THE STUDY ON SHAKING TABLE TEST OF INTELLIGENT VIBRATION CONTROL FOR SPACE STEEL STRUCTURE

Penggang Tian[1,2] ,Sheliang Wang[2],Zhaowei Bian[2], Junqiang Zhu[2]

[1] *Doc, Shaanxi Research Institute of Architecture and Science, Shaanxi, China.*
[2] *Professor, Institute of Civil Engineering, Xi'an University of Architecture and Technology, Shaanxi, China*
Email: wangshel@yahoo.com.cn,tpg97537@163.com

ABSTRACT :

According to the excellent piezoelectric effect and converse piezoelectric effect, this paper designs and fabricates piezoelectric pivot element bars which can accomplish testing-controlling functions, that is, integrate a piezoelectric stack into the element bars playing a major role to form a so-called piezoelectric pivot element bar, and then integrate this piezoelectric pivot element bar into space steel structure thus to realize an intelligent monitoring and vibration control on space steel structure. Based on the above principle, this paper performs shaking table tests on intelligent vibration control for two models of space steel structure with the piezoelectric pivot element bars applied. By respectively inputting an acceleration record of El-Centro earthquake wave and a simple harmonic load, followed by changing the peak acceleration of earthquake wave and the frequency of simple harmonic wave, this paper investigates the influences of such factors on control effectiveness as the size of piezoelectric stack, the stiffness and deformation of model structure, the magnitude and characteristic of external excitation, and excitation voltage etc.. The experimental results indicate that:(1)the size variation of piezoelectric stack in pivot element bar is of little influence on the effectiveness of structural control, (2)when the amplitude of external excitation is big, for a flexible structure the effectiveness of control is rather conspicuous, but when the amplitude of external excitation is comparatively small, the effectiveness of control is relatively obvious for a stiff structure, (3)if the characteristic of external excitation is kept constant, the control effectiveness of pivot element bar over model structures is increasingly obvious with the increase in magnification times of excitation voltage.

KEYWORDS: space structure, piezoelectric pivot element bar, intelligent vibration control, shaking table test

1. Introduction

Space steal structure which has the characteristics of novel structural forms, graceful architectural sculpt and good ability of span is widely researched an applied day by day and also developed rapidly in the world. This structural form provides possibility for enlarging the span ability and diversity of space forms and is widely used civil buildings and industry structure. According to the statistics, our country has dozens of important buildings been built yearly such as large gymnasium, opera house, garage, museum, launch shelves. The construction area has exceeded 10 million square meters each year. With the quick development of economy and incessant improvement of living standard, the span ability and space forms of space structure will be required more and the need of space steal structure will also grow day by day. But this kind of structure has the character of structure containing defects， such as the dense distribution of frequency and the complexity of bearing state, deformation, details of structure and failure mechanism and performance evaluate theory, speciously for many complicated high nonlinear, magnetic field coupling, failure mechanism and collapse mechanism caused by excitation of earthquake. Additionally the effect and influence of design loads in use , construction quality, environment and people, material performance of the structure will be changed. As the same time cumulative scathe will be inevitable, disaster resistance reliability decreased constantly and unexpected collapse will possibly happen. It will be worse when there is dynamical effect like severe earthquake. According to the excellent piezoelectric effect and converse piezoelectric effect, this paper designs and fabricates piezoelectric pivot element bars which can accomplish intelligent vibration control (Gao. W 2000; Chen.C.Q 1997; Li.J.B 1996) and testified the effectiveness by the shaking table test.

