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Research Article

Seismic Responses of an Added-Story Frame Structure with Viscous Dampers

Xuansheng Cheng, Chuansheng Jia, and Yue Zhang

School of Civil Engineering, Lanzhou University of Technology, Lanzhou 730050, China

Correspondence should be addressed to Xuansheng Cheng; chengxuansheng@gmail.com

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The damping ratio of an added-story frame structure is established based on complex damping theory to determine the structure seismic response. The viscous dampers are selected and arranged through target function method. A significant damping effect is obtained when a small velocity index is selected. The seismic responses of a five-floor reinforced concrete frame structure with directly added light steel layers and light steel layers with viscous dampers are compared with the finite element software SAP2000. Calculation results show that, after adding the layers, the structure becomes flexible and the shear in the bottom layer decreases. However, the interlaminar shear of the other layers increases. The seismic response of the added layers is very significant and exhibits obvious whiplash effect. The interstory displacement angles of some layers do not meet the requirements. The seismic response of the structure decreases after the adoption of viscous dampers; thereby seismic requirements are satisfied.

1. Introduction

Added-story frame structures in seismic zones must meet the requirements of foundation-bearing capacity as well as the requirements of the current seismic design code. The traditional seismic design method places priority on "resistance," that is, increasing the structure section size and reinforcement to resist the seismic load. This method not only fails to ensure the safety of the added-story frame structure but also increases the cost of the project significantly. Energy dissipation technology, which was first proposed in 1971 by American scholar Yao [1], is a good option for strengthening such buildings. This technology is different from the traditional seismic strengthening method, which relies mainly on setting dampers or isolation devices to reduce earthquake damage.

Ma et al. [2] employed the finite element software ANSYS to analyze the seismic performance of a four-floor reinforced concrete frame structure with two-floor steel frame added layers in an office building. The seismic performance of the entire structure with different added layers, damping ratios ζ, and sway and nonsway frames was discussed. Liu et al. [3] utilized SAP2000 to establish a 3D finite element model of a reinforced concrete frame structure with directly added light steel layers. The seismic response was obtained by analyzing the modal and response spectrum of four-, five-, and six-floor reinforced concrete frame structures with one or two light steel added layers. Li et al. [4] proposed the use of friction dampers and sand cushion as the shock absorber. Shake table testing was implemented in an added-story frame structure with friction and energy dissipation devices. The test results were analyzed and compared through nonclassical damping theory. Mitropoulou et al. [5] established the European energy dissipation seismic design criteria by assessing two reinforced concrete buildings. Rakicevic et al. [6] utilized a shake table to test a five-floor steel frame structure with a TMD system in the Republic of Macedonia. The influence of the TMD parameters on the seismic performance of the structure was analyzed by producing seismic waves with different frequencies. Tsai and Chang's studies [7] showed that the performance of dampers has a direct impact on the vibration frequency of a building, which means that high-mode criteria cannot be directly applied in the modal analysis of a structure with viscoelastic dampers. Ribakov [8]

studied the applied structure of vibration isolation pads and friction dampers and found that this method can effectively reduce seismic response and displacement. Weng and Lü [9] derived the curve of the equivalent damping ratio and the parameters and recommended a reasonable range for these parameters by theoretically analyzing the characteristics of energy dissipation. G. Li and H.-N. Li [10] adopted the design of structural components and energy dissipation devices as a supplement and reduced the large number of iterations involved in traditional displacement-based designs. Lü et al. [11] presented the shake table test results of a 1/15 scale model of a complex high-rise CFRT frame structure with installed viscous dampers. The results showed that (1) the structure had no obvious weak layer and met the code for the seismic design of buildings and (2) the dampers produced a certain energy dissipation effect, which improved seismic performance. Ou and Ding [12] investigated the characteristics and properties of different viscous fluid materials and analyzed the performance of the cylinder gap-type viscous damper. Reinhom et al. [13] conducted a comprehensive seismic analysis of a 1/4 scale model of a three-layer steel structure with installed viscous dampers. The results showed that damping ratio can be improved by adding viscous dampers; story drift and interlaminar shear can also be reduced.

The forms of original buildings differ because the forms of the added layers are different. Selecting the appropriate form of the added layers is extremely important in ensuring the feasibility, security, and economic rationality of the added layers. Numerous studies have focused on earthquake resistance or protection and the energy dissipation mechanism of added-story structures. However, only a few studies have focused on the design of energy dissipation reinforcement, especially in added-story structures. Such design requires the theoretical analysis of seismic performance indicators and comparative analysis of seismic performance and other parameters of the structures after adopting viscous dampers. The seismic responses of directly added layers and added layers with viscous dampers were compared and analyzed with the finite element software SAP2000 in this study to provide a theoretical basis for practical engineering.

