Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia
Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain
Alberto DOMINGO and Carlos LAZARO (eds.)

Research on Dynamic Performance of Large-Span Complex Shape Spatial Lattice shell

Xiuli WANG*, Wang LEI
* Prof. School of Civil Engineering, Lanzhou University of Technology
287#, Langongping Road, Lanzhou, Gansu, PR China,730050
Email: wangxl9104@126.com

Abstract

Take Qingyang gymnasium in Gansu province as study background in this paper. Nonlinear finite element method is applied. Using finite element software of ANSYS program, through the dynamic time interval analysis about complex spatial shell structure with two calculative models, which were with sub-structure or not. Firstly , the complex spatial shell with sub-structure or not is analyzed under natural vibration□Secondly, dynamic response under the effect of 3-dimension El-Centro wave and Taft wave is analyzed; Finally, analyze the influence of different damping radio, different seismic input to its overall performance. The results of study are showed that the effect of the sub-structure can not be ignored. We could consider the flounce of cooperative performance to large-span complex spatial structure in the structural design.

Key words: complex spatial structure; cooperative performance; time-history analysis; damping radio

1. Introduction

Lattice shell is belonged to spatial grid structure with curved surface. Its characteristic is combined the member and the thin shell structure. The principal advantage is its large-span, the good overall rigidity, the reasonable bearing capacity and the good earthquake resistance performance. For large-span complex lattice shell with curved surface, the method of simulated shall not be applied to it because of geometrical specificity and irregular constraint condition. Upper lattice shell roof structure and lower part supporting system are counted respectively with calculation diagram, and design by this. But in the project practical work, substructure inertia effect has influence on the lattice shell internal force and the nodal displacement. Especially under macroseism function, the effect of the substructure can not be ignored because it will cause the noticeable seismic function and affect the bearing capacity of the lattice shell. "Shell Structure Technique mode"□JGJ 61—2003□stipulated: Regarding complex or important large-span lattice shell should be used time history method as a supplement computation. Recent years, research[1] and design only to conventional lattice shell, but really few researches on dynamic performance of large-span complex lattice shell. Therefore, cooperative performance is considered in this paper. The large-span complex spatial structure is analyzed by time history method. This theory can be used in the reality engineering design.

2. Analytical model

Qingyang gymnasium in Gansu province is used in this paper. Using finite element software of ANSYS program, the complex spatial structure is analyzed with dynamic time interval. This stadium is regarded as the important competition facility, which will take the 12th Gansu Province Games in 2010. The basketball, the volleyball, the badminton, and so on large-scale event will be undertaken. In the hall may hold 4950 people, so it will become the biggest indoor gymnasium in Gansu Province scale. This hall modelling is unique (impression drawing see Figure 1).The floor area is 10821.6□. The substructure is the reinforced concrete frame structure. The roofing is used the double-decked lattice shell which is constituted with the steel structure overlapping trussed system. Partial is used the arch structure of the arc surface modelling. The plane span 75.8m short, long to 83.6m. Structure is along lengthwise fixed triangle tridimensional truss. This truss width is 3.5m, highly is 5m. The structure according to the surface relations gradually changes section. The superstructure is used the peripheral support.

