Influence of Frequency Sensitivity on Energy Dissipated in VE damper Subjected to Wind Force

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Abstract— **Authors discussed the influence of frequency sensitivity on energy dissipated in viscoelastic damper under 500-return-year's along- and across-wind excitation. In this paper, the simplified numerical models with different frequency sensitivity, including the Kelvin system and Maxwell system, were used to compare with the energy dissipated of the fractional derivative (FD) system.**

I. INTRODUCTION

Equipping the high-rise building with viscoelastic (VE) dampers has been considered as an effective solution for the vibration control to reduce not only the wind response but also the seismic response. VE damper is one kind of damper with the storage stiffness that accompanied by frequency sensitivity, and it can reach a hysteresis loop of a tilted ellipse (Fig.1.) when applying a sinusoidal wave on the damper. Besides, the VE damper is adopted to dissipate the input energy of vibration for the building, ensuring the comfort and safety of residents inside.

In the previous papers, the influence on the wind-induced response of the frequency sensitivity for the VE damper has discussed by Sato et al. (2009) [1]. However, the influence on the energy dissipated of the frequency sensitivity of the VE damper didn't be discussed in the previous researches yet.

The purpose of this paper is to clarify the influence on the energy dissipated of the frequency sensitivity of the VE damper subjected to wind force. Based on the VE system with different frequency sensitivity, the fractional derivative FD system, Kelvin system, and Maxwell system were adopted to conduct the time history analysis under the along- and across-wind excitation. Finally, this paper discussed the comparison of the energy dissipated between the FD system, Kelvin system, and Maxwell system subjected to the along- and across-wind excitation.

II. ANALYTICAL MODEL

A. Building Model

Table.1 indicated 45 models that consist of the FD system, Kelvin system, and Maxwell system for the analysis. It can be separated into 3-groups (I, II, and III) by natural periods of frame (T_1 =2, 4, and 6 sec). In addition, there are 3 kinds of damper (hard: 'H,' soft: 'S,' and weak: 'W') and 2 kinds of brace stiffness (hard: 'H' and soft: 'S') considered.

B. Fractional Derivative System

The fractional derivative (FD) system of the type ISD 111 (Fig.2a.), which combined with the storage stiffness $K_d'(\omega)$ (Eq.1a) and the loss factor $\eta_d(\omega)$ (Eq.1b), where ω is the circular frequency. The formula of the storage stiffness $K_d'(\omega)$ and loss factor $\eta_d(\omega)$ of the damper proposed by Kasai et al. (2006)[2]. The damping coefficient of the FD system C_d' is given by Eq.(2).

$$K_d'(\omega) = G\frac{1+ab\omega^{2\alpha}+(a+b)\omega^{\alpha}\cos(\alpha\pi/2)}{1+a^2\omega^{2\alpha}+2a\omega^{\alpha}\cos(\alpha\pi/2)}\frac{A_s}{d}, \tag{1a}$$

$$\eta_d(\omega) = \frac{(-a+b)\omega^{\alpha}\sin(\alpha\pi/2)}{1+ab\omega^{2\alpha}+(a+b)\omega^{\alpha}\cos(\alpha\pi/2)}, \tag{1b}$$

$$C_d'(\omega) = \frac{K_d'(\omega)\eta_d(\omega)}{\omega}. \tag{2}$$

Where, A_s = laminations of VE damper, d = thickness of VE material lamination, G=3.92×10^4 N/m^2, a =5.6 ×10^{-5}, b =2.10, α =0.558.

C. Kelvin System

The Kelvin system (Fig. 2b.) is a system that combined with spring and dash-pot in parallel connection, which has the same dynamic feature (i.e. K_d' and η_d) with the FD system while at its natural circular frequency ω_n. The calculation of the storage stiffness of Kelvin system K_k and damping ratio of Kelvin system C_k came from the derivation of the FD damper, which is given by Eq.(3) and Eq.(4).

$$K_k = K_d' = K_d'(\omega_n) \quad , \quad C_k = \eta_d(\omega_n)\cdot\omega_n/K_k . \tag{3,4}$$

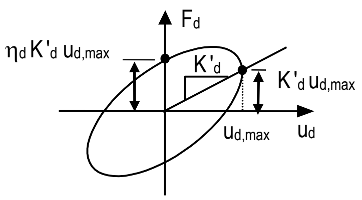


Fig. 1. hysteresis loop of a VE damper

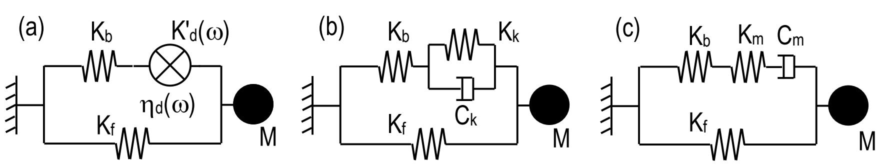


Fig. 2. (a)FD system, (b)Kelvin system, (c)Maxwell system

Table.1. Setups of the FD system, Kelvin system, and Maxwell system

Group	K_f (N/m)	K_b (N/m)	ξ_n	f_n (Hz)	FD system	Kelvin system	Maxwell system
I	9.870	∞	0.311	0.866	F1-HH	K1-HH	M1-HH
			0.126	0.592	F1-SH	K1-SH	M1-SH
		29.61	0.121	0.777	F1-HS	K1-HS	M1-HS
			0.098	0.588	F1-SS	K1-SS	M1-SS
			0.020	0.512	F1-WS	K1-WS	M1-WS
II	2.467	∞	0.281	0.433	F2-HH	K2-HH	M2-HH
			0.112	0.296	F2-SH	K2-SH	M2-SH
		7.401	0.113	0.385	F2-HS	K2-HS	M2-HS
			0.088	0.293	F2-SS	K2-SS	M2-SS
			0.020	0.257	F2-WS	K2-WS	M2-WS
III	1.097	∞	0.261	0.289	F3-HH	K3-HH	M3-HH
			0.103	0.197	F3-SH	K3-SH	M3-SH
		3.290	0.107	0.256	F3-HS	K3-HS	M3-HS
			0.081	0.195	F3-SS	K3-SS	M3-SS
			0.020	0.172	F3-WS	K3-WS	M3-WS

