Numerical Response Analysis and Shaking Table Tests for Bridge and Building Complex Structural System (Part I: Complex Structure Dynamic Test Research)

D.M. Feng[1] W.F. He[2] Y.Q. Yang[3] and W.G. Liu[4]

[1]*Chief Researcher, Fujita Corp., Kanagawa, Japan*
[2]*Postdoctor, Shanghai University, Shanghai, China*
[3]*Associate Professor, School of Estate, Shanghai University, Shanghai, China*
[4]*Professor, Dept. of Civil Eng., Shanghai University, Shanghai, China*

ABSTRACT :

In the paper, the bridge and building complex structural system is proposed as a new seismic structural system, and a steel frame complex structural model with the dissipation devices is designed for a large scale shaking table dynamic test. Based on the new complex structural system and dynamic test results, the computation model, design parameters, earthquake response numerical analysis and the earthquake response decrease effect are mainly researched in our research. The basic concept system of bridge and building complex structure with energy dissipation devices is provided firstly, and a steel frame structural model weighted 4.5 ton is designed. The research results show that the complex structure has a good reduction vibration effect; the acceleration response decreases nearly 50% in horizontal direction for building part. Compared to the pure bridge structure system, the acceleration response in deck of the bridge of the complex structure decreases 9%~30%, and the displacement responses decrease is 8% to 30%. The dynamic test results showed the new bridge and building complex structural system has good reduction vibration effect for both parts of bridge and building.

KEYWORDS: The bridge and building complex structure, earthquake responses, isolation system

1. INTRODUCTION

Since the concept of structural seismic control was proposed by J. T. P. Yao in 1972 (Yao.1972), there have been 30 years for anti-vibration technology development. The new damping control technology is different from the method used before and can transform the thought of making bearing structural system resist lateral loads, specially for the seismic effect(L.Wenguang.2003). After that, the researches and applications based on structural seismic control have developed quickly. The scholars and engineering and technical personnel from America, Japan and China have improved a variety of anti-vibration technologies, including the base isolation system, passive control (TMD and TLD) and active control (AMD) (Kobori, et al.1993, Symans, et al.1996,). All this technologies have been already applied in the fields of bridges, high-rise structures and common civil buildings. A series of research results have been obtained in anti-vibration technology related on the applied foundation theory and engineering applications (Housner et al.1997). This anti-vibration technology has become the focus at home and abroad because of the clear principles. The effective use of land resources and seismic resistance behavior of roads and bridges have also become the focus owning to rapid development of cities, including transportation systems. In 2001, a long of 200 meters shopping street has been built in Atsugi (Japan)；Beijing Xizhimeng (2003, China) light railway station adopted a form that the track punctured into the building; in 2006, a new planning railway station would also adopt the scheme of high-rise station in Guangzhou (China). Therefore, the bridge and building complex structural system is the research trend in passive control fields, corresponding technologies and problems need to be solved as soon as possible.

In the paper, the bridge and building complex structural system is proposed as a new seismic structural system, which is based on existing theory of seismic control, and a steel frame complex structural model with three dimensional energy dissipation devices is designed in our research for a large scale shaking table dynamic test.

2. SHAKING TABLE TESTS FOR COMPLEX STRUCTURAL STEEL FRAME MODEL

2.1. Test Summary

A overhead bridge and building complex structural seismic model is used in this test，the model scale ratio is 1:12, the longitudinal and transverse distance of the overhead bridge piers is 1.6m and 1.6m, respectively; the monolayer height of the building is 0.8m, the horizontal width is 0.8, the longitudinal length is 1.6m. The plan view and elevation view are presented in figure 1, and the picture of the model is presented in figure 2.
The resemble parameters ratios are presented in table 1.