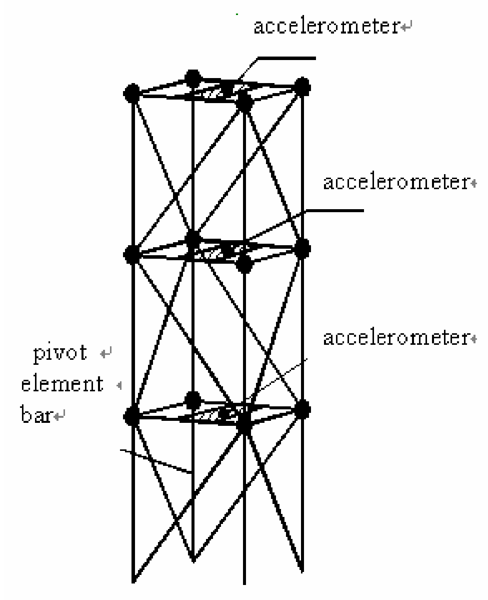

Figure 1 Model structure

2. Research of Intelligent Vibration Control by Shaking Table Test

There are two models in this test. Oblique bracing was fixed in Model 1. Compared with Model 1, Model 2 has no oblique bracing in long-distance direction. The difference is to find the general law of piezoelectric pivot element bars' effect on different space structure. Both of the two models are all made from PTBS2. (The bars are all Q235 steel tube with 5mm outside diameter and 1mm thickness.) The whole model is 300x400mm and three stories. Each story is 400mm high. Steel balls each weighing 0.5Kg are arranged on every joint to simulate the weight and also can help the connection. (Fig.1)

2.1 Methods of Loading and Measure Pionts.

We carried out 69 kinds of load cases including the peak acceleration of El-centro earthquake wave by 200gal, 400gal, 600gal, 800gal, 1000gal and 1200gal and we also changed the magnification times of excitation voltage of some of those load cases. Carrying out the shaking table test of the model structure by using the magnification times of voltage 1, 10, 20 and 30 to discuss the general law of intelligent monitoring and vibration control over space structure with the piezoelectric pivot element bars applied and check the corresponding results so as to made the results of widely representation. In order to make it obvious, this paper listed parts of testing load cases and methods of loading in Tab.1 and measure points and physical measure items in Tab.2

Table 1. The list of parts of testing load cases and methods of loading

Load-Case	peak acceleration	control sort	magnify	model	remark
Load-Case 8	200gal	uncontrolled		Model 1	
Load-Case 9	200gal	controlled	10	Model 1	(driving
Load-Case 12	600gal	uncontrolled		Model 1	
Load-Case 13	600gal	controlled	10	Model 1	(driving
Load-Case 17	200gal	uncontrolled		Model 2	
Load-Case 18	200gal	controlled	10	Model 2	several reach

Load-Case 19	200gal	controlled	20	Model 2	1/4 reach to 202
Load-Case 20	200gal	controlled	30	Model 2	half reach to 202
Load-Case 30	1200 gal	uncontrolled	5	Model 2	
Load-Case 31	1200 gal	controlled	5	Model 2	half reach to 202
Load-Case 48	1.87HZ	uncontrolled		Model 2	
Load-Case 49	1.87HZ	controlled	10	Model 2	Half reach to 202
Load-Case 50	1.87HZ	controlled	20	Model 2	majority reach
Load-Case 51	1.87HZ	controlled	30	Model 2	4/5 reach to 202

Table 2.Measure points and corresponding physical measure items

measure points number	physical measure items	measure points number	physical measure items
1	strain	2	speed of table-board
3	acceleration at 1st floor	4	acceleration at 2nd floor
5	acceleration at 3rd floor	6	displacement of table-board
7	displacement at 1st floor	8	displacement at 2nd floor
9	displacement at 3rd floor	10、11、12	strain at 1st floor
13、14、15	strain at 2nd floor	16、17、18	strain at 3rd floor

2.1 Methods of Loading and Measure Points

2.1.1 Contrast of model 1's test results of control and uncontrolled.

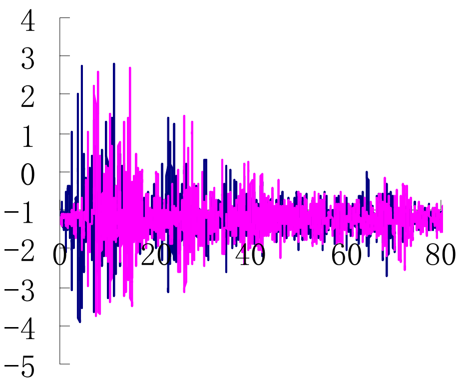

Figure 2. Control and uncontrolled contrast of measure point 7 under peak acceleration of 200gal

