Design of Base-Isolated Structure with Rubber-Bearing

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ABSTRACT :

Base isolation design is a new technology on seismic control of structures. In this paper, the theories and steps of base-isolated structure with rubber-bearing design are introduced, then a practical example with isolating rubber-bearings and the corresponding design process are introduced and the simulation results are analyzed. The flexible connecting device of isolation layer design and a connection method of isolation bearing without top fixing plate are introduced. At last, the proposed isolated structure and the non-isolated structure are compared, the result shows the base isolation method can reduce the seismic response of structure evidently.

KEYWORDS : Frame-shear wall structure, isolation, design

Base isolation is a new technology proposed in 1960’s, its theory is simple while the effect is safe, which has more advantages than the traditional antiseismic structure design methods, and has been used in many projects, the corresponding specification standards and schematic handbook have been published. In this paper, the theories and steps of base-isolated structure with rubber-bearing are introduced, from the comparison of the proposed isolating structure’s experimental results with that of the non-isolating structure, we can see that the base isolation method can reduce the seismic response of structure evidently. The details of several steps of base isolation design are introduced, such as base isolated structure model test, flexible connecting device of isolation layer, a connection method of isolation bearing without top fixing plate.

1. Project introduction

To protect the building’s safety and that of the equipments setupped in the building，which is located in xicheng district, beijing, the seismic isolation with laminated rubber bearing isolators was used in this project. The building is frame-shear wall structure, the type of the base is stiffened raft foundation, the height of the building above the ground is 31m, 8 floors, while the height under the ground is 17m, 3 floors. The isolation layer is between the first floor and the roof slab of basement, the height of the isolation layer is 1.65m.

2. Base isolation design

2.1. Analysis Methods

The base isolation analysis is composed of 4 steps:
Step 1. Isolation layer character estimation. Firstly, confirm the design factors and aseismic fortification objects, supposing the superstructures is single-degree-of-freedom system and using response spectrum method of SDOF, the factors of isolation layer can be optimized by circular computation. The disposal, specification and number of rubber bearings of isolation layer can be estimated.
Step 2. Finite element analysis. The factors deduced from step 1 are regarded as the original factors, with the finite element analysis, we can get the natural vibration characteristics, inter-surface shear stress ratio, maximum displacement of isolation layer, bearing’s carrying capacity of the structure.

Step 3. Comparing confirmation. Compare the computation results with the aseismic fortification objects and verify the requirements of seismic design code.
Step 4. Recursive computing analysis. If the comparison shows that the computation results can't meet the requirement of the aseismic fortification objects and standards, the rubber isolation bearing factors need to be modified by the recursive calculation mentioned in step 2 and 3 until the results meet the aseismic fortification objects.

2.2. Aseismic fortification objects

The expected horizontal seismic decrease coefficient is 1/4～1/2, the isolation layer max horizontal displacement is 32cm.

2.3. The choice of isolation bearing

There are 3 types of aminated rubber bearings with 600mm,700mm,and 800mm diameter are selected in the isolated structure.
Each type of laminated rubber bearings with different diameter has two kinds: with lead and without lead.

2.4. The verification of computation results

The time-history analysis of Spatial finite element is used in the Structural Seismic Response computation.
The computation results of seismic response should meet the requirements mentioned in Ref 5 and 6.

3. The selection of seismic wave

During the time-history analysis of Seismic Response, the peak of natural seismic wave was regulated by the Site-related horizontal peak acceleration Amax，the artificial seismic wave is generated by the corresponding acceleration response spectra。
In the computation process, El Centro wave, Taft wave, two artificial seismic wave are selected.
The influence coefficient curve of the Site-related response spectrum and the average response spectra of each wave with the effect of frequently- occurred earthquake is shown in figure 1, the influence coefficient curve of the site-related response spectrum and the average response spectra of each wave with the effect of severe earthquake is shown in figure 2.
In the range of $T = 0.04s \sim 6.0s$, either frequently- occurred earthquake or severe earthquake, the difference between site-related seismic effect coefficient and the average response spectra of each wave on the corresponding cycle point is no more than 20%. Therefore, the curve of average seismic effect coefficient statistically matchs the curve of Site-related seismic effect coefficient.