Table 1 The resemble factor of the model

Physical quantity	Length	Modulus	Stiffness	Acc.	Time	Velocity	Deferment	Mass
symbols	Sl	SE	Sk	Sa	ST	Sv	Sx	Sm
dimension	L	ML-1T-2	MT-2	L/T2	T	L/T	L	M
similar-coefficient	1/12	1	1/12	1	1/3.46	1/3.46	1/12	1/12

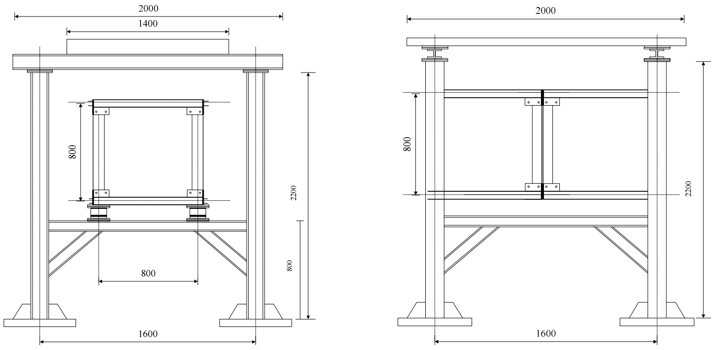

Figure 1 Sketch of model structure


Figure 2 Model structure

2.2. Bearings Choice

Given the stability mechanical properties of the rubber bearings and gross mass of the model, the side length of quadrate lead-core rubber bearings a=90mm, central pore diameter of lead b=10mm, the monolayer thickness of rubber t_r=3mm, the total layer of rubber n_r=9, the gross thickness of rubber T_r=27mm; the monolayer thickness of steel t_s=1.5mm, the total layer of steel n_s=8, the gross thickness of steel T_s=12mm, the thickness of uppers and lowers connecting steel sheet of isolation bearing is 20mm.

In order to check the basic mechanical properties, a test have been planed to do when the vertical press is 5MPa, shear strain γ=50% and γ=100% for 8 specimens. The test results are presented in the table 2. It can be seen from the table 2 that the mechanical properties of rubber bearing are very stable, therefore, that conform to test requirements very well.

2.3. Inputting Earthquake Waves

Given the varieties of factors, such as complexity compositions of frequency spectrum, the amplitude of ground motion, site classifications, seismic area intensity and ground fault, etc. Therefore, the test adopted 5 recorded high-earthquake waves, including El Centro wave, Taft wave, Chi-Chi wave, Kobe wave, and Rinaldi wave. Among them, the earthquake waves of Kobe and Rinaldi are typical near field earthquake waves. The characters of 5waves are listed in the table 3. Before the test, the recorded waves would be change into the test waves in terms of the time and amplitude. And according to 8 degree design seismic intensity, seldom seismic intensity for 8 degree and 9 degree, the amplitude could be changed into the 0.2g, 0.4g and 0.6g respectively.

Table 2 Detailed Properties of LRB

No.	Vertical-stiffness K_v /(kN/mm)	Yielding-post-stiffness K_2 /(kN/mm)		Equivalent-stiffness K_{eff} /(kN/mm)		Yielding-load Q_D /kN	
	5MPa	γ=50%	γ=100%	γ=50%	γ=100%	γ=50%	γ=100%
No.1	116	0.278	0.211	0.326	0.265	0.444	0.588
No.2	134	0.295	0.202	0.334	0.289	0.408	0.572
No.3	122	0.268	0.192	0.321	0.267	0.436	0.608
No.4	101	0.274	0.211	0.318	0.268	0.408	0.564
No.5	127	0.285	0.198	0.309	0.255	0.424	0.596
No.6	102	0.267	0.217	0.326	0.288	0.46	0.632
No.7	119	0.281	0.211	0.315	0.279	0.404	0.576
No.8	107	0.251	0.190	0.283	0.242	0.508	0.692
mean	116	0.275	0.204	0.317	0.269	0.436	0.604

Table 3 Selected earthquake waves table for the experiment

Earthquake wave	Earthquake	Years	Distant (km)	The maximum acceleration(g)		
				EW	NS	UD
El Centro	Imperial	1940	8.3	0.313	0.205	0.205
Taft	KJMA	1995	41	0.156	0.178	0.109
Chi-Chi3	CHY015	1999	32	0.145	0.157	0.032
Kobe	Kobe	1995	7.1	0.509	0.503	0.371
Rinaldi	Northridge	1994	11.1	0.838	0.472	0.852