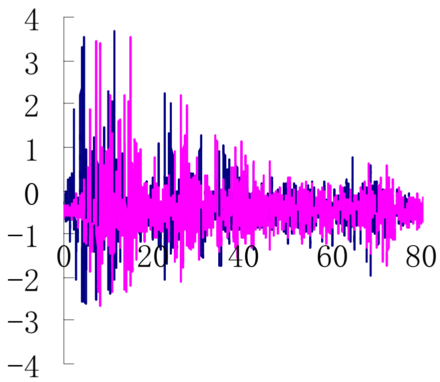

Figure 3. Control and uncontrolled contrast of measure point 8 under peak acceleration of 200gal

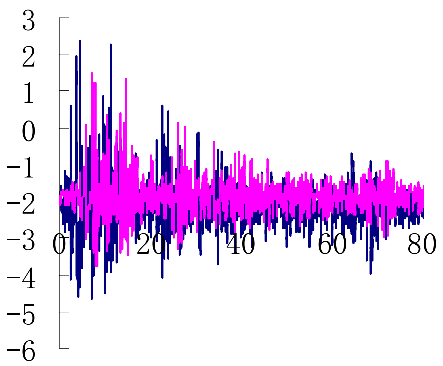

Figure 4. Control and uncontrolled contrast of measure point 9 under peak acceleration of 200gal

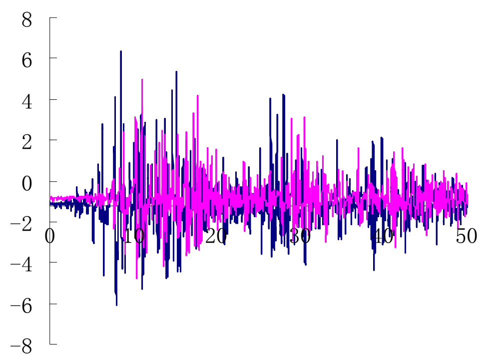

Figure 5. Control and uncontrolled contrast of measure point 7 under peak acceleration of 600gal

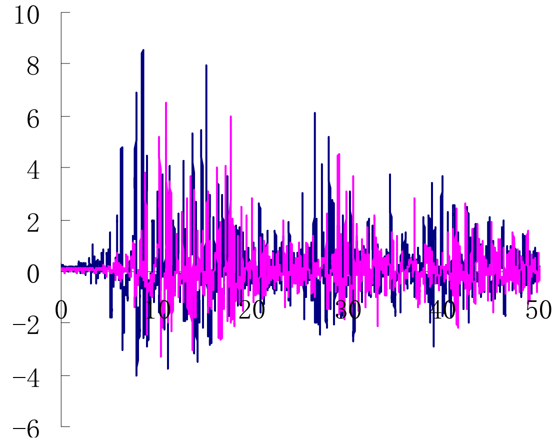

Figure 6. Control and uncontrolled contrast of measure point 8 under peak acceleration of 600gal

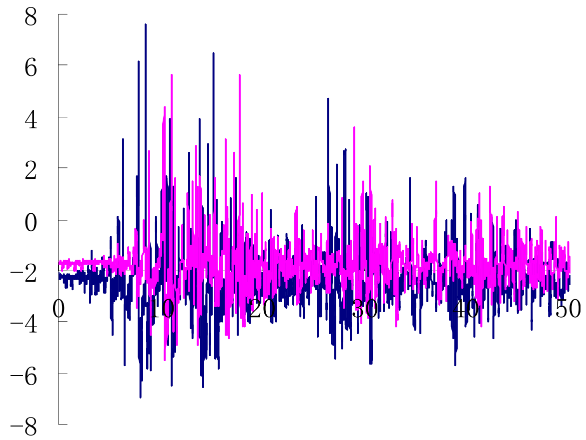

Figure 7. Control and uncontrolled contrast of measure point 9 under peak acceleration of 600gal

