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Numerical Analysis Model for Viscoelastic Dampers under Long Duration Excitation considering Heat Transfer and Uniform Strain Distribution (Part 2: Random and Sinusoidal Loadings)

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Viscoelastic Damper　　Uniform Strain Distribution
Wind Loading　　Sinusoidal Loading

1 INTRODUCTION

In 2006, Kasai et al[1)] presented that the heat generation, conduction, and convection greatly affect the temperature distribution in the viscoelastic dampers under long duration excitations (Fig. 1). As reported in Part 1, the detailed long duration (DLD) model[1)] was further simplified by idealizing uniform strain distribution in the viscoelastic (VE) material. Under long duration harmonic loading, analytical results from the simplified long duration (SLD) model showed high congruency with those from the DLD model.

This study presents the SLD model analysis of a VE damper under long duration random and sinusoidal loadings.

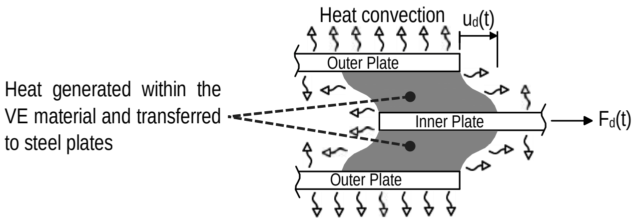

Fig. 1. Heat generation, transfer, and convection of VE damper

2 IMPLEMENTATION

Sato et al in 2015[2)] conducted experiments on a VE damper (Fig. 2) subjected to random wind loading and sinusoidal wave. For both loadings, they carried-out analysis using the DLD model.

The data from the above mentioned study[2)] will be compared with analytical prediction by the SLD model. Table 1 indicates the cases presented in this study.

Table 1. Case description

Case*	Description
A-3L Ran A-3L Sin	Along-wind response of a structure with a natural period of 3s and low damping of 2%

*Ran = Random Loading;　Sin = Sinusoidal Loading

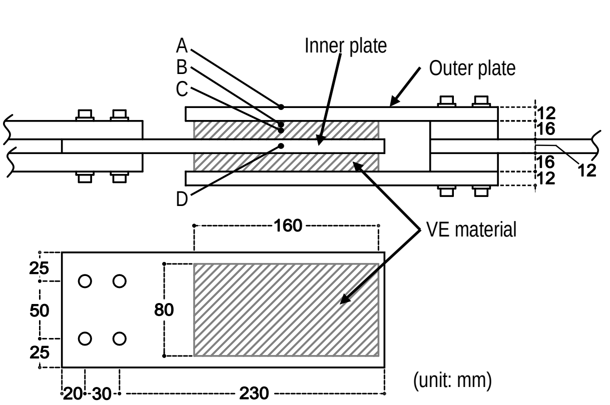

Fig. 2. Damper specimen and temperature measurement locations

2.1 Damper Properties

The viscoelastic material used was a 3M-ISD111 type with dimensions W = 8.0cm, L =16.0cm, and H = 1.6cm (Fig. 2). Thickness of steel plates d_s = 1.2cm. Total shear area A_v = 256.0cm^2.

Properties of the VE material used were provided by the manufacturer and were as follows: static shear modulus G = 3.92 N/cm^2; fractional derivative order $\alpha = 0.558$; at reference temperature θ_{ref} = 20°C, temperature-dependent constants a_{ref} and b_{ref} were 5.6 x 10^{-3} and 2.10, respectively, and; p_1 = 14.06 and p_2 = 97.32.

Additional properties such as thermal conductivity κ, specific heat capacity s, and mass density ρ are indicated in Table 2.

Table 2. Material properties of steel and VE material

Case	Steel	VE
κ (N/s/°C)	43.128	0.188
$s\rho$ (N/cm²/°C)	364.0	187.0

2.2 Heat Transfer Coefficients

Unlike in the 2006 study[1)], the heat transfer coefficients[2)] were not determined by steady-state heat transfer analysis using three-dimensional (3-D) finite element, rather by trial-and-error.

Considering the reasonable ratio $\alpha_{c,out}/\alpha_{c,in}$ = 1.824 by Kasai et al[1)], it was later found out by the authors[2)] that more appropriate values for heat transfer coefficients can be used. Hence, $\alpha_{c,out}$ and $\alpha_{c,in}$ for the outer and inner plates are 0.265 and 0.145 N/s/cm/°C, respectively.

2.3 Loading Conditions

For both cases considered, the ambient temperature was maintained to be at 24°C. Damper was subjected to loadings by applying corresponding damper deformation for a duration of 12,000s.

Random Loading. Shown in Fig. 3 is time-history of damper deformation under random loadings for case A-3L Ran. The maximum and minimum values of the deformation were 2.10 and -2.06 cm, respectively. Standard deviation σ_u of 0.50 cm and the peak factor PF was 4.2.

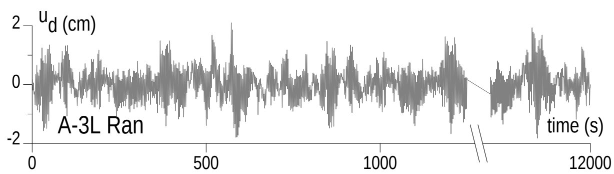

Fig. 3. Time history of damper deformation

Sinusoidal Loading. For case A-3L Sin, the damper was subjected to harmonic displacement peaking at 0.707 cm at 0.288 Hz frequency.

