TESTING STUDY ON ISOLATING SOFT-COLLISION LIMITING DISPLACEMENT

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ABSTRACT :
The experimental model of base isolation soft-collision limiting displacement and nine kinds of buffers are designed and made. The test mechanical characteristics of buffers are given. Twenty-eight kinds of workmanship shaking table model test have been performed. The experiment data are analyzed, and the law of influence of soft-collision buffer's parameters on structure response is clarified. At last the optimistic soft-collision test workmanships which are suitable for this isolated experimental model are chosen.

KEYWORDS: Base Isolation; Soft-Collision; Limiting Displacement; Model Test

1 INTRODUCTION

Currently, the passive control technology has already begun to apply in the actual engineering, and base isolation using steel-laminated rubber bearing is applied most. The fundamental of base isolation using steel-laminated rubber bearing is setting flexible isolation layer between the building upper structure and the base, prolonging the building fundamental period, keeping away from dominating period which is input by ground movement in the earthquake, decreasing the earthquake response of upper structure. It demands the isolation layer's level rigidity as small as possible, but it will result in level displacement increasing, so isolation layer should have bigger deformation ability. For example, adopting diameter of isolation rubber bearing as big as possible, it can satisfy the demand of bigger deformation ability，but the level rigidity and the cost will increase. In order to prolong period as well as lower building cost, it is proper to choose the rubber bearing whose level rigidity and diameter are both smaller. But the level deformation ability of the rubber bearing of smaller diameter is limited, so we need to set bigger deformation protection device in order to prevent the rubber bearing from losing side steady. In other words, when decreasing the earthquake response of upper structure, we must firstly ensure that isolation layer can't be destroyed or lose steady.
Literature [1] puts forward "soft-collision limiting displacement" protection solution, which is setting soft-collision buffers in the isolation layer and reserving certain distance between buffers and isolation layer. When isolation layer deformation increases to the reserve distance in the earthquake, the soft-collision between isolation layer and soft-collision buffer will take place. The soft collision buffer will deform at this time, providing certain restoring force and damping force, and restricting isolation layer deformation in the scope of allowable deformation. The theoretical analysis of "soft-collision limiting displacement" protection solution indicates that choosing soft-collision buffer's design parameter in reason can achieve prospective limiting displacement effect. The main design parameter of the soft-collision buffer includes: (1) the reserved distance of the soft-collision buffer functions for the first time; (2) the damping characteristic of the soft-collision buffer; (3)

the rigidity characteristic of the soft-collision buffer.

This paper will perform shaking table model test study to the “soft-collision limiting displacement” protection project, then will perfect and develop theoretical analysis result.

2 DESIGNING TEST MODEL

2.1 Designing the Upper Structure Model

The plane size of the upper structure model is 1100mm×1200mm, totally one floor, the floor high is 0.5m. The model is made of various jointing profiled bar. The elevation of the test model is shown in figure 1.

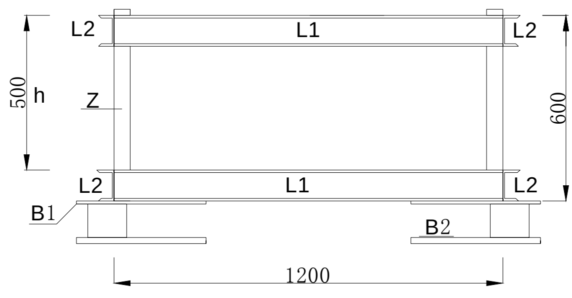
The isolation layer mass m_1 is 1190kg, the structure floor mass m_2 is 953kg.The structure floor rigidity K_2 is 8867.56N/mm, the secondary rigidity is $0.2K_2$. The structure floor damping ratio ξ_2 is 0.02, the structure floor elastic limited displacement is 1.67mm (500mm/300).

The computed basic period of upper structure model is 0.065s.

2.2 Designing Laminated Rubber Bearing

In order to gain smaller rubber bearing level rigidity, the test adopts hollow columned type rubber bearing. The inside diameter is 40mm and the outside diameter is 105mm. The limited displacement is 50mm. The testing level rigidity k_1 is 157.9N/mm. the isolation layer is placed four rubber bearing in all, so isolation layer level rigidity K_1 is 631.65N/mm.

