RESEARCH ON APPLICATION OF VISCOUS DAMPING TECHNOLOGY IN REINFORCEMENT AND RECONSTRUCTION OF EXISTING BUILDINGS

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Abstract. In this paper, the basic principle, secondary software development and practical application of viscous damper vibration reduction technology are studied. The viscous damping coefficient velocity function equivalence method is used, and the secondary development is carried out in the finite element software ANSYS through program compilation, and the operation interface of the velocity function equivalence method is established. On this basis, the complex vibration problems of an existing building are studied, and the arrangement and installation of viscous dampers are guided on site. Through comparative analysis, it is concluded that the UIDL program and APDL macro command stream in the finite element software ANSYS can be used to establish the operation interface of the speed function equivalent method, which makes the method have better applicability and operability, improve the work efficiency and facilitate the popularization and application. By adopting the nonlinear viscous damper damping technology, before the structure and equipment produce strong vibration, the damper first enters the energy dissipation state, produces large damping, greatly consumes vibration energy, and rapidly attenuates the dynamic response of the structure and equipment to ensure the safety and normal use of the structure and equipment.The field dynamic test results and the finite element analysis results both show that the viscous damper vibration reduction technology based on the velocity function equivalent method has a significant vibration reduction effect, and is an effective means to solve the existing building vibration problems.

Keywords: viscous damping, viscous damping coefficient, equivalent method, nonlinear.

Introduction

The issue of earthquake resistance and vibration reduction in buildings has always been one of the important issues that civil engineering practitioners are committed to solving. In order to solve the seismic and vibration reduction problems of existing buildings, many scholars have conducted extensive research. Some scholars have conducted extensive damper design and experiments, and used experimental data to determine the damping coefficient and damping characteristics of viscous dampers [1]; Some scholars have evaluated the impact of different viscous damper damping coefficients on the seismic response of towers by analyzing the impact of towers with different damper damping coefficients on low rise buildings [2]; Some scholars have conducted different types of simulations using modal analysis and seismic time history analysis, and obtained data that can determine the nonlinear characteristics of fluid dampers [3]; Some scholars even use genetic algorithm based search methods to test the optimal distribution of damping coefficients [4]. Scholars have also conducted research on the impact of viscous damping on low-rise reinforced concrete frame structures under earthquakes, compared the seismic evaluation of RC buildings with and without friction dampers, and studied the impact of friction damping isolation systems on the performance of prefabricated concrete buildings [5-7]. Through continuous research by scholars, various types of dampers have emerged, including a new type of seismic damper based on the yielding of cantilever metal components proposed by TS Ahn and other scholars [8], a magnetorheological (MR) grease damper proposed by T. Sakurai and other scholars [9], and a prestressed viscous damper (PVD) proposed by A Bogdanovic and other scholars [10].

Based on the research of previous scholars, this article deduces the equivalent method of viscous damping coefficient velocity function with high calculation accuracy and conducts secondary development in the finite element software ANSYS, establishing the operation interface of the velocity function equivalent method. And the results were applied to a seismic reinforcement steel structure project in Guizhou, guiding the layout and installation of viscous dampers on site, and conducting dynamic tests. The results showed that the numerical analysis results were consistent with the actual situation, which can provide reference for similar engineering practices.

Velocity function equivalence

In practical engineering, in order to ensure that the viscous damper has a good energy dissipation and vibration reduction effect, the value range of the velocity index is usually 0.2-0.5. The calculation of the differential equation of motion under the action involves a lot of nonlinear problems, which is not convenient for practical application. For this reason, some scholars have put forward the equivalent concept of nonlinear damping coefficient. At present, there are two linear equivalent methods for the viscous damping coefficient, namely the energy equivalent method and the power equivalent method. However, both the energy equivalent method and the power equivalent method linearly simplify the nonlinear viscous damper, which usually brings certain analysis errors. In the existing research , after the nonlinear viscous damper is linearly equivalent, the maximum error calculated by the step-by-step integration method is about 20%, and the maximum error calculated by the mode shape superposition method is close to 45%.Therefore, in view of the characteristic that the damping force of the nonlinear viscous damper is a velocity power function, an equivalent method is proposed that uses a linear function with velocity as a variable as the damping coefficient, that is, the velocity function equivalence method, which can be used in the existing linear equivalent method. Based on the method, the calculation accuracy is significantly improved.

Based on a large number of research results, it is recommended to use the Maxwell model to calculate the damping force:

$$P(t) = C\,\mathrm{sgn}[\dot{u}(t)]\left|\dot{u}(t)\right|^{\alpha}\ . \quad (1)$$

The velocity function equivalence method defines the equivalent damping coefficient as:

$$C_{\mathrm{e}} = C_{\mathrm{V1}} + C_{\mathrm{V2}}\left|\dot{u}\right|, \quad (2)$$

where C_e – equivalent damping coefficient;
C_{V1} and C_{V2} are constants;
$|\bar{u}|$ – absolute value of speed.