2. Damping Ratio

The damping ratio of a particular material cannot be considered the overall damping ratio in dynamic analysis because the forms and materials of added-story structures are different. Research shows that complex damping theory is suitable for the study of material internal friction energy dissipation, whereas viscous damping theory is more suitable for the analysis of foundation energy loss.

A structure can be divided into different parts according to the different materials of the added layers. For example, the reinforced concrete frame structure with added light steel layers can be divided into two parts: structure 1 (the reinforced concrete frame structure) and structure 2 (the light steel frame structure), as shown in Figure 1.

The stiffness matrix of structure 1 is $\mathbf{K}_1$, and the stiffness matrix of structure 2 is $\mathbf{K}_2$.

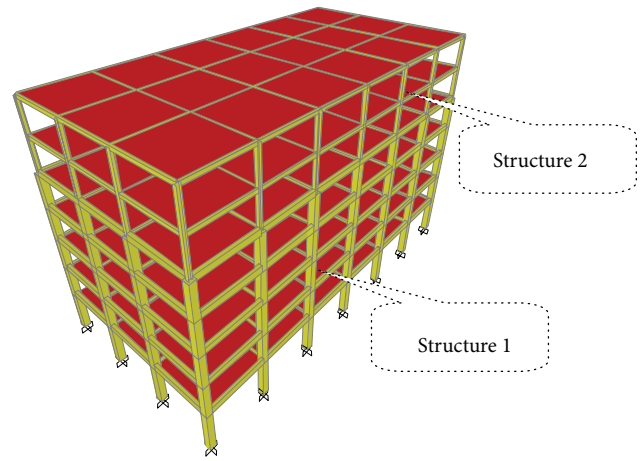

Figure 1: Analysis model.

We assume that the natural frequency of model i is ω_i, vibration mode is φ_i, the modal vector associated with structure 1 is $\boldsymbol{\varphi}_{i1}$, and the modal vector associated with the structure 2 is $\boldsymbol{\varphi}_{i2}$.

We also assume that deformation is proportional to vibration mode shape while inputting resonance with the frequency of vibration mode i:

$$\begin{aligned} \mathbf{u}_{i1} &= \boldsymbol{\varphi}_{i1} \sin\left(\omega_i t + \theta_i\right), \\ \dot{\mathbf{u}}_{i1} &= \omega_i \boldsymbol{\varphi}_{i1} \cos\left(\omega_i t + \theta_i\right). \end{aligned} \tag{1}$$

The damping matrix with multidegrees of freedom can be written as

$$\mathbf{C}_1 = \frac{2\xi_1}{\omega_i}\mathbf{K}_1, \tag{2}$$

where $\mathbf{C}_1$ is the damping coefficient of structure 1 and ξ_1 is the damping ratio.

The energy and strain energy consumed by the damping of structure 1 are

$$\begin{aligned} E_D(i,1) &= \pi\omega_i \mathbf{u}_{i1}^T \mathbf{C}_1 \mathbf{u}_{i1} = 2\pi\xi_1 \boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1}, \\ E_s(i,1) &= \frac{1}{2}\mathbf{u}_{i1}^T \mathbf{K}_1 \mathbf{u}_{i1} = \frac{1}{2}\boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1}, \end{aligned} \tag{3}$$

where $E_D(i,1)$ is the energy dissipated by damping in the i-type vibration of structure 1 and $E_s(i,1)$ is the strain energy dissipated by damping in the i-type vibration of structure 1.

Similarly, the energy and strain energy consumed by the damping of structure 2 are

$$\begin{aligned} E_D(i,2) &= \pi\omega_i \mathbf{u}_{i2}^T C_2 \mathbf{u}_{i2} = 2\pi\xi_2 \boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2}, \\ E_s(i,2) &= \frac{1}{2}\mathbf{u}_{i2}^T \mathbf{K}_2 \mathbf{u}_{i2} = \frac{1}{2}\boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2}. \end{aligned} \tag{4}$$

Thus, the energy consumed by the damping of the added-story structure is

$$E_D(i) = 2\pi\left(\xi_1 \boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1} + \xi_2 \boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2}\right). \tag{5}$$

The strain energy of the added-story structure is

$$E_s(i) = \frac{1}{2}\left(\boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1} + \boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2}\right). \quad (6)$$

The damping ratio of the added-story structure is

$$\xi_i = \frac{E_D(i)}{4\pi E_s(i)} = \frac{\xi_1 \boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1} + \xi_2 \boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2}}{\boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1} + \boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2}}, \quad (7)$$

where $\boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1} + \boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2}$ is the sum of the strain energy of the two parts, that is, the strain energy of the entire structure.

