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Energy Dissipated in Wind-induced Response of VE dampers with Frequency-sensitivity

VE damper, wind excitation, frequency sensitivity,
Kelvin, Maxwell, fractional derivative.

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1. Introduction

VE damper is one kind of damper with the storage stiffness that accompanied by frequency sensitivity [1], 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.

The purpose of this paper is to understand 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.

2. Analytical Model

2.1. Building Model

The analytical model of the building is a 10-degree-of-freedom model with the height of 200 m, the width of the base, $B = D$ = 50m, and the density of 175 kg/m^3. In this paper, the single degree-of-freedom models were subjected to the wind excitation in the 1st mode. Hence, the generalized mass (M= 1 kg), generalized stiffness of frame K_f were used.

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.

2.2. 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.

2.3. 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).

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

2.4. 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 Km and damping ratio of the Maxwell system Cm came from the derivation of the FD damper, which is given by Eq.(5), and it can derive into Eq.(6).

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

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

3. 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.

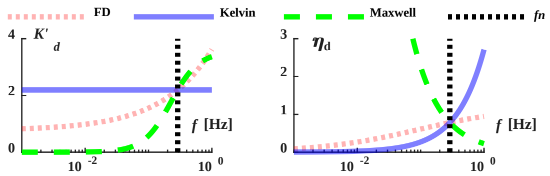


Fig.3. Frequency Sensitivity of K'_d and η_d

4. Energy Dissipated of Wind-Induced Response

Fig.4 and Fig.5 show that the hysteresis loop of the FD system, the Kelvin system, and the Maxwell system subjected to along- and across-wind force. Fig.6 shows that the accumulated energy dissipated E_d subjected to 500-return-year's wind excitation[3] (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.

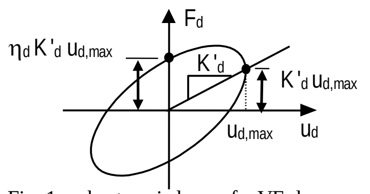


Fig. 1. hysteresis loop of a VE damper

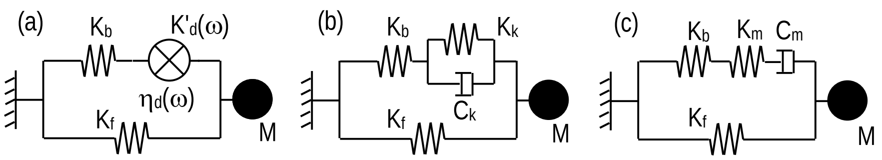


Fig. 2. (a)FD system, (b)Kelvin system, (c)Maxwell system

Table.1. Parameters for the FD system, Kelvin system, and the Maxwell system

Group	K_f (N/m)	Damper	Brace	K_b (N/m)	ξ_n	f_n (Hz)	FD system	A_s/d (m)	Kelvin system	K_k (N/m)	C_k (N-s/m)	Maxwell system	K_M (N/m)	C_M (N-s/m)
I	9.870	Hard	Hard	∞	0.311	0.866	F1-HH	1.1295E-04	K1-HH	19.74	3.379	M1-HH	36.87	7.274
		Soft			0.126	0.592	F1-SH	2.6533E-05	K1-SH	3.948	0.939	M1-SH	7.038	2.139
		Hard	Soft	29.61	0.121	0.777	F1-HS	1.1835E-04	K1-HS	19.74	3.715	M1-HS	36.40	8.116
		Soft			0.098	0.588	F1-SS	2.6607E-05	K1-SS	3.948	0.945	M1-SS	7.035	2.153
		Weak			0.020	0.512	F1-WS	3.5422E-06	K1-WS	0.497	0.134	M1-WS	0.871	0.312
II	2.467	Hard	Hard	∞	0.281	0.433	F2-HH	3.7592E-05	K2-HH	4.934	1.528	M2-HH	8.437	3.680
		Soft			0.112	0.296	F2-SH	8.6853E-06	K2-SH	0.987	0.418	M2-SH	1.599	1.092
		Hard	Soft	7.401	0.113	0.385	F2-HS	3.9326E-05	K2-HS	4.934	1.682	M2-HS	8.289	4.155
		Soft			0.088	0.293	F2-SS	8.7135E-06	K2-SS	0.987	0.421	M2-SS	1.596	1.104
		Weak			0.020	0.257	F2-WS	1.3182E-06	K2-WS	0.142	0.067	M2-WS	0.224	0.182
III	1.097	Hard	Hard	∞	0.261	0.289	F3-HH	1.9473E-05	K3-HH	2.193	0.947	M3-HH	3.541	2.487
		Soft			0.103	0.197	F3-SH	4.4504E-06	K3-SH	0.439	0.256	M3-SH	0.668	0.747
		Hard	Soft	3.290	0.107	0.256	F3-HS	2.0341E-05	K3-HS	2.193	1.043	M3-HS	3.476	2.825
		Soft			0.081	0.195	F3-SS	4.4656E-06	K3-SS	0.439	0.258	M3-SS	0.667	0.756
		Weak			0.020	0.172	F3-WS	7.4038E-07	K3-WS	0.070	0.045	M3-WS	0.104	0.138

