

Damping effect on structural energy dissipation in Abaqus

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Keywords: Time-history, Rayleigh damping, modal damping, Abaqus

Abstract. Rayleigh damping was used widely for dynamic analysis based on direct integration, especially for nonlinear analysis. Compared with Rayleigh damping, modal damping is considered more reasonable as it can simulate the damping of each mode accurately in a large range of frequency. Though those two parameters of Rayleigh damping can simulate the damping of only two selected frequencies, numerical results show that for those structures with relatively long periods as high buildings, the contribution of those high frequencies can be negligible, proper frequency selection for Rayleigh damping can present satisfied damping effect.

Introduction

The structural energy dissipation depends on many factors, such as the plastic development, damage, damping actions and so on. For an elastic system, damping is the most important action which will induce vibration attenuation. For elastic-plastic analysis, plastic development and damage usually are the major inducements of energy dissipation, but contribution of damping still cannot be negligible.

For steel and concrete, 2% and 5% damping ratio are recommended by structural design codes respectively [1,2] in analysis of wind load and seismic action. A 5 percent damping ratio indicates that 46.7 percent of the strain energy is dissipated during each cycle [3]. Therefore, a 5 percent damping ratio produces a significant effect on the results of a dynamic response analysis.

Modal damping and Rayleigh damping are the most widely used forms in structural dynamic analysis. For mode-based dynamic analysis solver, modal damping is preferred to be used as it has the merit of simulating the damping of each mode accurately in a large range of frequency. But for dynamic analysis using direct integration, Rayleigh damping is more convenient, especially for nonlinear analysis in which that the structural natural frequencies and modes would change with the time-history. For the merit of longer time increment, Rayleigh damping is still used as the main damping form of many software. On the other hand, Rayleigh damping cannot make the damping ratio of different modes to be equal, and about its influence on high frequencies, physical demonstrations are still not plenary. For most of structures, only the primary frequency and the second-order frequency are used to formulate those two parameters of Rayleigh damping. For more rational application, many scholars have researched the methods of parameter assuming for Rayleigh damping [4, 5, 6].

Rayleigh damping model

Rayleigh damping model, which is also called stiffness and mass proportional damping, is a very common type of damping used in nonlinear incremental analysis of structures. The damping is assumed that the damping matrix is proportional to the mass and stiffness matrices as:

$$\mathbf{C} = \alpha \mathbf{M} + \beta \mathbf{K} \quad (1)$$

Where α is the parameter of mass proportional damping and β is the parameter of stiffness proportional damping, \mathbf{M} and \mathbf{K} are the mass matrix and stiffness matrix respectively.

As α and β can be written as:

$$\alpha = \frac{2\omega_i \omega_j}{\omega_i + \omega_j} \quad \beta = \frac{2\omega_i \omega_j}{\omega_i + \omega_j} \quad (2)$$

The most important two frequencies can be used for solving out these two unknown parameters. For high-building structures, the primary frequency and the second-order frequency are often chosen according to their mode participation factors, then α and β can be written as follows:

$$a = \frac{4px}{T_1 + T_2} \quad b = \frac{T_1 T_2 x}{(T_1 + T_2)p} \quad (3)$$

Analysis model

Free vibrations with damping of a column and a shear wall are analyzed respectively (Fig.1) with the initial condition of displacement at tops to research the time-history of top displacement and energy. In order to simulate building structures, the primary period of the column and wall are designed as 2.5s and 0.3s. Element B31 and S4R[7] are used for meshing, and four different damping models are used as follows:

- (1) Both Rayleigh mass proportional damping and stiffness proportional damping;
- (2) Only Rayleigh mass proportional damping;
- (3) Only stiffness proportional damping;
- (4) Free vibration without damping.