2.1.2 Contrast of model 2's test results of control and uncontrolled.

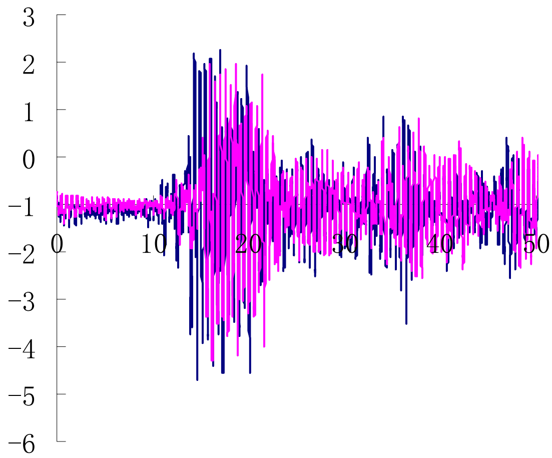

Figure 8. Control and uncontrolled contrast of measure point 7 (amplification coefficient of 10)

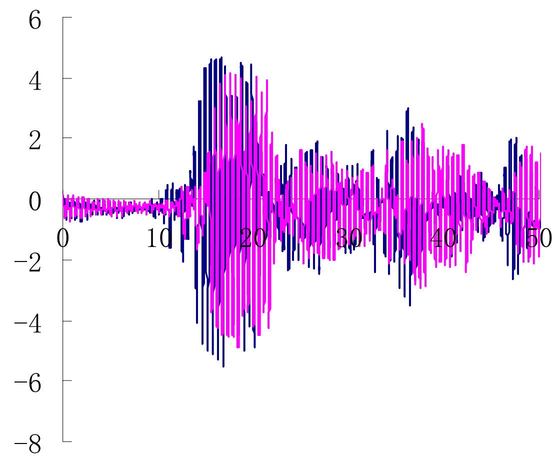

Figure 9. Control and uncontrolled contrast of measure point 8 (amplification coefficient of 10)

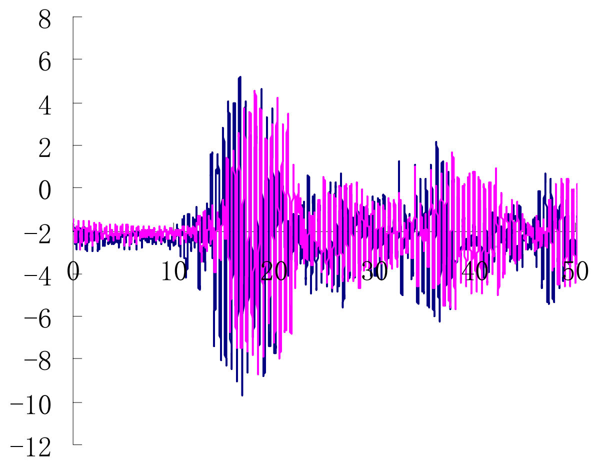

Figure 10. Control and uncontrolled contrast of measure point 9 (amplification coefficient of 10)

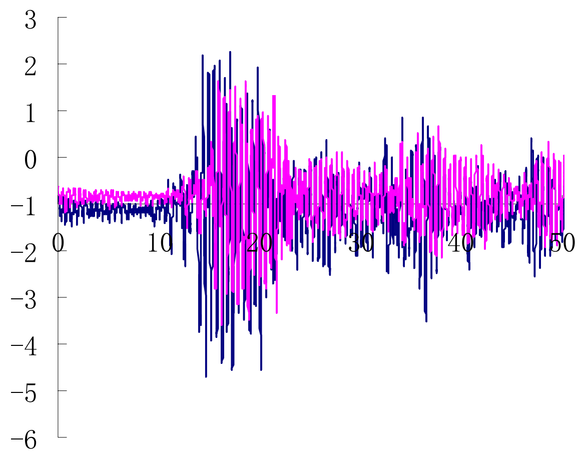

Figure 11. Control and uncontrolled contrast of measure point 7 (amplification coefficient of 20)

