NONLINEAR SEISMIC ANALYSIS OF JIANGNAN UNIVERSITY STADIUM DOME UNDER MULTI-SUPPORT EXCITATION

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ABSTRACT :

In the seismic analysis of engineering structures, the support acceleration is postulated to be the same. For long span engineering structures, this postulate is not true. The seismic spatial effect is important for long span spatial structures. The multi-support seismic excitation should be considered. As a case for study, the seismic analysis of Jiangnan University new stadium dome under multi-support seismic excitation is performed. The OPENSees analysis program is used to perform the nonlinear time-history analysis. In the finite element analysis, the fiber section fiber beam element is used to model the nonlinear behavior of steel tube member under seismic excitation. The structure dynamical response under both the consistent seismic excitation and the multi-support seismic excitation is analyzed using different seismic time-history record. The numerical analysis result shows that the steel dome dynamic response under multi-support seismic excitation is different from that under consistent seismic excitation. The influence of the traveling wave and the multi-support excitation on the steel dome response is analyzed. The analysis result gives more guidance on the stadium dome aseismic assessment.

KEYWORDS: multi-support seismic excitation, long span space structure, time-history analysis

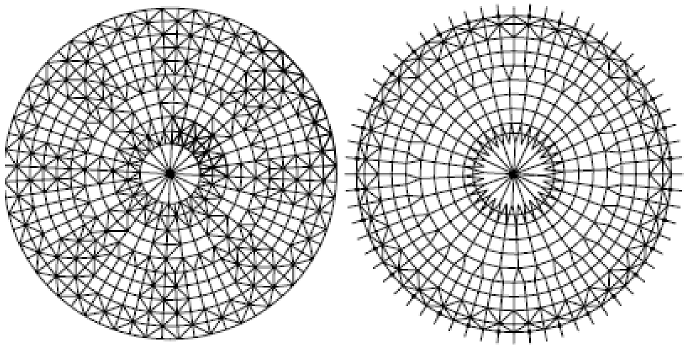
1 INTRODUCTION

The seismic spatial effect should be considered in the seismic response for the long-span spatial structures, as a result that the supports move un-uniformly under seismic excitation. The seismic input is assumed as the consistent seismic input for structural seismic analysis according to the China Code for Seismic Design of Building (GB50011-2001). For the long span spatial structure, the spatial variation effect for seismic input should be considered appropriately. It is important to determine the seismic input for long span spatial structures. The energy released from the earthquake source is transited in the seismic wave propagation form, which induces the ground vibration. The seismic wave received at different locations on the ground may travel through different path, different ground geography and different geological stratum, which in turn gives rise to different ground vibrations. Even if the other conditions are the same for two different ground locations, there exists time lag between ground seismic waves received at those two locations due to the fact that the distances between the ground location and the earthquake source center are not the same. According to the earthquake seismic monitoring results, there exists ground vibration variation. Especially for long span spatial structures, the ground vibration variation should be considered appropriately to consider the unfavorable loading condition. As a case for study, the seismic analysis of Jiangnan University new stadium dome under multi-support seismic input is performed to investigate the internal force time-history result for aseismic assessment.

2 STATIC AND MODAL ANALYSIS

2.1 Structure Layout of the Stadium Dome

The total building area for Jiangnan University new stadium is 14433.93m2. There are 3 floors for the new stadium building structure. The total height of the structure is 23.65m with 4.5 m for each floor height. The planar shape of the new stadium is circular as shown in Fig. 1, the diameter of which is 99m. The concrete building frame structure is used from +0.000 height to 11.000 m height. Above 11.00m height the stadium dome is covered by a semi-sphere shell spatial structure with circular planar layout, as shown in Fig. 2. The steel semi-sphere shell structure is supported by 32 supports uniformly distributed at 36 concrete columns of the concrete frame. The main structural part for the steel stadium dome is two layer sphere shell structure with prestressed chords in the center of the shell structure. The sphere shell structure is composed of positively located foursquare pyramid. The mesh for upper chord and bottom chord is the equal waist trapezoid shape. There are 32 radial chords in the inner side of the shell structure while there are 64 radial chords in the outside of the shell structure. The distance between the neighbor annular chords is about 4.3 m. Annular braces are added at the outside for both the upper chords and the bottom chords. 8 prestressed chords are placed in the center of the sphere shell structure with rung shape distribution.



