Analysis and Application of Shock Absorption Measures for High-rise Inpatient Building of a Hospital in High Intensity Fortification Area

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Abstract. A proposed 22-storey hospital building is located in an area with 8-degree seismic fortification and is a reinforced concrete frame-shear wall structure. Through the establishment of structural model, calculation and comparative analysis are carried out by using ETBAS and PERFORM-3D software. The viscous damping wall is used for energy dissipation and damping, and the optimal damping scheme is determined by multi round time history analysis and optimal adjustment of the number and location of dampers.

1. Introduction

The Wenchuan earthquake of 5.12 in 2008 and the new crown pneumonia epidemic ravaging the world in early 2020, medical buildings are of great significance in earthquake relief and fighting against the epidemic to ensure the safety of people's lives and are being paid more and more attention by governments and construction units at all levels. The Classification Standard for Seismic Fortification of Construction Projects (GB20223-2008) specifically points out that the seismic fortification of Level II and III hospitals and "township hospitals with surgical operating rooms or emergency departments" should be the key fortification category, while the level III hospitals undertaking especially important medical tasks should be upgraded to the special fortification category. Based on a hospital project, taking the high-rise IP2 as the calculation and analysis object, this paper discusses the feasibility of high-rise damping measures in the 8-degree fortification area, and puts forward the layout scheme of viscous damping wall.

2. Engineering survey

A new hospital with a total construction area of 380000 m2. The high-rise inpatient building IP2 has 2 floors underground, 22 floors above the ground, 4.0m high in standard floor and 93.85m high in total structure. The structural system is a reinforced concrete frame-shear wall structure.

The seismic fortification intensity of the project building is 8 degrees, and the design service life of the structure is 50 years. The seismic fortification of the project building is classified as key fortification category (category B). The design basic earthquake and velocity are 0.2g The maximum impact coefficient of horizontal earthquake is 0.16 under small earthquake and 0.90 under large
earthquake. The design earthquake group is the third group, and the site category is class II. The basic wind pressure is 0.45kn/m², and the ground roughness is class A. Vfd-1700kn viscous damping wall is proposed to reduce the seismic response of the structure. The energy dissipation and damping objective is to provide 5% equivalent additional damping ratio for the damping wall under frequent earthquake.

3. Establishment of Analytical Model

3.1. Computing software

Using the finite element software ETBAS to establish a reliable three-dimensional finite element model of the damping structure and non-damping results can truly reflect the dynamic characteristics of the structure, and can accurately analyze the dynamic response of the structure in the elastic and elastic-plastic stages. The etbas element developed by CSI company has a high calculation reliability. It uses spatial bar system to calculate beam column components, and simplifies the shear wall without hole or small hole into membrane element with side beam and side column. The membrane element only bears the in-plane load, and the side column action is equivalent to the out of plane stiffness of the shear wall. In addition to the general calculation function of high-rise buildings, etbas can also calculate special components such as shock absorption bearings, sliding plate bearings, dampers, gaps, springs, inclined plates, variable section beams, etc.

PERFORM-3D software for nonlinear analysis and performance evaluation of three-dimensional structures performs dynamic elastoplastic analysis of conventional structures and energy dissipation structures.

3.2. Establishment of Analysis Model for High-rise IP2 Non-seismic Structure

In the non-shock-absorbing finite element model, both beam and column members adopt spatial beam and column elements. The three-dimensional view of the model after completion is as follows:

![Figure 1. 3D view of model.](image-url)
4. Evaluation of input earthquake

4.1. Design ground motion

According to the Code for Seismic Design of Buildings, the calculated bottom shear force of each ground motion time-history curve under frequent earthquakes is less than 65% of the calculated results by the mode decomposition response spectrum method and less than 135% of the calculated results by the mode decomposition response spectrum method. The average value of the shear force at the bottom of the structure calculated by the eight time history curves is more than 80% of that calculated by the mode decomposition response spectrum method.

