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Research Article

Research on Seismic Design Method for Reinforced Concrete Frame Structure

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In this paper, the losses caused by earthquake and the damage brought to engineering structures are firstly introduced. Then, the types of seismic damage of such structures are introduced with reinforced concrete frame structure as an example. Next, the seismic design methods of structures in domestic and foreign codes are summarized, mainly including seismic measures and seismic structural measures, and the types and applications of seismic shock absorption technology are further introduced. Finally, the effectiveness of the seismic shock absorption technology is verified by using the passive control method as an example.

1. Introduction

Earthquake disaster or seismic damage is a type of natural disaster, characterized by suddenness, wide area of damage, strong localization, sequence and multidirection, disastrous, social, and the difficulty of earthquake relief. Earthquake disasters can directly cause casualties and property damage but also indirectly cause floods, fires (tsunamis and large lake waves), epidemic diseases, or a series of economic losses due to labor losses and transportation disruptions. The major earthquakes that have occurred in recent years have left many painful lessons to be learned, especially in the increasing awareness of the seismic performance of buildings [1]. Because earthquakes can cause serious damage to engineering structures, engineering structures are load-bearing structures built by building materials such as wood, steel, and concrete. They are often used in such as housing construction, buildings for industrial and civil buildings such as bridge engineering, transportation buildings, and communication buildings. According to the classification of material types, common building structures include wood structure, masonry structure, steel structure, and reinforced concrete structure. According to statistics, after the Wenchuan Earthquake on May 12, a total of 19.33 million m^2 Sichuan urban residents housing collapsed, 68.766 million m^2 of serious damage. 6,350,600 houses of rural residents collapsed, and 7,221,900 houses were seriously damaged. At present, most of the housing structures in China are mainly reinforced concrete frame structures. This paper mainly analyzes the earthquake damage, damage types, and seismic design methods with reinforced concrete frame structure as an example.

2. Types of Damage to Reinforced Concrete Frame Structures

The main components of reinforced concrete frame structure include columns, beams, joints, and infilled walls. Frame beams and frame columns play the role of bearing the horizontal and vertical loads of the structure. Infilled walls are nonload-bearing structures that play the role of dividing space areas and maintenance. Therefore, the three components are damaged to varying degrees in the earthquake, mainly reflected in the following types. The specific details of the five types of damage to reinforced concrete frame structures are shown in Figures 1–5.

2.1. Filler Wall Damage. In frame structures, infill walls are nonstructural components that play a role in maintenance and division; most of the structural loads are carried by beams, columns, etc. Infill walls are basically not load-bearing, and solids are usually added to beams as external loads

Figure 1: X-shaped crack.

Figure 2: Overall collapse.

Figure 3: Wall column connection failure.

during calculations to simplify the calculations. However, in actual engineering, infill walls often suffer extremely serious damage in earthquakes. As the first line of seismic defense of the frame structure, due to its high stiffness, the wall is first subjected to strong shear damage brought about by the earthquake, offsetting part of the seismic energy. In addition to this, there are other multifaceted reasons, such as weak shear-bearing capacity of the wall, frame infill wall tie construction is not in place, and poor quality of pipe preburial weakens the cross-section of the components.

The main damage of filler wall in earthquake is X-shaped crack, block collapse along the crack line, overall collapse of wall failure, and connection damage between wall and column due to shear damage. In addition, due to the deformation of frame structure is shear type, the horizontal displacement at the bottom is large, which makes the damage of filler wall present the phenomenon of "bottom heavy and top light."

Figure 4: Roof parapet damage.

2.2. Beams, Columns, and Their Node Damage. The frame structure mainly relies on the beam and column nodes to resist the seismic waves. The beam is a typical bending member during the earthquake. In concrete frame structure, due to the large shear stress generated at both ends of the beam after yielding, it exceeds the shear-bearing capacity of the beam, leading to beam damage in two main forms: positive section damage and diagonal section shear damage. Among them, the main reasons for shear damage are the large shear stress after yielding at both ends, which exceeds the shear-bearing capacity of the beam, the nondense configuration of the hoop reinforcement within the beam, and the reduction of the concrete shear strength under repeated loading; shear damage is brittle damage, and its damage characteristics are unpredictable, so it will cause disastrous damage in the earthquake.