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 damper systems. Fig.7(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.7(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.

5. Conclusions

This paper indicated the influence of frequency-sensitivity on the total energy-dissipated in the single degree-of-freedom model in the 1st mode. 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.

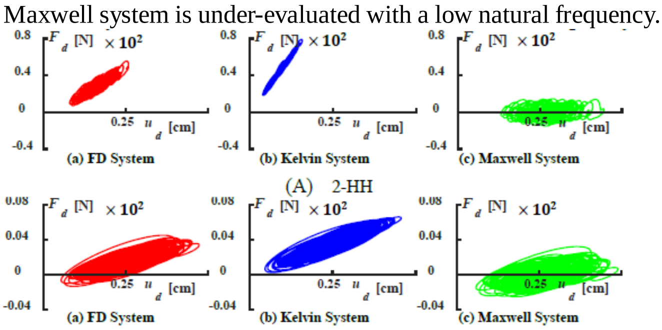


Fig.4. Hysteresis loop of the along-wind response

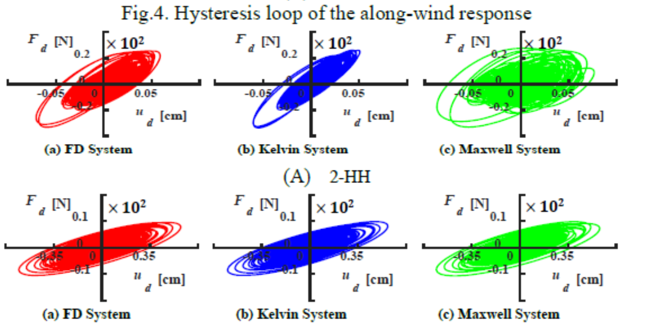
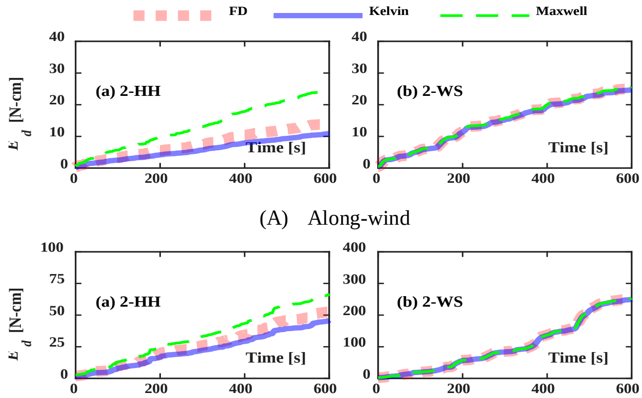
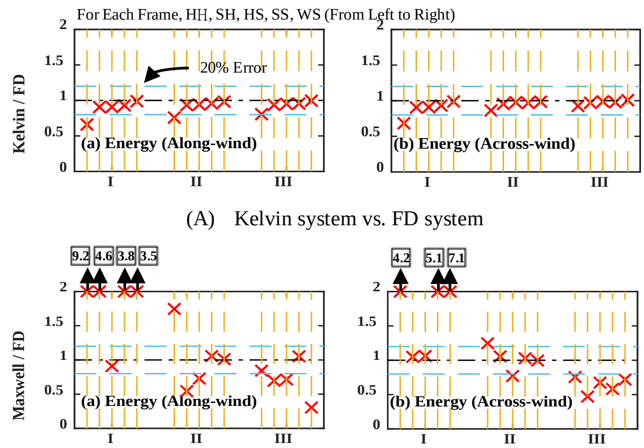


Fig.5. Hysteresis loop of the across-wind response



(B) Across-wind
Fig.6. Time variation of energy dissipated



(B) Maxwell system vs. FD system
Fig.7. Comparison in total energy dissipated

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