Therefore,

$$\boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1} + \boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2} = \boldsymbol{\varphi}_i^T \mathbf{K} \boldsymbol{\varphi}_i, \quad (8)$$

where $\mathbf{K}$ is the stiffness of the entire structure. Equation (7) can be rewritten as

$$\xi_i = \frac{E_D(i)}{4\pi E_s(i)} = \frac{\xi_1 \boldsymbol{\varphi}_{i1}^T \mathbf{K}_1 \boldsymbol{\varphi}_{i1} + \xi_2 \boldsymbol{\varphi}_{i2}^T \mathbf{K}_2 \boldsymbol{\varphi}_{i2}}{\boldsymbol{\varphi}_i^T \mathbf{K} \boldsymbol{\varphi}_i}. \quad (9)$$

3. Selection and Arrangement of the Viscous Dampers

The viscous dampers are selected and arranged through target function method. The design of the energy dissipation structures with viscous dampers involves three parameters of the damper: velocity index α, damping matrix C_α, and maximum output f_d. The objective function, which is generally the story drift limit or expected displacement $[u]$, was selected. The values of α and C_α are assumed to calculate the story drift, which should satisfy $u < [u]$. If the story drift does not satisfy the requirement, the parameters will be reselected until they meet the requirement. The viscous dampers are selected or designed based on the parameters calculated above [14]. Assuming that C_α is a constant, the damping effect of the viscous dampers will become apparent as α decreases; thus, a small α value should be selected. If a small α value is selected, damping force (which changes with speed) can easily achieve the maximum design value at an early stage. If the speed exceeds the estimated maximum value, damping force will increase slightly and become almost constant. Thus, the support system would be protected and the connection points would not fail because of the extremely large damping force.

Design steps of energy dissipation structure are as follows.

(1) Determination of the Structure Design Parameters. Parameters determined by structure design include design target displacement Δ_u, ductility coefficient μ, and additional damping ratio of energy dissipation components. Determination of the target displacement can be selected according to different requirements on the performance of structure. For example, 1.5% structural height can be considered a limitation of boundary vertex displacement value, and ductility coefficient which reflects the ductility of the structure is usually the ratio of target displacement and yield displacement. Additional damping ratio of energy dissipation components can usually be chosen according to the economic situation, and the energy dissipation device that can provide larger damping ratio has relatively high price under normal circumstances. Although the additional damping ratio has great influence on damping performance of the structure, the bigger the damping ratio is, the better the damping effect is not. In China seismic code when the energy dissipation device damping ratio is greater than 20%, damping ratio is selected as 20%. Considering the state of the economy, the literature suggests that energy dissipation structure damping ratio is selected between 10% and 20% [15].

(2) Determination of the Equivalent Single Freedom Degree System Parameters. Damping ratios ζ_{eq} of equivalent single freedom degree system include the intrinsic damping ratio ζ_1 of structure, additional damping ratio ζ_d of calculation energy dissipation element, and equivalent damping ratio ζ_s due to yield. That is,

$$\zeta_{eq} = \zeta_1 + \zeta_s + \zeta_d. \quad (10)$$

According to the existing literature [16], mass of multifreedom degree is changed into equivalent quality M_{eq} of single freedom degree:

$$M_{eq} = \frac{\sum_{i=1}^{N} m_i h_i}{h_N}, \quad (11)$$

where m_i and h_i are layer mass and layer height of the actual structure, respectively, and h_N is height of top layer.

The existing literature has given the calculation method of vertex displacement about the multifreedom degree converted into equivalent vertex displacement about the single freedom degree [17]. Namely,

$$\Delta_{eq} = \Delta_u \frac{2N+1}{3N}, \quad (12)$$

where Δ_{eq} is the equivalent displacement and N is the stories of the structure.

(3) Determination of the Equivalent Period. According to the equivalent damping ratio ζ_{eq} of determined single freedom degree system and the equivalent displacement Δ_{eq}, the equivalent period T_{eq} of single freedom degree system is determined using the displacement response spectrum.

(4) Determination of Equivalent Stiffness. Equivalent stiffness of single freedom degree system is

$$K_{eq} = \left(\frac{2\pi}{T_{eq}}\right)^2. \quad (13)$$

(5) Determination of the Base Shear and Design Shear of Each Layer. The base shear of equivalent single freedom degree system is

$$V_{eq} = K_{eq} \cdot \Delta_{eq}. \quad (14)$$

The equivalent yield shear is

$$V_y = \frac{V_{\text{eq}}}{1 + \alpha(\mu - 1)}. \tag{15}$$

When multifreedom degree structure is transformed to the equivalent single freedom degree system, it is assumed that single freedom degree system and the actual structure have the same base shear. According to the existing literature [18], in the multifreedom degree structure, the layer shear distributed by the base shear is

$$F_x = V_y \frac{w_x h_x}{\sum_{i=1}^{N} w_i h_i}, \tag{16}$$

where F_x, w_x, and h_x are shear, weight, and height in x layer, respectively.