The frame column bears the weight and resists the lateral force caused by the earthquake in the frame, which has an important position in the structure, and it mainly includes three damage types: bending damage, shear damage, and bond damage. Bending damage usually occurs at the top or bottom of the column, and accompanied by larger deformation, the concrete crushing, spalling, bending reinforcement, and yield state of tensioned reinforcement occur. Shear compression damage can be divided into the following three according to the different forms of damage: shear diagonal damage, shear tension damage, and shear compression damage, and when the column's shear span ratio is less than 1.5, the shearing force from diagonal cracks is greater than the bending yield shearing force. When the lateral wrap reinforcement is not enough, the steel reinforcement column

Figure 5: Roof parapet damage.

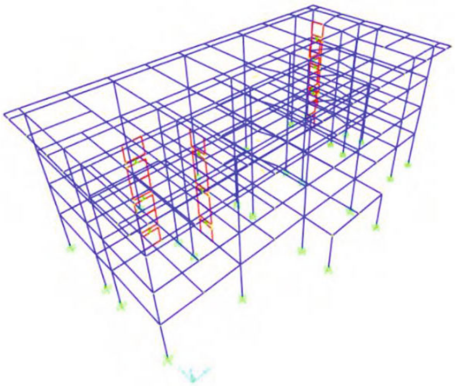

Figure 6: Model of a multistory dormitory building of an elementary school in Yunnan Province.

will produce shear diagonal damage. The shear for column is large; diagonal cracks produce a shearing force smaller than the shearing force from bending yielding, and the axial pressure ratio of the column is small; the reinforced concrete column with low reinforcement ratio will produce shear tensile damage. When the axial pressure is larger, the reinforced concrete column with high reinforcement ratio will produce shear compression damage and bond cracking damage, which can be divided into the following two according to different forms of damage; the first damage is due to insufficient anchorage of reinforcement is pulled out and occurs damage; another is when the column bending or shear crack occurs, with repeated loading, bond cracks along the main reinforcement occur, so that the concrete finally occurs peeling damage.

Node damage, beam-column nodes are the force transmission members in frame structures. Concrete frame structures are widely used in seismic zones because of their good structural integrity, high bearing capacity, and flexible plan layout. With the progress of scientific research, the material properties of each member in the frame structure have been greatly improved, the ductility and bearing capacity of the frame beam and column members have also been greatly improved, the size of the beam and column members have become smaller, so the cross-sectional size of the nodes is getting smaller and smaller, and the beam-column node area of the frame structure has gradually become the weak link in the seismic resistance of the reinforced concrete frame structure. However, the results of a large number of seismic damage survey show that many concrete frame beam-column nodes are damaged before the failure of the beam and column members, thus causing damage to the structure as a whole, i.e., the frame nodes are damaged before the frame beam-column damage, the shear bearing capacity of the nodes is insufficient, the internal hoop density does not meet the requirements, and the anchorage length of the beam bars is insufficient, which lead to early damage and go against the design principle of "strong nodes and weak structure."

2.3. Stairwell Damage. Stairwell is the vertical channel of the building, and in many domestic and foreign such as Wenchuan, Yushu, and other large earthquake heavy, the damage of the stairwell often brings serious casualties and a variety of huge losses. Stairwell due to its stiffness and wall height and thickness is relatively large, and its damage performance is shown below: (1) the stair treads are repeatedly pulled and compressed, resulting in yielding of the longitudinal stressing bars, cracking, and collapse of the stair treads; (2) the platform beam is repeatedly pushed and pulled by the stair treads, and shear-torsion damage occurs, and the cracks of the platform beam extend to the platform tread; (3) the upper and lower ends of the stair columns are broken, and the concrete is cracked; (4) the filler wall of the stairwell is cracked and collapsed; (5) the frame column is connected to the stair landing at the half floor, and short column damage occurs [2–9].