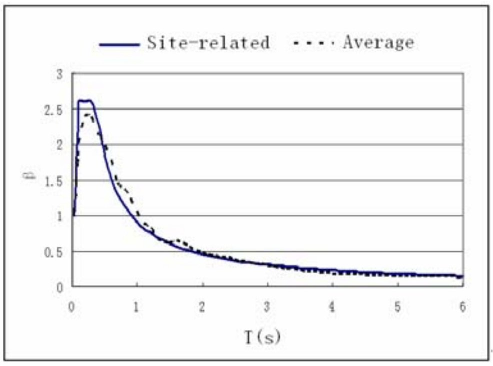


Figure 1 The curve of seismic effect coefficient (frequently- occurred earthquake)

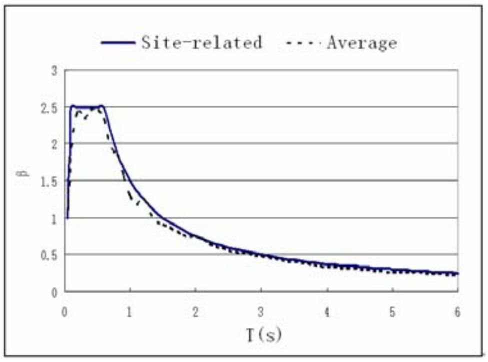


Figure 2 The curve of seismic effect coefficient (severe earthquake)

4 The computation results

4.1 Natural vibration characteristics

The natural vibration characteristics of non-isolated structure and isolated structure are shown in table 1, the difference between the horizontal and vertical basic cycle of isolated structure is less than 30%.

Table 1 The natural vibration characteristics of non-isolated structure and isolated structure（m）

Non-isolated structure			Isolated structure (frequently-occurred earthquake)			Isolated structure (severe earthquake)		
Vertical(v)	Horizontal(h)	(v-h)/h	Vertical(v)	Horizontal(h)	(v-h)/h	Vertical(v)	Horizontal(h)	(v-h)/h
0.662	0.521	27%	2.308	2.283	1.1%	2.541	2.526	0.6%

4.2 Inter-surface shear stress

In the analysis of structure seismic response, earthquake wave is input into the top of the first floor of basement from the horizontal and vertical directions simultaneously.

4.2.1 Inter-surface shear stress

With the effect of frequently-occurred earthquake, the inter-surface shear stresses of non-isolated structure and isolated structure are shown in Figure 3. Major axis is X direction, minor axis is Y direction.，The real line represents the non-isolated structure, the broken line represents the isolated structure。
Figure 3 shows that with the effect of frequently- occurred earthquake, the inter-surface shear stress ratio range of non-isolated structure and that of isolated structure is 1/10～1/3.

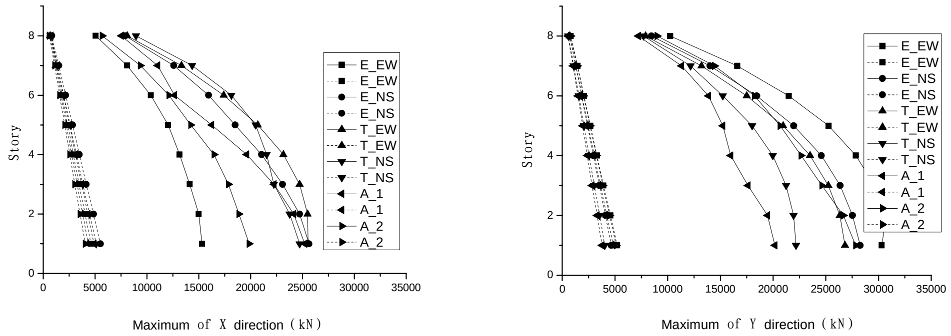
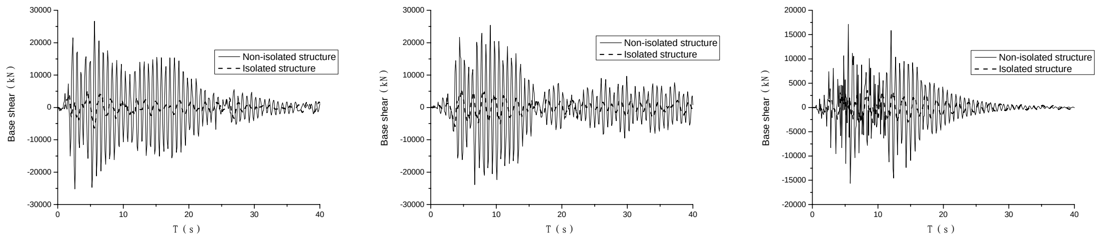


Figure 3 Inter-surface shear stress

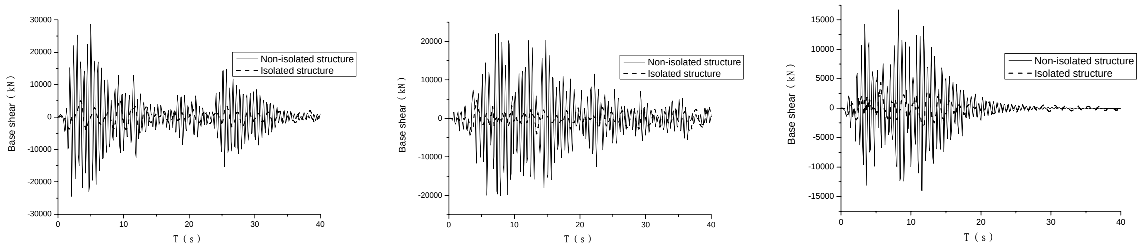
4.2.2 Time-history curve of base shear

The curves of non-isolated structure’s time-history curve of base shear and that of isolated structure with the effect of frequently-occurred earthquake are shown in Figure 4 and 5.