3. EARTHQUAKE RESPONSE RESULTS OF DYNANIC TESTS

3.1. Acceleration Response of the Complex Model Test

3.1.1 Single direction earthquake wave

The results of comparison of the maximum acceleration response induced by single direction earthquake wave between building and table are presented in the figure 3. (Table: deck; Building: building structure). From the results, it can be observed that the acceleration response of building structural is obviously lower 13% to 50% than that of table. Under the minor and middle earthquake of El-Centro wave, the acceleration response has decreased by 25% and 44%, respectively. Under the middle and high earthquake of Chi-Chi wave and Rinaldi wave, it has decreased by 23% and 18%, respectively. It can be obtained that the acceleration response of the building of complex structure is obviously lower than that of the table, regardless of action of the near or long field earthquake waves.

The results of comparison of the maximum acceleration response induced by single direction earthquake wave between building and support are presented in the figure 4. (Support: part of support; Building: building structure). It can be observed from the fig.4 that the acceleration response of the building structural is lower 16% to 50% than that of the support. The acceleration response of the support is amplified so as to be far higher than that of the table. Under the minor earthquake of El-Centro wave, the maximum acceleration response has decreased by 31%, under the high earthquake of Chi-Chi and Rinaldi wave, it has decreased by 38% and 21%. It can be obtained that the acceleration response of the building of complex structure is obviously lowered by installing isolation devices.

The results of comparison of the displacement response induced by single direction earthquake wave between building and support are presented in the figure 5. (Support: part of support; Building: building structure). From the fig.5, it can be observed that the displacement response of the building structural is obviously larger than that of the support. The displacement induced by the middle and high earthquake of Rinaldi wave is 40.73mm.

From the comparison of the acceleration response or displacement response induced by single direction earthquake wave between building and table or building and support, it can be found that the complex system has a good reduction vibration effect on building structure. The acceleration response goes down and the displacement response goes up, compared to traditional building structure.

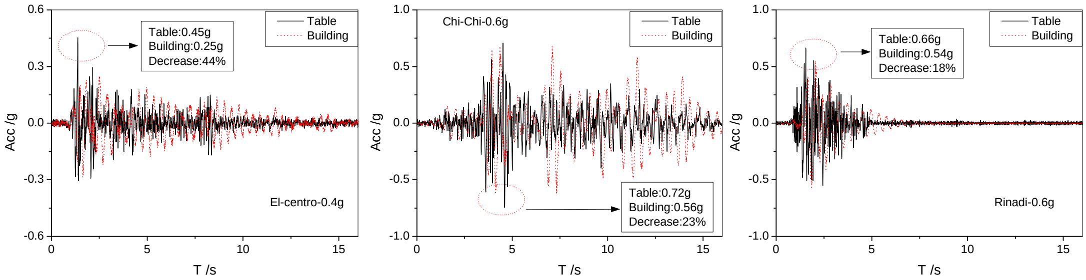

Figure 3 Comparison of the maximum acceleration response between building and table

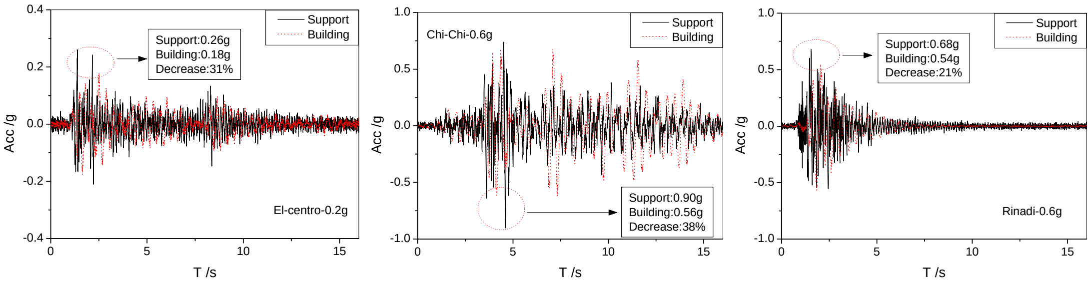

Figure 4 Comparison of the maximum acceleration response between building and support

