論文 / 著書情報
Article / Book Information

論題(和文)	
Title(English)	Numerical Analysis Model for Viscoelastic Dampers under Long Duration Excitation considering Heat Transfer and Uniform Strain Distribution (Part 1: Formulation)
著者(和文)	OSABEL DAVE M, 笠井 和彦, 佐藤 大樹
Authors(English)	Osabel D., Kasai. K., Sato D
出典(和文)	日本建築学会大会学術講演梗概集, vol. B-2, , pp. 169-170
Citation(English)	, vol. B-2, , pp. 169-170
発行日 / Pub. date	2016, 8
権利情報	一般社団法人 日本建築学会

Numerical Analysis Model for Viscoelastic Dampers under Long Duration Excitation considering Heat Transfer and Uniform Strain Distribution (Part 1: Formulation)

正会員 ○OSABEL Dave *1
同 笠井和彦 *2
同 佐藤大樹 *3

Viscoelastic Damper　Long Duration Excitation　Uniform Strain Distribution
Fractional Derivative　Heat Transfer

1 INTRODUCTION

1.1 Background

Viscoelastic dampers (Fig. 1) are among the most widely-used devices to control structural vibrations. The energy induced by the seismic or wind excitations is dissipated by these devices which then generates heat within the viscoelastic (VE) material, affecting its dynamic mechanical properties. Heat will then flow through the material and dispersed to the surrounding air by convection (Fig. 2).

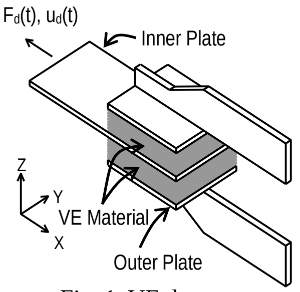

Fig. 1. VE damper

Based on fractional derivative of strain and stress, Kasai et al[1] formulated a time-analysis model which considers heat generation. It is accurate enough specifically for short duration excitation as heat transfer and convection are negligible.

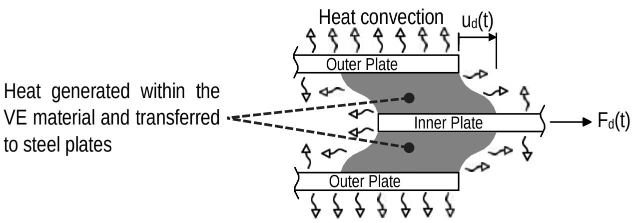

Fig. 2. Heat generation, transfer, and convection of VE damper

1.2 Long Duration Model

For longer duration excitation such as wind, however, temperature distribution in the damper is greatly affected by heat transfer and convection (Fig. 2).

In 2006, Kasai et al[2] conducted steady-state heat transfer analysis by using three-dimensional (3-D) finite elements for VE damper experimented under long duration harmonic loading (Fig. 1). Temperature distribution in the VE material as well as the corresponding stiffness and damping were accurately simulated in the analysis.

From these findings, Kasai et al proposed a 'long duration model' – a time-history model combining the simplified one-dimensional (1-D) heat transfer analysis with the constitutive rule[2]. The model accurately predicts lower temperature and less shear strain near the steel plate interface, and higher temperature and more shear strain at the inner locations (Fig. 2).

However, the analytically obtained deformed shape of the VE material is almost straight, suggesting uniform strain distribution (Fig. 3).

Therefore, the present study aims to formulate a simplified long duration (SLD) model idealizing uniform shear strain in the VE material compared to the original detailed long duration (DLD) model.

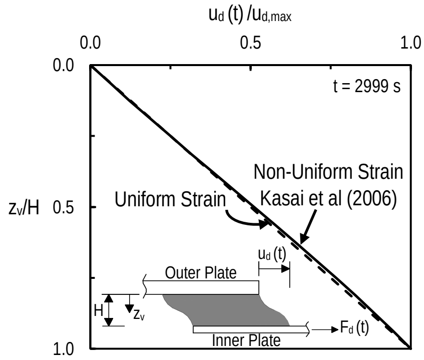

Fig. 3. Analytically obtained deformed shape of VE material

2 FORMULATION

2.1 Damper Stress and Strain

Consider a VE damper (Fig. 4a) subjected to dynamic loading, where $F_d^{(n)}$ and $u_d^{(n)}$ are damper force and deformation at time step n, respectively. Stress $\tau^{(n)}$ is uniform along the thickness direction by equilibrium rule. The constitutive equation of the DLD model for node j of the VE material (Fig. 4b) was given as[2]:

$$\tau^{(n)} + a_j^{(n)} D^{\alpha} \tau^{(n)} = G \cdot \left[\gamma_j^{(n)} + b_j^{(n)} D^{\alpha} \gamma_j^{(n)} \right] \tag{1}$$

where $\tau^{(n)}$ = shear stress $(\mathrm{N/cm^2})$; $\gamma_j^{(n)}$= shear strain; G = static shear modulus $(\mathrm{N/cm^2})$; $a_j^{(n)}$ and $b_j^{(n)}$ = temperature-dependent constants at node j, and; D^{α} = fractional derivative operator [1), 2)] of order α.