D. *Maxwell System*

The Maxwell system (Fig.2c) is a system that combined with spring and dash-pot in series connection, which also has the same dynamic feature (i.e. K_d' and η_d) with the FD system while at its natural circular frequency ω_n. The calculation of the storage stiffness of the Maxwell system K_m and damping ratio of the Maxwell system C_m came from the derivation of the FD damper, which is given by Eq.(5), and it can derive into Eq.(6).

$$K'_d(\omega) = \frac{K_m (C_m \omega)^2}{K_m^2 + (C_m \omega)^2}, \quad \eta_d(\omega) = \frac{K_m^2 C_m \omega}{K_m (C_m \omega)^2} \tag{5a,b}$$

$$K_m = K'_d(\omega_n)\left(\eta_d^2(\omega_n) + 1\right), \quad C_m = \frac{K_m}{\eta_d(\omega_n) \cdot \omega_n} \tag{6a,b}$$

E. *Frequency Sensitivity of Dampers*

Fig.3 shows the influence of frequency-sensitivity on the storage stiffness K_d' and loss factor η_d among damper systems, including the FD system, Kelvin system, and Maxwell system.

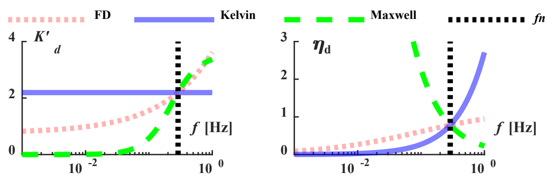
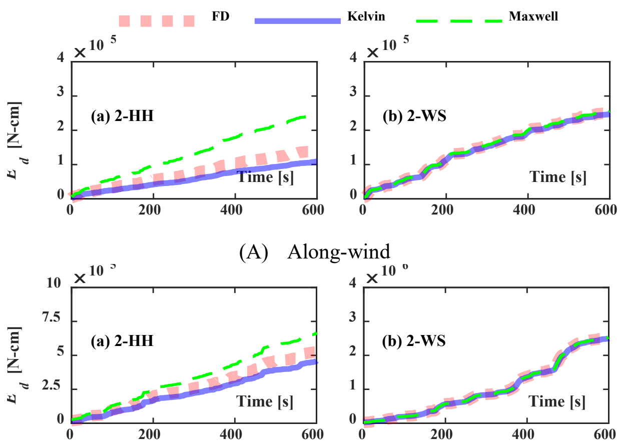


Fig.3. Frequency Sensitivity of K_d' and η_d

III. Energy dissipated of wind-induced response

Fig.4 shows that the accumulated energy dissipated E_d subjected to 500-return-year's wind excitation (along-wind and across-wind). According to 2-HH models (among the FD system, Kelvin system, and Maxwell system), it shows that the accumulated energy-dissipated of the Kelvin system is under-evaluated than which of FD system; in contrast, the accumulated energy-dissipated of the Maxwell system is over-evaluated than which of FD system. For 2-WS models, it had a high agreement of accumulated energy dissipated among these three damper systems.

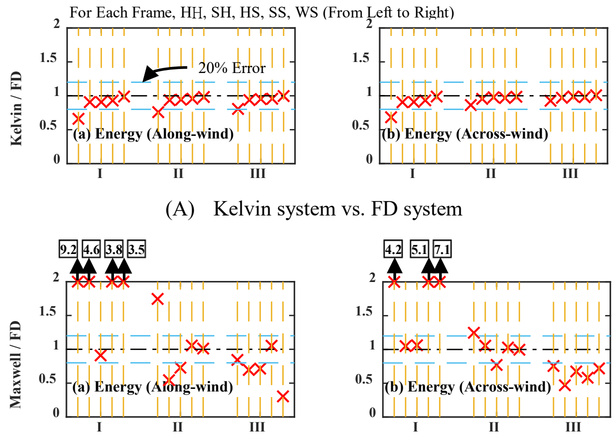
Fig.5 shows the comparison of total energy-dissipated between simplified numerical systems (Kelvin and Maxwell systems), and FD systems. Fig.5(A) indicates that the total energy-dissipated of the Kelvin system matches well to the FD system. It is about 0.7~0.8 times to that of the FD system. On the other hand, Fig.5(B) indicates that the total energy-dissipated of the Maxwell system relies on its frequency-sensitivity. When the natural frequency of the system is high, the energy-dissipated of the Maxwell system is over-evaluated than the FD system. In contrast, the total energy-dissipated of the Maxwell system is under-evaluated with a low natural frequency.



(A) Along-wind

(B) Across-wind

Fig.4. Time variation of energy dissipated



(A) Kelvin system vs. FD system

(B) Maxwell system vs. FD system

Fig.5. Comparison in total energy dissipated

IV. Conclusions

This paper indicated the influence of frequency-sensitivity on the total energy-dissipated. It shows that the total energy-dissipated of the Kelvin system matches well to the FD system. However, the total energy-dissipated of the Maxwell system relies on its frequency-sensitivity. That is, the total energy-dissipated of the Maxwell system is under-evaluated with a low natural frequency.

References

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