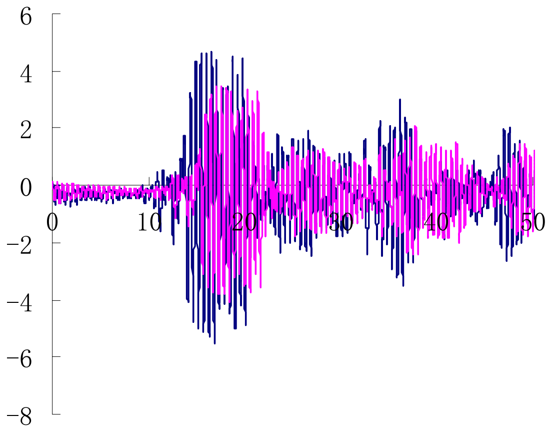

Figure 12. Control and uncontrolled contrast of measure point 8 (amplification coefficient of 20)

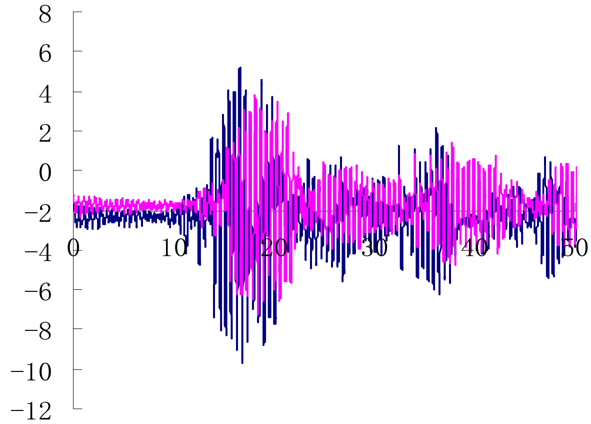

Figure 13. Control and uncontrolled contrast of measure point 9 (amplification coefficient of 20)

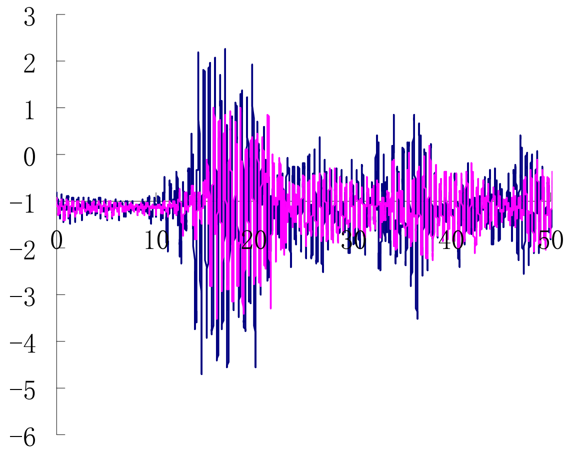

Figure 14. Control and uncontrolled contrast of measure point 7 (amplification coefficient of 30)

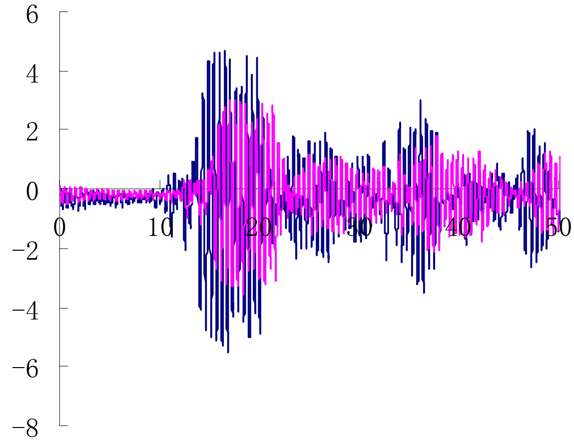

Figure 15. Control and uncontrolled contrast of measure point 8 (amplification coefficient of 30)