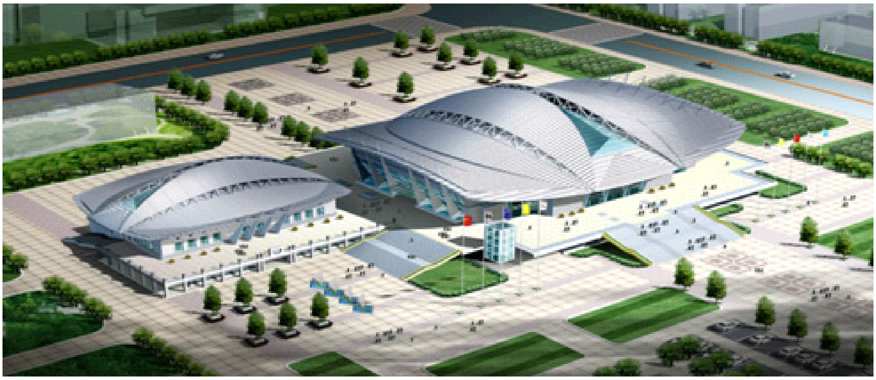


Figure. 1 Stadium impression drawing

The lattice shell of this stadium has two differences from the common: 1) the planform is anomalous. The existing project cases are like circular, the rectangle, polygon and so on regular shapes. Large-span lattice shell is not many researched; 2) the spatial stress is asymmetric. This shell is used peripheral support. Its two direction sections are the variable sections that are created the structural grid anomalous in partial. So the partial stress has differ from the regular place. This stadium is used finite element of ANSYS program (as shown in Figure 2) in this paper. The beam column of the reinforced concrete frame structure lower part is used the Beam188 unit, the board is used the Shell63 unit, the upper lattice shell member is used the LINK8 unit. The roofing equivalent load is concentrated in the lattice shell node by the quality unit form. The quality unit is used the Mass21 unit. The analysis has considered geometrical nonlinearity and the lattice shell initial dead load (used acceleration of gravity g) of the whole structure. The material constitutive relations are used the ideal elastoplastic model. The yield criterion is used Von Mises. The node is used hinge form. MST program of Zhejiang University (2006) that makes static calculation to superstructure of the lattice shell and optimize the design. Finally determined the member section has 12 kinds. Smallest sectional dimension is φ76x3.5□maximum is φ325x16. In the model, the lattice shell member and the substructure all used two materials□□ $EX = 2.06e11\,N/m^2$, $\lambda = 0.3$, $dens = 7850\,kg/m^3$; ②

$EX = 3.0e10\,N/m^2$, $\lambda = 0.2$, $dens = 2700\,kg/m^3$ 。

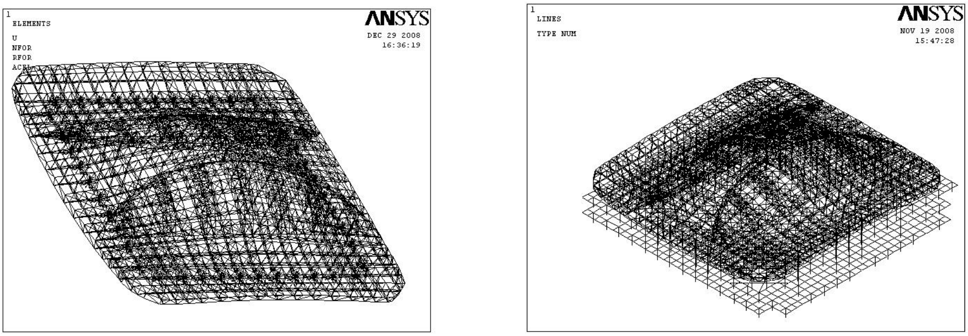


Figure. 2 The superstructure and the overall model

3. Characteristics analysis of structural free vibration

Considered the complex spatial lattice shell with substructure or not as a model, using subspace iteration method carries on the modal analysis to two kinds of models. Extract preceding 50-order vibration mode, are listed respectively in a multi-band typical frequency and vibration mode as shown in table 1, as shown in Figure 4, 5, frequency comparison of substructure or not as shown in figure 3.