The computed basic period is 0.366s when isolating.



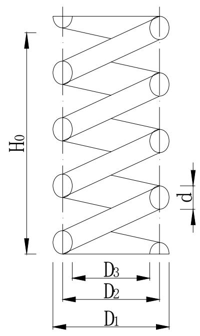


Figure 1 the elevation of isolation structure

Figure 2 the sketch map of steel spiral spring

2.3 Designing Soft-Collision Buffers

2.3.1 Designing the column spring (compressed type) buffer

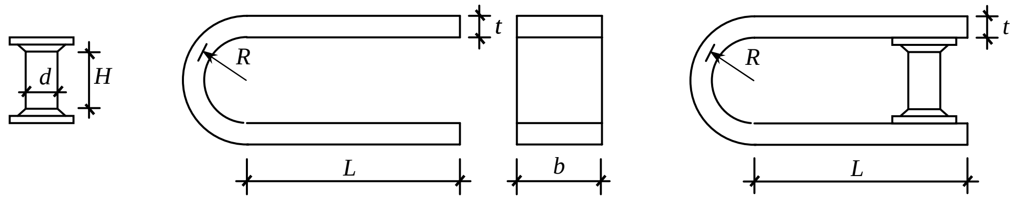
The steel spring[3] has the advantage of material even, function steady, load higher, durableness good, calculation dependable and so on. But its damping is very small. The sketch map of steel spiral spring is shown in figure 2. Three kinds of steel spiral spring buffers are designed and made Design parameters and test mechanics function parameters are shown in table 1.

Table 1 Steel spiral spring design parameters and test mechanics function parameters

Type	Steel wire diameter d (mm)	Spring middle diameter D_2 (mm)	Spring working loop (loop)	Spring total loop (loop)	Spring free high H_0 (mm)	Spring computed rigidity (N/mm)	Spring test rigidity (N/mm)
I	8	40	4.5	6	116.0	72.82	73.41
II	8	50	4.5	6	93.5	142.22	156.88
III	12	60	3.5	5	113.5	274.29	296.72

2.3.2 Designing the compound buffer of U-shaped steel plates and lead

In order to make the soft-collision buffers restore to the beginning position after soft-collision, and to make the reserved distance the same each time when collision occurs, conceive that the buffer is constituted by two parts: one part is used to absorb energy, which is chose to use figure 3(a) I-shaped lead damper; Another part is mainly used to restore after soft-collision, which is chose to use figure 3(b) U-shaped steel plate. The compound soft-collision buffer which is compounded by these two parts is shown in figure 3(c). This kind of compound soft-collision buffer's material is got easily, and its structure is simple, it is suitable to use in the building structure.



(a) I-shaped lead (b) U-shaped steel plate (c) compound soft-collision

Figure 3 compound soft-collision buffer

The characteristic of I-shaped lead damper[4] is decided by the bending part section diameter d and the bending part high H. In addition, lead's pureness degree is also very importance, it should be higher than 99.99%. U-shaped steel plate[5] is made of the steel plate, its main design parameters are U-shaped steel plate level part length L, length R from U-shaped steel plate arc center to the steel plate neutral axes, U-shaped steel plate thickness t, and U-shaped steel plate width b. The compound soft-collision buffer design parameters should consider following several aspects: (1) provide enough energy absorption ability to limit isolation layer's excessive displacement; (2) provide enough restoring force (rigidity) to make buffer restore to the beginning position after soft-collision; (3) ensure that upper structure's most displacement don't exceed its limited elastic displacement.

This test designs six kinds of compound buffer of U-shaped steel plates and I-shaped lead, the design parameters and test mechanics function parameters are shown in table 2.

3 SHAKING TABLE TEST AND TEST DATA ANALYSIS

This test is completed in earthquake engineering and structure treatment laboratory shaking table of Beijing University of Technology.