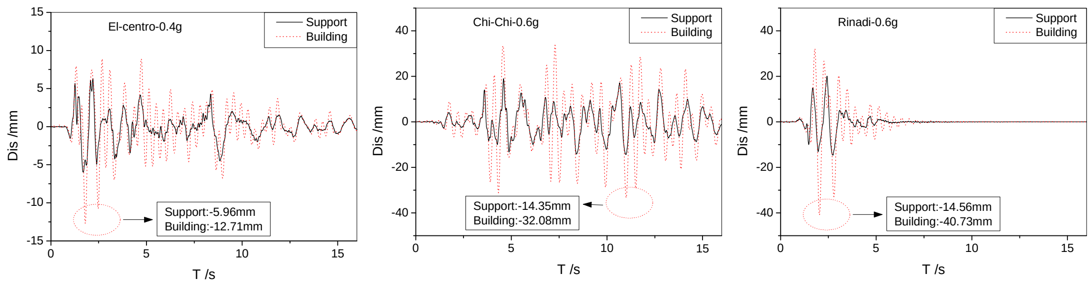

Figure 5 Comparison of the maximum displacement response between building and support

3.1.2 Bi-direction earthquake wave

The results of comparison of the maximum acceleration response induced by the bi-direction earthquake wave between building and table are presented in the figure 6. It can be seen from the Fig.6 that the X-direction acceleration response of the bridge deck is lower 37% to 52% than that of the table, and the Y-direction acceleration response of the bridge deck is lower 10% to 63% than that of the table. Under the minor and middle earthquake waves, the X-direction acceleration response is 54% and 62%, the Y-direction acceleration response is 63% and 62%, respectively. The acceleration response induced specially by near field earthquake wave would decrease much more.

The results of comparison of the maximum acceleration response induced by the bi-direction earthquake wave between building and support are presented in the figure 7. From the fig.7, it can be found that the acceleration response of the support of bridge is obviously lower than that of the table. Besides, the X-direction acceleration response of the building structure has decreased by 41%, 45% respectively under the minor and middle earthquake wave of El-Centro, decreased by 43%, 56% under Kobe NIS wave. The Y-direction acceleration response of the building structure has decreased by 36%, 59% respectively under the minor and middle earthquake wave of El-Centro, decreased by 69%, 72% under Kobe NIS wave.

The results of comparison of the displacement response induced by bi-direction earthquake wave between building and support are presented in the figure 8. It can be seen from the Fig.8 that the displacement response of the building structural is obviously larger than that of the support. The X-direction displacement of the support and building is 5.61mm and 14.54mm under the middle earthquake wave of El-Centro, and 2.48mm and 4.68mm, 5.87mm and 9.27mm under the minor and middle earthquake wave of Kobe NIS. The Y-direction displacement of the support and building is 11.17mm and17.78mm, 15.30mm and 24.85mm under the minor and middle earthquake wave of El-Centro, and 1.96mm and 3.52mm, 5.26mm and 7.93mm under the minor and middle earthquake wave of Kobe NIS.

It can be obtained that under the bi-direction interaction of varieties of earthquake intensities for near-field or middle-far-field earthquake wavers, the bridge and building complex structure have a good reduction vibration effect. The structural acceleration responses have decreased by 37% to 52%, meanwhile, the structural acceleration responses are lower than that in bridge piers by 41% to 72%. It reaches the conclusion that the bridge and building complex structure has a good reduction vibration effect as to the different period.