Table 1 Typical frequency of two kind structure （HZ）

Exponent number	1	2	4	8	10	20	35	40	49	50
Non-substructure	3.2803	3.3210	3.4417	3.7401	4.1542	4.8881	5.9798	6.4676	7.4901	7.5844
substructure	2.2438	2.3128	3.0206	3.1629	3.1942	3.8714	4.8629	4.9539	5.0505	5.0546

Through the typical modal analysis, from Table 1 and Figure 3, we can see that the substructure of the model frequency is small. The primary cause is the overall rigidity with substructure is larger than non-substructure. The preceding 10-order frequency difference vibration mode is between 20~30%. With the vibration mode order is increased, the frequency difference will be increased. It can be seen that for such large-span complex lattice shell structure, the modal analysis can not only take

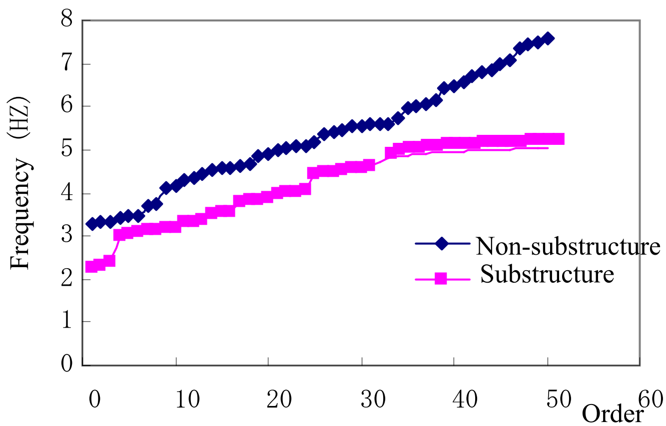
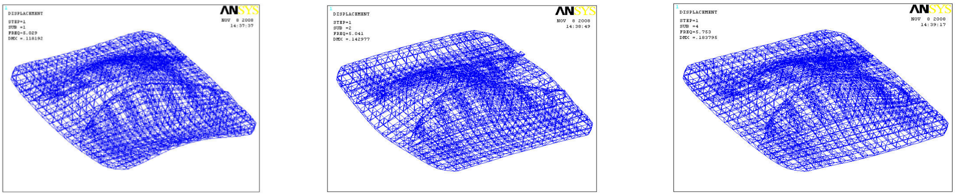


Fig.3 The comparison of frequency with substructure or not

the preceding several step vibration mode, but also consider the multistage modal analysis. Under the horizontal seismic force, the substructure has the good coordination performance to the shell. But under vertical seismic force (for example the fourth-order vibration mode) or under horizontal and vertical seismic force combination function, the coordinated performance of substructure is weaken, even causes more serious destruction.

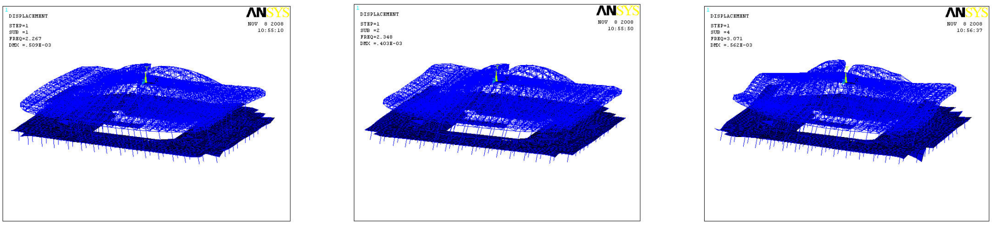
4. Structure dynamic response and parametric analysis

The shell structure is only considered the singer deck stability at present. It is a qualitative understanding that double deck doesn't have the stability problem. The quantity is not considered on it. The characteristic of structure instability is similar in the brittle fracture. Before the destabilization, it is not obvious indication. If you neglect the overall stability examination, it is inappropriate for this large-scale complex lattice shell. Therefore, this paper had abundant analysis on the parameters. The influence including: with substructure or not, different damping ratio and different earthquake.