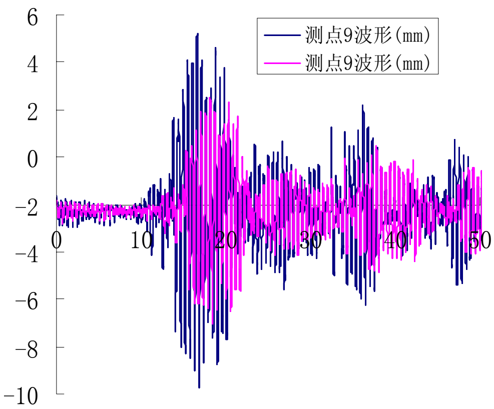

Figure 16. Control and uncontrolled contrast of measure point 9 (amplification coefficient of 30)

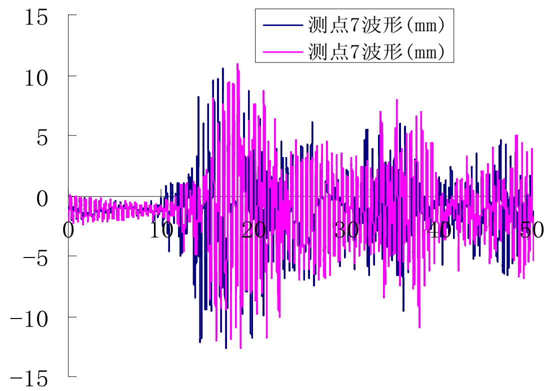

Figure 17. Control and uncontrolled contrast of measure point 7 under peak acceleration of 1200gal

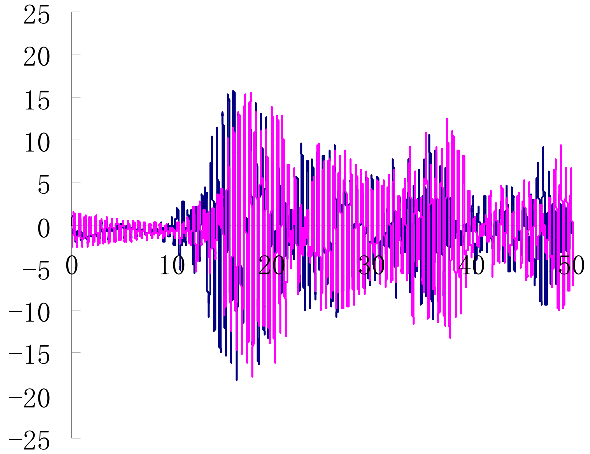

Figure 18. Control and uncontrolled contrast of measure point 8 under peak acceleration of 1200gal

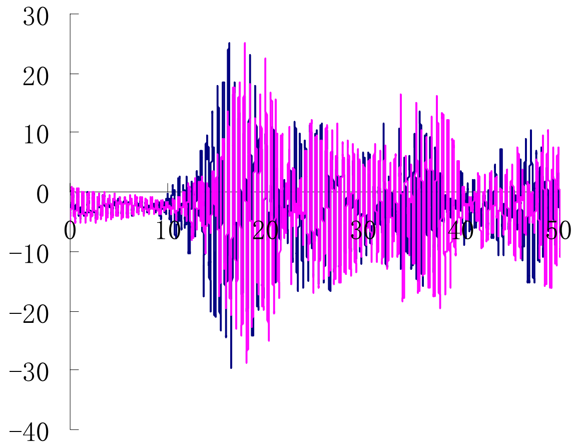

Figure 19. Control and uncontrolled contrast of measure point 9 under peak acceleration of 1200gal