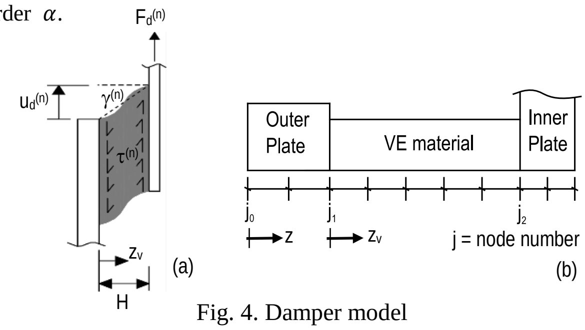

Fig. 4. Damper model

For the SLD model, $\gamma_j^{(n)}$in Eq. (1) is idealized to be uniform strain $\gamma^{(n)} = u_d^{(n)}/H$; where H is the thickness of the VE material. It follows that $a_j^{(n)}$ and $b_j^{(n)}$ are to be approximated by uniform values $a^{(n)}$ and $b^{(n)}$. Thus, Eq (1) becomes:

$$\tau^{(n)} + a^{(n)} D^{\alpha} \tau^{(n)} = G \cdot \left[\gamma^{(n)} + b^{(n)} D^{\alpha} \gamma^{(n)}\right] \tag{2}$$

Also, values of $a^{(n)}$ and $b^{(n)}$ vary due at every time step due to change of the temperature as follows:

$$a^{(n)} = a_{ref} \cdot \lambda^{(n)} \quad , \quad b^{(n)} = b_{ref} \cdot \lambda^{(n)} \tag{3}$$

where a_{ref} and b_{ref} are values at reference temperature θ_{ref}, and $\lambda^{(n)}$ = shift factor defined below:

$$\lambda^{(n)} = \exp \frac{-p_1\left(\bar{\theta}^{(n)} - \theta_{ref}\right)}{\left(p_2 + \bar{\theta}^{(n)} - \theta_{ref}\right)} \tag{4}$$

$\bar{\theta}^{(n)}$ is average of the nodal temperature $\theta_j^{(n)}$ at time-step n. Considering step-by-step integration scheme for Eq. (2), the stress can then be calculated by Eq. 5

$$\tau^{(n)} = \frac{\frac{u_d^{(n)}}{H} GB + G b^{(n)} \sum_{i=1}^{N} w^i \gamma^{(n-i)} - a^{(n)} \sum_{i=1}^{N} w^i \tau^{(n-i)}}{A} \tag{5}$$

where $A = [(\Delta t)^{\alpha} + a^{(n)} w^{(0)}]$ and $B = [(\Delta t)^{\alpha} + b^{(n)} w^{(0)}]$. Damper force $F_d^{(n)}$ can then be calculated by

$$F_d^{(n)} = \tau^{(n)} \cdot A_v \quad ; \; A_v = \text{sheared area} \tag{6}$$

2.2 Rise in Temperature and Heat Transfer

For a given time step n, the energy dissipated $\Delta E_d^{(n)}$ is uniform at any node in the VE material, i.e.

$$\Delta E_d^{(n)} = \frac{(\tau^{(n)} + \tau^{(n-1)})(\gamma^{(n)} - \gamma^{(n-1)})}{2} \tag{7}$$

And so the temperature rise due to dissipated energy $\Delta\theta^{(n)}$will be uniform given in Eq. 8; where ρ is mass density (kg/cm^3) and s = specific heat capacity (N · cm/kg/℃) of the VE material

$$\Delta\theta^{(n)} = \frac{\Delta E_d^{(n)}}{s\rho} \tag{8}$$

With heat transfer and convection, the temperature of the VE damper at time-step $(n+1)$ at node j will be:

$$\theta_j^{(n+1)} = \hat{\theta}_j^{(n)} + \Delta\theta^{(n)} \tag{9}$$

where $\hat{\theta}_j^{(n)}$is calculated by the 1-D heat transfer analysis method used for the DLD model[2].