（1） First-order vibration mode （2） Second-order vibration mod （3） Fourth-order vibration mode

Figure .4 Typical vibration mode of superstructure



(

1） First-order vibration mode （2） Second-order vibration mode （3） Fourth-order vibration mode

Figure .5 Typical vibration mode of overall construction

4.1 Computation parameter selection

Studies have shown that large-span spatial lattice shell structure under the multi-dimensional seismic response is always greater than under the one-dimensional. Speaking of certain nodal displacement and internal forces of member, the difference may be greater [3]. Therefore, in the analysis direct input of 3-dimensional seismic wave. The wave shape is selected the actual seismic records EL-Centro wave. And the X, Y, Z, direction respectively is its north-south, east-west and vertical record, according to 1:0.85:0.65 made the adjustment. According the fortification intensity 8 degree （0.2g）, the peak acceleration of rare earthquake is taken 400 GAL. The time interval is 0.02 seconds. Sub-step is set to 10. Namely the time-step iteration is 0.002 seconds. Total duration is 16 seconds.

4.2 Response analysis of structure displacement

The displacement of transverse and the longitudinal mid-span essential node (as shown in Figure 6, 7) is analyzed. Calculating data is shown as Table 2, 3.

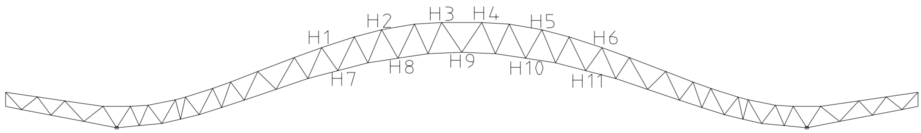


Figure .6 Midspan span of transverse truss

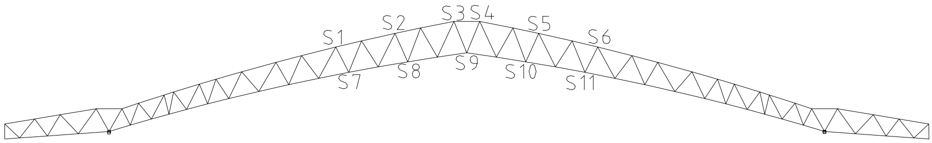


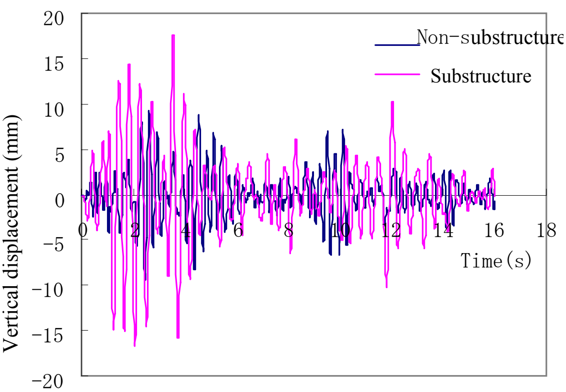
Figure .7 Midspan of longitudinal truss

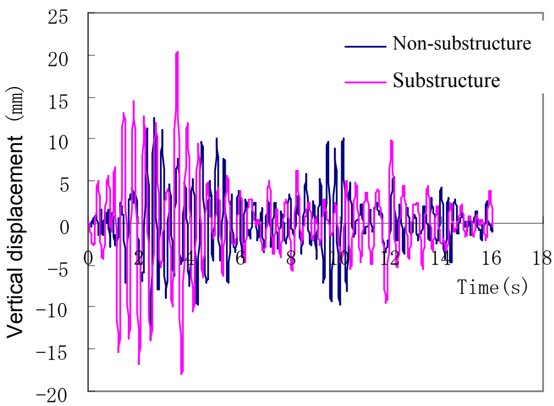
Table 2 Nodal displacement comparison of transverse truss midspan（mm）

Point	H-1	H-2	H-3	H-4	H-5	H-6	H-7	H-8	H-9	H-10	H-11
Non-substructure	44	58	62	63	66	68	65	62	58	57	39
substructure	75	79	83	83	84	84	83	82	81	82	79