Table 2 Design and test mechanics parameters of compound buffers of U-shaped steel plates and I-shaped lead

compound buffer type	U-shaped steel plate buffer design parameters				I-shaped lead damper design parameters		test elastic rigidity
	T(mm)	*B*(mm)	*R*(mm)	*L*(mm)	*D* (mm)	*H* (mm)	*K*(kN/mm)
I	10	25	56.5	130	8	79	0.68485
II	10	60	56.5	170	15	79	2.15373
III	10	100	56.5	170	25	79	3.35523
IV	14	67	55.5	170	10	73	5.60354
V	14	73	55.5	170	38	73	5.87372
VI	10	100	56.5	170	11	79	3.35523

3.1 Test Model Basic Period

In order to confirm the basic period of test adoptive base isolation model, we choose frequencies that are closed to test model theories calculation frequency, and scan the isolation structure with sine wave. According to the principle of the same frequency resonance, namely structure's acceleration arrives the biggest when it takes place resonance ,we obtain its natural frequency. Finally, we get the test model basic period test value 0.301s, but the theories analyzed value is 0.366s, the error is 21.6%.Test period is smaller than the theories calculation period because the rubber mat adopted is a hollow pure rubber and rubber mat's rigidity differs from each other, meanwhile structure actual total mass and theories computed mass are also different.

3.2 Test Workmanship

In order to provide practical superior limiting displacement device design parameter for the rubber mat isolation structure which is installed limiting displacement device. We choose different kinds of buffers in different reserved distances to carry on the test. We choose to use the El Centro seismic wave as the test input seismic wave, adjust the acceleration peak value to 0.4g during test, and input it according 1:1, choose soft-collision reserved distance as follows: 10mm, 20mm, 30mm. We design 9 types of soft-collision buffer: 3 types steel spiral spring buffers and 6 types compound buffers of U-shaped steel plates and I-shaped lead. The buffers test workmanship are 27 types, there is also 1 type non-limiting displacement workmanship. Totally test workmanship are 28 types.
Figure 4 and figure 5 respectively gives out the installation of spring buffers and compound buffers in the test.

Figure 4 spring buffers installation

Figure 5 compound buffers installation

3.3 The Peak Interstory Drift Reaction

To isolation structure, the isolation layer's peak displacement and the upper structure's peak interstory drift effect main control to the structure parameters design.

3.3.1The influence of reserve distance d to the peak interstory drift reaction

Figure 6 is the influence of the spring buffer reserve distance to isolation layer peak displacement, figure 7 is the influence of the spring buffer reserve distance to the structure floor peak interstory drift. Figure 8 is the influence of the compound buffers reserve distance to isolation layer peak displacement, figure 9 is the influence of the compound buffers reserve distance to the structure floor peak interstory drift.

From the figure 6~figure 9 we can see that under the same buffer rigidity and damping, along with reserved distance *d* aggrandizement, isolation layer's peak displacement and the structure floor peak interstory drift aggrandize, and the aggrandizement trend of isolation layer peak displacement is bigger than the structure floor peak interstory drift's. Therefore, for insuring isolation layer don't take place soft-collision in small earthquake, we should adopt smaller reserve distance *d* to the same rigidity and damping buffer.

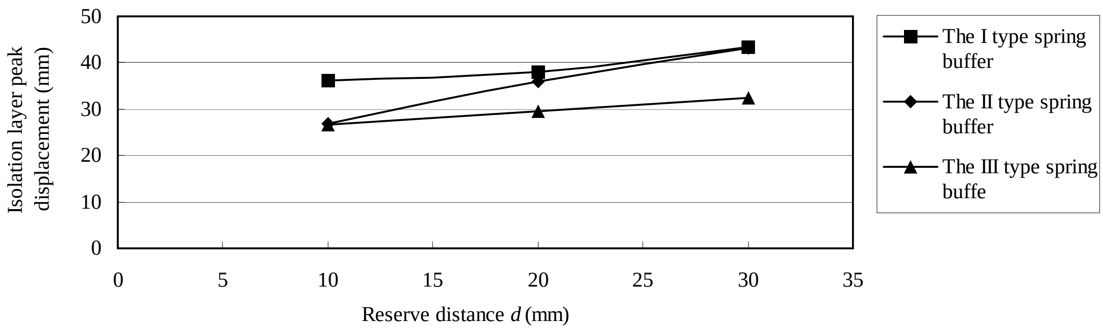


Figure 6　the influence of spring buffer reserve distance to isolation layer peak displacement