4.2. Evaluation of high-rise IP2 seismic response

Comparison results of seismic shear force and displacement angle between X-direction and Y-direction non-seismic structure time history and response spectrum floors. (X direction only)

Comparison of seismic shear forces between time history and response spectrum of X-direction non-seismic structures. (unit: kN)

Table 1. Comparison of inter story seismic shear force between time history and response spectrum of X-direction non-seismic structures.

| Level number | X02 9FP | X72 8FP | X80 2FN | X80 3FN | X11 58FP | X15 45FP | XL7 451 | XL7 452 | Wave average | 65% Response spectrum | 80% Response spectrum | 120% Response spectrum | 135% Response spectrum |
|--------------|---------|---------|---------|---------|----------|----------|---------|---------|--------------|-----------------------|-----------------------|----------------------|-----------------------|
| 22           | 414 0   | 405 1   | 3745    | 3698    | 4804     | 3854     | 440 3   | 474 2   | 418 0        | 2387                  | 2938                  | 4407                 | 4958                  |
| 21           | 765 4   | 711 0   | 7055    | 6877    | 8742     | 7342     | 787 6   | 806 5   | 758 9        | 4352                  | 5356                  | 8034                 | 9038                  |
| 20           | 102 09  | 888 0   | 9610    | 9287    | 1156 7   | 1011 5   | 100 64  | 103 98  | 100 16       | 5799                  | 7138                  | 1070 7               | 1204 5               |
| 19           | 119 97  | 961 9   | 1156 6  | 1118 1  | 1367 2   | 1227 2   | 117 41  | 121 45  | 117 74       | 6940                  | 8541                  | 1281 2               | 1441 3               |
| 18           | 130 76  | 102 56  | 1305 8  | 1294 4  | 1519 6   | 1385 2   | 135 19  | 132 75  | 131 47       | 7937                  | 9768                  | 1465 3               | 1648 4               |
| 17           | 142 90  | 106 95  | 1423 0  | 1464 8  | 1591 1   | 1471 5   | 147 49  | 139 09  | 141 33       | 8761                  | 1078                  | 1617 4               | 1819 6               |
| 16           | 149 50  | 116 82  | 1677 4  | 1616 7  | 1593 2   | 1503 3   | 160 60  | 151 62  | 152 20       | 9476                  | 1166                  | 1749 3               | 1968 0               |
| 15           | 155 27  | 125 53  | 1901 6  | 1737 5  | 1565 0   | 1507 6   | 174 48  | 169 31  | 161 97       | 1012                  | 1246                  | 1869 1               | 2102 7               |
| 14           | 157 45  | 140 73  | 2067 1  | 1811 9  | 1664 8   | 1611 5   | 181 75  | 183 37  | 172 35       | 1068                  | 1314                  | 1972 4               | 2218 9               |
| 13           | 157 34  | 155 15  | 2177 9  | 1845 2  | 1789 9   | 1760 4   | 184 84  | 193 51  | 181 42       | 1121                  | 1380                  | 2070 7               | 2329 6               |
| 12           | 155 53  | 168 96  | 2230 0  | 1844 6  | 1852 1   | 1930 0   | 199 60  | 199 24  | 188 62       | 1176                  | 1447                  | 2171 7               | 2443 2               |
| 11           | 151 66  | 181 36  | 2216 8  | 1818 0  | 1851 9   | 2041 9   | 214 79  | 200 35  | 192 62       | 1227                  | 1510                  | 2265 4               | 2548 6               |
| 10           | 167 39  | 193 02  | 2147 8  | 1775 6  | 1977 8   | 2096 9   | 226 40  | 197 41  | 198 01       | 1276                  | 1571                  | 2356 8               | 2651 4               |
From the results of structural time-history analysis, it can be seen that the ground motion used in the time-history analysis of this project meets the requirements of "Code for Seismic Design of Buildings".