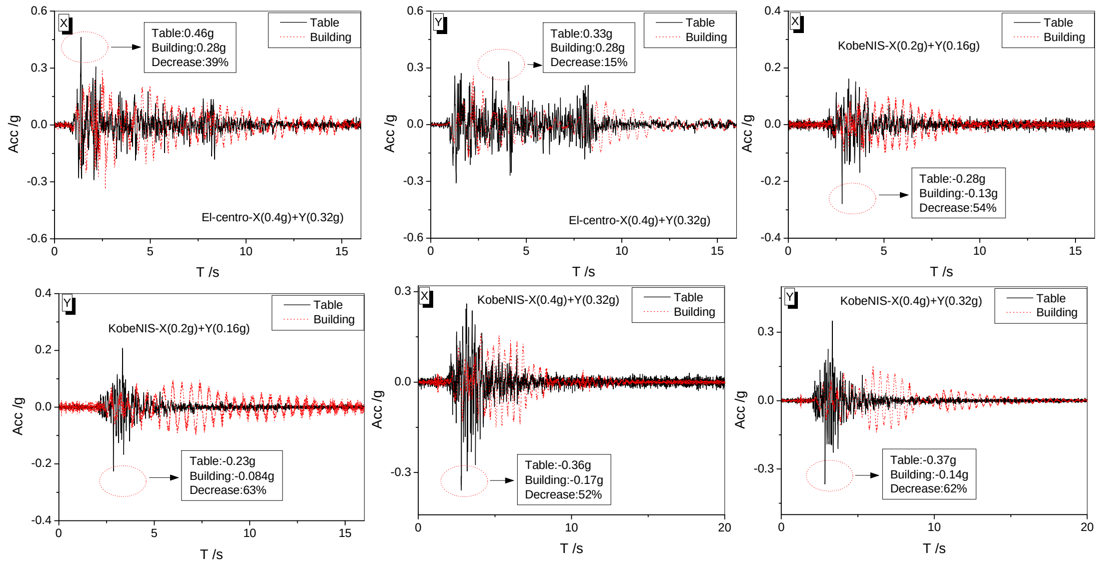

Figure 6 Comparison of the maximum acceleration response between building and table

3.2. Comparison of the Bridge-building Complex Structure and Pure Bridge Structure

3.2.1 Comparison of the Bridge Deck Acceleration Response

The results of comparison the acceleration responses of the bridge-building complex structure and pure bridge structure represented in the figure 9. The both acceleration responses are normalized to the same bridge deck acceleration response. It can be obtained from the fig.9 that the bridge-building complex structural responses are lower 9% to 30% than the pure bridge. The acceleration responses of complex structural induced by the middle earthquake wave of El-Centro have decreased by 16%, decreased 18% respectively under Chi-Chi wave, decreased by 10% under Rinaldi wave respectively.

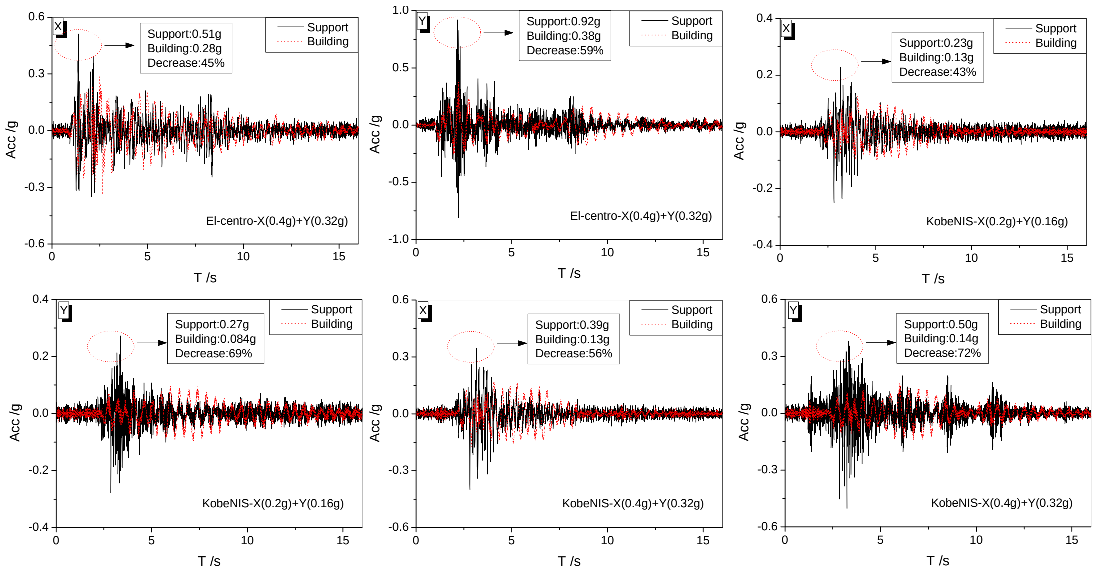

Figure 7 Comparison of the maximum acceleration response between building and support