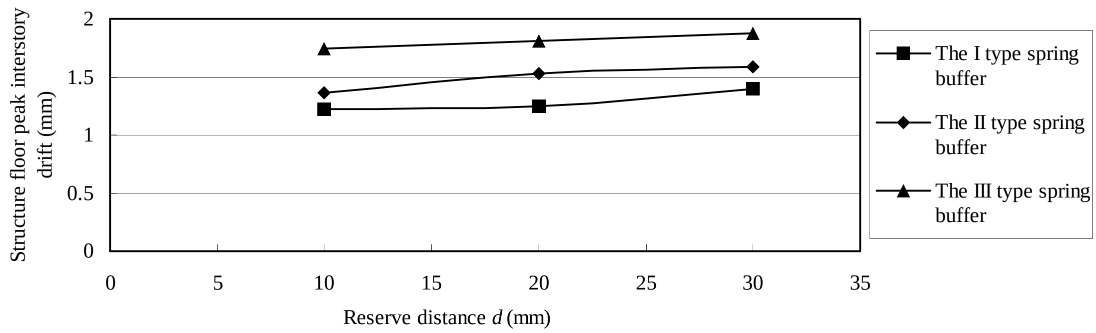


Figure 7　the influence of spring buffer reserve distance to the structure floor peak interstory drift

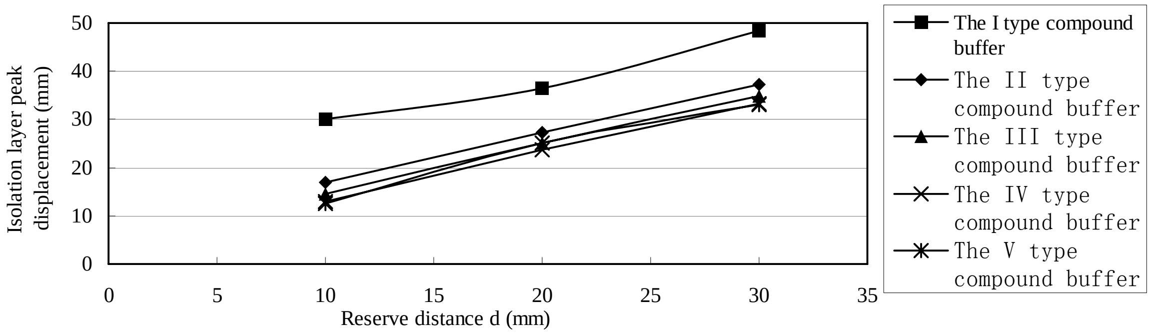


Figure 8 the influence of the compound buffers reserve distance to isolation layer peak displacement

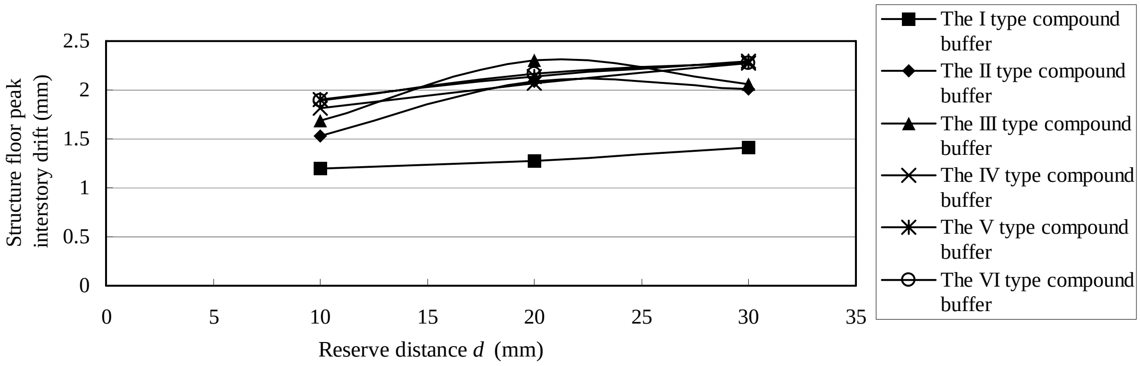


Figure 9 the influence of the compound buffers reserve distance to the structure floor peak interstory drift

3.3.2 The influence of buffer rigidity to the peak interstory drift reaction

Figure 10 and figure 11 are the influence of buffer rigidity to isolation layer peak displacement, figure 12 and figure 13 are the influence of buffer rigidity to the structure floor peak interstory drift.