2.4. Local or Overall Collapse of Structure. The overall seismic performance of the frame structure is good, and the housing building collapse rarely occurs. The collapse can be divided into the following two types: vertical continuous collapse and lateral deformation collapse. The former is mainly due to the damage of individual members in the earthquake, which leads to the failure of normal work and the loss of bearing capacity, resulting in the local collapse of the frame structure, thus leading to the vertical continuous collapse of the structure. The latter is mainly due to the structure occurs excessive vertical deformation, exceeds the limit deformation capacity of the structure and collapse under the action of the earthquake.

2.5. Other Damage. During the earthquake, the small attic on the top of the house, parapet, small chimney, and other damage are due to the whipping effect. The main reason is that the weight of the top floor is smaller than the weight of the lower, the earthquake vibration of the upper part of the house is more powerful than the lower, large deformation, and the most serious damage. For industrial and civil buildings in the earthquake zone, the design should try to avoid the possibility of the whipping effect from the structure. For the protruding structure of the top of the house,

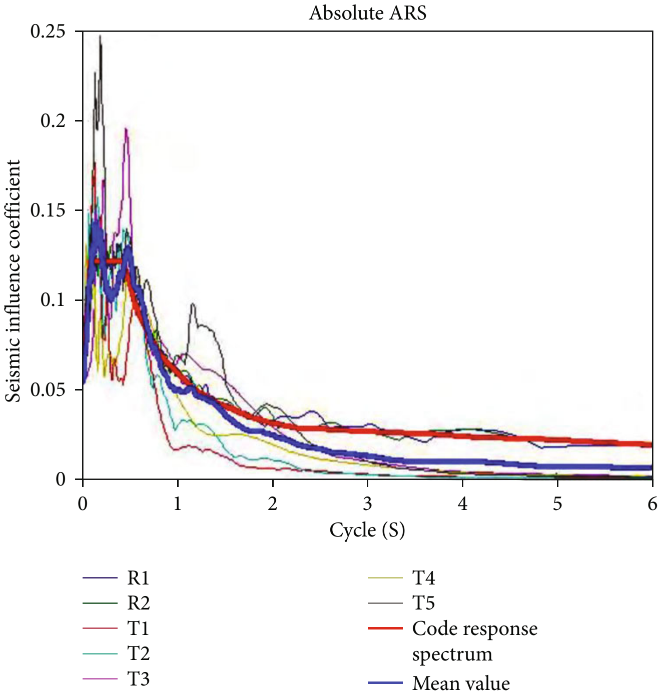

Figure 7: Seven time-history response spectrum and code response spectrum curves.

Table 1: Technical parameters of viscous damper.

No.		Name	Parameter
Dormitory	1	Damping coefficient C (kN/(mm/s)α)	70
	2	Damping coefficient α	0.25
	3	Satisfy the damping equation	F=CV α

Table 2: Dormitory layout plan and usage summary.

Name	Layout floor	X-direction	Y-direction	Subtotal
Dormitory	4F	2	2	4
	3F	2	2	4
	2F	2	2	4
Total amount of dampers			12	

parapet, small chimney, etc., special reinforcement measures should be taken.

3. Seismic Design Method

Seismic codes are regulations in engineering construction and are requirements and specifications that must be observed in planning design and building engineering design for the prevention and mitigation of earthquake damages and a series of secondary damages caused by earthquakes, etc. Seismic codes can be divided into two categories according to their relationship with other load-acting structural design codes. One category is combined with other load-acting design codes as included in the structural design codes; conversely, the second category is independent of the two designs, i.e., seismic design codes are considered separately. After comparing the seismic design codes of many countries such as China, the United States, Japan, and Europe, the seismic design codes of China, Japan, and the United States belong to the latter; the seismic design codes of Mexico, New Zealand, and other countries belong to the former [11–15]. The building will be protected against earthquake damage and destruction by the local or national seismic departments, which will provide detailed information on the division of local seismic intensity zones and their local topography, determine the basic seismic intensity of the construction area where the building is located, reinforce the details of the structure and set up reinforced concrete structures within the specified range, strengthen wall connections, or strengthen the integrity of stairwells, etc. to reduce the damage to the building. We will also improve the efficiency of postearthquake recovery work, reduce the cost of activities and projects, and shorten the recovery time.

