Research on the distribution of viscous damping based on numerical simulation

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Abstract. Based on a 20-layer rigid frame structure, a viscous damper is selected. First determine an amount of viscous dampers. Assign the determined damping amount in different ways, Then different seismic responses are obtained under different seismic waves. Compare interlayer displacement and velocity under various operating conditions, and find a distribution scheme with better shock absorption.

1. Introduction
Earthquake action is actually a process of energy input, transformation and consumption. Dampers are added to the structure so that when the earthquake comes, the structure itself can be protected by absorbing seismic energy through the dampers. Up to now, the research has been very mature. However, there are few studies on the distribution of viscous dampers in the floor. In the book on the Design and Construction Manual of passive damping structures, Kasakai Kazuhiko proposed to allocate according to the loss stiffness 2. Based on the previous studies, this paper seeks a simple arrangement through the comparison of different distribution methods.

2. Theoretical model
The object discussed in this paper is a 20-story steel frame structure with 7 horizontal frames and 4 vertical frames with a length of 38.4 m and a width of 32 m (refer with: Fig. 1). The first layer is 5m high, the remaining layers are 3.6m high, the total height is 73.4m, and the Y-direction span is 12m, 8m, 12m (refer with: Fig. 2). The beam and column are connected by consolidation. The column adopts box section, the beam adopts H-section, the steel grade is Q345, and the elastic modulus is 206GPa. The cross-section form and size of the component (refer with: Table 1). In this paper, we only discuss the seismic response in the Y direction, assuming that the mass distribution is uniform and the magnitude is 1000kg / m².
Figure 1. Structural plan

Figure 2. Structure elevation

Table 1. Beam and column section form and size

| Floor | Component | Section size       |
|-------|-----------|--------------------|
| 1-5   | Column    | 600 × 600 × 50    |
| 6-10  | Column    | 600 × 600 × 46    |
| 11-15 | Column    | 600 × 600 × 42    |
| 16-20 | Column    | 600 × 600 × 38    |
| 1-6   | Beam      | H 850 × 300 × 16 × 32 |
| 7-12  | Beam      | H 800 × 300 × 16 × 32 |
| 13-20 | Beam      | H 800 × 300 × 19 × 25 |

Calculation of interlaminar shear and interstory displacement curves of structural particle model based on static elastoplastic analysis. Resilience characteristics are expressed using a three-fold line standard model. Resilience characteristic parameter of each layer. (refer with: Table 2). Up1 represents the first yield displacement, up2 represents the second yield displacement, and Sk1, Sk2 and Sk3 represent the elastic stiffness, the second lateral stiffness and the third lateral stiffness respectively.