From the figure 10~figure 13 we can see that under the same reserve distance d and buffer damping, isolation layer peak displacement decreases when the buffer rigidity aggrandizes, but the structure floor peak interstory drift varies contrary. That buffer rigidity increase is equal to isolation layer rigidity increase when soft-collision happens, and the isolation layer rigidity makes isolation layer peak displacement decrease. The increase of isolation layer rigidity causes the high frequency vibration mode of the upper structure participative coefficient becoming bigger, so the structure floor peak interstory drift increases.

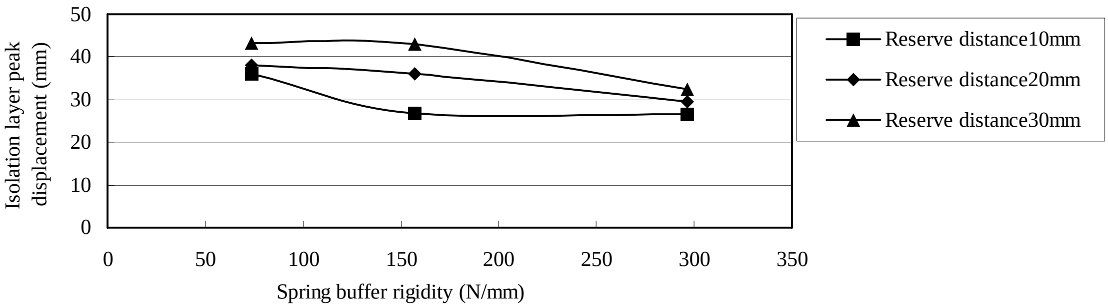


Figure 10 the influence of spring buffer rigidity to isolation layer peak displacement

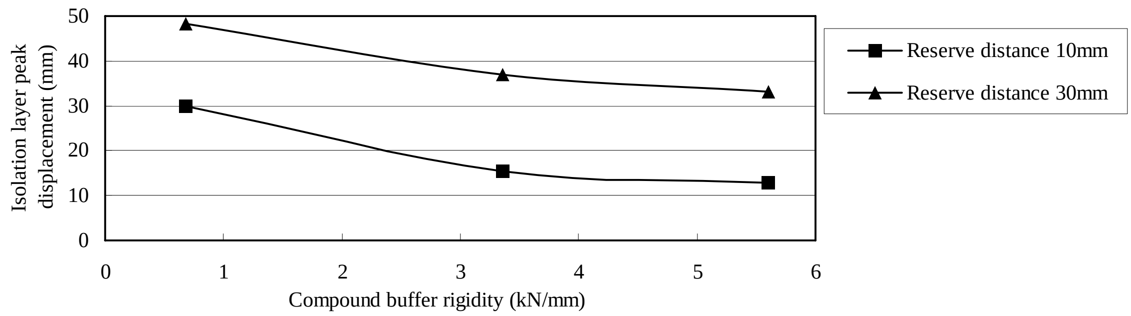


Figure 11 the influence of the I,IV and VI compound buffers rigidity to isolation layer peak displacement

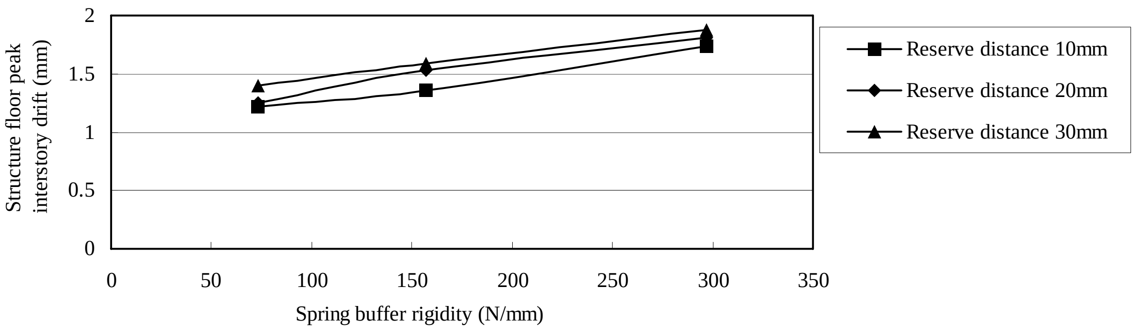


Figure 12 the influence of spring buffer rigidity to the structure floor peak interstory drift

