論文 / 著書情報
Article / Book Information

論題(和文)	
Title(English)	Frequency-domain Method for VE Systems with Frequency Sensitivity Subjected to Along-wind without Mean Component
著者(和文)	張庭維, 佐藤大樹
Authors(English)	Ting-Wei Chang, Daiki Sato
出典(和文)	日本建築学会大会学術講演梗概集, II, , pp. 469-470
Citation(English)	, II, , pp. 469-470
発行日 / Pub. date	2022, 9
権利情報	一般社団法人 日本建築学会

日本建築学会大会学術講演梗概集
（北海道） 2022 年 9 月

Frequency-domain Method for VE Systems with Frequency Sensitivity Subjected to Along-wind without Mean Component

正会員 ○張庭維*
同 佐藤大樹**

Frequency-Domain Method, Power Spectral, Fourier Transform,
Frequency Sensitivity, Viscoelastic, Fractional Derivative.

1. Introduction

Time-domain method (TDM) of the dynamic analysis on viscoelastic (VE) systems is a stable and reliable method to obtain the response in the time domain. However, compared with frequency-domain method (FDM), time-domain method is complicated and costs time because it bases on the convolution of the function of external force and the equation of motion of the system [1]. In addition, VE system needs to consider its frequency sensitivity [2]. And, the along-wind excitation includes a wide range of frequency contents [3]. However, the research on frequency-domain method of the dynamic analysis on the frequency-sensitive VE systems is limited in the seismic response. Therefore, the purpose of this paper is to evaluate the wind-induced response subjected to the along-wind without mean component by FDM. The results compared the frequency-domain method and the time-domain method of single-degree-of-freedom (SDOF) models of fractional derivative (FD) model (Fig.1a), 4-Element model (Fig.1b), and 6-Element model (Fig.1c).

2. Frequency-domain method

Frequency-domain method of the dynamic analysis is a fast calculation method, which makes an inner product between Fourier spectral of wind and transfer function of the system in the frequency domain. Fourier spectral of the 1st modal displacement response of the system is given by Eq. (1).

$$X(i\omega) = H(i\omega) \cdot P(i\omega) \tag{1}$$

Where, transfer function of displacement $H(i\omega)$ is given by Eq. (2).

$$H(i\omega) = \frac{1}{1-\left(\dfrac{\omega}{\omega_0}\right)^2 + \dfrac{K'_a(\omega)}{K_f} + i\left(2\xi_0\dfrac{\omega}{\omega_0} + \dfrac{K''_a(\omega)}{K_f}\right)} \cdot \frac{1}{K_f} \tag{2}$$

$P(i\omega)$= Fourier spectral of the 1st modal wind force.

The response in the time domain obtained by inverse Fourier transform of Fourier spectral of the 1st modal displacement $x(t)$ response of the system, which is given by Eq. (3).

$$x(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(\omega)e^{i\omega t}d\omega \tag{3}$$

3. VE systems

Storage stiffness K'_a, loss factor η'_a, and loss stiffness K''_a of the added component are given by Eq. (4a, b, c), which is composed of a series connection of damper and brace stiffness K_b. However, storage stiffness K'_d and loss factor η_d of damper are different caused by different VE models, which are discussed from Section 3.1 to Section 3.3.

$$K'_a(\omega) = \frac{\left\{\left(1+\eta_d^2(\omega)\right)K'_d(\omega)+K_b\right\}K'_d(\omega)K_b}{\left(K'_d(\omega)+K_b\right)^2+\left(\eta_d(\omega)K'_d(\omega)\right)^2} \tag{4a}$$

$$\eta_a(\omega) = \frac{\eta_d(\omega)}{1+\left(1+\eta_d^2(\omega)\right)K'_d(\omega)/K_b} \tag{4b}$$

$$K''_a(\omega) = K'_a(\omega)\cdot\eta_a(\omega) \tag{4c}$$

3.1. FD model

Storage stiffness $K'_d(\omega)$ and loss factor $\eta_d(\omega)$ of FD model (Fig. 1a) in the frequency domain are given by Eq. (5a, b).

$$K'_d(\omega) = G\frac{1+ab\omega^{2\alpha}+(a+b)\omega^{\alpha}\cos(\alpha\pi/2)}{1+a^2\omega^{2\alpha}+2a\omega^{\alpha}\cos(\alpha\pi/2)}\frac{A_s}{d} \tag{5a}$$

$$\eta_d(\omega) = \frac{(-a+b)\omega^{\alpha}\sin(\alpha\pi/2)}{1+ab\omega^{2\alpha}+(a+b)\omega^{\alpha}\cos(\alpha\pi/2)} \tag{5b}$$

Where, A_s = area of VE damper, d = thickness of VE material lamination. In this paper, the 3M material ISD111 is adopted. Then, G = 3.92x10^4, a = 5.6x10^{-5}, b = 2.10, α = 0.558.