Table 2. Restoring force characteristic parameters

| Floor | up1(m) | up2(m) | Sk1(N/m) | Sk2(N/m) | Sk3(N/m) |
|-------|--------|--------|----------|----------|----------|
| 1     | 0.037  | 0.200  | 1.12 × 10^9  | 5.95 × 10^6 | 4.39 × 10^6 |
| 2     | 0.034  | 0.150  | 1.12 × 10^9  | 1.34 × 10^7 | 1.72 × 10^5 |
| 3     | 0.031  | 0.140  | 1.07 × 10^9  | 5.74 × 10^6 | 1.44 × 10^5 |
| 4     | 0.030  | 0.130  | 1.05 × 10^9  | 8.13 × 10^6 | 2.40 × 10^5 |
| 5     | 0.026  | 0.064  | 1.03 × 10^9  | 9.17 × 10^5 | 1.49 × 10^5 |
| 6     | 0.026  | 0.055  | 9.98 × 10^8  | 1.29 × 10^6 | 1.81 × 10^5 |
| 7     | 0.025  | 0.050  | 9.50 × 10^8  | 9.57 × 10^5 | 2.14 × 10^5 |
| 8     | 0.025  | 0.045  | 9.84 × 10^8  | 2.67 × 10^6 | 3.42 × 10^5 |
| 9     | 0.025  | 0.051  | 9.53 × 10^8  | 9.23 × 10^5 | 2.50 × 10^5 |
| 10    | 0.024  | 0.060  | 9.01 × 10^8  | 8.00 × 10^5 | 2.22 × 10^5 |
| 11    | 0.020  | 0.050  | 9.07 × 10^8  | 7.50 × 10^5 | 1.50 × 10^5 |
| 12    | 0.020  | 0.050  | 8.54 × 10^8  | 6.00 × 10^5 |           |
| 13    | 0.016  | 0.040  | 8.56 × 10^8  | 5.70 × 10^5 |           |
| 14    | 0.014  |        | 8.40 × 10^8  |           |           |
| 15    | 0.013  |        | 8.11 × 10^8  |           |           |
| 16    | 0.011  |        | 7.26 × 10^8  |           |           |
| 17    | 0.010  |        | 6.82 × 10^8  |           |           |
| 18    | 0.010  |        | 6.63 × 10^8  |           |           |
| 19    | 0.010  |        | 4.94 × 10^8  |           |           |
| 20    | 0.010  |        | 3.32 × 10^8  |           |           |
The period of the structure is \( T = 2.9 \text{s} \). According to the empirical formula \( T = (0.1 \sim 0.15)n \), \( n = 20 \), the calculation results are in \((2.0 \sim 3.0)\text{s}\), which conforms to the code.

3. Vibration differential equation and ground motion.

Vibration differential equations of multi particle system layer model under ground motion:

\[
[M][\ddot{x}] + ([C] + [C_d])[\dot{x}] + [k][x] = -[M][\ddot{x}_g]
\]

(1)

Where \([M]\) represents the structural mass matrix; \([C]\) represents the internal viscous damping matrix of the structure, Using Rayleigh damping, \([C_d]\) indicates the additional viscous damper damping coefficient matrix.\([k]\) represents the elastic stiffness obtained by the static elastoplastic analysis method, \([\ddot{x}_g]\) represents the ground seismic acceleration matrix, \([x], [\dot{x}], [\ddot{x}]\) represents structural displacement, velocity and acceleration response vector matrix.

In this paper, three seismic waves are used to analyze the elastoplastic time history of the structure. Acceleration time history curve of three seismic waves (refer with: Fig.3,Fig.4,Fig.5), Adjust the peak acceleration of the seismic wave to \( 5 \text{m/s}^2 \), The time interval is \( 0.02 \text{s} \).

![Figure 3. Gaoshi wave](image)

![Figure 4. Building wave](image)

![Figure 5. Rijian wave](image)

4. Comparison of different ways of distribution and shock absorption

This paper mainly discusses the damping distribution scheme, which can achieve better damping effect by changing the different distribution of damping on the floor. The damping amount is selected as the total amount of damping when the displacement is reduced by 57% under uniform distribution. At this time, the total amount of damping is \( C_d = 1.6 \times 10^7 \text{N} \cdot \text{s/m} \). Compare the different distribution methods and the shock absorption effect under different seismic waves.

1, uniform distribution, that is, the same damping capacity for each layer, \( 8 \times 10^5 \text{N} \cdot \text{s/m} \) for each layer.

2, Distribute damping according to the lateral stiffness of each floor.

\[
C_i = C_d \times \frac{k_i}{\sum k_i}
\]

(2)
$C_i$ is the additional damping of layer $i$. $k_i$ is the lateral stiffness of layer $i$. $C_d$ is the total amount of additional damping.