2.1.3Analysis of Testing Results

It is shown from Fig.2-4 that when the peak acceleration record of El-Centro earthquake wave is 200gal the deformation of all three floors of structure model 1 had decreased with control compared to uncontrolled. The deformation decrease of the top floor is the most obvious one reaching to about 30%. The second floor is less and the first floor is the least only about 7.6%. But from Fig.5-7, when the peak acceleration was 600gal the changing trend of deformation of the whole structure after control is just same as that was 200gal. Compared with the results under two load cases synthetically we can see the deformation decrease of each floor of structure model 1 had increased a lot than when the peak acceleration was 200gal. Deformation decrease of the top floor after control can reach to 40% contrast with that of when the peak acceleration was 200gal. It proves that the stronger seismic excitation the better result of vibration control of piezoelectric pivot element. It was because that driving force from piezoelectric pivot element was bigger when the peak acceleration was 600gal than that of 200gal. So it was more effective to adjust the internal force and restrain the deformation.

The stiffness of model 2 on the seismal direction is much lower than model 1 for the oblique bracing is only set in the short-distance direction. Correlative curve can be drawn according to the results of the test. From Fag.8-16, the reactive deformation of all the floors of model 2 had decreased about 10% under control when affected by 200gal peak acceleration of El-centro earthquake wave compared with uncontrolled. It was mainly because that when the stiffness of structure is low, the period is long and driving force from piezoelectric pivot element is smaller therefore the control effect was less than model 1. But test results of model 2 indicated that if the external excitation is kept constant and just magnify the magnification times of excitation voltage of pivot element bar by 10, 20 and 30 the control effectiveness of pivot element bar over model structures is increasingly obvious with the increase in magnification times of excitation voltage. When the magnification is 10, the deformation of the first floor decreased about 10% before and after control. The deformation of the second floor decreased about 20% and the deformation of the third floor decreased about 25%. When the magnification is 20, the deformation of the first floor decreased about 20% before and after control. The deformation of the second floor decreased about 25% and the deformation of the third floor decreased about 30%. When the magnification is 30, the deformation of the first floor decreased about 30% before and after control. The deformation of the second floor decreased about 35% and the deformation of the third floor decreased about 40%. It proved that when doing the intelligent vibration control over the space structure with piezoelectric pivot element bar, the control character can be effectively mastered by changing excitation voltage and the bigger excitation voltage the more obvious control effect. In addition, by Fig. 17-19 we may see that applying piezoelectric pivot element bar to accomplish vibration control on model structure 2 is effective when external excitation is El-centro earthquake wave with the peak acceleration of 1200gal. Moreover piezoelectric pivot element bar has certain restrain ability on all the three floors' deformation and the control effect of the top floor is the most obvious one. The deformation of the first floor changed about 20% before and after control. The deformation of the second floor changed about 25% and the deformation of the third floor changed about 40%.

Comparing the test results of model 1 and model 2 we can see that when there is external excitation the deformation of model 2 with out control, generally speaking, is bigger than model 1 and the change amount of model 2 which get increasing with the increase of external excitation with out control is bigger than that of model 1. When carry out the vibration control over model structure with piezoelectric pivot element bar the control effect of model 1 is better than that of model 2 under the El-centro earthquake wave with the peak acceleration of 200gal. But when we changed the peak acceleration to 600gal the control effect of model 2 is better than that of model 1. It illustrated that when carry out the vibration control over space structure with piezoelectric pivot element bar if the amplitude of external excitation is big, for a flexible structure the effectiveness of control is rather conspicuous, but if the amplitude of external excitation is comparatively small, the effectiveness of control is relatively obvious for a stiff structure.

