Study on seismic performance of frame structure with viscous damping staircase

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Abstract: Based on the significant energy dissipation performance of the viscous damper, the force-displacement hysteresis curve is full and the Maxwell mechanical model has a weak dependence on vibration frequency. Combining the failure mode of the staircase damage with the Maxwell mechanical model, this paper proposes an earthquake-resistant frame staircase model with damped bearings. A finite element analysis of a nine-story reinforced concrete structure is performed using SAP2000. By setting three different connection methods on the staircase structure, the similarities and differences of different staircase structures to the input seismic wave feedback are analyzed to compare the advantages and disadvantages of its seismic performance.

1. Introduction
At present, there are two main directions for staircase seismic research. One idea is to disengage the staircase from the main structure, in other words, it considers the stairway as a cavity, and performs the overall analysis and calculation of the structure [1-2]. However, according to research, if the staircase is simply disengaged from the structure, due to insufficient constraints, the staircase may appear to be tripped and unstable under the action of earthquakes [3-4]. The other is not to separate the staircase from the main structure [5], and to analyze and design according to the actual real situation; because of impact of small earthquakes, the structural seismic performance is benefited to the lateral stiffness provided by the stair bracing. For other frequent earthquakes and fortification-level earthquakes, many scholars no longer simply separate the above two methods completely, and the compromise method is a good solution. In the theory of Zhou Yun's energy-absorbing shock-absorbing stairs with viscoelastic dampers [6], or the theory of Zhou Yun's damp-filled walls in stairwells [7], the above Energy dissipation are through the damper's stroke. The energy input to the structure by an earthquake. Because the amount of damping material in the wall is too large, and the storage and sealing requirements are high, this paper proposes to use a viscoelastic damping support in the stairwell.

2. Introduction of viscous damping bearings
One of the core technologies of energy dissipation is the energy dissipation bearing. Among them, the rubber bearing is the most widely used, but the disadvantage is that the ordinary sandwich rubber bearing can provide a damping ratio of not more than 3%. Capabilities are no longer sufficient for today's frame stairwells. If we want to make up for the shortcomings of ordinary rubber bearings, it will need to add a damper, which makes the structure more complicated and is not conducive to design and construction.
Therefore, on the premise of ensuring the seismic performance, more excellent viscoelastic dampers have received more attention. Among the more mature viscoelastic dampers and mechanical models, and the consideration of stairwell space, viscoelastic bearings are more convenient to construct than damped filled walls; Considering the frequency dependence of vibration of viscoelastic materials, the applicable range of Maxwell mechanical model and viscoelastic bearing combination will be more extensive.

Therefore, this paper proposes a viscoelastic damping support shown in Figure 1, and the Maxwell mechanical model based on this support is shown in Figure 2. It is set at the joint of the ladder beam (or frame beam) and the segment plate. Because the damping bearing occupies less space than the damping filling wall, and the viscous medium uses silicone and methyl silicone oil [8], it has unique advantages. It has the advantages of silicone oil, such as better fluidity, high viscosity, good temperature durability and small compressibility, odorless, colorless, non-toxic, non-volatile, non-flammable, etc.; and it is not easy to leak, but easy to store, and has a small viscosity coefficient. Silicone oils do not have characteristics. Excellent characteristics can make the force-displacement hysteresis curve of the damper full, and can provide the damper with appropriate dynamic stiffness, which significantly enhances its energy dissipation capacity.

Figure 1. Maxwell model viscous damping bearing

Figure 2. Maxwell mechanical model

2.1. Vibration damping mechanism of viscous damper

Viscous damper units dissipate energy through viscous friction and pore shrinkage effects, while viscous dampers are considered too stiff in the field of shock absorption and design, and do not have initial stiffness like metal dampers or anti-buckling supports. It will cause the stiffness distribution of the structure, which will cause the seismic force to be redistributed in the structure [9]. The stiffness of the viscous damper is too small under certain conditions, that is, the operating frequency of the viscous damper is below the "cut-off frequency", which means that the damper has a large dependence on the
operating frequency. Considering some specific working environments or special high-frequency external load excitation, the existing damper needs to adjust the internal pressure of the damper through a pressure valve. This article believes that through the understanding of the "Maxwell viscous damper model" of the damping-stiffness continuity, a spring of moderate elastic modulus is added to the piston rod and connecting rod of the existing cylinder gap damper. That is to say, the damping stick pot unit and the spring unit are connected in series in the Maxwell model.

