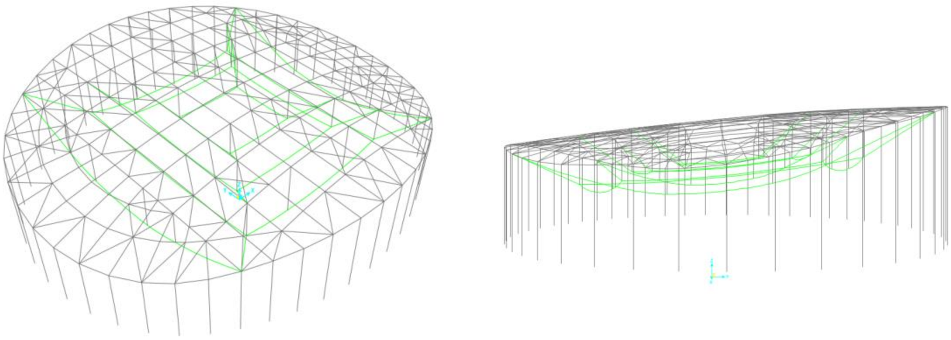
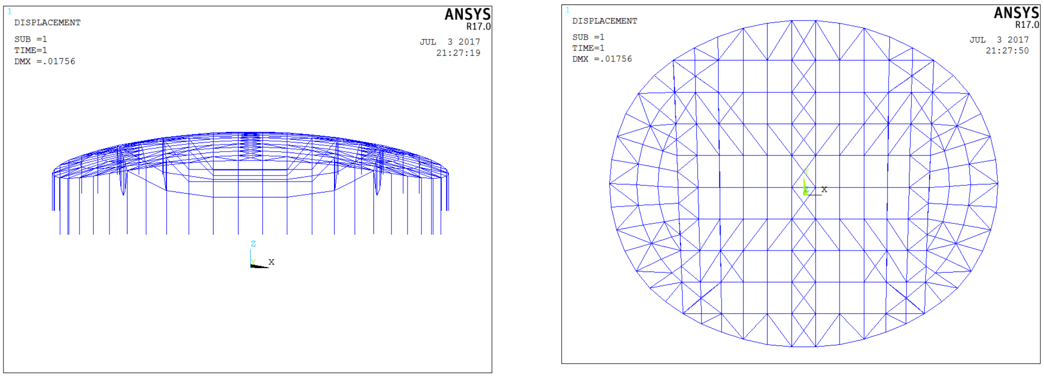


Figure 1 Fuzhou Strait Olympic Sports Center

2.2 The Finite Element Model

A three-dimensional calculation model is established by using ANSYS, upper cord, belly Bar and stay bar of the Link8 element, the Link10 element is used in the cable element, The prestressing force in the prestressed cable is applied to the structure by defining the initial strain. The total number of elements is 643, the total number of nodes is 821. The finite element model is shown in figure 2.



a) Sketch map of elevation b) Sketch map of horizontal projection

Figure 2 The Finite Element Model

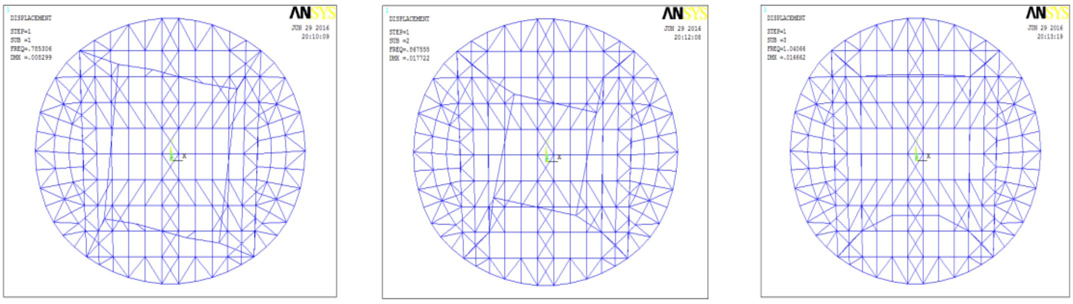
To establish a computational model that conforms to the initial state of the actual structure, the shape of BBS must be formfinding. Because the BSS belongs to the prestressed beam cable structure system, The geometry and dimensions of the system in the initial state are generally given by the design unit: that's the size of the blueprint. In the process of exerting prestressing force, Zero State(setting out state without self weight or prestress, the equivalent of BSS placed on the temporary support, no amount of prestressed tension) of BSS gradually deforms to the initial state(the equilibrium state of gravity and prestress acting together, after the end of tension tensioning, the temporary support has exited the working state). When the deformation reaches the geometric requirement of the initial state, the prestress of the external cable reaches the tensile design requirement, this means that the tension of the external cable ends. The spatial position of each node of the structure and the overall stiffness of the structure can be determined by means of formfinding. formfinding has a great influence on the dynamic characteristics of the structure and the wind load response[8].

