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Energy Distribution of Nonlinear Viscous Damper in the Height Direction of High-rise building

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Abstract— **In previous studies, the energy distribution of linear viscous damper had been proposed. And the accuracy of this method for nonlinear viscous damper with the velocity exponent 0.6 had been verified. In this paper, the energy distribution of nonlinear viscous damper was proposed. The accuracy of this method was also shown.**
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I. Introduction

The use of vibration control in buildings is increasing in recent years. The time history analysis method and the earthquake-resistant design method based on energy balance (energy method) [1] are adopted for the design of vibration control buildings. The viscous damper is the most frequently used as a passive control member.

Many kinds of research on the energy method are carried out. Akiyama proposed the prediction method of damage distribution of each story. Harada et al. proposed a prediction method of the energy distribution of linear viscous dampers (linear prediction method) [2] based on the energy method. Arii et al. applied the prediction method to nonlinear viscous dampers by using the Maxwell model and verified the accuracy of this method [3]. However, only the dampers with the velocity exponent (α) of 0.6 had been considered in the research of Arii, the dampers with a small velocity exponent, had not been discussed. Because the use of the nonlinear viscous dampers is more than linear viscous dampers, it is necessary to research the energy prediction method of nonlinear viscous dampers.

In this paper, a prediction method of the energy distribution of nonlinear viscous damper (nonlinear prediction method) was proposed. And the accuracy of the linear prediction method and the nonlinear prediction method were verified.

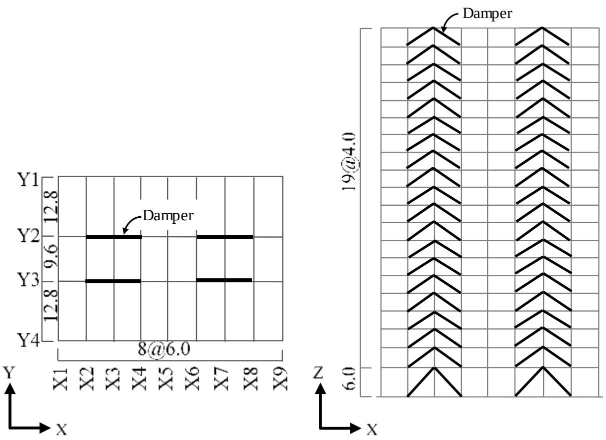
II. Analysis condition

A. Structure

The height of the steel-frame building is 82.0m, 20-stories [4]. Figure 1 presents the plan and elevation of the building. The 1st and 2nd periods T_f (X direction) are 2.29s and 0.81s. In order to examine the energy distribution of the dampers, the structural damping is set to 0 and the structure is elastic.

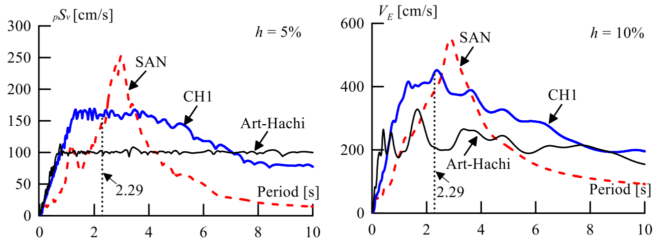
B. Earthquake

Three earthquakes were selected in this paper. Art-Hachi (phase value: HACHINOHE 1968 EW), which is equivalent to an earthquake of level 2, and the long-period ground motion CH1 [5] and SAN [5]. Fig.2 (a), (b) present the pseudo-velocity response spectrum ${}_pS_v$ (h=5 %) and energy spectrum V_E (h = 10 %).



(a) Plan (b) Elevation

Fig. 1-Plan and Elevation (m)



(a) Pseudo-velocity response spectrum (b) Energy spectrum

Fig. 2-Response spectrum

C. Viscous damper

Dampers and the support members are connected in series. In this paper, 5 velocity exponents α (1.00, 0.80, 0.60, 0.38, 0.20) and 3 shear coefficients of damper α_{d1} (0.01, 0.05, 0.10) were considered. The shear coefficient of damper α_{d1} in the first story is given by Eq.(1).

$$\alpha_{d1} = \frac{F_{dD1}}{W_f} \quad (1)$$

Where, W_f is the weight of the structure and F_{dD1} is the horizontal force of all dashpot when the story drift angle of the first story R_{D1} is 1/100.

III. PREDICTION METHOD

A. Linear prediction method

The linear prediction method of the energy distribution of dampers is shown as Eq.(2). Where γ_d is the energy distribution coefficient of dampers, W_d is the energy absorbed by dampers. s_i' and h_i' is given by Eq.(3). Where M is the mass of the structure, m_i is the mass of i story, k_{fi} is the stiffness of i story and $\hat{C}_{di}$ is the viscosity coefficient in the axis direction of the dampers. $\overline{\alpha}_{ri}$ is the optimal distribution of the yield-shear force coefficient and can be expressed by Eq.(4).