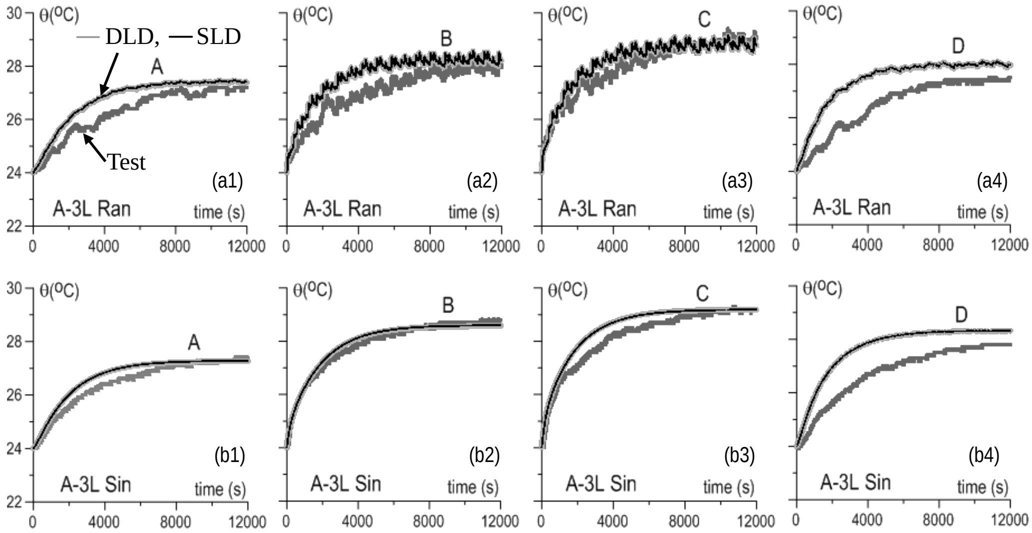

Fig. 4. Damper temperature time-history

2.4 Damper Model

Analysis using SLD model was carried out by discretizing the VE material into 12 elements, and the outer and inner plates were divided into 4 and 2 elements, respectively.

Temperature at different measurement points shown in Fig. 2 were observed. These points were at: A at the surface of the outer plate; B and C were at 1/4 point and 1/2 point of VE material, respectively, and; D was at the midpoint of the inner plate.

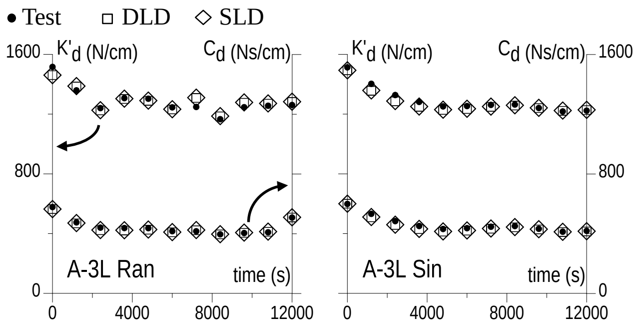

Fig. 5. Comparison of K'_d and C_d

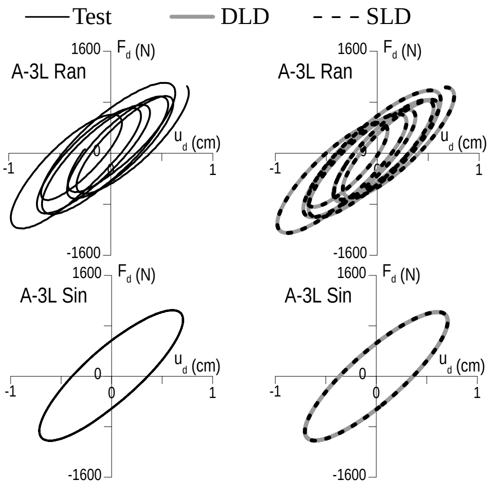

Fig. 6. Hysteresis loops for t = 8400~8420s

3 RESULTS

Damper temperature by SLD model agrees well with that of the DLD model (Fig. 4). Predictions of both models highly matched to those of the test result, except for temperature at D in Figs. 4 (a4) & (b4). Temperature measured by the sensor at D did not correspond to the one dimensional (1-D) heat flow in the thickness direction as idealized in the simplified (1-D) heat transfer analysis of the long duration models.

In addition, the storage stiffness K'_d (Eq. 1) and the damping coefficient C_d (Eq. 2) were determined. Fig. 5 shows good agreement between the test results and the predictions of the DLD and SLD models for both random and sinusoidal loadings.

$$K'_d = \frac{n\sum\left(u_d^{(i)} \cdot F_d^{(i)}\right) - \sum u_d^{(i)} \sum F_d^{(i)}}{n\sum\left(u_d^{(i)}\right)^2 - \left(\sum u_d^{(i)}\right)^2} \tag{1}$$

$$C_d = \frac{n\sum\left(\dot{u}_d^{(i)} \cdot F_d^{(i)}\right) - \sum \dot{u}_d^{(i)} \sum F_d^{(i)}}{n\sum\left(\dot{u}_d^{(i)}\right)^2 - \left(\sum \dot{u}_d^{(i)}\right)^2} \tag{2}$$

where F_d = damper force (N); u_d = damper deformation (cm); $\dot{u}_d$ = damper velocity (cm/s), and; n = number of data.

Generally, the hysteresis loops of the test and the two models for each case are similar. As shown in Fig. 6, similar loops can be seen for each loading case for t = 8400~8420s.

4 CONCLUSION

With high congruency to test results and DLD model results, VE dampers subjected to long duration random and sinusoidal loadings can be accurately analyzed using SLD model which idealized uniform strain distribution.

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