5. Analysis of Energy Dissipation and Damping of Structures under Frequent Earthquakes

5.1. Selection of Shock Absorption Scheme
Reasonable arrangement of dampers in a structure is an effective way to achieve shock absorption effect under the condition of a given number of configurations. In addition to following the principle of "large dispersion and small concentration" in the arrangement of dampers, some characteristics of the building itself should also be considered. Through the multi wheel time history analysis of the number and location of dampers, the final damping scheme is determined after the optimal adjustment. The specific distribution quantity of each layer in the layout scheme of IP2 damper for high-rise building of the project is shown in the table below.

Table 2. Viscous damping wall parameters

| Damping coefficient C | Damping index α | Design damping force/kN | Design travel/mm |
|-----------------------|-----------------|-------------------------|------------------|
| 4000                  | 0.45            | 1700                    | ±100             |

Table 3. Layout Scheme and Dosage of High-rise IP2 Viscous Damping Wall

| Arrange floors | X direction | Y direction | Subtotal |
|----------------|-------------|-------------|----------|
| 1~22 floors    | 2           | 2           | 4        |
| Total          | 44          |             |          |

5.2. Nonlinear Time-history Analysis of High-rise IP2 Frequent Earthquakes
(1) According to the analysis and calculation results, the maximum inter-story displacement angle of the energy dissipation structure in both directions is less than 1/800 under the action of 8-degree frequent earthquakes, which meets the requirements of the Code.

(2) Calculation of additional damping ratio by response method
In order to determine the value of the total equivalent damping ratio of the structure after the viscous damping wall is installed, ETABS software is used to carry out structural shock absorption analysis.
analysis of the structure under the action of seismic waves. The X and Y directions of each wave and the interlayer shear force of each floor are compared before and after shock absorption, and the interlayer shear force shock absorption coefficient of each wave, each direction and each floor is obtained. On the basis of it, the average value of seismic wave in each direction and each floor is used as the actual interlayer shear damping coefficient after the structure is set with viscous damper.

In addition, under the action of 5% damping ratio and 10% damping ratio, yjk model is used to calculate the inter story shear damping coefficient of each direction and each floor. The results show that the actual interlaminar shear damping coefficient calculated by ETABS model is better than that calculated by YJK model. The structure can be designed with a total equivalent damping ratio of 10% and is relatively safe.

(3) Calculation of additional damping ratio by standard method

| Time wave | Wcj damper energy dissipation (kN·mm) | Ws strain energy (kN·mm) | Additional damping ratio | Average damping ratio |
|-----------|--------------------------------------|--------------------------|--------------------------|-----------------------|
| X029FP    | 387120                               | 335853                   | 9.17%                    | 7.58%                 |
| X728FP    | 324411                               | 342404                   | 7.54%                    |                       |
| X802FN    | 526172                               | 600974                   | 6.97%                    |                       |
| X803FN    | 400436                               | 406558                   | 7.84%                    |                       |
| X1158FN   | 569237                               | 764046                   | 5.93%                    |                       |
| X1545FP   | 405416                               | 430312                   | 7.50%                    |                       |
| XL7451    | 407788                               | 428314                   | 7.58%                    |                       |
| XL7452    | 386669                               | 379388                   | 8.11%                    |                       |
| Y029FP    | 369885                               | 396249                   | 7.43%                    |                       |
| Y728FP    | 308882                               | 408824                   | 6.01%                    | 7.58%                 |
| Y802FN    | 479896                               | 629072                   | 6.07%                    |                       |
| Y803FN    | 363990                               | 452940                   | 6.39%                    |                       |
| Y1158FN   | 522503                               | 811384                   | 5.12%                    |                       |
| Y1545FP   | 370496                               | 457131                   | 6.45%                    |                       |
| YL7451    | 379906                               | 489770                   | 6.17%                    |                       |
| YL7452    | 354099                               | 431604                   | 6.53%                    |                       |

As can be seen from the above table, the additional damping ratio of viscous damping wall is calculated by the standard method, and the additional damping ratio in X direction is 7.58%, and that in Y direction is 6.27%. It can be seen that the structure can be designed with a total equivalent damping ratio of 10%.