(1) El Centro wave (2) Taft wave (3) Artificial wave

Figure 4 Time-history curve of base shear （X Driection）



(1) El Centro wave (2) Taft wave (3) Artificial wave

Figure 5 Time-history curve of base shear （Y Driection）

4.2.3 The ratio of inter-surface shear stress

Based on the average of each computation result, the max ratio of inter-surface shear stress is 0.21.

4.3 The displacement of structure

4.3.1 The max displacement of structure

The max displacement of structure of non-isolated structure and isolated structure are shown in figure 6.

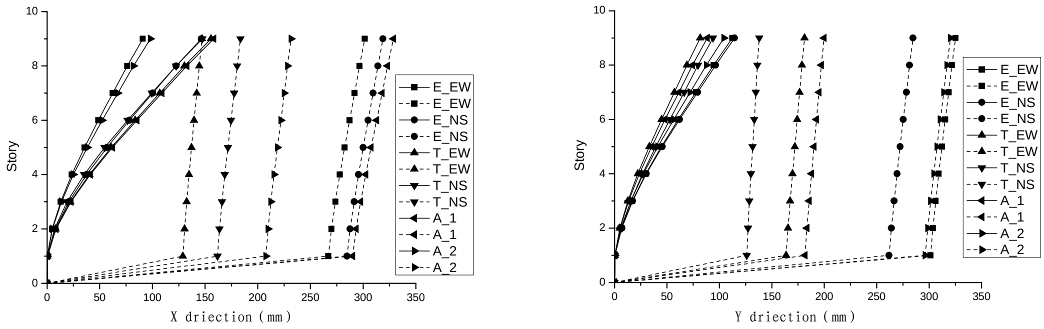
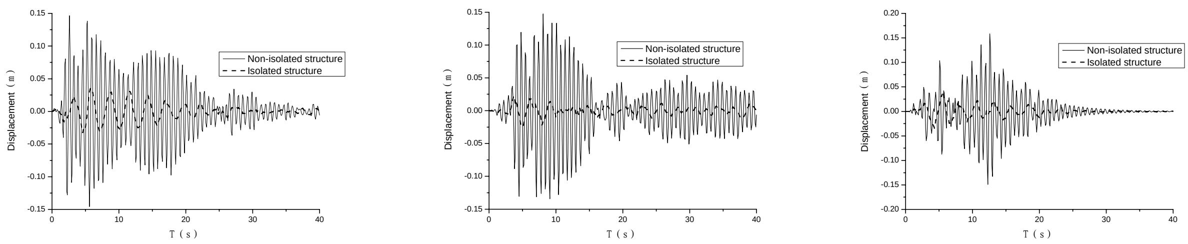


Figure 6 The max displacement of non-isolated structure and isolated structure

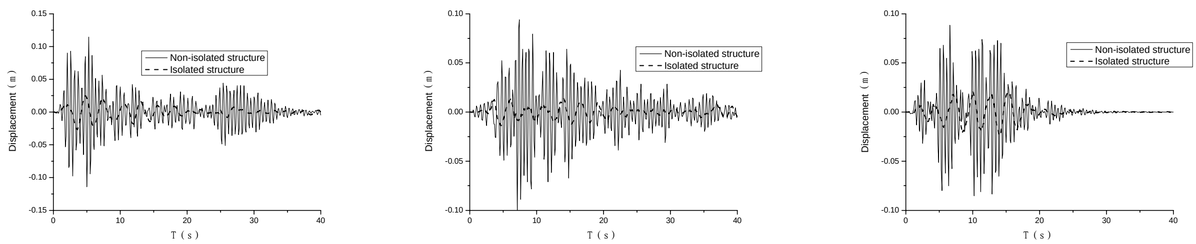
4.3.2 Time-history curve of Top-Bottom relative displacement

The curves of non-isolated structure's time-history curve of Top-Bottom relative Displacement and that of isolated structure with the effect of severe earthquake are shown in Figure 7 and 8.