3.1. Concept of Seismic Measures. Seismic measures refer to the seismic design contents other than seismic action calculation and resisting force calculation, including seismic structural measures. Seismic measures are other than seismic structural measures, such as conceptual design and internal force adjustment. Seismic structural measures refer to the various detailed requirements for structural and nonstructural parts according to the conceptual seismic design principles, such as seismic rating, reinforcement rate, anchorage length, axial compression ratio, densification of beam and column hoop reinforcement, and seismic structural measures for nonstructural members without calculation. The seismic measures and seismic structural measures can be determined according to the intensity and seismic level.

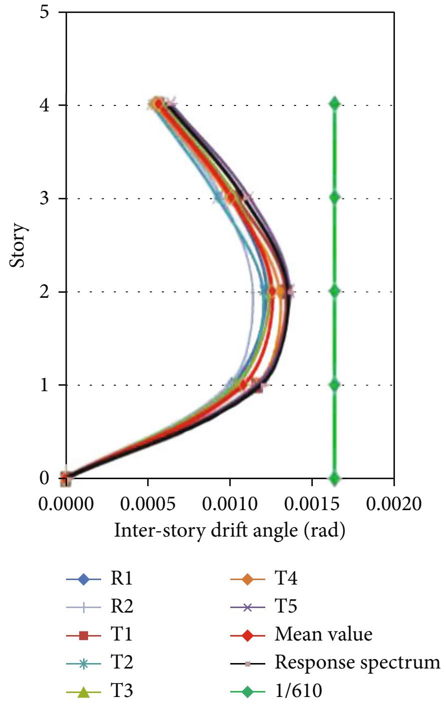

Figure 8: *X*-directional small-earthquake interstory drift angle curve before shock absorption.

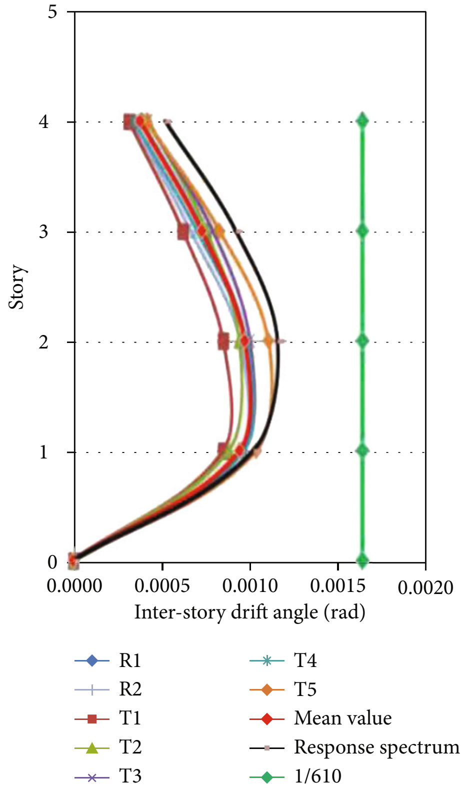

Figure 9: *X*-directional small-earthquake interstory drift angle curve after shock absorption.

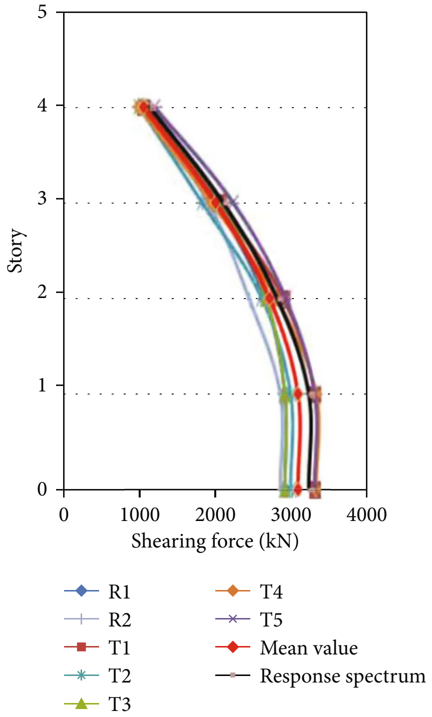

Figure 10: *Y*-directional small-earthquake shearing force curve before shock absorption.