3. According to the above floor allocation, the following floor allocation is less to allocate 20 floors are allocated according to the allocation ratio of 1:2:3:4:5 from the bottom to the top of each unit, and four floors in each unit distribute damping equally.

$$C_{1,2,3,4} = \frac{C_d}{15}$$  \hspace{1cm} (3) \\
$$C_{5,6,7,8} = \frac{2C_d}{15}$$ \hspace{1cm} (4) \\
$$C_{9,10,11,12} = \frac{3C_d}{15}$$ \hspace{1cm} (5) \\
$$C_{13,14,15,16} = \frac{4C_d}{15}$$ \hspace{1cm} (6) \\
$$C_{17,18,19,20} = \frac{3C_d}{15}$$ \hspace{1cm} (7)

$C_d$ is the total amount of additional damping. $C_i$ is the additional damping of layer

4. Damping is allocated according to the ratio of the absolute displacement of each layer to the absolute displacement reduction of each layer without damping under the average distribution formula.

$$C_i = \frac{C_d \times x_{ci}}{\sum(x_i - x_{ci})}$$ \hspace{1cm} (8)

$x_i$ is the interlaminar displacement of the $i$ layer under the condition of no damping. $x_{ci}$ is the structure in the average distribution of the $i$ layer of the interlayer displacement.

5. For 1-20 stories, $8 \times 10^5$ N. s/m is added separately to each floor. The damping is allocated by the ratio of the absolute displacement of the top story in 20 cases and the absolute displacement reduction of the top story without damping.

$$C_i = \frac{C_d \times x_{dci}}{\sum(x_{d} - x_{dci})}$$ \hspace{1cm} (9)

Where $x_{dci}$ is the absolute displacement of the 20th layer after the damping of $8 \times 10^5$ N. s/m is added separately in the $i$ layer, and $x_{d}$ is the absolute displacement of the 20th layer without damping. The damping effects of different layout schemes are as follows (refer with Fig.6, Fig.7, Fig.8)

4.1 Comparison of the maximum absolute displacement of the floor of the seismic wave structure:

![Figure 6. Gaoshi wave](image)

![Figure 7. Building wave](image)
4.2 Comparison of relative displacement of structural floors under three kinds of seismic waves (refer with: Fig.9, Fig.10, Fig.11)

4.3 The seismic response is shown in the table below (refer with table.3, table.4, table.5)

| Allocation | Seismic wave | Gaoshi wave | Building wave | Rijian wave |
|------------|--------------|-------------|---------------|-------------|
| Original structure | 0.045 | 0.089 | 0.059 |
| 1 | 0.019 | 0.042 | 0.032 |
| 2 | 0.017 | 0.039 | 0.028 |
| 3 | 0.016 | 0.039 | 0.027 |
| 4 | 0.020 | 0.043 | 0.033 |
| 5 | 0.015 | 0.038 | 0.027 |
Table 4. Mean value of maximum interlayer displacement reduction rate

| Seismic wave Allocation | Gaoshi wave | Building wave | Rijian wave |
|-------------------------|-------------|---------------|-------------|
| 1                       | 0.575       | 0.531         | 0.459       |
| 2                       | 0.623       | 0.559         | 0.526       |
| 3                       | 0.655       | 0.565         | 0.540       |
| 4                       | 0.565       | 0.523         | 0.443       |
| 5                       | 0.667       | 0.569         | 0.542       |

Table 5. Reduction rate of maximum relative displacement in floor

| Seismic wave Allocation | Gaoshi wave | Building wave | Rijian wave |
|-------------------------|-------------|---------------|-------------|
| 1                       | 0.575       | 0.759         | 0.675       |
| 2                       | 0.625       | 0.754         | 0.694       |
| 3                       | 0.640       | 0.792         | 0.697       |
| 4                       | 0.572       | 0.755         | 0.671       |
| 5                       | 0.622       | 0.796         | 0.701       |

5. Conclusions

According to the displacement response results, after adding the viscous damper, the displacement reduction rate under various working conditions is about 60%. For different seismic waves, the damping effect of working condition 3 and working condition 5 is the most. good. The following conclusions are obtained:

- Better damping effect can be obtained by installing more damping on the upper part of the building. The distribution method of working condition 3 is simple and the damping effect is good, which can save time.
- First apply damping to each layer, and distribute the damping according to the top displacement reduction rate, and can obtain better damping effect.

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