(a) upper chords (b) bottom chords

Figure 1 Planar layout for the new stadium

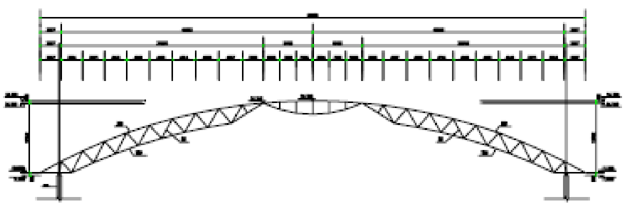


Figure 2 Section layout for the new stadium

2.2 Static Analysis of the Stadium

In order to achieve the initial stress for the dynamical analysis, the static analysis for the stadium under gravity is performed first using the three dimensional finite element analyses. The three dimensional beam elements with circular shape are used to model the upper chords, the bottom chords and the brace chords of the stadium dome. 32 supports for the stadium dome is neither fixed nor pinned. They are elasto-plastic support type. The nonlinear spring element is used to model the stadium dome support. The truss element is used to model the prestressed chord at the center of the stadium dome. In the finite element model, 4849 spatial beam elements, 128 spring elements and 48 truss elements are used to model the chords (braces), elastic supports, the prestressed chords respectively.

The initial stress for the prestressed chords is included in the finite element analysis to model the pretension construction. All the dead loading and the construction loading are applied to the structure at one step with the assumption that the shell structure construction is constructed in one step without considering the real construction process in detail. And this assumption does not give significant influence on the static analysis result for the member internal force and the displacement distribution. The vertical displacement distribution for the stadium dome structure under gravity and prestress loading is done using the static analysis. According to the static analysis result, the maximum displacement for the shell structure is 2.07 cm downward, the location of which is in the center of the upper chord. This means that the structure deformation is small and in elastic state under gravity. The final deformation state under gravity and prestress loading provides basic state for both the modal analysis and time-history analysis.

2.3 Modal Analysis of the Stadium

After the static analysis, the modal analysis of the stadium is performed to recognize the basic vibration shape of the structure, which is fundamental for the dynamical analysis. The base state of the structure is taken as the final deformation state under gravity and prestress loading. The Lanczos frequency extraction method is used to do the modal analysis. For comparison, the stadium dome modal analyses are done for both elastic and fixed type supports. The frequency results for both elastic and fixed type supports are listed in Table 1.

Table 1 Frequency results for both elastic and fixed type supports

Modal No.	Frequency	
	Elastic type supports	Fixed type supports
1^{th}	1.9981 Hz	3.8049 Hz
2^{nd}	1.9981 Hz	3.8049 Hz
3^{rd}	2.6467 Hz	5.8795 Hz
4^{th}	3.8220 Hz	6.3670 Hz
5^{th}	3.9062 Hz	6.3670 Hz
6^{th}	3.9062 Hz	7.8367 Hz
7^{th}	5.9501 Hz	7.8367 Hz
8^{th}	5.9501 Hz	8.3424 Hz
9^{th}	7.9568 Hz	8.6076 Hz
10^{th}	7.9568 Hz	8.6076 Hz

It can be obviously seen Table1 that the frequency result for elastic supports is ranging from 1.9981Hz to 7.9568Hz for the first 10 modal shapes. The first two frequencies are the same with the horizontal rigid translation and vertical translation of 1.9981 Hz frequency. In contrast, the first two frequencies for fixed support types are the same with the horizontal rigid translation and vertical translation of 3.8049 Hz frequency. It can be seen clearly that the first two frequencies for fixed supports are almost twice times as that for the elastic supports.