There are two main ways of energy consumption of this viscoelastic damper. One is to dampen the pore shrinkage effect of the sticky pot by a single rod. The resistance caused by the fluid flowing through a local obstacle is called local resistance. Sudden changes in pipe bending, reduction or expansion of the cross section of a fluid pipe, or a throttle control valve provided in the pipe. The main causes of local resistance are mainly due to the vortex vortex, liquid deformation (especially the fluid with higher viscosity), redistribution of velocity, impact and secondary flow of disturbed liquid flow when the fluid flows through these obstacles. The energy loss caused by local resistance is called local loss. In a cylinder viscoelastic damper, when the viscous material in the cylinder flows through the gap between the piston and the cylinder wall or the pores on the piston, the fluid cross section suddenly expands or shrinks, which in turn generates local resistance, causing Local loss, which is mainly composed of energy loss due to inlet contraction and energy loss due to beam expansion. The other way to dissipate energy is through the mutual conversion of the elastic potential energy and kinetic energy of the spring. In the conversion process, energy is inevitably lost to internal energy.

2.2. Maxwell model structure construction

In this paper, the energy method is used to analyze and explain the damping mechanism of the damper. As shown in Figure 2, the mechanical model is connected in series by a "damping stick pot unit" and a "spring unit". Assuming that the displacements of the damping unit and the spring unit are $u_1(t)$ and $u_2(t)$, respectively, the model has the following relationship:

$$u(t) = u_1(t) + u_2(t)$$

(1)

$$C_0 \ddot{u}_1(t) = k \dot{u}_2(t) = F_d(t)$$

(2)

The above two formulas can be obtained simultaneously:

$$F_d(t) + \lambda \dot{F}_d(t) = C_0 \ddot{u}(t)$$

(3)

Inside the formula $F_d(t)$—Resistance of the damper;
$C_0$—Linear damping constant at zero frequency;
$k$—Stiffness factor of spring;
$\lambda$—Coefficient, $\lambda = C_0/k$.

As a component of energy storage and stroke compensation, when an impact load is encountered, the spring first bears most of the displacement, so that the damping unit always works at low speed. In the above compression process, the compression stroke of the spring is greater than the volume of the piston rod pressed into the cylinder. As the amount of the piston rod pressed increases, the spring will gradually recover quite.

2.3. Equivalent viscous damping

However, the mathematical description of viscoelastic damping described above is more complicated, and one of the commonly used processing methods is the energy method; the basic assumption of using the energy method is to simplify viscoelastic damping (non-linear) to equivalent viscous damping (Linear) principle: the energy consumed by equivalent viscous damping in one vibration cycle is equal to the energy consumed by simplified non-viscous damping in the same cycle, and the stability of the viscoelastic damping system under the action of simple harmonic excitation is assumed. The state response is still simply harmonic. Due to the incomplete elasticity of the viscoelastic viscous material, there is an area surrounded by the hysteresis curve in the stress-strain curve, that is, the energy consumed
by the viscoelastic damper in a period is $\Delta E_1$ as shown in (4), which is equivalent. The energy consumed by viscous damping in the same cycle is $\Delta E_2$ such as (5).

$$\Delta E_1 = -\int_0^T c \dot{x} dx = -\int_0^T c \dot{x} dt = -c\omega_0^2 A^2 \int_0^T \cos^2(\omega_0 t + \theta) dt = -\pi c\omega_0^2 A^2$$ (4)

$$\Delta E_2 = -\nu A^2$$ (5)

$C$: viscous damping coefficient in N * s / m
$X(t)$: displacement time relationship
$k$: spring force coefficient
$\omega_0$: natural frequency

Then (2.4) and (2.5) are combined to obtain the equivalent viscous damping coefficient, $Ce=-\frac{\nu}{\pi \omega_0}$. And bring it into the kinetic equation (6)

$$m\ddot{x}(t) + c \dot{x}(t) + kx(t) = 0$$ (6)

Based on this differential equation, corresponding vibration conditions can be obtained by providing corresponding initial conditions, and the response graphs of the damper and structure can be drawn. The problems related to structural eigenvalues, eigenvectors and complex transient solutions are transformed into general vibration problems. As a result, the calculation process is significantly simplified and the calculation efficiency is significantly improved.

3. Comparative analysis of structural dynamic characteristics

This paper is based on a nine-story reinforced concrete frame structure. The schematic diagram of the frame structure is shown in Figure 3. The specific parameters of the model are as follows. The seismic fortification intensity is 8 degrees, 0.2g, and the site category is Class II. There are 9 floors above ground, the height of the first layer of the structure is 4.2m, and the remaining layers are 3.5m. The cross section of the main beam of the frame is 400mm700mm, the cross section of the secondary beam is 350mm500mm, the cross section of the ladder beam is 300mm500mm; the cross section of the corner frame of the frame is 700mm700mm; the rest of the frame columns are 600600mm; The concrete strength grade used for beams, slabs and columns is C40. The floor dead load is the live load of the room and the corridor, and the line load on the frame beam is all.