3.2. 4-Element model [3]

Storage stiffness $K'_d(\omega)$ and loss factor $\eta_d(\omega)$ of 4-Element system (Fig. 1b) in the frequency domain are given by Eq. (6a, b, c).

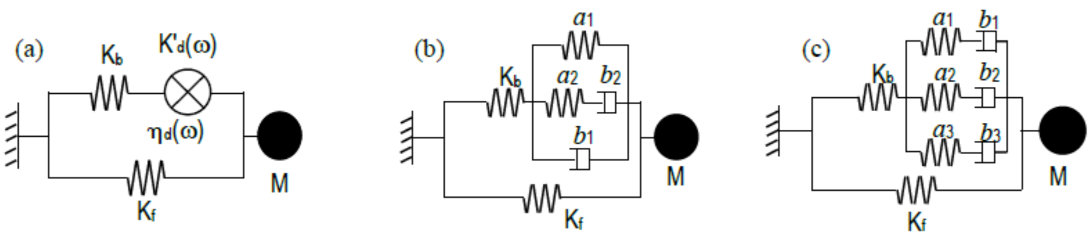

Fig. 1. Viscoelastic systems: (a) FD system, (b) 4-Element system, (c) 6-Element system

$$K'_d = \frac{A_s}{d}\left[a_1 + \frac{a_2(b_2\omega)^2}{a_2^2+(b_2\omega)^2}\right] \quad (6a)$$

$$K''_d = \frac{A_s}{d}\left[\frac{b_1\left\{a_2^2+(b_2\omega)^2\right\}\omega + a_2^2(b_2\omega)}{a_2^2+(b_2\omega)^2}\right] \quad (6b)$$

$$\eta_d(\omega) = \frac{K''_d(\omega)}{K'_d(\omega)} \quad (6c)$$

3.3. 6-Element model [3]

Storage stiffness $K'_d(\omega)$ and loss factor $\eta_d(\omega)$ of 6-Element system (Fig. 1c) in the frequency domain are given by Eq. (7a, b, c).

$$K'_d = \frac{A_s}{d}\left[\sum_i^3 \frac{a_i(b_i\omega)^2}{a_i^2+(b_i\omega)^2}\right] \quad (7a)$$

$$K''_d = \frac{A_s}{d}\left[\sum_i^3 \frac{a_i^2(b_i\omega)}{a_i^2+(b_i\omega)^2}\right] \quad (7b)$$

$$\eta_d(\omega) = \frac{K''_d(\omega)}{K'_d(\omega)} \quad (7c)$$

4. Analytical wind

This paper employed wind forces with a return period of 500 years. Wind force was determined by using a wind tunnel test [4]. The airflow in the experiment was determined by referring to the building design load in Japan [5] (terrain: III, directional angle: 0 degree). The design wind velocities of the 100-year-return period is 57.9 m/s.

Fig. 2 shows power spectral density (PSD) of 1st modal along-wind force obtained by 10 waves-ensemble average. Where $S_F(f)$= power spectral of the 1st modal wind force. σ_F= standard deviation of the 1st modal wind force.

Fig. 3 shows one example of the 1st modal along-wind force (600 s) without the mean component in the time domain. To eliminate the extra transient response, the wind force (700 s) was modified in the first 50 s and the end 50 s by envelope, and add zeros of 150 s before the start and after the end (a total analytical time = 1000 s). Thus, the response only 600 s considered in each case.