(6) Design of Structure Member. According to the determined shear at step (5) and the design method of the current seismic code [19], structure components are preliminarily designed. In the design process, *strong column and weak beam*, *strong shear and weak bending moment*, *seismic construction requirements, and so on* need to be paid attention to.

(7) Verification of the Yield Displacement. By step (6) structure member is determined, and then the actual yield displacement and yield shear $F_{sy,i}$ are calculated. When the actual yield displacement meets the certain precision compared with the design yield displacement, the next step of design goes on. Otherwise, return to step (6), the frame structure components are designed again. Because the energy dissipation device can provide some initial stiffness (except for viscous dissipation device), component actual strength can be less than the design strength.

(8) Determination of Energy Dissipation Device Parameters. As the design of main member is relatively complex and the energy dissipation device design is relatively easier and less in quantity, it is easy to realize small changes of energy dissipation device parameters in engineering. This paper suggests that the main components are designed in the reasonable design range using the idea of energy dissipation device as the structure strength supplement. Specific ways are that when layer shear F_i, layer yield shear $F_{sy,i}$, and layer stiffness $K_{s,i}$ (calculated in accordance with the size of the actual design component) are known, the stiffness of energy dissipation device is

$$K_{d,i} = \frac{F_i - F_{s,i}}{F_{s,i}} \cdot K_{s,i}. \tag{17}$$

The other parameters of energy dissipation device are calculated according to steps (1), (2), and (3).

4. Seismic Response Analysis

4.1. Engineering Situation. The original structure is a five-floor office building with a reinforced concrete frame structure. The width of the building is 18 m in the north-south direction, and its length is 36 m in the east-west direction. Column spacing is 6 m in both north-south and east-west directions. The height of the bottom story is 4.0 m and that of the other stories is 3.3 m. The structural diagram of the standard layers is shown in Figure 2. The design strength of the concrete of the original structure is 30 MPa, elastic modulus E is 30 GPa, and Poisson's ratio is 0.2. The in situ concrete slab is 120 mm. The material of the two added layers is Q235 steel; design strength is 215 MPa, elastic modulus E is 206 GPa, and Poisson's ratio is 0.3. The story height and structural layout of the added layers are consistent with those of the original structure. The section of component is shown in Table 1. The permanent load of the floor is 2.50 kN/m^2 (excluding component weight), and variable load is 2.00 kN/m^2. The variable load of the roof is 0.5 kN/m^2. Seismic precautionary intensity is 8 degrees.

4.2. Damping Ratio and Seismic Waves. Calculations performed with (9) and those in the literature [20] showed that the modal damping ratios are between 0.04761 and 0.04999 when the additional layers are increased, indicating that the basic modal damping ratio of the added-story structure is greatly influenced by the concrete structures.

Appropriate seismic waves should be selected to ensure the accuracy and rationality of time-history analysis. The 70 gal (intensity of 8 earthquake) El Centro wave (peak value of 341.7 cm/s^2) and 0.01s sampling period were adopted in this study.

4.3. Directly Added Story. The numerical simulations of the original and added-story structures were performed with SAP2000 software. The added-story structure is classified as an irregular structure because of stiffness mutation in the added layer where the section and material of the column and beam are changed. Thus, time-history analysis was performed. Analysis shows that the Y direction is the weak direction of the structure in an intensity of 8 earthquake. Floor displacement, story drift, interstory displacement angle, and interlaminar shear in the Y direction of the original and added-story structures are shown in Tables 2 and 3.

Tables 2 and 3 indicate that story drift, interstory displacement angle, and interlaminar shear significantly increased except on the bottom floor because of changes in structural mass and stiffness distribution. The seismic response in stiffness mutation position is amplified because the added steel layer is flexible in the upper part and rigid in the lower part, so significant whiplash effect is caused. According to GB50011-2010, the elastic interstory displacement angle of reinforced concrete frame structures in minor earthquakes should be limited to 1/550 [19]. As can be seen in Table 3, the interstory displacement angle of the 2nd floor in the directly added-story structure does not satisfy the code and the bearing capacity of the frame columns does not meet seismic requirements. The displacement of the added layers is large. Stiffness is weak and reinforcement in Y direction is less than that in other directions.

Table 1: Component section.

Original section		Added-story section	
Member number	Section	Member number	Section
Z	600 mm × 600 mm	GZ	300 mm × 300 mm × 12 mm × 14 mm
L	300 mm × 600 mm	GL	400 mm × 200 mm × 8 mm × 12 mm

Table 2: Original structure.

Story	Floor displacement (mm)	Story drift (mm)	Interstory displacement angle (rad)	Interlaminar shear (kN)
5	19.40	1.99	1/1658	170.1
4	17.41	3.24	1/1018	290.1
3	14.17	4.35	1/758	357.6
2	9.82	5.09	1/648	424.9
1	4.73	4.73	1/846	494.4

Table 3: Added-story structure.