3 The Analysis Of Dynamic Characteristic

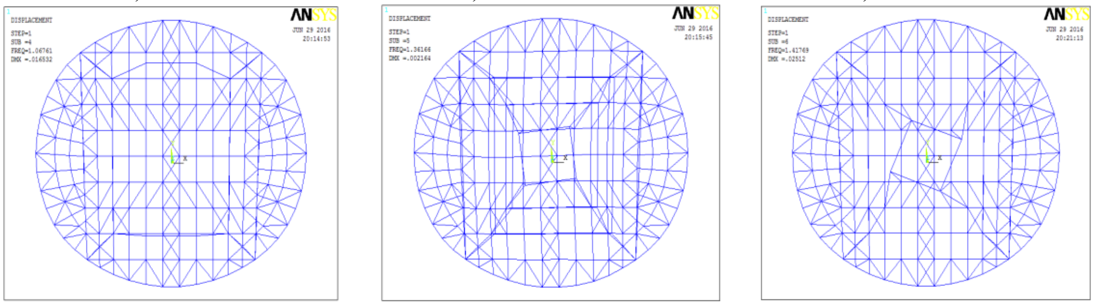
The structure is analyzed by modal analysis after the structure is formfinding, after removal of out of plane (lateral) vibration modes, the first 10 order natural frequencies as Table 1 and the first 6 modes are shown in Figure 3.

Table 1 Structural Natural Frequency

Formation	1	2	3	4	5	6	7	8	9	10
Frequency (Hz)	0.79	0.87	1.04	1.07	1.36	1.42	1.71	1.78	1.93	2.185



a) The 1st Mode b) The 2nd Mode c) The 3rd Mode



d) The 4th Mode e) The 5th Mode f) The 6th Mode

Figure 3 Vibration pattern of BSS in Olympic Sports Center

From Table 1, the fundamental frequency of the structure is about 0.785, the frequency distribution tends to rise uniformly. The structure is similar to some large span space structures such as reticulated shell, its frequency spectrum is close, the mode characteristic frequency is shown in Figure 4.

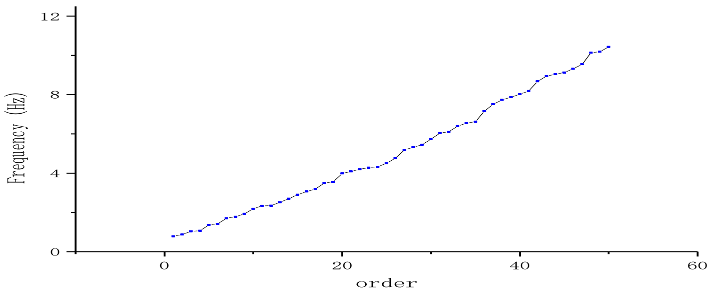


Figure 4 Spectrum Characteristic Of Structure

Figure 4 shows the ladder like distribution of frequency, at the section of the formation ladder, the vibration modes of structures also exhibit obvious characteristics of change. The frequency distribution is relatively dense, and the order reaches 40, when the structure is subjected to dynamic analysis, the number of vibration modes is best not less than 40 order. The vibration modes of structures are mainly the vibrations of cables, the upper space truss structure does not participate in vibration, Therefore, it is necessary to pay attention to the structure of the ring cable.

4 Simulation of Wind Load

4.1 Static Wind Loads

According to the regulations, the basic wind pressure in Fuzhou area is 0.7 kN/m^2, the horizontal average wind speed at the h=10m is 26.8 m/s. The site roughness class is B, the elevation of the constraint position is 32.3m, the direction of the wind is 0°(90°). In this design, the wind load on the windward (leeward) side of the structure is selected along the direction of the wind direction along 0°(90°). The calculation is carried out according to the standard.

a) $\theta = 0^{\circ}$ b) $\theta = 90^{\circ}$

Figure 5 Structural Region Division Under Different Wind Directions

According to the code for load of building structural load regulation[4]: Calculate according to the following formula when standard value of wind load perpendicular to the surface of a building.

$$\omega_i = \mu_s \mu_z \omega_0$$

The building is divided into three zones according to the type and shape of the building, as shown in Figure 5.

4.2 Fluctuating Wind Load

The wind speed vector at any time can be considered as two parts: mean velocity and fluctuating velocity,

for the average wind speed $\overline{v}$, the wind speed and wind direction data recorded at the wind speed station near the engineering site can be fitted by the extreme wind speed respectively, and the extreme wind speed during the return period of the structure is predicted. The mean wind speed last night is [5]. The basic wind pressure ω_0 can be determined by $\omega = 0.5\rho v^2$, and then the average wind speed of the structure is obtained by the formula conversion.