$$\frac{1}{\gamma_{di}} = \frac{W_{di}}{\sum_{i=1}^{N} W_{di}} = \frac{s_i' h_i}{\sum_{i=1}^{N} s_i' h_i} \tag{2}$$

$$s_i' = \left(\sum_{j=i}^{N} \frac{m_j}{M}\right)^2 \times \overline{\alpha}_{ri}^{\,2} \times \left(\frac{k_{f1}}{k_{fi}}\right)^2, \quad h_i = \frac{\hat{C}_{di} T_{f1}}{4\pi M} \tag{3}$$

$$\overline{\alpha}_{ri} = \begin{cases} 1+0.5x & 0 \le x \le 0.2 \\ 1+1.5927x-11.8519x^2+42.5833x^3 & \\ -59.4827x^4+30.1586x^5 & 0.2 < x < 1 \end{cases} \tag{4}$$

Where $$x = \sum_{j=i}^{i-1} m_j / M \tag{5}$$

B. Nonlinear prediction method

The nonlinear prediction method is shown as Eq.(6) to Eq.(8). Where, $\hat{K}_d''$ is the loss stiffness of the damper and $\hat{u}_{di\max}$ is the maximum deformation of the damper which is calculated by time history analysis. The optimal distribution of the yield-shear force coefficient $\overline{\alpha}_{rdi}$ and the maximum shear coefficients of damper α_{di} are shown as Eq.(9).

$$\frac{1}{\gamma_{di}} = \frac{W_{di}}{\sum_{i=1}^{N} W_{di}} = \frac{s_i'' h_{eqi}}{\sum_{i=1}^{N} s_i'' h_{eqi}} \tag{6}$$

$$s_i'' = \left(\sum_{j=i}^{N} \frac{m_j}{M}\right)^2 \times \overline{\alpha}_{rdi}^{\,2} \times \left(\frac{K_{d1}''}{K_{di}''}\right)^2, \quad h_{eqi} = \frac{\hat{C}_{eqi} T_{f1}}{4\pi M} \tag{7}$$

$$\hat{C}_{eqi} = \frac{4e^{-0.24\alpha}\hat{K}_{di}''}{\pi\ \omega}, \quad \hat{K}_{di}'' = \frac{\hat{C}_{di}\omega^{\alpha}}{\hat{u}_{di\max}^{1-\alpha}} \tag{8}$$

$$\overline{\alpha}_{rdi} = \frac{\alpha_{di}}{\alpha_{d1}}, \quad \alpha_{di} = \frac{\hat{F}_{di\max}}{\sum_{j=i}^{N} m_j g}, \quad \hat{F}_{di\max} = \hat{K}_{di}'' \hat{u}_{di\max} \tag{9}$$

IV. VERIFICATION

In this part, the accuracy of the linear prediction method and the nonlinear prediction method are verified. Since it was confirmed that the influence of the earthquake on γ_d was small, the result under CH1 is shown as a representative. Fig.3 (a) to (c) show a comparison of γ_d by the analytical value and the predicted value. From Fig.3 (a), it can be seen that when the lower velocity exponents is, the lower the accuracy is. From Fig.3, it can be seen that the accuracy of the nonlinear prediction method is more than the linear prediction method.

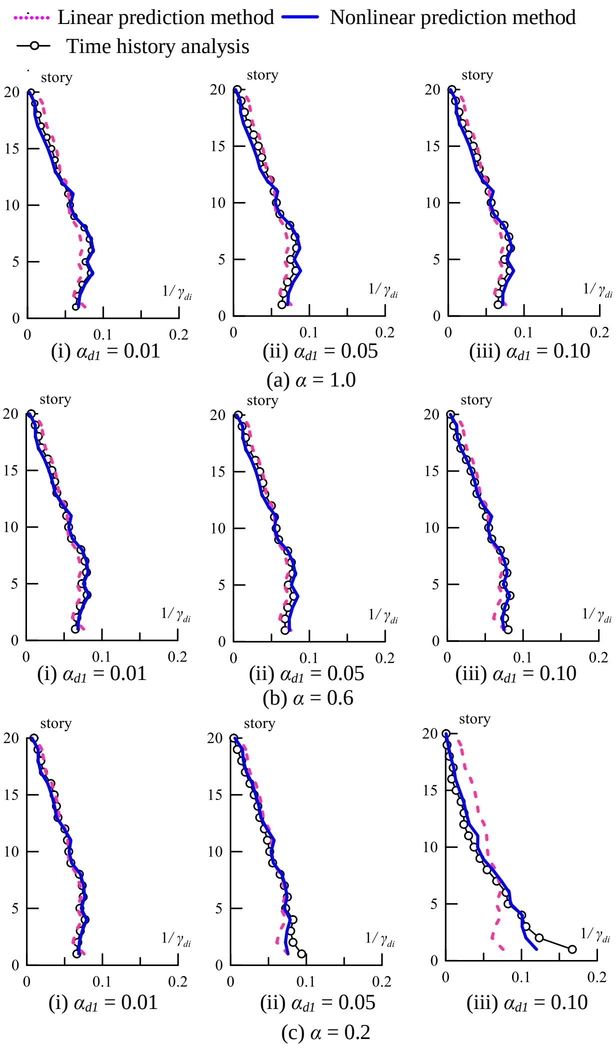


Fig. 3- Comparison of the energy dispersion coefficient (CH1)

V. CONCLUSIONS

In this paper, a prediction method of the energy distribution of nonlinear viscous damper was proposed. The accuracy is also discussed. The accuracy of the nonlinear prediction method is more than the linear prediction method. However, when the velocity exponent is small and the shear coefficient of the damper is large, the accuracy of the nonlinear prediction method is not clear.

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