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Seismic Resilience Analysis of a Concrete-Framed Hospital Building with Viscous Dampers

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Abstract: To study the seismic resilience of a concrete-framed hospital building with viscous dampers, the elastoplastic time history analysis of a three-story concrete-framed hospital building under moderate and rare earthquakes was carried out by finite element analysis software. The structure's overall response was studied, meanwhile, the seismic resilience of the building was evaluated from three aspects: repair cost, repair time, and casualties. The results show that viscous dampers can effectively reduce the repair cost, repair time, and casualties under earthquakes. Compared with the structure without dampers, the repair cost and repair time of the structure with dampers have been reduced by 67% and 69% respectively under moderate earthquakes, 42% and 39% respectively under rare earthquakes, and the seismic resilience grade has been increased from zero to one star.

Keywords: Medical buildings; Viscous dampers; Seismic resilience; Repair cost; Repair time

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1. Introduction

Ensuring the continuation of hospitalization services and reducing overcrowding in emergency departments is critical for minimizing social and economic losses after earthquakes [1]. However, seismic damage surveys have shown that although the structure of the hospital building does not collapse, the damage to non-structural components such as medicine cabinets and medical equipment also leads to medical function disruption. More recently, the 2017 Mexico earthquake forced the main hospital to be evacuated after it suffered major damage, resulting in the patients being transferred to other hospitals [2]. Therefore, the seismic resilience of hospital buildings, including the functional recovery after the earthquake, is very important, and related research has also received great attention in recent years.

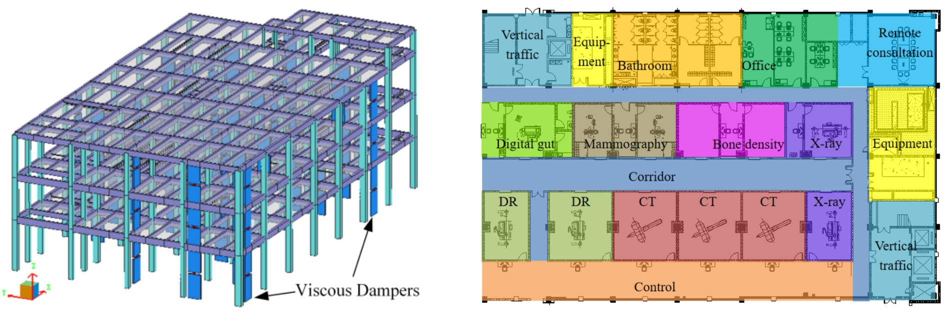
The Chinese seismic resilience evaluation standard, Seismic Resilience Assessment of Buildings (SSRAB) GBT38591-2020, has been published. This standard uses elastoplastic time history analysis of building structures and Monte Carlo simulations to calculate building repair costs, repair times, and casualties, thereby quantifying the seismic resilience index of buildings [3]. While the standard still lacks medical-related equipment seismic fragility parameters cannot be directly used in the seismic resilience evaluation of hospital buildings.

The viscous damper is a speed-related energy-consuming member, that adds damping to the structure without changing its stiffness and brings great convenience to the design of the structure. The viscous damper can effectively reduce the seismic shear force and seismic drift of the structure, while the influence on the seismic resilience of the building is not very clear. In this paper, the seismic resilience of a three-story concrete-framed hospital building with viscous dampers was analyzed based on the standard SSRAB and medical equipment fragility parameters, which provides a reference for the seismic resilience evaluation of similar hospital buildings.

2. Hospital building with viscous dampers

The hospital building is a three-story reinforced concrete frame structure and its total area is about 12,000 m^2. The building height is 20.3 m and its plane size is about 110 m × 37 m. There are seismic seams in the middle of the building, which divide the building into two parts, left and right. This paper takes the right part as the example, which structure modal is shown in **Figure 1(a)**, and the layout of the medical function room on the first floor is shown in **Figure 1(b)**.

The construction costs of the main structural components, enclosure and decoration components, heating, ventilation, air conditioning (HVAC) plumbing and equipment, and main medical equipment are 19.58, 14.75, 13.50, and 50.68 million Chinese yuan, respectively. The construction cost of the main medical equipment is highest, which takes about 51.4% of the total. The main medical equipment in this paper is classified into three categories, which are large, medium, and small medical equipment. The seismic fragility parameter of large medical equipment refers to the data of diesel generators in standard SSRAB. The seismic fragility parameter of medium and small medical equipment refers to the shaking table test data in previous studies [4,5].



(a) Building structure model (b) Medical function room layout

Figure 1. Schematic diagram of the hospital building

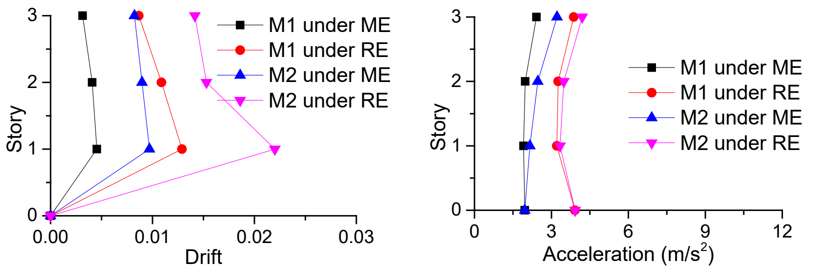
3. Seismic resilience analysis

3.1. Elastoplastic time history analysis

Software SAUSG-RES was used to establish the finite element model of the hospital building structure with (modal M1) and without (modal M2) viscous dampers. Fiber beam element was used to simulate the frame beams and columns and the Maxwell model was used to simulate the viscous dampers. The viscous dampers do not change the natural periods of building and the first three natural periods of model M1 and M2 are 1.21 s, 1.13 s and 1.09 s respectively.