3.2. Seismic Measures. Seismic measures refer to the structural design follows the design rules of "strong column and weak beam, strong shear and weak bending, strong nodes and weak structure." Strong column and weak beam mean that the bending capacity of the column in the structure is stronger than that of the beam, i.e., the internal force adjustment method is adopted to make the member fully redistribute the internal force, so that the plastic hinge at the end of the column is avoided or delayed, and the plastic hinge appears at the end of the beam first. Strong shear and weak bending ensure that the reinforced concrete will not produce brittle damage due to its own lack of bearing capacity, that is, the shear bearing capacity is greater than its bending capacity in the design of the structure, so that the structure can be in the form of bending damage rather than shear damage and in the form plastic hinge, and the structure will not occur brittle damage. For strong nodes and weak structure, in the case of external load, the nodes cannot withstand excessive deformation and need stronger deformation performance. In order to prevent the nodes from damage under external load, the strength of the nodes should be greater than the strength of the columns and beams during structural design. In summary, the order of strength size of the designed structure is as follows: node, column, and beam, so as to ensure that the plastic hinge appears at the end of the beam first, which makes the node bearing capacity larger than the beam and improves the node deformation capacity.

3.3. Seismic Structural Measures. For seismic structural measures, according to the damage survey, the serious parts of the seismic damage of frame structure mostly occur at the nodes of frame beams and columns and filler walls.

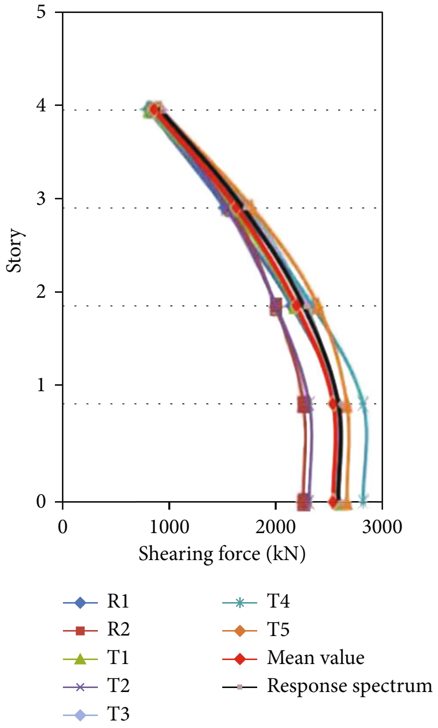

Figure 11: Y-directional small-earthquake shearing force curve after shock absorption.

Generally, the seismic damage of column is more than that of beam, the seismic damage of column top is more than that of column bottom, the seismic damage of corner column is more than that of inner column, and the seismic damage of short column is more than that of general column, for which a series of measures are taken.

First of all, for the structural design of frame beam, in terms of geometry, the beam should not be too wide; otherwise, it will not be conducive to the restraint of the nodes; in addition, because when the beam and the wall beam enter the nonlinear range, they have obvious differences in mechanical properties, so the height to width ratio and the length to height ratio should be limited. In order to avoid plasticity at the end of the beam, the end hoop should be encrypted; in the transverse reinforcement, in order to improve the shear strength, the reinforcement should be placed within a certain range of the shear to compression ratio, and the hoop distance should be encrypted to improve the ductility of the concrete; in order to prevent the reinforcement from slipping before yielding and crushing the concrete at the contact, short bars should be set at the bend to strengthen the anchorage.

Second, for the structural design of the frame column, in geometry, in order to avoid being damaged, column net height to section height ratio should be greater than 4, and column axial pressure ratio and shear pressure ratio are an important factor affecting the ductility of the member, so the column section should be controlled by these two factors; limit the longitudinal reinforcement rate of the column to ensure the ductility of the member; the use of close spaced steel hoop and depending on the situation, choose a reasonable steel hoop type to improve the ductility of the section and shear resistance; in anchoring and connection, avoid the location of the possible plasticity as the joint, choose welded joints, and the number of section joints should be limited.