(4) Calculation of Additional Damping Ratio by Energy Method

Similarly, the energy method is used to calculate the ratio of the total energy consumption of the damper to the damping energy consumption of 5% mode shape under each seismic wave input. It is found that the energy dissipation of the damper can be calculated according to the equivalent additional damping ratio of 10.71% under the input of X-direction ground motion. Under the input of Y-direction ground motion, the energy dissipation of the damper can be calculated according to the equivalent additional damping ratio of 9.23%. The energy diagram under each seismic wave is as follows.
Figure 2. The energy pattern of each seismic wave
6. Dynamic Elastoplastic Analysis of Structures under Large Earthquakes

6.1. Evaluation Method for Seismic Performance of Structural Members
Seismic performance evaluation will be conducted through the overall seismic performance of the structure and the deformation level of members.

The evaluation of the whole performance will be based on the displacement angle between elastic-plastic layers, the plastic development process and the plastic development area. The evaluation of components evaluates the structure from the relationship between the plastic deformation of components and the limit value of plastic deformation, the plastic deformation of key parts and key components, so as to ensure that the structural components can still bear the vertical earthquake force and gravity during the earthquake process and the structure can still bear the gravity load acting on the structure after the earthquake, thus ensuring that the structure cannot be seriously damaged or collapsed due to the damage of local components.

6.2. Material constitutive model
The structural analysis of this project adopts non-buckling steel constitutive model and bilinear follow-up hardening model. Elastic-plastic damage model is adopted for concrete.

6.3. Dynamic elastoplastic analysis of high-rise IP2 under large earthquake
The finite element model for shock absorption analysis is established. Beam and column members are all spatial beam-column elements. After completion, the model is shown in the following figure:

![Figure 3. Perform-3D model 3D perspective](image1.png)

![Figure 4. Perform-3D model plan view](image2.png)

6.4. Additional damping ratio of large earthquake
The energy method is used to calculate the ratio of the total energy consumption of the damper to the damping energy consumption of 5% mode shape under the earthquake input of each seismic wave. It
is found that the energy consumption of the damper can be calculated according to the equivalent additional damping ratio of 2.6% under the earthquake input of X direction. Under the input of Y-direction ground motion, the energy consumption of the damper can be calculated as 3.0% of the equivalent additional damping ratio. The energy map under each seismic wave is shown in the figure below.

**Figure 5.** Energy map of X803 seismic wave

**Figure 6.** Energy diagram of X1158FN seismic wave
Figure 7. Energy diagram of XL7451 seismic wave

Figure 8. Energy map of Y803 seismic wave

Figure 9. Energy diagram of Y1158FN seismic wave
6.5. Overall response of structure under large earthquake
According to the analysis and calculation results, the maximum inter-story displacement angle of the damping structure is obtained when each group of seismic waves are input. When seismic waves are input in the X direction, the maximum interlayer displacement angles of the damping structure are respectively 1/166, 1/123 and 1/127 (803FN, 1158FN and L7451), and the envelope value is 1/123, which is less than the limit value of 1/100. The seismic wave is mainly input in the Y direction, and the maximum interlayer displacement angles of the shock absorbing structure are 1/150, 1/120 and 1/105 (803FN, 1158FN, L7451), respectively, with the envelope value of 1/105, which is less than the limit value of 1/100.