The stairwell of the frame structure is 7m long and 4.5m wide, the width of the rest platform is 1.8m, and the width of the stair plate is 2.1m. The plate thickness of the staircase and rest platform is set to 120mm, the dead load of the staircase is set to, and the live load is set to use the SAP2000 finite element analysis software to establish a staircase structure model under different constraints from the main structure, corresponding to the two current research directions of stairs, Respectively, a frame structure model with an ordinary stairwell and a frame structure model with only the opening of the stairwell; a frame structure model with an ordinary plate staircase, a frame structure model with a sliding support, and three models As shown in Figure 4.
3.1. Structural dynamic model

When the finite element analysis of the existing model is performed using SAP2000, both the frame beams and the ladder beams and columns are simulated using rod elements, the floor and ladder panels are simulated using shell elements, and the support damping is performed using a non-linear viscous damping element (damper) Perform simulation [10]. The models thus established are all analyzed with SAP2000 for seismic time history analysis. The results obtained are measured in terms of the natural frequency of the first three modes as shown in Table (Table 1).

| Frame model                              | Quality (Ton) | T1 (x Translation) | T2 (y Translation) | T3 (zTwist) |
|------------------------------------------|---------------|--------------------|--------------------|-------------|
| Empty frame                              | 5848          | 0.921              | 0.893              | 0.754       |
| Ordinary stairwell frame structure       | 5889          | 0.885              | 0.652              | 0.795       |
| Stairwell frame structure with damping support | 5902          | 0.901              | 0.890              | 0.708       |

As can be seen from the table above, the installation of the viscous damper reduces the stiffness of the structure and effectively improves the ductility of the structure, especially in the translation period (rigidity) in the y direction. Compared with the frame structure of ordinary stairs, it has a damping bearing. The lateral stiffness of the stairwell frame structure is significantly reduced. Among them, in the Y-direction translation period, the frame structure of the stairwell with damping supports increased by 36.5% compared with the ordinary staircase, and the frame structure of the stairwell with damping supports increased by 1.8% compared to the ordinary staircase in the X direction.

3.2. Comparison of displacement angles between structural layers.

(a) X-direction interlayer displacement angle (b) Y-direction interlayer displacement angle

Figure 5. X-direction, Y-direction maximum inter-layer inter-layer displacement angle
As shown in Figure (Fig. 5), in the X direction, the staircase with the damping support under the damping effect, the end of the step plate is in a semi-constrained state, resulting in increased ductility of the frame, the overall lateral stiffness of the structure and the staircase with ordinary. The structure of the frame is reduced compared with that of the frame structure, so the impact on the dynamic characteristics of the structure is relatively small. The ordinary staircase provides a larger vertical run because the stair plate is fixed to the rest platform or the two ends of the frame beam. The lateral stiffness has a relatively large impact on the dynamic characteristics of the structure.

In the Y direction, compared with the empty frame structure, the frame structure with ordinary stairs and the frame structure with damped staircases have viscous dampers that can significantly reduce the vibration of the structure. The maximum value of the inter-layer displacement angle of each model structure appears on the second floor, among which the inter-layer displacement angle with the damping bearing is the largest, which is closer to the inter-layer displacement angle of the empty frame structure, which is increased compared with the ordinary stair frame 19.5%, which indicates that the damping bearing increases the ductility of the structure and reduces the overall stiffness of the structure while ensuring safety. The minimum inter-story displacement angle of the ordinary stairwell frame structure indicates that the step plate in the frame structure with ordinary staircases provides greater overall lateral stiffness in the Y direction and has a greater impact on the dynamic characteristics of the structure.

3.3. Structural Shear Force Comparison

![Graphs showing shear force comparison](image)

As shown in Figure (Fig. 6), the shear force of the floor where the viscous damper is installed is effectively reduced, but it can be seen that the damping support can pass the displacement of the damping unit and the spring unit, thereby eliminating the oblique support effect and the restraining effect of the end plate. To reduce the influence of seismic energy on the maximum floor shear force of the overall structure. Among them, the maximum inter-layer shear force in the Y direction of each model structure appears on the second floor. The maximum inter-layer shear force of the stairwell structure with damping supports is reduced by 8.4% compared with the empty frame structure and the ordinary stairwell frame structure. 28.1%, the addition of the damping support effectively reduces the floor shear of the structure.

4. Conclusion

In this paper, a viscoelastic damping bearing is combined with Maxwell mechanical model, and an optimized viscoelastic damping bearing model is proposed. The SAP2000 finite element analysis software is used to analyze the seismic history of the frame stairwell using the damping bearing, and the following conclusions are obtained:

(1) Compared with the traditional frame staircase structure, the improved viscous damping bearing based on the Maxwell mechanical model can change the uneven distribution of the stiffness of the
structure caused by the stairs, improve the ductility of the structure as a whole, and the seismic performance is relatively good.

(2) For the current research on the earthquake resistance of stairs, this article improves the existing stair bearings based on the current codes and atlases, and the seismic performance of the structure is significantly improved. Repair, the earthquake will not fall "fortification target."

(3) The optimized energy dissipating stairwell plays a good role in consuming energy. While providing an effective additional damping ratio for the structure, it also reduces the floor shear force in the structure, especially in the Y direction, it reduces the total energy of the seismic input structure.

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