Frame node should be analyzed as an isolated free body, and the node core area is its main stress part, so the node to configure transverse reinforcement, and in this area, choose the minimum reinforcement rate; in addition, the node around the beam to the node generated by the restraint can effectively improve the shear strength of the members [16].

4. Shock Absorption Technology

4.1. Concept of Shock Absorption Technology. The traditional seismic design usually relies on the structure itself to resist and consume the earthquake energy. It is difficult to ensure the safety of the structure under the action of overdesigned baseline earthquake, which has been fully verified in the earthquake damage in recent years, while the existing old buildings all adopt the traditional seismic design scheme, which are highly vulnerable to damage in the earthquake [1]. In the traditional seismic design, the mass of the structure increases, the reinforcement rate or the thickness of the wall increases, but the seismic force of the building increases, the seismic capacity of the building decreases, and the cost of the building becomes higher. In contrast, by setting dampers or seismic isolation devices, the seismic shock absorption technology reduces the internal force and deformation between floors of the internal structure of the building, reduces the seismic response of the upper structure, fully reflects the "energy dissipation" characteristics of the seismic shock absorption technology, greatly improves the safety of the building, reduces the cost of the building, and is more convenient than the traditional seismic measures. At present, a large number of scholars at home and abroad have carried out research on the seismic energy dissipation technology and put forward many practical and effective research results [17–20]. Meanwhile, with the gradual maturity and wide application of seismic shock absorption and isolation technology, it has also been included in other design-related regulations such as the *Code for Seismic Design of Buildings* (GB50011-2010) [13] in China [19].

4.2. Classification of Shock Absorption Technology. There are various classifications of seismic shock absorption technology, among which they can be classified into passive seismic shock absorption, active seismic shock absorption, semiactive seismic shock absorption, and hybrid seismic shock absorption according to the different ways of applying forces to the structure.

Passive seismic shock absorption is to reduce the vibration of a structure by taking certain measures or additional substructures to absorb and consume the energy transmitted to the main structure by an earthquake. Passive seismic shock absorption technology mainly includes energy dissipation, impact reduction, and shock absorption.

Energy dissipation is the use of damping forces, plastic deformation, or frictional forces generated by various damping elements, energy-absorbing components, or frictional supports to attenuate the vibration response of a structure under external disturbances (e.g., wind and seismic loads). The essence of energy dissipation is to rely on dampers to provide damping, consume seismic input energy, and reduce the structural vibration response [22]. It has the characteristics of high energy dissipation capacity and low-cycle fatigue property. Impact reduction is a technique to reduce the seismic response of a structure by exchanging momentum and dissipating kinetic energy by relying on the incomplete elastic collision between the additional active mass and the structure. In practice, a pendulum is usually suspended from a part of the structure (usually at the top), and when the structure vibrates, the pendulum hits the structure to attenuate the structural vibration. This pendulum impact damper is commonly used in chimneys, towers, etc. Shock absorption uses the additional substructure displaces the vibration of the structure. The vibration energy of the structure is redistributed between the original structure and substructure, so as to achieve the purpose of reducing the vibration of the structure.

According to the seismic response of the structure, the active seismic shock absorption actively applies control forces to the structure through the actuator of the seismic system. For semiactive control seismic shock absorption, it has the advantages of both active control and passive seismic shock absorption designs, and the cost performance is higher than the two, so it is the most used in the building structure. In addition, for the hybrid control, it combines the active and passive control and then put into application or use other composite control methods for different kinds of combination.

4.3. Example [23]

4.3.1. Project Overview. The project is a multistory dormitory building for an elementary school in Yunnan Province, with a concrete frame structure system, five floors, 3.9 m high of each floor, and a total construction area of 5000 m^2 (according to the government's requirements, seismic isolation and shock absorption technology should be used), and the building model is shown in Figure 6. The basic design parameters are as follows: the seismic fortification is category B, the seismic fortification intensity is 8 degrees, the design basic acceleration is 0.20 g, and the seismic groups is 3. In this project, seven seismic waves are selected for calculation and analysis, including five natural waves and two artificial waves, and the time-history response spectrum and code response spectrum curves are shown in Figure 7.