6.6. Overall Deformation and Damage of Structures
Under rare earthquakes, the overall damage degree of the structure is relatively low. Some frame beams and shear walls exceed the first performance level, while frame columns do not exceed the first performance level. A few frame beams as energy dissipation members yield, exceeding the second performance level, while a few shear walls exceed the second performance level. A small number of frame beams exceed the third performance level and shear walls do not exceed the third performance level. The structure can meet the performance requirement of large earthquake failure under rare earthquake.
The damper outputs the maximum damping force and stroke

The damping wall of this project is connected with the reinforced concrete beam, and the maximum output force of the damping wall under the action of elastic rare earthquake shall be taken as the checking load of the reinforced concrete beam connected with it. According to the calculation results, the maximum output damping force of the damping wall X to the damping structure of this project
under rare earthquake is 1853kN, which is located on the 19th floor. The maximum output damping force in Y direction is 2128 kN, which is located on the 19th floor.

The displacement of elastic-plastic damping wall under rare earthquake is 39.48mm in x direction and 57.15mm in y direction.

Hysteresis curve reflects the deformation characteristics, stiffness degradation and energy consumption of the structure during repeated loading, which is the basis for nonlinear seismic response analysis. The following figure shows the hysteresis curve of the damper in the typical position of the damping structure under the rare earthquake. It can be seen that the hysteretic curve is full and the damping wall has good energy dissipation performance.

Figure 15. Hysteretic energy dissipation curve of damper with X direction 170 tons damper under elastic earthquake

Figure 16. Hysteresis energy dissipation curve of Y-directional 170-ton damper elastic under rare earthquake

7. Checking Calculation of Beam-column Connection of Damping Wall

(1) According to the calculation results, the internal force and reinforcement of the frame column adjacent to the damping wall under large earthquake all meet the requirements of shear elasticity under large earthquake;

(2) The P-M points of all frame columns adjacent to the damping wall are within the envelope, indicating that the bending relationship of frame columns meets the requirement of non-yielding under large earthquakes.
Figure 17. Envelope Diagram of column bearing capacity
8. Seismic Performance Evaluation of Structures and Application Examples

Through the shock absorption design and dynamic elastoplastic analysis of the system, the following conclusions can be drawn:

(1) Proper selection of seismic wave for time history analysis

The selected ground motions are evaluated based on acceleration and velocity respectively. When evaluating based on acceleration, the corresponding maximum velocity values have little difference. The bottom seismic shear force calculated by each time-history curve is greater than 65% of the calculation result of response spectrum method, and the average value of the bottom seismic shear force calculated by time-history curve is greater than 80% of the calculation result of response spectrum method. The average value of the maximum seismic response value under the action of time history curve is used as the final calculation value of time history analysis. The result is reliable and can be used in engineering design.

(2) In the case of frequent earthquake, the plane position of damping wall can be configured by using three-dimensional model and meet the design requirements

After the damper is installed, the maximum floor seismic shear force distribution of the energy dissipation structure is reasonable under the action of 8-degree frequent earthquakes, and the maximum interlayer displacement angle in both directions of the frame-shear wall structure is less than 1/800. The maximum interstory displacement angle of the frame structure in both directions is less than 1/550, which meets the requirements of the code for seismic design of buildings in China.

(3) Under rare earthquake, the structure with dampers can meet the requirements of seismic performance design

According to this energy dissipation scheme, the effect of viscous damping wall on reinforced concrete multi-storey structure can be equivalent to 5% additional damping ratio. Generally speaking, the damper arrangement scheme can well protect the main structure under the condition of rare intensity ground motion input, and can achieve the fortification goal of ensuring life safety. The frame beam connecte with that damping wall meet the requirements of large earthquake bending bearing capacity and shear elasticity.

(4) Notes on installation and construction of viscous damping wall

1) Select embedded components corresponding to damping walls that meet the requirements of viscous damping wall distribution points.
2) Focus on checking whether the embedded steel bar of shear wall at the installation point hinders the installation of embedded parts.
3) The surface levelness error of embedded steel plate is less than 1:500.
4) After the positioning of embedded parts is completed, reliable measures shall be taken to avoid the deviation of components in the subsequent shear wall pouring process.
5) Protect the finished product after installation.

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