Eleven groups of strong earthquake records were selected as the input motions of time history analysis, which response spectrum fit well with the design spectrum. The ratio of the peak acceleration of the main and secondary direction of earthquake motion is 1:0.85, and the peak acceleration of the main direction was scaled to 200 gal and 400 gal under moderate earthquake (ME) and rare earthquake (RE) respectively.

The mean value of story drift and floor acceleration for modal M1 and M2 under 11 groups of earthquakes ME and RE are shown in **Figure 2**. The viscous dampers can effectively reduce the structural floor response through the response comparison of modal M1 and M2. Compared with the structure without viscous dampers, the maximum story drift in a structure with viscous dampers is reduced by 49.2% and 38.8% under ME and RE respectively, and the maximum floor acceleration is reduced by 22.2% and 8.2% under ME and RE respectively.



(a) Mean value of story drift (b) Mean value of floor acceleration

Figure 2. Comparison of structural response under earthquake motions

3.2. Additional engineering demand parameter generation

A large sample of the engineering demand parameter (EDP) vector is necessary to accurately estimate the cost of damage, while the computational cost hampers the time history analysis. Therefore, additional correlated EDP vectors are generated using a simulation method. The process enables the efficient generation of large numbers of artificial EDP vectors that have the same statistical distribution as the seed data that were generated by the dynamic analyses of the building model.

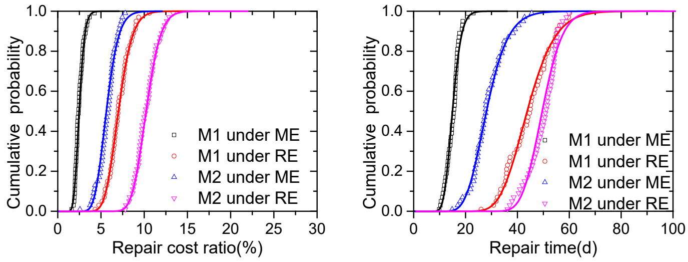
3.3. Seismic resilience index calculation

3.3.1. Repair cost ratio

The repair cost ratio cumulative probability of buildings model M1 and M2 under earthquakes ME and RE is shown in **Figure 3(a)**, in which 84% quantile of the probability distribution is used as the repair cost ratio index. The repair cost ratio index of models M1 and M2 is 2.80% and 7.03% under earthquake ME, while 8.61% and 12.0% under earthquake RE. The building can be rated as one star when the repair cost ratio index is less than 10% under ME, which can be further rated as two stars when the repair cost ratio index is less than 10% under RE. Thus model M1 can be rated as two stars while model M2 can only be rated as one star.

3.3.2. Repair time

The repair time cumulative probability of buildings model M1 and M2 under earthquakes ME and RE is shown in **Figure 3(b)**, in which 84% quantile of the probability distribution is used as the repair cost ratio index. The repair time index of models M1 and M2 is 16 d and 33 d under earthquake ME, while 52 d and 54 d under earthquake RE. The building can be rated as one star when the repair cost ratio index is less than 30 d under ME, which can be further rated as two stars when the repair cost ratio index is less than 30 d under RE. Thus, model M1 can be rated as one star while model M2 can only be rated as zero star.



(a) repair cost ratio (b) repair time

Figure 3. Seismic resilience index

3.3.3. Casualties

Casualties are related to the degree of damage to both structural and non-structural components of a building. As the 84% quantile of the mortality rate probability distribution of model M2 is greater than 0.01%, model M2 can only be rated as zero stars. While the mortality rate index of model M1 is less than 0.01% and its injury rate index is less than 0.1%, thus model M1 can only be rated as one star.

3.3.4. Resilience grade

The Resilience Standard takes the lowest grade of the three resilience index as the seismic resilience grade of the building. Although the repair cost of model M2 can be rated as one star, the repair time and casualties can only be rated as zero stars, so its seismic resilience grade is zero stars. Similarly, the repair cost of model M1 can be rated as two stars, but the repair time and casualties can only be rated as one star, so its seismic resilience grade is one star. Thus, adding viscous dampers can improve the seismic resilience grade of concrete frame hospital buildings from zero star to one star.

4. Conclusion

Based on the comparison of time history analysis and seismic resilience analysis between concrete frame structure hospital buildings with and without viscous dampers, the following conclusions can be drawn:

(1) Adding viscous dampers can reduce the maximum story drift of concrete frame structure hospital building by about 40% to 50% and maximum floor acceleration by about 10% to 20%.

(2) Compared with the structure without dampers, the repair cost and repair time of the structure with dampers have been reduced by 67% and 69% respectively under moderate earthquakes, 42% and 39% under rare earthquakes.

(3) Adding viscous dampers can effectively reduce the repair cost, repair time, and casualties, thus improving the seismic resilience of concrete frame hospital buildings from zero star to one star.

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Disclosure statement

The authors declare no conflict of interest.

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