4.3.2. Parameters of Viscous Damper and Its Layout Plan. Based on the seismic intensity of the area where the project is located, viscous dampers were selected as the structural seismic shock absorption equipment for this project. The viscous dampers were first proposed by Miyazaki et al. from Japan [24]. It is a velocity-related structural energy dissipation and shock absorption device designed and made by using the principle of damping force generated by the interaction of viscous fluid and structural components of the damper. When the building is under the action of external forces, in order to consume the powerful energy of the earthquake, the energy dissipation and shock absorption device is installed at the large displacement place between building floors to passively dissipate the earthquake energy [25–28].

The viscous dampers were initially used in the military field, but due to their high accuracy and precision and good stability, they have been widely used in the field of civil construction in the course of continuous development. Many scholars at home and abroad have conducted in-depth research on the application and performance of viscous dampers in mechanical construction engineering. The results show that viscous dampers have good energy dissipation capability and can greatly reduce the internal force and displacement response of the structure after attaching viscous dampers at predetermined points according to the type of structure; the most significant point is that viscous dampers can almost only add damping to the structure without increasing the structural stiffness [29–37]. Thus, when viscous dampers are used as when the viscous dampers are used as energy devices in the building, the phenomenon of increased seismic effects caused by the reduction of the self-oscillation period of the structure after the apparatus is attached can be avoided. In addition, the viscous dampers have obvious structural features and occupy less space in the construction and installation and are easy to install; their operating conditions are not affected by external environmental factors such as temperature and excitation efficiency. In summary, the viscous damper has both high efficiency and reliable performance. The damper parameters, quantity, and arrangement of the building are shown in Tables 1 and 2.

4.3.3. Analysis of Experimental Results. The comparison of before and after seismic shock absorption was performed for the model with and without viscous dampers under the action of seven seismic waves. The model is calculated to obtain the interstory drift angle and interstory shearing force diagrams (X-direction only) of the structure before and after seismic shock absorption in Figures 8–11.

As it can be seen from Figures 8–11, under the action of seven different seismic waves, the maximum X-directional interstory drift angle before damping is about 0.00135 rad, which occurs at 2 floors, and the maximum interstory shearing force is about 3300 Kn, which occurs at the first floor; the maximum X-directional interstory drift angle after seismic shock absorption is about 0.00117 rad, which occurs at the first floor, and the maximum interstory shearing force is about 3850 Kn, which appears in the first floor. The above data analysis shows that the interstory drift angle of the model structure of a multistory dormitory building of an elementary school in Yunnan Province meets the code requirements. After the deployment of viscous dampers, the interstory drift angle of each floor is reduced about 13%, and the interstory shearing force value is increased about 17%, which achieves the safety performance index of the structure. The viscous dampers played a good role in energy dissipation and damping, and the overall seismic performance of the structure was greatly improved.

5. Conclusion

(1) Earthquakes have been occurring more frequently in recent years, and they often cause heavy casualties and large economic losses and are extremely destructive. Concrete frame structures can be damaged by seismic waves, such as filler wall damage, beam, column and node damage, stairwell damage, and local or overall collapse of the structure

(2) In view of the above structural damage types, the seismic design methods in domestic and international codes are summarized, including seismic measures and seismic structural measures. These measures are designed to improve the seismic performance of concrete frame structures by following the design principles of "strong columns and weak beams, strong shears and weak bends, strong nodes and weak structures" to set the beams, columns, structural nodes, and other building structures, so as to improve the seismic resistance of the building effectively

(3) The types of structural seismic shock absorption include passive seismic shock absorption, active seismic shock absorption, semiactive seismic shock absorption, and hybrid seismic shock absorption. The effectiveness of seismic shock absorption technology is verified by arithmetic examples

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The author declares no conflicts of interest.

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