The damping force is defined as:

$$F_{\mathrm{d}} = C_{\mathrm{e}}\dot{u} = C_{\mathrm{V1}}\dot{u} + C_{\mathrm{V2}}\dot{u}^2\,\mathrm{sgn}(\dot{u}), \quad (3)$$

where F_d – damping force.

The damper energy consumption power represented by formula (1) and formula (3) is respectively:

$$W_{\mathrm{c,1}} = \int_0^{u_0\omega} f_{\mathrm{d}}(t)\mathrm{d}\dot{u}(t) = \int_0^{u_0\omega} C_{\alpha}\dot{u}(t)^{\alpha}\,\mathrm{d}\dot{u}(t)\ , \quad (4)$$

$$W_{\mathrm{c,3}} = \int_0^{u_0\omega} f_{\mathrm{d}}(t)\mathrm{d}\dot{u}(t) = \int_0^{u_0\omega} C_{\mathrm{V1}}\dot{u}(t) + C_{\mathrm{V2}}\dot{u}(t)^2\,\mathrm{d}\dot{u}(t)\ . \quad (5)$$

In the formula, $W_{c,1}$ and $W_{c,3}$ are the energy dissipation power of the damper; u_0 and ω are the maximum vibration displacement amplitude and the corresponding vibration frequency of the structure, respectively; α is the velocity index.If the energy consumption is required to be equal, the relationship between C_{V1} and C_{V2} can be obtained from $W_{c,1} = W_{c,3}$:

$$\frac{3C_{\mathrm{V1}}}{\omega u_0} + 2C_{\mathrm{V2}} = \frac{6C_{\alpha}\omega^{\alpha-2}{u_0}^{\alpha-2}}{\alpha+1}\ , \quad (6)$$

where C_α – damping coefficient of the nonlinear viscous damper.

After considering the equivalent energy consumption, the maximum output damping force of the damper may be too large, so the maximum output damping force calculated according to equations (1) and (3) is required to be equal, and the relationship between C_{V1} and C_{V2} can be obtained as follows:

$$C_{\mathrm{V1}} = -2C_{\mathrm{V2}}\omega u_0, \quad (7)$$

$$C_{\mathrm{V2}} = \frac{-{C_{\mathrm{V1}}}^2}{4C_{\alpha}\omega^{\alpha}{u_0}^{\alpha}}\ . \quad (8)$$

Introducing the weighting coefficients a, b, $a + b = 1$, the expressions of C_{V1} and C_{V2} can be obtained as:

$$\begin{cases} C_{V1} = \dfrac{(3a + 2b\alpha + 2b)C_{\alpha}\omega^{\alpha-1}u_0^{\alpha-1}}{(\alpha+1)} \\ C_{V2} = -\dfrac{(3a + 2b\alpha + 2b)C_{\alpha}\omega^{\alpha-2}u_0^{\alpha-2}}{2(\alpha+1)} \end{cases} . \tag{9}$$

In the formula, the value of the weighting coefficient a = 0.4, b = 0.6.

Calculation program design of velocity function equivalent method

Using the UIDL program and APDL macro command flow in the finite element software ANSYS, the operation interface of the velocity function equivalent method can be established, which makes the method have better applicability and operability, improves the work efficiency, and is convenient for popularization and application.The program of velocity function equivalence mainly includes the human-computer interaction module, calculation module and result reading module.The human-computer interaction module is completed by the UIDL program, including menus, dialog boxes, and interactive interfaces. Users can input parameters through the menus and dialog boxes.The calculation module is compiled by APDL, and the equivalent damping coefficient can be automatically calculated on the basis of reading the basic parameters and vibration dynamic parameters of the nonlinear viscous damper.The main menu "The Speed Function Equivalent Method" is created by programming, and the submenus "Input Relevant Parameter", "Calculation of Equivalent Damping Coefficient" and "Define the Real Constants of Dampers" are also written, as shown in Fig. 1.

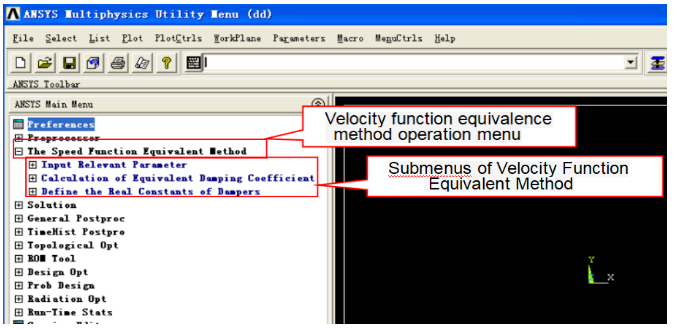

Fig. 1. **Main interface and all levels of menus**

Click the function button "Input Damper and Vibration Parameters" under the "Input Relevant Parameter" submenu, and the relevant parameter input dialog box will pop up, as shown in Fig. 2.