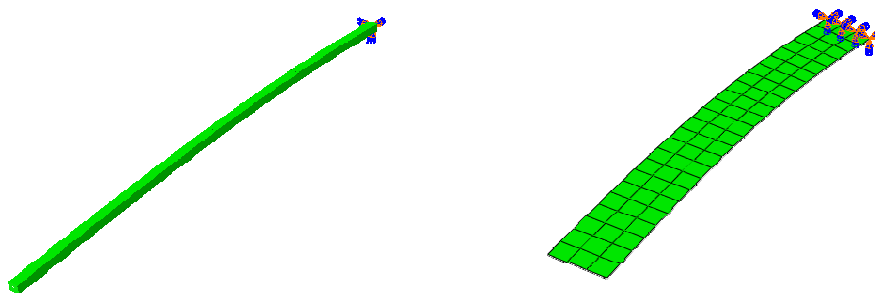


Fig.1 Structural models

Analysis of column

Time-histories of top displacement of the beam are shown in Fig. 2 and Fig. 3 (Compared with modal damping).

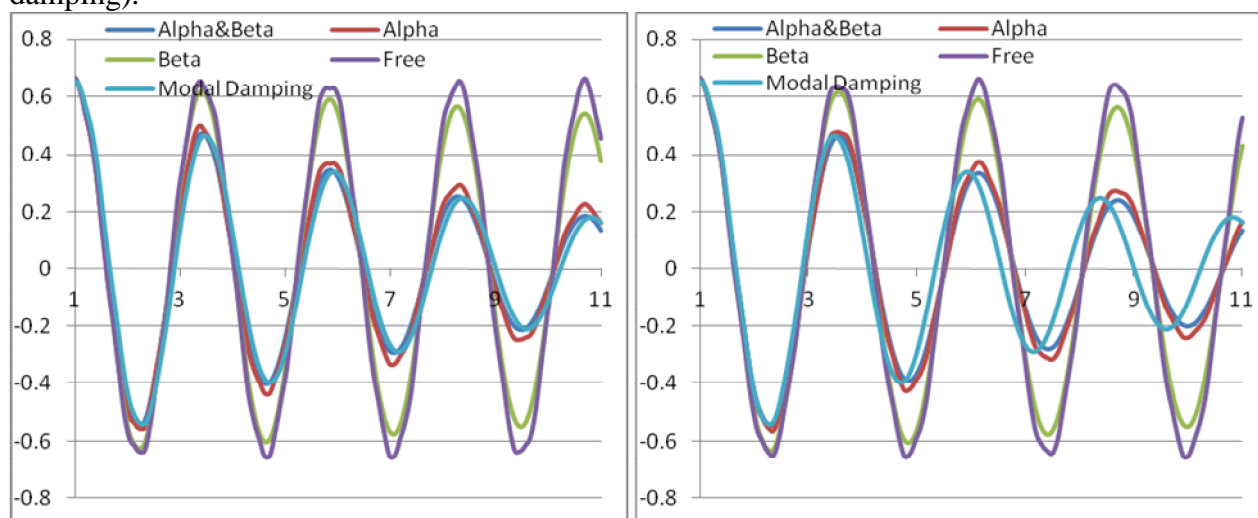


Fig.2 Column displacement of implicit solution Fig.3 Column displacement of explicit solution

Time-histories in Fig.2 show that Rayleigh damping with both mass and stiffness proportional coefficients can present nearly the same results as modal damping. For this kind of structures, the contribution of stiffness proportional coefficient can be even negligible.

Compared with the results of mode-based solution and Rayleigh-based implicit direct integration, Rayleigh-based explicit solution can present nearly the same amplitudes of displacement, but it can be seen that the effect to frequency has somewhat been overestimated.

Normalized results of internal energy time-histories formulated by using implicit direct integration are shown in Fig. 4 and Fig. 5 with the results of mode-based method.