Table 3 Nodal displacement comparison of longitudinal truss midspan（mm）

Point	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	S-11
Non-substructure	33	37	41	46	54	55	48	44	39	35	32
substructure	61	63	67	74	79	81	79	75	70	68	66





（1） The biggest vertical displacement of transverse truss （2） The biggest vertical displacement of longitudinal truss

Figure. 8 Time interval displacement response curve contrast with substructure or not

Through the ANSYS analysis, Table 2, 3 are listed the biggest nodal displacement of middle truss of the complex lattice shell with substructure or not, which is effected under 3-dimensional EL-Centro seismic wave. Simultaneously, the biggest displacement responds surface of the transverse and the longitudiual truss is drown (as shown in Figure 8). From the list of each nodal location of the two kinds model, we can see that although the biggest nodal displacement is changed, but the rule of each nodal displacement change is basically accord. And the biggest vertical displacement response curve, as a result of substructure cooperation perTableance, the overall rigidity is reduced. Although the biggest vertical displacement of nodes has reduced, but the overall displacement of the structure is large when not consider the substructure. Therefore, we could consider the flounce of cooperative performance to structure in the structural design.

4.3 The influence of damping ratio

The lower part supporting of lattice shell structure is generally the reinforced concrete frame or the column. Because the different material its energy loss mechanism is different. At present, in seismic design regarding the steel structure the damping ratio ζ is 0.02, the reinforced concrete structure ζ is 0.05. Toward the shell and the supporting combination system which consist of two different materials (steel - concrete), the corresponding damping ratio can not be simply used a certain kind of material damping ratio. The MIDAS/Gen structure finite element analysis software is applied in this paper. Damping ratio practical computational method - - potential energy weighting mean method of composite structure of different materials which is included the beam element and the bar element is used [2]. The group damping ratio is set in the analysis. The preceding 200-order vibration mode corresponding damping ratio is calculated respectively (Figure 9).