Story	Floor displacement (mm)	Story drift (mm)	Interstory displacement angle (rad)	Interlaminar shear (kN)
7	43.78	8.34	1/395	122.2
6	35.44	11.35	1/290	204.1
5	24.09	3.54	1/932	243.9
4	20.55	4.65	1/709	348.8
3	15.90	5.45	1/605	418.5
2	10.45	5.68	1/528	455.7
1	4.77	4.77	1/838	477.3

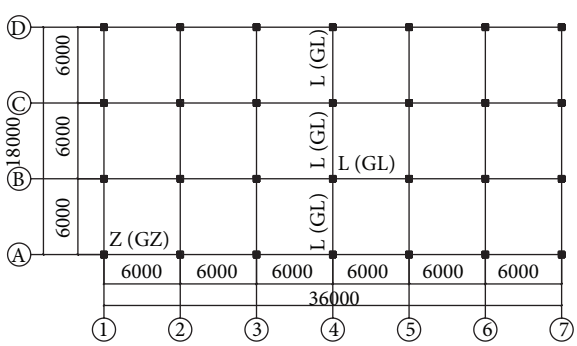

Figure 2: Plane graph of the standard layers.

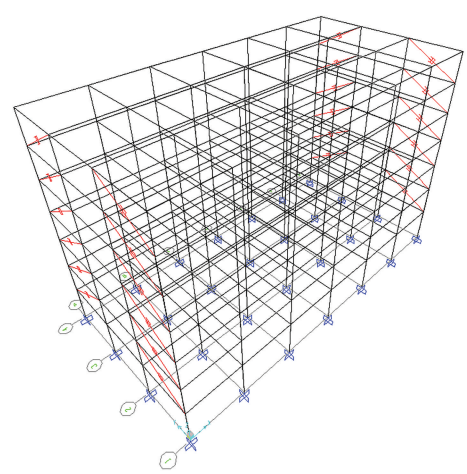

Figure 3: Damper arrangement.

4.4. Added Story with Viscous Dampers. Seismic analysis was conducted with SAP2000, and viscous dampers were simulated with an N-link unit damper. We assumed that damping matrix $C_\alpha = 1000\,\text{kN·S/m}$, velocity index $\alpha = 0.2$, and the stiffness coefficient is 100 to 10000 times that of the damping coefficient. The dampers were set in the weak Y direction on the 2nd to 7th floors of the outermost frame. The arrangement of the dampers is shown in Figure 3.

The floor displacement, story drift, interstory displacement angle, and interlaminar shear of the reinforced structure in Y direction after calculation are shown in Table 4.

Floor displacement, story drift, and interlaminar shear decrease when the viscous damper is installed. The story displacement of the top floor is reduced from 43.78 mm to 24.64 mm at a decline of 43.7% and from 8.34 mm to 1.95 mm at a decline of 76.7%, indicating that the displacement of the structure can be well controlled by the damper. The whiplash effect caused by the structure is effectively controlled with the addition of the damper; thus, the added-story structure meets the requirements of seismic design code.

The displacement and shear value of each floor are shown in Figures 4 and 5.

Table 4: Added-story structure with viscous dampers.

Story	Floor displacement (mm)	Story drift (mm)	Interstory displacement angle (rad)	Interlaminar shear (kN)
7	24.64	1.95	1/1692	14.3
6	22.69	3.99	1/827	41.3
5	18.70	2.26	1/1460	157.4
4	16.44	3.27	1/1009	263.7
3	13.17	4.10	1/805	333.8
2	9.07	4.73	1/698	390.7
1	4.34	4.34	1/921	448.9

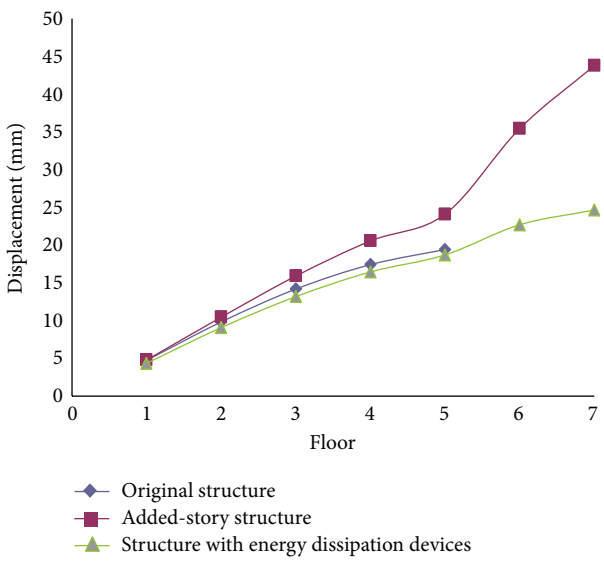

Figure 4: Floor displacement.