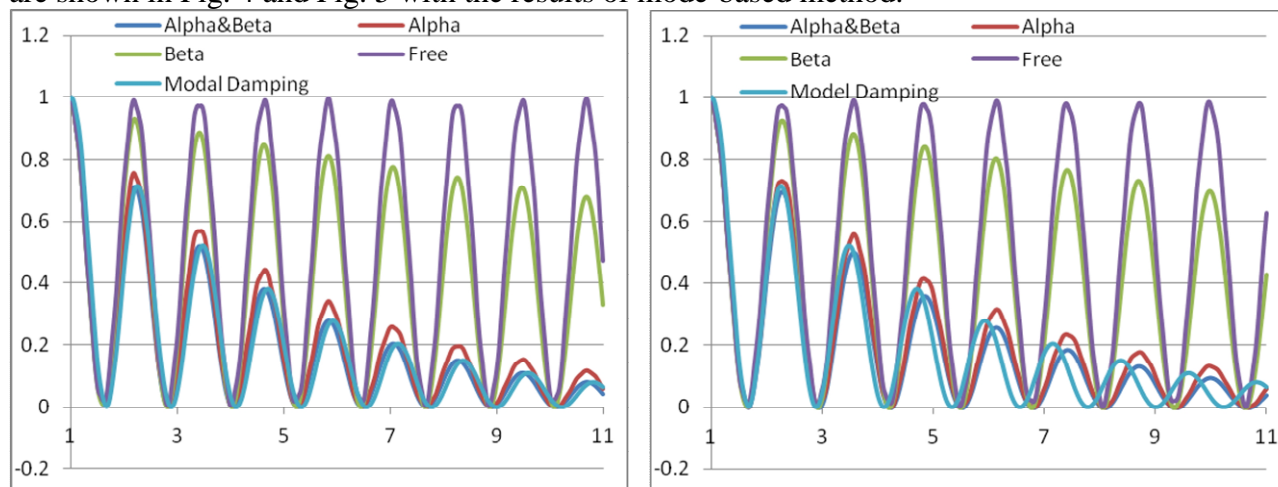


Fig.4 Column internal energy of Implicit solution Fig.5 Column internal energy of explicit solution

The results in Fig.4 and Fig.5 show that the attenuation of internal energy is similar to the displacement results. For each cycle, the energy dissipation of modal damping is about 48%, the model with both α and β for implicit and explicit method are about 48% and 50% respectively, if only α is considered, the relative value are all about 44%, which are still similar to theoretical result .

In spite of the deviation of periods, the results of explicit solution also show that mass proportional coefficient can simulate the damping as well as the modal damping.

Analysis of shear wall

Time-histories of top displacement of the shear wall are shown in Fig. 6 and Fig. 7. (Compared with modal damping)