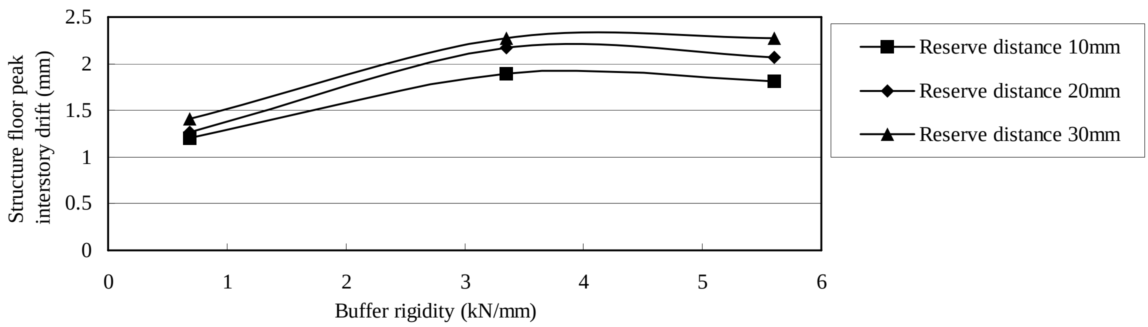


Figure 13 the influence of I,IV and VI compound buffers rigidity to the structure floor peak interstory drift

Obviously, under the same reserve distance *d* and buffer damping, the more smaller buffer rigidity the more bigger isolation layer displacement is, it is more dangerous to isolation layer, so we can confirm the minimal buffer rigidity according that isolation layer peak displacement don't exceed its extreme displacement. But the more bigger buffer rigidity the more larger structure floor peak interstory drift is, it is more disadvantageous to the upper structure, so we can confirm the maximal buffer rigidity according that upper structure floor peak interstory drift should possibly control in the flexible scope.

3.3.3 Optimize buffer

To optimize buffer parameter should consider various request at the same time.
(1) Isolation layer: in order to prevent rubber bearing from losing steady because of isolation layer's oversize displacement, isolation layer's peak displacement can't exceed its extreme displacement.

(2) Upper structure: the upper structure peak interstory drift should possibly control in flexible scope, that is to say the structure floor peak interstory drift don't exceed the floor extreme displacement. At the same time, upper structure each floor's acceleration is as small as possible.
(3) Construction and cost: it is possible to use small quantity buffers to reduce engineering quantity installation and engineering cost at the same time.
Integrates above analysis, according to the influence of the reserve distance *d* and buffer rigidity to the isolation layer and upper structure displacement reaction, analyses the 27 kinds of test workmanship and optimizes the following test workmanship with better limiting displacement effect. The displacement of isolating layer is smaller. The displacement of upper structure is less than 1.67mm, its working state is elasticity.
Spring buffers: four types workmanship of the I、II kinds of reserves distance *d* 10mm、20 mm.
Compound buffers: six types workmanship of the I~III kinds with reserve distance *d* 10 mm, and the I kind of the reserve distance *d* 20 mm, totally 4 types workmanship.

4 CONCLUSION

Designs and makes the experimental model of base isolation soft-collision limiting displacement, and 3 types column spring (compressed type) buffers 6 types compound buffers of U-shaped steel plates and lead, puts forward the test mechanics characteristic parameters of buffer.
Performs 28 kinds of different workmanship shaking table model test, proves that soft-collision limiting displacement can control the interstory drift of isolation layer and upper structure in the allowable scope at the same time. Analyses the influence of reserve distance *d* and buffer rigidity to isolation layer and upper structure displacement reaction, puts forward 8 types soft-collision buffers experimental workmanship which are suitable for this isolated experimental model.

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