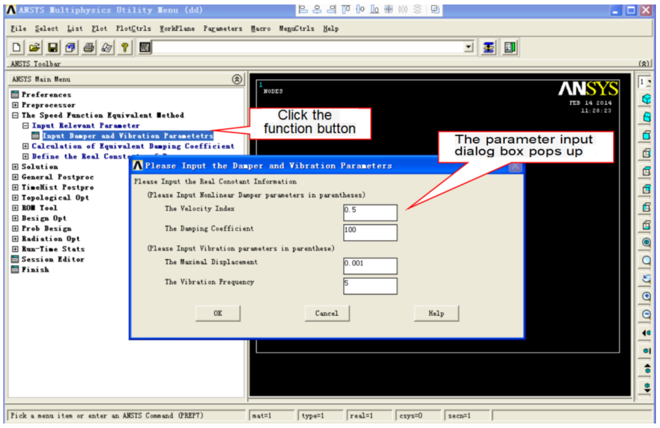

Fig. 2. **Related parameter input dialog**

Through the function buttons under other submenus, the calculation, analysis and assignment of the velocity function equivalent method can be realized, and the equivalent damping coefficient can be assigned to the real constant of the combine14 element of the simulated nonlinear viscous damper.

In order to verify the correctness of the calculation program "The Speed Function Equivalent Method", the relevant parameters are taken for comparative analysis. The results show that the calculation results of the program are the same as the theoretical calculation results and have high correctness.

Engineering applications

Project overview

A 10-storey existing building is a chemical plant, and chemical equipment such as motors and agitators have different degrees of mechanical vibration during the working process. At the same time, the forces of various chemical raw materials, catalysts, etc. in the transmission pipelines and equipment are constantly changing, which leads to complex vibration problems in the existing buildings, and the vibration is obvious and the noise is huge, which not only leads to poor work comfort, but also affects the building. The structure, equipment and personnel safety have caused hidden dangers. For this reason, methods such as adding members and tie rods are used to increase the structural rigidity for reinforcement and reconstruction, but the vibration reduction effect after reinforcement is not ideal. The structural vibration can be significantly reduced.

Dynamic testing and result analysis

In order to formulate an effective vibration reduction and reinforcement plan, this paper analyzes the vibration response, vibration characteristics and vibration source correlation of the existing building structure through dynamic tests, and it is clarified that the main vibration source of structural vibration is the flash tank and its inlet pipeline in the workshop. The main harmonic frequencies of structural vibration are 7.4, 3.2, 1.5 Hz, the extreme value of vibration displacement is 1.094 mm, and the extreme value of vibration speed is 15.719 $mm \cdot s^{-1}$.

This project adopts nonlinear viscous damper vibration reduction technology, that is, a nonlinear viscous damper is installed. Before the structure and equipment produce strong vibration, the damper first enters the energy-dissipating state, resulting in large damping and extremely high vibration. The ground consumes vibration energy, and rapidly attenuates the dynamic response of the structure and equipment to ensure the safety and normal use of the structure and equipment. The damper is a non-load-bearing component, which only plays an energy-dissipating role in the process of structural vibration, not as a load-bearing structure. Therefore, it does not affect the bearing capacity of the structure and is a safe and reliable vibration reduction method.

Finite element analysis

The velocity index of the nonlinear viscous damper is 0.2, and the damping coefficient is 160 $kN \cdot s \cdot m^{-1}$. The maximum output damping force is taken as 100 kN, and the finite element software ANSYS is used for numerical simulation analysis. The calculation model is shown in Fig. 3.

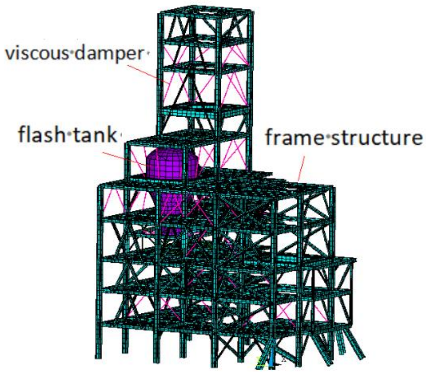

Fig. 3. **Computational model**

Under the menus at all levels of the secondary development of this study, input parameters such as structural vibration frequency, displacement amplitude, velocity index, damping coefficient, etc., to complete the analysis and assignment of the velocity function equivalent method, and obtain the equivalent damping coefficient C_{V1} = 3814, C_{V2} = -37492, and assign it to the real constant of combine 14 unit, as shown in Fig. 4.