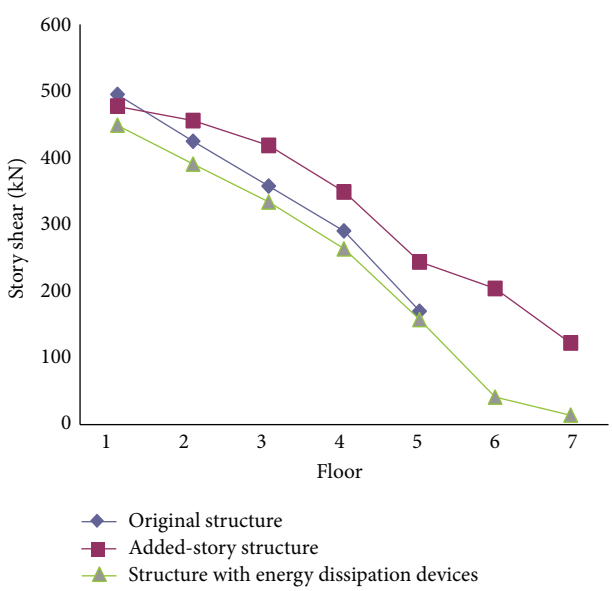

Figure 5: Interlaminar shear.

Figures 3 and 4 show that the floor displacement values of the added-story structure increased significantly when the floor displacement of the 5th floor increases from 19.40 mm to 24.09 mm, with an increase of 24%. The displacement values of the added layers are much larger than that of the original structure, indicating the obvious occurrence of whiplash effect. This result is due to the stiffness mutation of the added story forming a weak layer. The interlaminar shear value of the directly added story is smaller than that of the original structure because the structure became soft after the story was added. The structure period increased, and the horizontal earthquake influence coefficient decreased. However, structure base shear decreased. The story drift and interlaminar shear values of the other floors increased with the increase in the floor number as well as the increment rate because the whiplash effect enlarged the upper sheath seismic response, thereby increasing the story drift and interlaminar shear values.

After strengthening, floor displacement, interstory displacement angle, and interlaminar shear decline significantly. The interlaminar shear of the top floor decreases from 122.2 kN to 14.29 kN with a decline of 88%. The interstory displacement angle of the top floor is reduced from 1/395 to 1/1692 with a decline of 77%. The interlaminar shear of the top floor is reduced from 243.9 kN to 157.4 kN with a decline of 35%. The seismic performance of the structure is obviously improved. A great surplus in structural seismic capacity is generated owing to the energy dissipation effect of the damper. The whiplash effect of the added layer is significantly reduced, and the seismic capacity of this section is enhanced. Comparison of the seismic responses of the original structure and those of the energy dissipation structure indicates that displacement is reduced and force statement is improved by the energy dissipation of the viscous dampers. The integrity of the added layers and the original structure is also improved, allowing the entire structure to meet seismic requirements.

When added-story structure uses the damper device, damper device does not have much impact on the stiffness of the structure, and the size of the damping force is mainly related to the velocity index α and damping coefficient C. This paper firstly fixes damping coefficient and assumes 5 statuses of velocity index, which are 0.2, 0.4, 0.6, 0.8, and 1, and then the effects of different velocity indexes on structural seismic performance are studied, and the combination of optimal velocity index and damping coefficient is

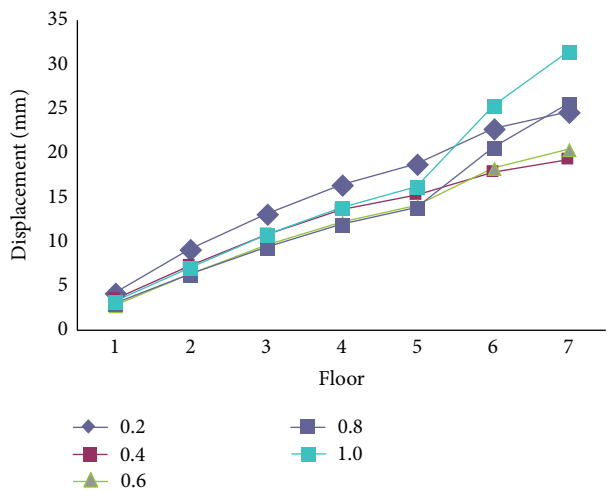

Figure 6: Floor displacement of the energy dissipation structure under different velocity indexes.