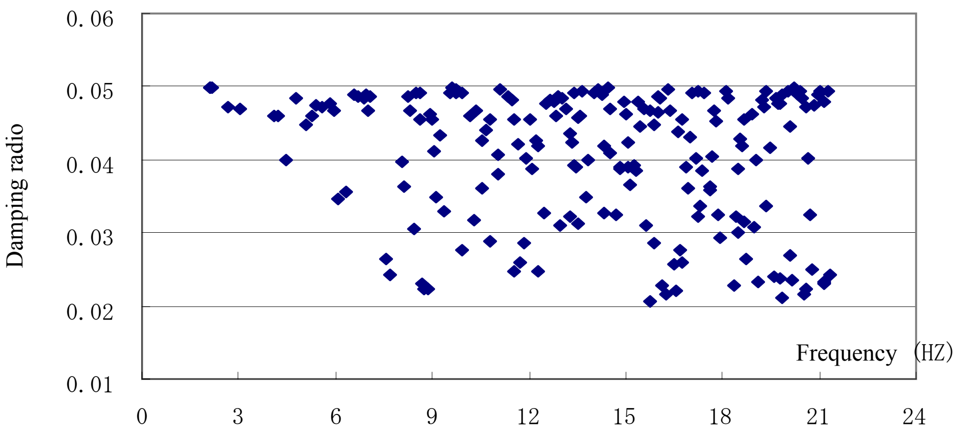


Figure. 9 Various steps vibration mode corresponding damping ratio

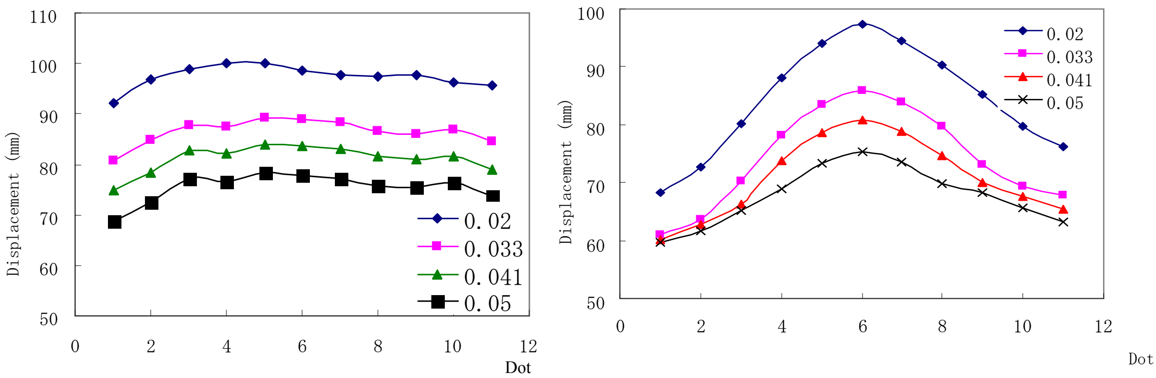
The reliability analysis of the structure is used the method of Probability and Mathematical Statistics. To calculate the average of the preceding 200-order vibration mode damping ratio $\mu_z = 0.041$, standard deviation $\sigma_z = 0.008$, obtained reliability index $\beta = 4.8$, meet the "Unified standard reliability design of building structures" requirement. Therefore, the overall structure of the damping ratio should be between 0.033 ~ 0.049. The damping ratio is respectively taken 0.02, 0.033, 0.041 and 0.05 in this paper. The trifarious EL-Centro seismic wave is entered. The earthquake effect influence of different damping ratio to the large-span complex lattice shell structure which to consider substructure is analyzed.

Table 4 Nodal displacement comparison of transverse truss midspan（mm）

Point / ζ	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11
0.02	92	97	99	100	100	99	98	98	98	96	96
0.033	81	85	88	88	89	89	88	88	86	87	84
0.041	75	78	83	82	84	84	83	82	81	82	79
0.05	69	72	77	77	78	78	77	76	76	76	74

Table 5 Nodal displacement comparison of longitudinal truss midspan（mm）

Point / ζ	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
0.02	68	73	80	88	94	97	95	90	85	80	76
0.033	61	64	70	78	84	86	84	80	73	69	68
0.041	60	63	66	74	79	81	79	75	70	68	66
0.05	60	62	65	69	73	75	74	70	68	66	63



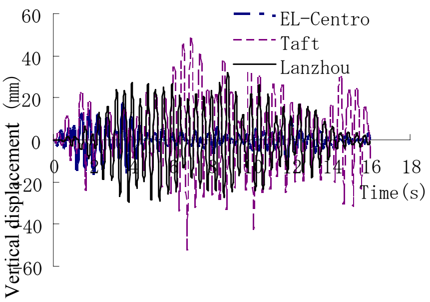
1）The biggest node displacement of transverse truss2）The biggest node displacement of longitudiual truss

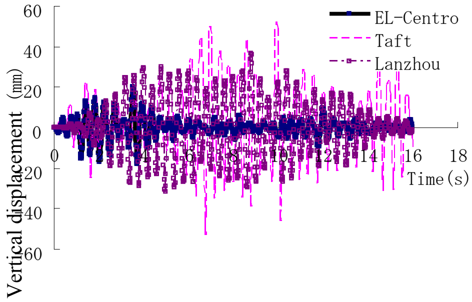
Figure 10 The structure time interval displacement response contrast under the different damping ratio

4.4 The influence of different seismic wave

The above conclusion is based on the analysis result of a seismic wave. Because seismic randomicity is strong, so used different seismic waves to study the influence of seismic response that complex lattice shell structure with substructure have certain significance. The model is input separately by the 3-dimensional EL-Centro wave, the Taft-wave and the

Lanzhou wave. The duration of the three seismic waves all is 16s. Drawing conclusions through the computation, the biggest vertical displacement of the transverse and the longitudiual truss which under the three seismic waves respectively is 18mm, 53mm, 34mm and 21mm, 54mm, 37mm. The structural biggest displacement time interval response curve (as shown in Figure 11). We can see from the chart, the dynamic response of the complex lattice shell structure that under different seismic waves is obviously different. Therefore, the dynamic time interval analysis of the actual project under macroseism function should be chosen a number of seismic waves, and to choose reasonably according to the specific filed.