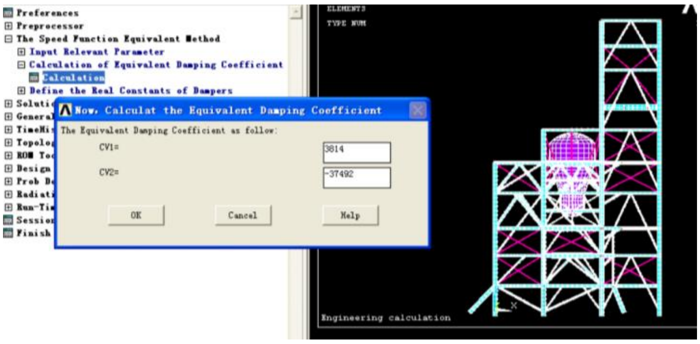

Fig. 4. **Calculation results**

The boundary conditions of the finite element model are determined according to the actual situation, and the bottom end of the frame column is clamped and restrained. According to the vibration test results, the dynamic response equivalent principle is adopted to simulate the vibration caused by the flash tank to the plant structure with the acceleration time history load, and the structural vibration response before and after the reconstruction is compared and analyzed.The time-history curves of the vibration displacement of the flash tank before and after the vibration reduction are shown in Figure 5. It can be seen from Fig.5 that the vibration response of the structure after vibration reduction by the nonlinear viscous damper is greatly attenuated, and the vibration reduction effect is remarkable, and the maximum reduction of the he vibration rate is about 80%.

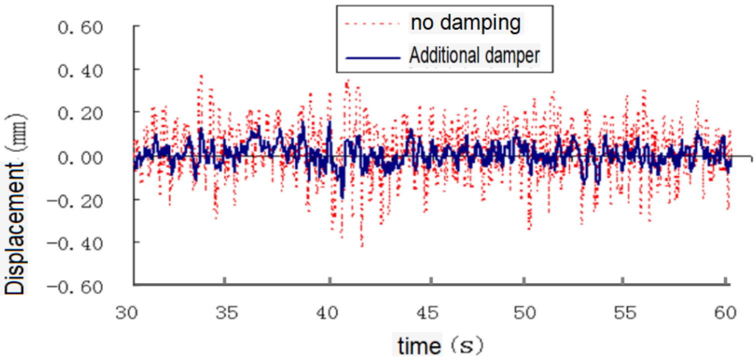

Fig. 5. **Time history curve of vibration displacement before and after vibration reduction**

Vibration reduction effect evaluation

According to the on-site dynamic test results, 58 sets of nonlinear viscous dampers were arranged at the position where the relative vibration velocity of the frame structure was relatively large, and the double inclined rod support was adopted, as shown in Fig. 6. The remaining 42 sets of dampers are arranged at the main vibration equipment such as the flash tank to dissipate the energy input of the vibration source and provide lateral restraint for the equipment when it vibrates.

Fig. 6. **Frame structure damper arrangement**

After the vibration reduction, the owner reported that the vibration reduction effect of the structure was remarkable, and the original strong vibration was significantly reduced.In order to quantitatively analyze the vibration reduction effect, this paper conducts on-site dynamic test again on the structure after vibration reduction, and compares it with that before reconstruction.The actual measurement results show that the actual vibration and displacement reduction rate of the reconstructed building structure is 35.5% to 94.6%, and the vibration and displacement vibration reduction rate obtained by the finite element calculation is 20.5% to 80.3%. Although there is a certain error between the measured results and the finite element calculation results, but the error is related to the adopted equivalence principle and simulation parameters, which is reasonable.

Conclusions

1. In view of the large error of the linear equivalent method of the commonly used viscous damping coefficient, combined with the characteristic that the damping force of the nonlinear viscous damper is a velocity power function, the velocity function equivalent method is proposed, which can be used in the existing linear equivalent method. The calculation accuracy is significantly improved.
2. The UIDL program and APDL macro command stream in the finite element software ANSYS can be used to establish the operation interface of the speed function equivalent method, which makes the method have better applicability and operability, improve the work efficiency and facilitate the popularization and application.
3. By adopting the nonlinear viscous damper vibration reduction technology, before the structure and equipment produce strong vibration, the damper first enters the energy dissipation state, generating greater damping, greatly consuming vibration energy, and rapidly attenuating the dynamic response of the structure and equipment to ensure the safety and normal use of the structure and equipment.
4. The field dynamic test results and the finite element analysis results both show that the viscous damper vibration reduction technology based on the velocity function equivalent method has a significant vibration reduction effect, and is an effective means to solve the existing building vibration problems, which can be popularized and applied.

Author contributions

All the authors have contributed equally to creation of this article.

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