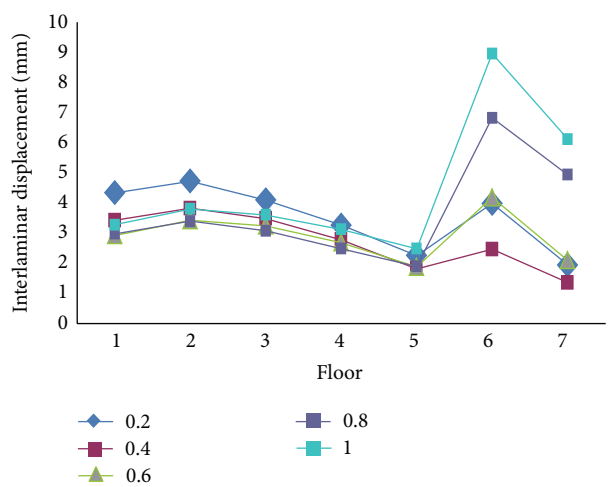

Figure 7: Interlaminar displacement of the energy dissipation structure under different velocity indexes.

determined. The floor displacement, interlayer displacement, and interlaminar shear of the energy dissipation structure under different velocity indexes are shown in Figures 6, 7, and 8.

In the case of the same damping coefficient, damping effect of the damper device does not increase with the increase of velocity index. This is because when the velocity index is 1, damper device exhibits a linear change. Hysteretic curve is close to elliptic. When the velocity index is smaller than 1, the hysteretic curve is rectangular, and so the damper device has stronger effect of energy dissipation.

This paper fixes damping coefficient and assumes 5 statuses of acceleration index, which are 0.1 g, 0.2 g, 0.3 g, 0.4 g, and 0.5 g, and then the effects of different acceleration indexes on structural seismic performance are studied, and the combination of optimal speed index and damping coefficient is determined. The floor displacement, interlayer displacement, and interlaminar shear of the energy dissipation structure

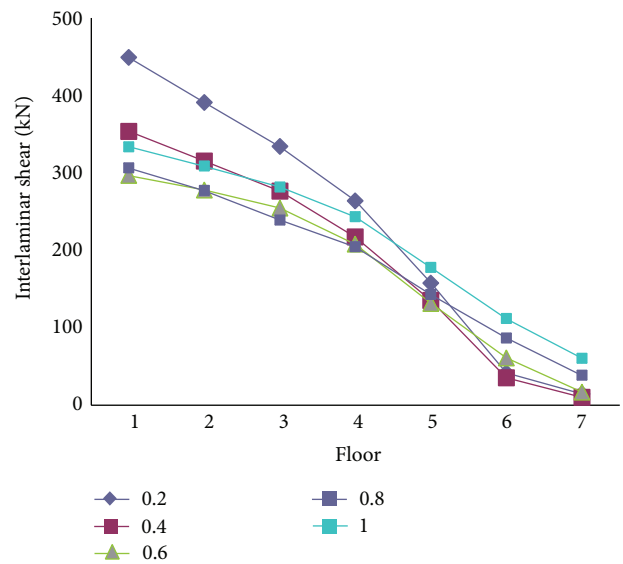

Figure 8: Interlaminar shear of the energy dissipation structure under different velocity indexes.

under different acceleration indexes are shown in Figures 9 and 10.

Figure 9 shows that the displacement growth of added-story part is significantly greater than the lower floors in the case of larger acceleration (e.g., 0.3 g, 0.4 g, and 0.5 g). That explains that added-story structure part is relatively soft and adding damper devices cannot increase the stiffness of the structure. When the earthquake acceleration is larger, the upper floors may produce whiplash effect.

Figure 10 shows that the joint of added-story part and original structure produces larger interlayer displacement and the corresponding parts of interlayer displacement are also the parts of larger stiffness mutation. As shown in Figure 10, the interlayer displacement of stiffness mutation position increases with the increase of earthquake excitation. That shows that stiffness mutation leads to generate larger interlayer displacement and increases with the increase of excitation under earthquake excitation.

The displacement time-history and acceleration time-history curves of the original structure, directly added-story structure, and added-story structure with viscous dampers are shown in Figures 11 and 12.

Figures 11 and 12 show that the peak acceleration of the energy dissipation structure was significantly lower than those of the directly added-story structure and original structure.

5. Conclusions

(1) The seismic response obviously increased after adding the story because of the stiffness mutations in the added story. The whiplash effect was observed in the added layers. The structure became soft and structure period increased when the story was added, leading to the decrease in the interlaminar shear of the bottom floor with an insignificant

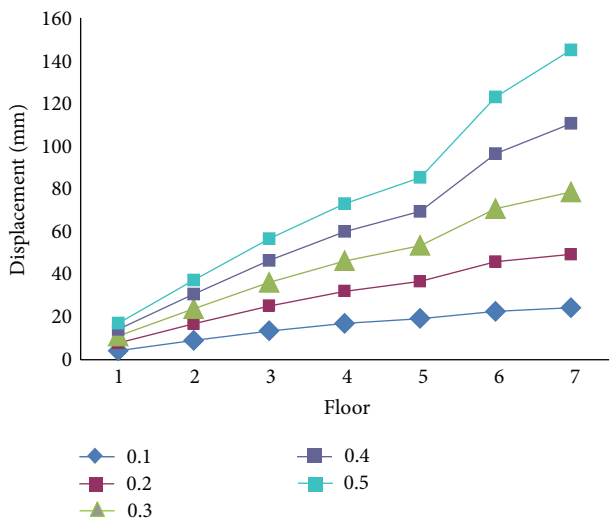

Figure 9: Floor displacement of the energy dissipation structure under different acceleration indexes.