1) The biggest vertical displacement of transverse truss 2) The biggest vertical displacement of longitudiual truss

Figure 11 The structure time interval displacement response contrast under different seismic waves

5. Conclusion

Through the above research and analysis can be drawn the following conclusions:

(1) When the modal analysis is carried on, owing to the cooperative performance is considered, the overall rigidity is reduced. The preceding 10-order frequency difference of vibration mode is between 20~30%. With the vibration mode order is increased, the frequency difference will be increased. Therefore, for such large-span complex spatial structure, modal analysis can not be only taken the several step of vibration modes, the multistage should be also considered. Simultaneously, the substructure has effect on the structural frequency.

(2) Input the 3-dimensional EL-Centro seismic wave to the model with substructure or not. Although the biggest nodal displacement of the middle truss is changed, but the rule of each node displacement change is basically accord. And the biggest vertical displacement response curve, as a result of substructure cooperation performance, the overall rigidity is reduced. Although the biggest vertical displacement of nodes has reduced, but the overall displacement of the structure is large when not consider the substructure.

(3) The method of Probability and Mathematical Statistics is applied. To calculate the preceding 200-order vibration mode damping ratio of the overall structure should be between 0.033～0.049. With the damping ratio increase, the biggest nodal displacement is affected obviously. Therefore, consider the influence of the overall structure cooperative

performance, the structure damping ratio is selected reasonably. It is especially important to steel - concretes combination spatial structure design.

（4）Drawing conclusions through the computation, the biggest vertical displacement of the transverse and the longitudiual truss which under three seismic waves respectively is 18mm, 53mm, 34mm and 21mm, 54mm, 37mm. The dynamic response of the complex lattice shell structure that under different seismic waves is obviously different. Therefore, the dynamic time interval analysis of the actual project under macroseism function should be chosen a number of seismic waves, and to choose reasonably according to the specific filed.

References

[1] Xue Suduo, Wang Jianning, CaoZi, ZhangYi-gang. Elastic-Plastic Seismic Response Analysis of Lattice Shells. Journal of Beijing University of Technology.2001, 27(1):50-53

[2] Cao Zi, Zhang Chao, Zhang Yigang, Xue Suduo. A Study on The Dynamic Interaction between Lattice Shells and The Supporting Structures. Spatial Structure.2001.7 (2)

[3] Wang Xiuli, ChenJi-yun, YanRen-gang. Seismic Response Analysis of Single-layer Combination Lattice Shell Considered The Influence of Substructure . [J]. Industrial Architecture.2007.

[4] Chen Yingbo, Chen Junming. Study of The Cooperative Effect between Reticulated Shell and Supporting Structure. Journal of Huazhong University of Science and Technology.2004,32(3):49-53

[5] Cao Zi, Xue Suduo. Anti-Semitic Theory and Design of Spatial Structure. [M].Beijing: Science Press.2005.

[6] Wang Xiuli, Wang Lei. The Performance Influence of Boundary Supporting to Complex Shell. Industrial Architecture [J].2008

[7] Guo Haishan, Qian Hongliang, Shen Shizhao. Dynamic Stability of Single-layer Reticulated Domes under Earthquake Excitation [J]. Earthquake Engineering and Engineering Vibration.2003, 23(1):31-35

[8] He Fanglong; Ma Zike. Nonlinear Analysis of Double-Layer Reticulated Spherical Dome under Strong Earthquake Motions. Journal of Hunan University.2007,34,(10):1-5