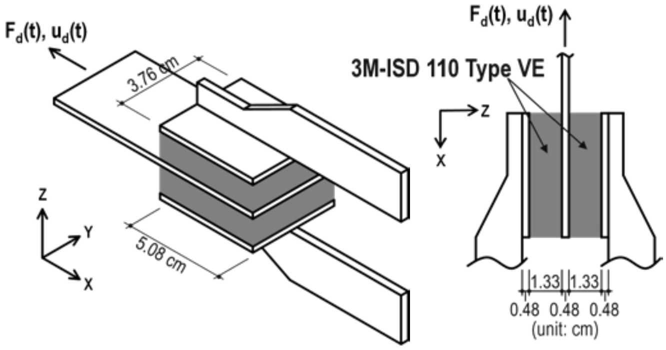

Fig. 5. Viscoelastic damper dimension

3 ANALYSIS CASE

The analytical results using the DLD model[2] will be compared with the proposed SLD model. Dimension of the damper with viscoelastic material 3M-ISD110 type is shown in Fig. 5.

Provided by the manufacturer are: $G = 6.519$ N/cm^2; $\alpha = 0.609$; at reference temperature $\theta_{ref} = 0.2$ ℃, $a_{ref} = 0.0115$and $b_{ref} = 21.157$, and; $p_1 = 19.5$ and $p_2 = 80$.

Indicated in Table 1 are the thermal conductivity κ, the specific heat capacity s, and mass density ρ of steel plates and VE material. From 3-D finite element analysis (Sec 1.2), the heat transfer coefficients $\alpha_{c,out}$ and $\alpha_{c,in}$, for the outer and inner plates, were 0.956 and 0.524 N/s/cm/℃.

Table 1. Material Properties of Steel and VE

	Steel	VE
κ (N/s/°C)	43.128	0.188
s (N·cm/kg/°C)	46.63 x 10^3	19.40 x 10^4
ρ (kg/cm^3)	7.80 x 10^{-3}	1.00 x 10^{-3}

1 N/s/cm/°C = 100 W/m^2/°C

Damper was subjected to harmonic displacement of peak value 0.66 cm (50% max strain level) at a frequency of 0.33 Hz. Loading duration was from $t = 0$s to 3000s with ambient temperature of 24°C. Temperature at points A, B, C and D were observed (Fig. 6). A at z = 0; B at z = 0.48cm + 0.25H; C at z = 0.48cm + 0.50H, and; D at z = 2.29cm.

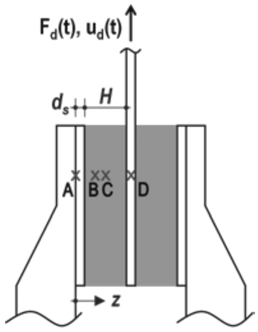

Fig. 6. Location of points

4 CONCLUSION

The analytical results from the SLD (simplified long duration) model and those from the DLD (detailed long duration) model showed high congruency (Fig. 7).

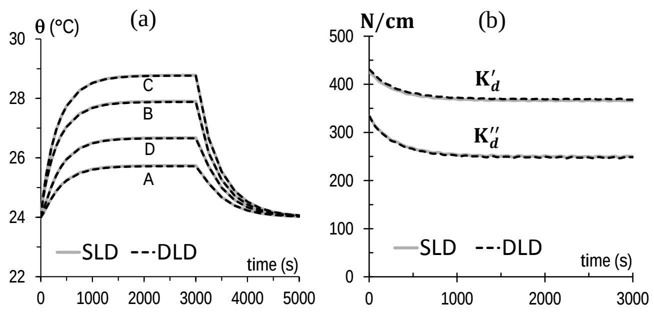

Fig. 7. (a) Temperature time-history and
(b) Storage stiffness K'_d and loss stiffness K''_d

REFERENCES:

1) Kasai, K., Munshi, J.A., Lai,, M.L. and Maison, B.F. (1993), Viscoelastic Damper Hysteretic Model: Theory, Experiment and Application. ATC-17-1 Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control; San Francisco, California, March 11-12, 1993

2) Kasai, K., Sato, D. and Huang, Y.H. (2006), Analytical Methods for Viscoelastic Damper Considering Heat Generation, Conduction and Transfer under Long Duration Cyclic Load, *J. Struct. Constr. Eng. AIJ No. 599*, 61-69, Jan. 2006 (In Japanese)

*1 東京工業大学 大学院生

*2 東京工業大学 教授 Ph.D.

*3 東京工業大学 准教授・博士（工学）

*1 Graduate Student, Tokyo Institute of Technology

*2 Professor, Tokyo Institute of Technology, Ph.D.

*3 Assoc. Prof., Tokyo Institute of Technology, Dr.Eng.