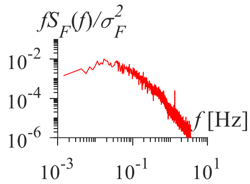

Fig. 2. PSD of along-wind

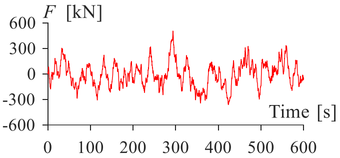

Fig. 3. Time history of the along-wind without mean component

5. Displacement response (along-wind without mean)

The 2H-HH system ($K_f = 2.467$ [kN m^{-1}], $K_b/K_f = \infty$, $K_d/K_f = 2.0$) and 2H-WS system ($K_f = 2.467$ [kN m^{-1}], $K_b/K_f = 3.0$, damping ratio = 2%) were employed in the analysis. Fig. 4 and Fig. 5 show that displacement response of 2H-HH systems and 2H-WS systems caused by frequency-domain method has good agreements with that by time-domain method. The error of the maximum response and standard deviation is less than 1%.

6. Conclusions

This paper presented the displacement response among FD system, 4-Element system, and 6-Element, by frequency-domain method has good agreement with that by time-domain method, subjected to the along-wind force without mean component.

Acknowledgement

This work was supported in part by JST Program on Open Innovation Platform with Enterprises, Research Institute and Academia （JPMJOP1723）; in part by Watanuki International Scholarship Foundation.

Reference

[1] Chopra, A. K. Dynamics of structures. Pearson Education India, 2007.

[2] D. Sato, K. Kasai, and T. Tamura. Influence of frequency sensitivity of viscoelastic damper on wind-induced response. (Transactions of AIJ), 74(635), 75-82, 2009 [in Japanese].

[3] Kasai K, Teramoto M, Okuma K, Yokoro K. Constitutive rule for viscoelastic materials considering temperature, frequency, and strain sensitivities. Journal of Structural and Construction Engineering. 2001;543:77-86. [in Japanese].

[4] Marukawa H, Ohkuma T, Kitimura H, Yoshie K, Tsurumi T, Sato D. 20097 energy input of local wind forces for high-rise building based on wind tunnel test: Part. 2 local wind force characteristics of rectangular high-rise buildings, no. 2010. Architectural Institute of Japan; 2010. [in Japanese].

[5] Architectural Institute of Japan, AIJ Recommendation for Loads on Buildings, Architectural Institute of Japan, 2015.

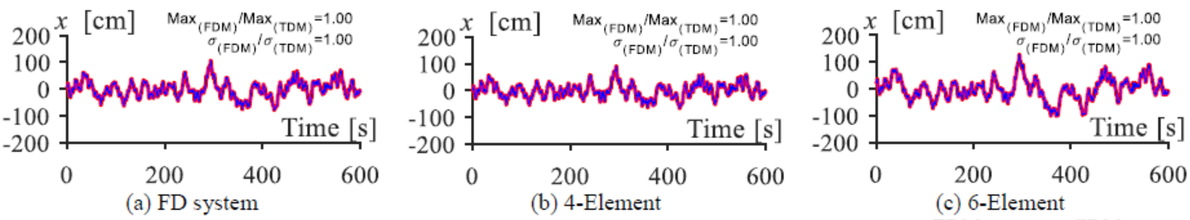

Fig. 4. Comparison of the wind-induced displacement in the time domain (2H-HH) (TDM FDM)

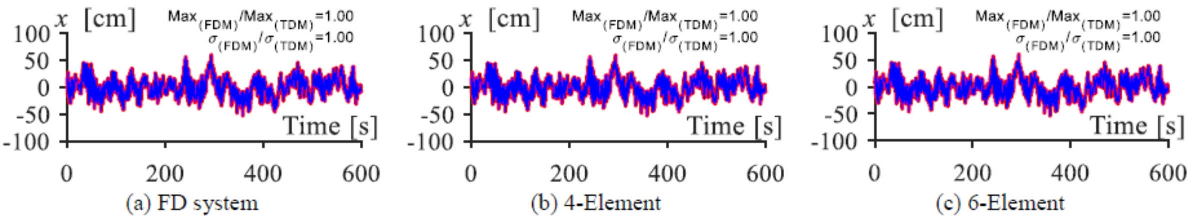

Fig. 5. Comparison of the wind-induced displacement in the time domain (2H-WS) (TDM FDM)

*東京工業大学環境・社会理工学院　大学院生

**東京工業大学未来産業技術研究所　准教授・博士（工学）

* Doctoral Student, School of Environment and Society, Tokyo Institute of Technology

** Associate Prof. , FIRST, Tokyo Institute of Technology, Dr. Eng.