For pulsating wind velocity vectors, it is assumed that the elements have the same spectrum and have some spatial correlation, and can be further written in the following form:

$$\vec{v}(t) = C \cdot \vec{u}(t)$$

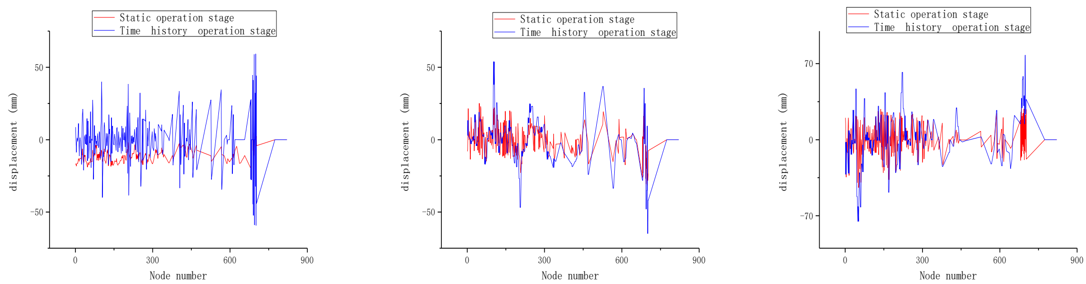
In the formula, C is the correlation matrix, which can be obtained by the inverse transformation of the cross spectral density of the wind speed. It is a vector Fourier composed of the uncorrelated fluctuating wind speed time histories[6]. This paper uses MATLAB programming to simulate the fluctuating wind speed of structure [7], the values of the relevant parameters are as follows: According to the basic wind pressure once every 50 years in Fuzhou area; at the height of 10m wind speed is 31m/s; Cx=16, Cy=8, Cz=10; the roughness coefficient y=0.185, K=0.003; the total time step N=1024, when the distance is 204.8s, the time step is 0.2s. The autoregressive order of the AR model is 6. The calculated wind speed time history is shown in Figure 6.

a) 44 wind spectrum time history curve b) 38 wind spectrum time history curve

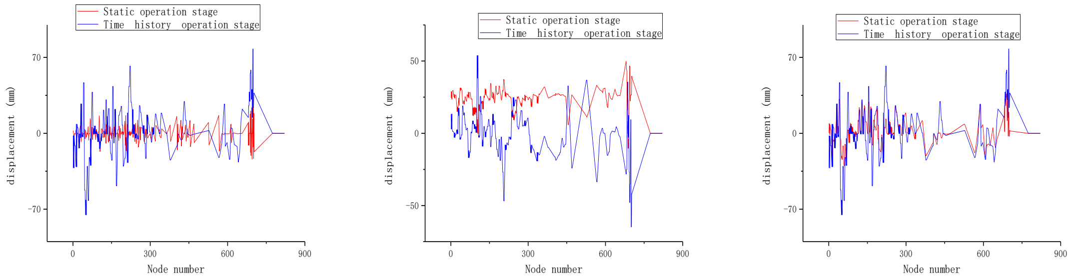
Figure 6 Wind Speed Time Curve

5 Structural Displacement Response

In the dynamic response analysis of structures, the static analysis gives the statistical moments of structural responses. In the analysis process, many mathematical simplifications of the structure are needed [9]. In particular, for the nonlinear system with BSS, its stiffness varies with the load, whereas in static analysis it is generally assumed to be invariant and its computational reliability is low. The time history analysis method for vibration frequency of intensive and large flexibility, obvious non-linear structure, the analysis of wind-induced response, the spectrum function for a given wind load, the wind load simulation as a function of time, and then use the finite element discrete structure and, in the role of simulation nodes the wind load, obtained the response of the structure through the method of time domain directly solving the differential equation of motion, correcting the stiffness of the structure in each time step, so the nonlinear factors have also been considered.



a) x displacement under X wind load b) y displacement under X wind load c) z displacement under X wind load



d) x displacement under Y wind load e) y displacement under Y wind load f) z displacement under Y wind load

Figure 7 Displacement Response Of Structures Under Wind Load

According to the analysis of Figure 7, with the static wind load, the response of each node under the action of fluctuating wind load is greater. And the displacement response of the node is almost envelope. When the structure is in use, the frame is dismantled, the prestressed cable plays a role, the structural rigidity becomes smaller, and the flexibility is larger. The structure moves larger under the action of the wind load, but it is still in a safe state.

6 Conclusion

In this paper, the dynamic characteristics and wind-induced vibration response of the space BSS structure of Fuzhou Olympic Sports Center are studied by the finite element method. The main conclusions are as follows：

1. The structural dynamic characteristics are studied. The fundamental frequency of the structure is 0.785, and the frequency distribution tends to rise uniformly. Like some long-span space structures, such as reticulated shell, the structure is dense and has no big jumps. The vibration modes of the structure are mainly the vibration of cables, the overall stiffness of the upper space grids is larger, and the formation of the structures is not involved in the formation, so it is necessary to pay more attention to the structure of the ring cables.

2. Comparison of structure wind vibration displacement response of key node, that node displacements the maximum value appears in the central axis, time-domain analysis frequency domain method of wind vibration displacement response is greater, trend and displacement response time Tagmemic frequency shift response similar trend. It can be seen that for the wind sensitive structure like BSS, the effect of fluctuating wind must be taken into account. The design of wind resistant structure is only unsafe when considering the equivalent static wind load only.

Acknowledgements

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