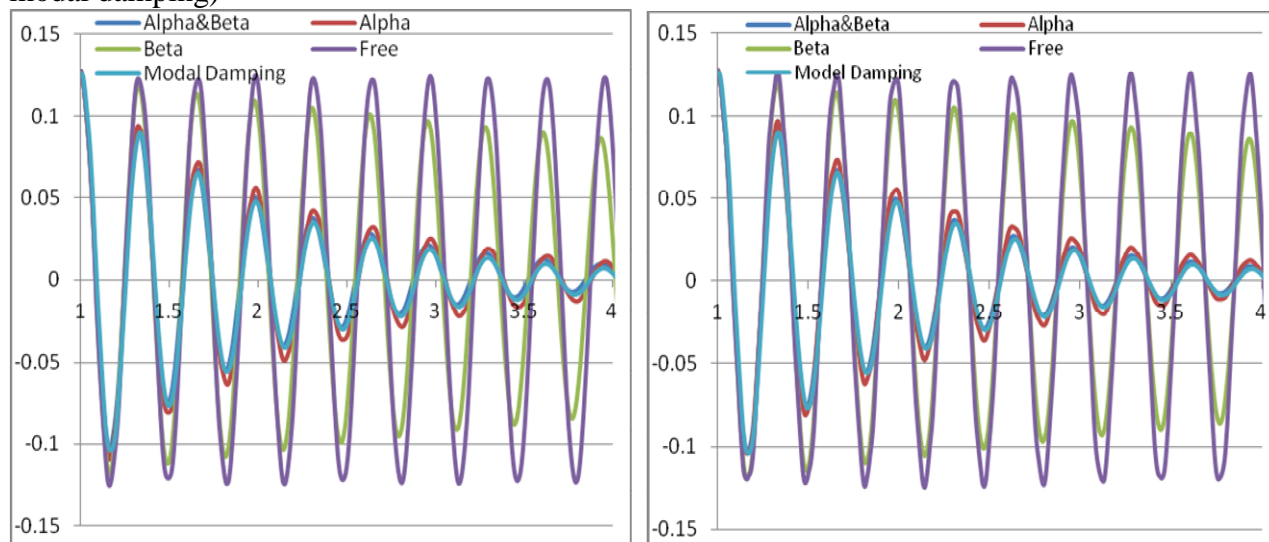


Fig.6 Wall displacement of implicit solution

Fig.7 Wall displacement of explicit solution

For the shear wall shown in Fig.1, displacement of different damping model is similar to the column model, but the frequency of explicit shown in Fig.7 has not been changed significantly as the column.

Normalized results of internal energy for the shear wall are shown in Fig. 8 and Fig. 9. (Compared with modal damping)

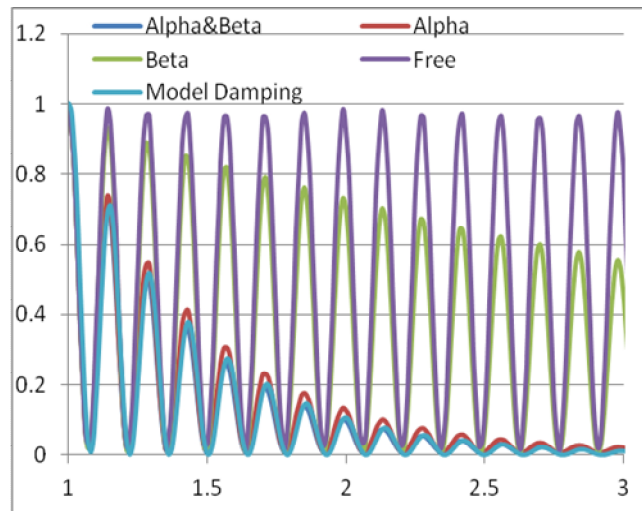
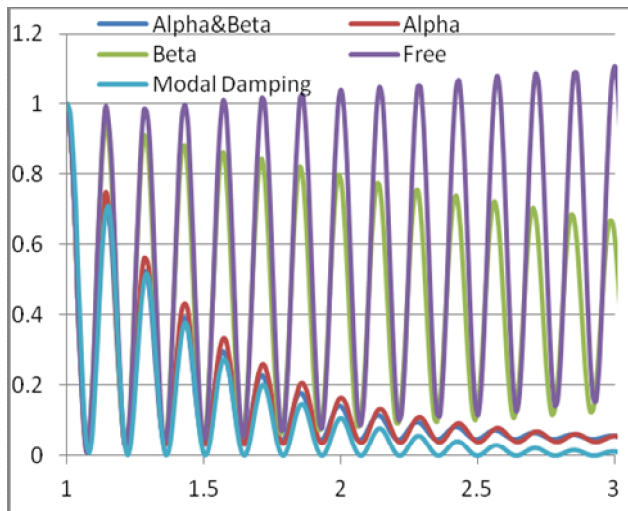


Fig.8 Wall internal energy of implicit solution

Fig.9 Wall internal energy of explicit solution

The results in Fig.8 and Fig.9 show that the attenuation of internal energy is similar to the column. For each cycle, the energy dissipation of modal damping is about 48%, the model with both α and β for implicit and explicit method are about 47% and 49% respectively, if only α is considered the relative value are all about 44% and 45% respectively.

For the implicit solution, results of the model without any damping cannot keep stable any longer because of the influence of hourglass effect.

Conclusions

Rayleigh damping are used widely for dynamic analysis of direct integration because of its convenient, especially for nonlinear analysis. But it is often regarded as only approximate simulation of modal damping, because it cannot be formulated with more than two frequencies. In theory, the strain energy would be dissipated about 46.7% during each cycle and mode-based dynamic analysis can present more approximate results. Numerical results show that for those structures with relatively long periods as buildings, Rayleigh damping can present satisfied damping effect. For explicit solver, even if the stiffness proportion damping is neglected, the mass proportional damping can still present satisfied results.

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