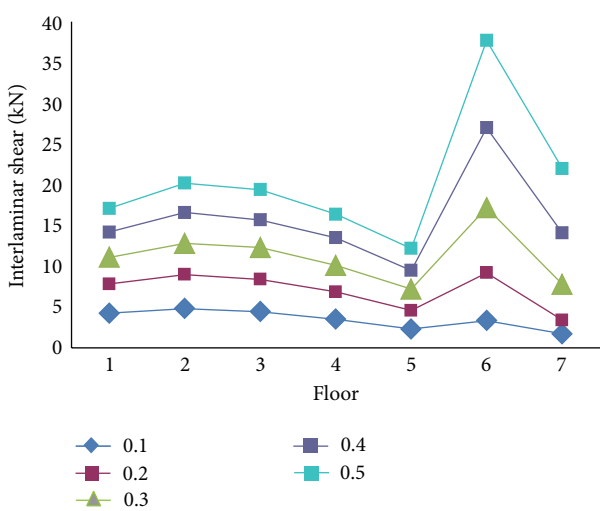

Figure 10: Interlaminar displacement of the energy dissipation structure under different acceleration indexes.

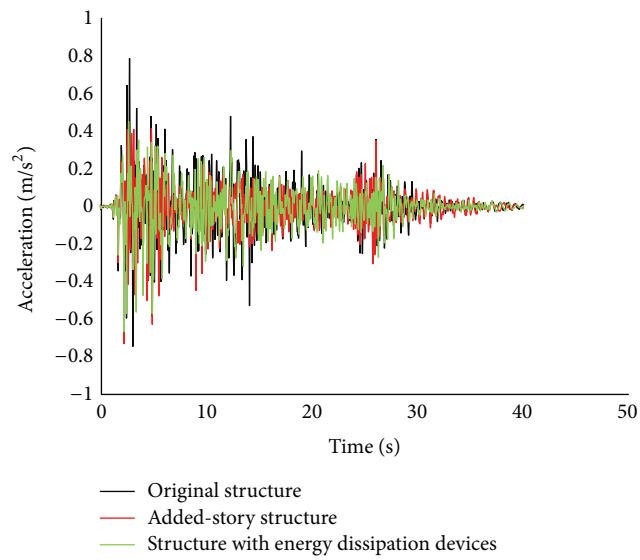

Figure 11: Top story displacement time-history curve.

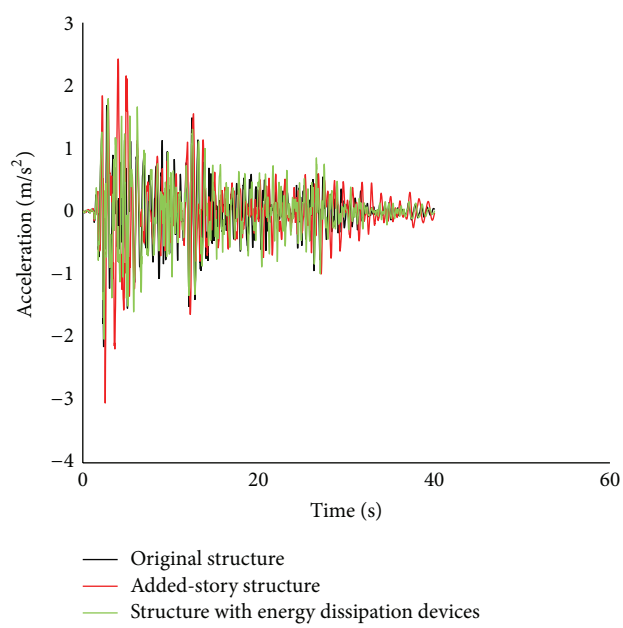

Figure 12: Top floor acceleration time-history curve.

decline of 3%. The story drift and interlaminar shear of the other floors increased with the increase in floor number, indicating that the directly added layers increased the seismic response (which had a negative effect on the structure).

(2) The seismic response (such as story drift, interstory displacement angle, and interlaminar shear) of the added-story structures can be effectively reduced by rationally arranging the viscous dampers. The seismic performance of the entire structure can then meet seismic requirements.

(3) Viscous damper reinforcement is a good choice for buildings without seismic fortification or those whose seismic fortification standard is below the seismic fortification intensity of the region.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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