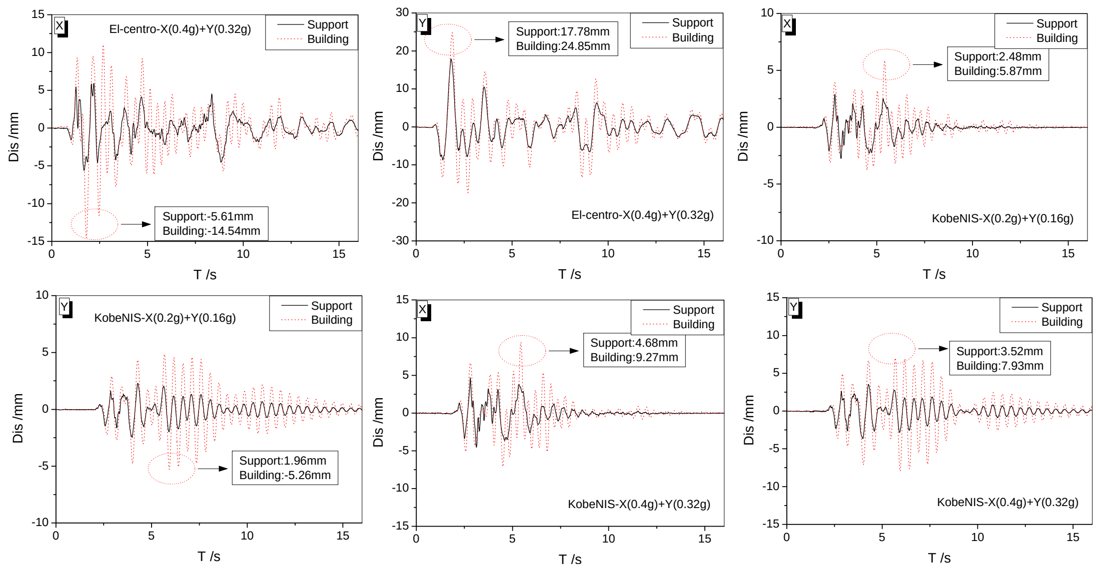

Figure 8 Comparison of the maximum displacement response between building and support

3.2.2 Comparison of the Bridge Deck Displacement Response

The results of comparison the displacement responses of the bridge-building complex structure and pure bridge structure represented in the figure 10. The both displacement responses are normalized to the same bridge deck acceleration response. It can be seen from the fig.10 that the bridge-building complex structural responses are lower 8% to 30%than the pure bridge. The displacement responses of complex structural induced by the middle earthquake wave of El-Centro have decreased by 13%, decreased 21% respectively under Chi-Chi wave, and decreased by 8% under Rinaldi wave.

3.2.3 Comparison of the Strain-response

The Comparison of the maximum strain-response between complex structure and bridge is presented in the figure 11. The data have been normalized to the same deck acceleration. It can be seen from the fig.11 that the maximum strain-response under the middle earthquake the El-Centro wave have decreased by 16%; and the Chi-Chi wave have decreased by 20% ; and the Rinaldi wave decreased by 11%; The strain in the bridge piers could go down in the bridge-building complex structure.

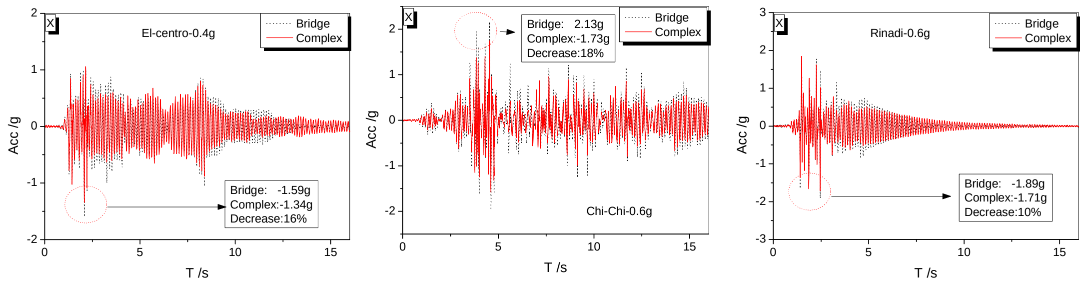

Figure 9 Comparison of the maximum acceleration response between complex structure and bridge