Making a comprehensive view of the test results of model 1 and model 2 we also can see that when affected by the El-centro earthquake wave with the peak acceleration of 200gal the control effect of both models is not prominent for the deformation of structure is comparatively small. When the peak acceleration is 600gal all the control effects were the most remarkable. But the deformation of model structures had decreased of different extent after control when the peak acceleration is 1200gal and the control effect was better than that of the peak acceleration is 200gal but worse than that of the peak acceleration is 600gal. This had reflected the general law of the vibration control over the space structure with piezoelectric pivot element bar and also may be the references of further study. In addition, bigger drive force can be obtained by increasing the magnification times of excitation voltage when affected by external excitation. So the effect of intelligent vibration control with piezoelectric pivot element bar will be much better if the magnification times of excitation voltage increase. It's mainly because that the drive force increase with the excitation voltage increasing and control effectiveness will be better too. More is indicated that it's feasible and practical to achieve the intelligent vibration control with piezoelectric pivot element bars by changing excitation voltage to accomplish the preconcerted control target.

3. Conclusion

This article studied the basic theory and the methods of intelligent vibration control on space structure with piezoelectric pivot element bars through the theoretical analysis and the model experiment and drew following main conclusions:

(1) When carrying out intelligent vibration control on space structure with piezoelectric pivot element bars the characteristic of stiffness and deformation of model structure, the size and characteristic of external excitation and the size of excitation voltage are all the main factors that influence the control effect. Ordinarily speaking, when the amplitude of external excitation is big, for a flexible structure the effectiveness of control is rather conspicuous, but when the amplitude of external excitation is comparatively small, the effectiveness of control is relatively obvious for a stiff structure. If the peak acceleration of external excitation is kept constant, the control effectiveness is increasingly obvious with the increase in magnification times of excitation voltage. That is to say the drive force provided by piezoelectric pivot element bars increase with magnification times of excitation voltage and the control effect over model structure will be much remarkable.

(2) The research results also indicated that when without regard to coupling between mechanic-electric of piezoelectric pivot element bars which namely means that there is no control over model structure the deformation of model structure increase with the accretion of external excitation. But when regard to coupling between mechanic-electric of piezoelectric pivot element bars which namely means that there is control over model structure the control effectiveness is of some rules. To both of the two models when the peak acceleration of earthquake wave is 200gal the control effect is unconspicuous which is normally about 10 % in spite of the stiffness of the structure; when the peak acceleration of earthquake wave is 400gal-1000gal the control effect is most obvious which can reach to 45 %.But if the peak acceleration of earthquake wave enlarge to 1200gal the control effect is inapparent compared with when the peak acceleration of earthquake wave around 400gal-1000gal for the driving force of piezoelectric pivot element bars already achieved its critical value of working state and the control effect is generally about 25%. It tells us that it is better to choose suitable piezoelectric pivot element bars and driving force when carry out intelligent vibration control on space structure with piezoelectric pivot element bars in order to ensure that piezoelectric pivot element bars work in normal working range under uncertain loads

like earthquake thus the good vibration control effect and social economy benefit can be obtained.

References

Wang She-liang, Tian Peng-gang (2006) Control of Intelligent Truss Structure with Piezoelectrical functional materials. Symposiumof Xi’an International Architecture，103-109.
Gao Wei (2000) Research on Active Vibration Control of Intelligent Truss Structure with Random Parameters. Xi’an：Xi’an University of Electronic Science and Technology .
Chen Chang-qing (1997). Mechanical Properties of Piezoelectric Intelligent Structures and its Application. Xi’an：Xi’an Jiao Tong University .
Li Jun-bao(1996). Study on the theoretical and experimental of Design, Modeling and Damping Control of intelligent truss structure. Nanjing：Nanjing University of Aeronautics and Astronautics.
Tani, J., Doki. H. (1982), Dynamic stability of orthotropic annular plate under pulsating radial loads. J. Acoustic. Soc. Am., 72：845-850.
Bert, C. W., Birman, V.（1987）, Dynamic instability of shear deformable antisymmetric angle-ply plates. Int. J. Solids Struct., 23：1053-1061.
Bolotin, V. V（1964）. The Dynamic Stability of Elastic Systems. San Francisco：Holden-Day.