(1) El Centro wave (2) Taft wave (3) Artificial wave

Figure7 Time-history curve of top-bottom relative displacement（X Driection）



(1) El Centro wave (2) Taft wave (3) Artificial wave

Figure 8 Time-history curve of top-bottom relative displacement（Y Driection）

4.3.3 the max horizontal displacement of isolation layer

the max horizontal displacement of each isolation bearing are verified based on handbook[6]. The table 2 is the each type of isolation bearing $u_{\max}$'s max value, the corresponding $0.55d$ and $3t_r$ and $u_{\max}$ is the max horizontal displacement of isolation bearing with the effect of severe earthquake; d is the diameter of the isolation bearing; t_r is the thickness of isolation bearing's rubber layer.

Table2 The max horizontal displacement of isolation layer（cm）

$u_{\max}$	$0.55d$	$3t_r$
24.0	33.0	32.6

The result show that the max horizontal displacement of isolation bearing can meet the expected target and the requirement of standard.

4.4 the others

According to specification (CECS 126), the paper has verified the rubber bearing’ shape factor, superstructure’ centroid and the center of rigidity, isolation layer’ and single isolation bearing’ pressure bearing capacity, wind-resistance safety of isolation bearing , isolation bearing’ elastic restoring force, superstructure’ story drift, and calculated the seismic decrease coefficient and max displacement with equivalent lateral force method. Both the computation results meet the design requirement.

5 THE DESIGN OF FLEXIBLE CONNECTING DEVICE OF ISOLATION LAYER

There are 16 types of pipeline through the isolation layer. Their importances are different while the size of cross-section is different, too. It is hard to realize in the design under the uniform requirement. The paper proposed the principle of flexible connecting device design according to the importance level, that is: for the important pipeline, severe earthquake horizontal displacement method will be taken; for the less important pipeline, design earthquake horizontal displacement will be taken; for the other pipeline, frequently- occurred earthquake horizontal displacement method will be taken.

6 CONNECTION METHOD OF ISOLATION BEARING

The connection of the isolation bearing to a structure must transmit shear forces, vertical loads and bending moments. In this paper, a connection method of isolation bearing without top fixing plate is used in the design, the cost of rubber bearing is saved 23% while fulfilling the requirements of safety.
The connection between the rubber isolation bearing and structure is show in figure 9.

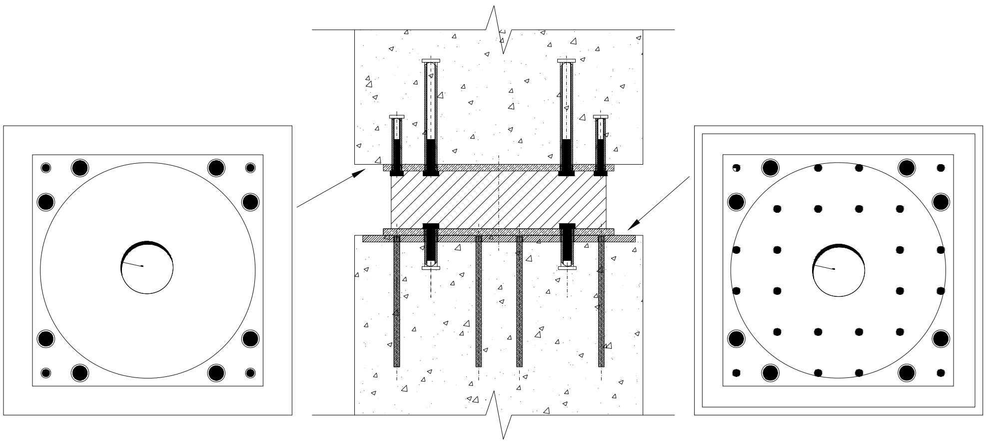


Figure 9 The connection between the rubber isolation bearing and structure

The rubber isolation bearing and upper rest pier are connected by 8 sets of M36 high strength bolt and 4 sets of M20 high strength bolt. Isolation bearing and bottom fixing plate are connected by 8 sets of M36 high strength bolt. Isolation bearing and rest pier are connected by 10.9 grade high strength bolt.
horizontal sheer, vertical loads and eccentricity of the isolation rubber bearing with the effect of severe earthquake are verified, and the shear bearing capacity of bottom fixing plate’ reinforcement anchorage has been verified，both fulfill the requirement.
To confirm the axial bearing capacity of high strength bolt’ and sleeve’ centric axial loads, the static loading

test is executed. The results show that the connection is safe when high strength bolt under 30t axial tensile force, which meets the requirement of design and construction.

7 CONCLUSION

The estimated isolation layer factors have already approached or met the design and aseismic fortification objects targets with the Iterative Computation of Response Spectrum Method of SDOF.
Taking the horizontal seismic decrease coefficient as 0.5, superstructure is designed by grade 7，whole structure is designed by grade 8， superstructure still has 0.5 grade antiseismic safety reserve。
With the effect of severe earthquake, the max displacement of isolation layer meets the requirement of code and standards。
The connection of isolation bearing without top fixing plate is safe, while the cost of isolation bearing is largely decreased.

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