3 SEISMIC ANALYSIS

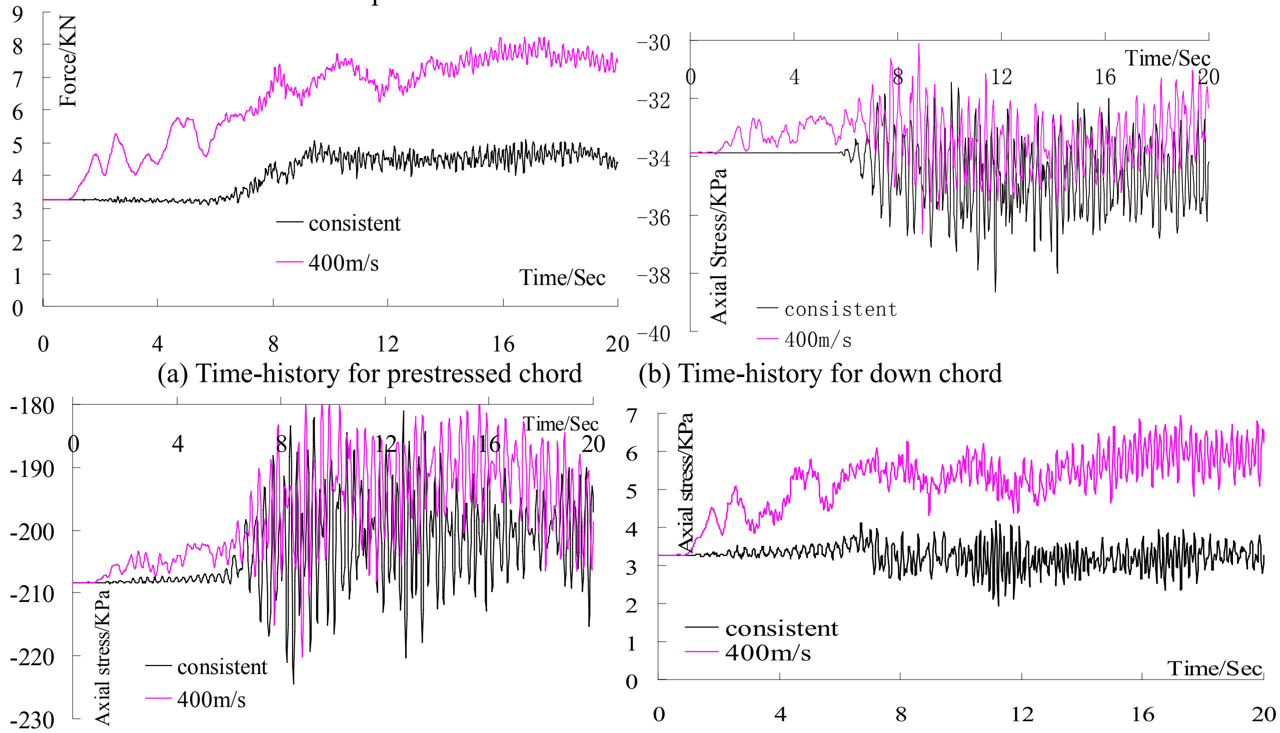
3.1 Seismic input considering traveling wave

The traveling wave effect is caused by distances difference between different monitoring locations and the earthquake source center. The support points are relatively fixed for most engineering structures. Then the time lag between different support points when the seismic wave arrives is determined by the pseudo wave velocity and the angle θ between the seismic wave propagation direction and the structure longitudinal axis. In the analyses, the θ is assumed as 0. The pseudo wave velocity is taken as 400m/s. The EL-Centro seismic wave is taken and is modulated with the swing value of 0.05g.

3.2 Time-history analysis

As the supports are elastic, the time-history analysis is used to perform the seismic analysis using the finite element dynamical incremental analysis. The time increment is taken as 0.02s which is the same as the sampling interval of EL-Centro seismic wave. The total analysis time is taken as 20s. For comparison, the time-history analyses for both the consistent seismic wave input and the seismic input considering traveling wave effect are performed in the paper. Some typical structural member time-history results are shown in Fig. 3.
It can be seen from Fig.3 (a) that the traveling wave effect with pseudo velocity 200m/s has a great influence on the prestressed chord time-history result. From Fig. 3(b) and Fig. 3(c), the traveling effect does not influence the

down chord and the upper chord time-history result greatly. For brace chord as seen from Fig. 3(d), the axial stress time-history result for brace chord under 200m/s pseudo wave velocity increases greatly compared with that under consistent seismic input.



(a) Time-history for prestressed chord (b) Time-history for down chord

(c)Time-history for upper chord (d) Time-history for brace chord

Figure 3 Time-history for typical shell structure members

4 CONCLUSION

For long span spatial structures, the traveling wave effect plays important role. In the seismic analysis of such structure, the proper seismic input considering the traveling wave should be taken into consideration. As a case for study, the Jiangnan University new stadium dome seismic analysis is performed under traveling wave for the frequent seismic analysis. The analysis result shows that the traveling wave effect has great influence for typical shell members for frequent designed earthquake. The typical shell structure members are in elastic state. For seldom earthquake seismic analysis, it is necessary to consider the traveling wave effect in detail for further study.

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