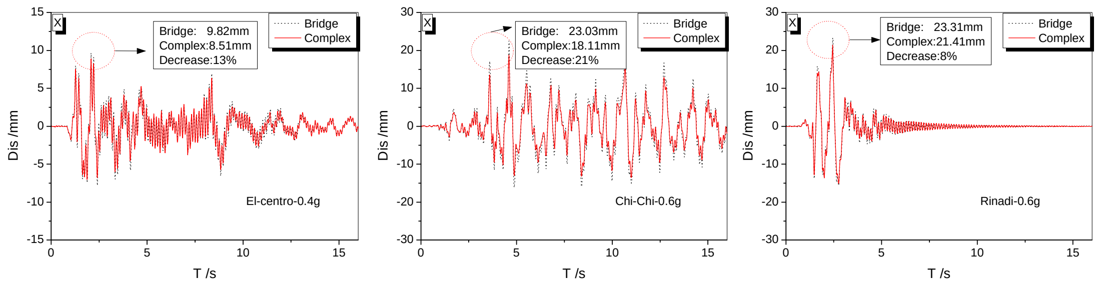

Figure 10 Comparison of the maximum displacement response between complex structure and bridge

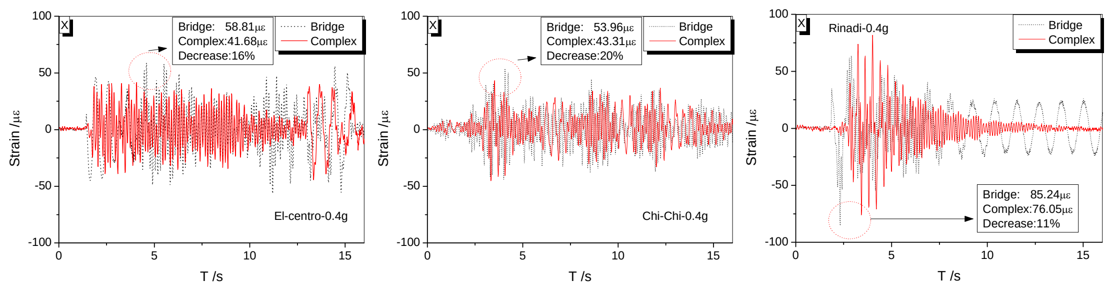

Figure 11 Comparison of the maximum strain-response between complex structure and bridge

4. CONCLUSIONS

In the paper, the bridge and building complex structural system is proposed as a new seismic structural system, and a steel frame complex structural model(1:12) with the energy dissipation devices is designed for a large scale shaking table dynamic test. From the test, results can be concluded as follows:

It can be observed that acceleration response of the building structural to inputting X-direction earthquake waves are obviously lower 13% to 50% than that of table. The acceleration responses of structure also are lower 16% to 50% than that of the supports, while the displacement responses of the structure also are eventually higher than that of the supports. Under the circumstances of different earthquake waves and inputting acceleration, the restoring force model of the connected supports has a good energy dissipation capacity and stability.

Under the bi-direction interaction of varieties of earthquake intensities for near-field or middle-far-field earthquake wavers, the bridge and building complex structure have a good reduction vibration effect. The acceleration responses of the structure have decreased by 13% to 52%, meanwhile, the structural acceleration responses are lower than that in bridge piers by 16% to 72%. It is observed that the bridge and building complex structure has a good reduction vibration effect as to the different period. It can be obtained that the bridge-building complex structural responses are lower than the pure bridge's, the range of decrease from 9% to 30%. The displacement responses of the bridge-building complex structural deck are lower than that in pure bridge, the range of the decrease from 8% to 30%. The strain in the bridge piers could go down in the bridge-building complex structure.

From results of the bridge and building complex structural model shaking table dynamic test, it can be conclude that the bridge and building complex structural system could has a good reduction vibration effect on building structure and bridge.

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