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Numerical Analysis of Viscoelastic Dampers under Long Duration Excitation (Part 3: Effects of Ambient Temperature and Damper Configuration)

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Viscoelastic Damper　　Long Duration Excitation　　Damper Configuration
Ambient Temperature

1. INTRODUCTION

Viscoelastic (VE) dampers had been known to be effective vibration-control devices for long-duration excitations, such as wind. In Part 1, the formulation of the *Simplified Long-Duration Model* (Simple-LD Model) was presented, and test result of Damper A1 (Fig. 1) at ambient temperature of 24°C verified the accuracy of the proposed method.

In practice, however, the ambient temperature can be varying and VE dampers can be configured in many ways.

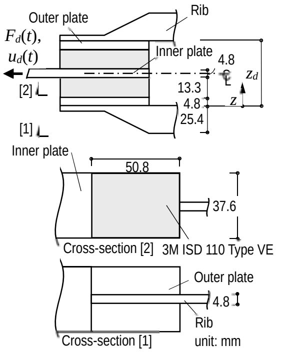

Fig. 1. Damper A1

The objectives of this paper, therefore, is to investigate the effect of ambient temperature and the behaviour of VE dampers with various configurations.

2. EFFECT OF AMBIENT TEMPERATURE

Using the original *Long-Duration Model* or LD Model (Eq. 1) of Kasai et al[1], Damper A1 (Fig. 1) was analyzed at ambient temperature θ_c = 15, 24 and 35°C.

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

where τ = shear stress (N/cm^2); γ = shear strain; G = static shear modulus (N/cm^2); a and b are temperature-dependent constants; D^{α} = fractional derivative operator[1), 2)] of order α. Note that this method utilizes finite element analysis at every time-step n, thus, the VE damper is discretized into element with j nodes.

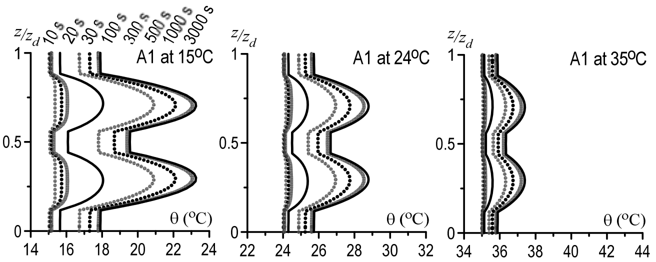

Fig. 2. Temperature distribution of Damper A1 at various ambient temperatures (left to right: 15°C, 24°C and 35°C).

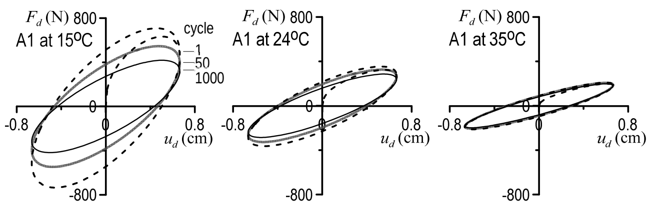

Fig. 3. Hysteresis loops of Damper A1 at various ambient temperatures (left to right: 15°C, 24°C and 35°C).

Damper Properties. As provided by the manufacturer for ISD 110 Type VE material: G = 6.519 N/cm^2; α = 0.609; at reference temperature θ_{ref} = 0.2°C, a_{ref} = 0.0115 and b_{ref} = 21.157, and; p_1 = 19.5 and p_2 = 80.0.

Thermal conductivity κ for VE and steel are κ_{VE} = 0.188 N/s/°C and κ_{steel} = 43.128 N/s/°C, respectively. Specific heat capacity s are s_{VE} = 19.40 x 10^4 N·cm/kg/°C and s_{steel} = 46.63 x 10^3 N·cm/kg/°C, respectively for VE and steel. Mass density of viscoelastic material is ρ_{VE} = 1.00 x 10^{-3} kg/cm^3 and for steel is ρ_{steel} = 7.8 x 10^{-3} kg/cm^3.

Loading Conditions. Damper A1 was subjected to harmonic displacement of peak value ±0.66 cm (±50% max strain level) at a frequency of 0.33 Hz. Loading duration is 3000 seconds.

Heat Convection Rate. From the 3D finite element analysis[1)] of Damper A1 at 24°C, the heat transfer coefficients $\alpha_{c,out}$ and $\alpha_{c,in}$, for outer and inner plates are 0.956 and 0.524 N/s/cm/°C, respectively.

Experimental studies[3), 4)] show that ambient temperature has no significant influence to α_c values. With this, the same $\alpha_{c,out}$ and $\alpha_{c,in}$ values were used for the analysis of Damper A1at θ_c = 15 and 35°C.

Results. Fig. 2 shows the temperature distribution at different time t; vertically normalized by the total damper thickness z_d, and equal scaling horizontally. For all three conditions, accumulation of heat is found at the middle portion of the VE material – signified by the peak temperature in the said part.

An 8.3°C peak increase in temperature is predicted for θ_c = 15°C which constitutes the largest increase among the conditions analyzed. This is because at lower temperature, the VE material is stiffer and dissipates more energy than at warmer environment. As seen in Fig. 3, the hysteresis loops at θ_c = 15°C are fatter and are more inclined compared to other conditions – indicating large amounts of energy dissipated E_d (Fig. 4) and temperature increase for every loading cycle. Fig. 3 also shows that at θ_c = 15°C, the loops notably decreased after several cycles while at θ_c = 24°C, the decrease is small and at θ_c = 35°C, the loops are almost similar over the loading duration.

Plots of storage stiffness K_d' and loss stiffness K_d'' (Fig. 5) show that dynamic properties of dampers greatly decrease from its initial value when the ambient temperature is low.

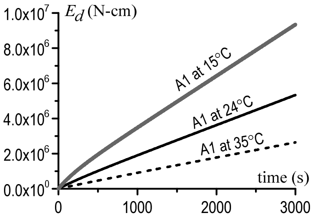

Fig. 4. Comparison of total damper energy of Damper A1.

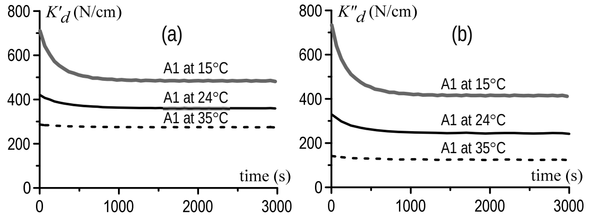

Fig. 5. Comparison of (a) storage stiffness K_d' and (b) loss stiffness K_d'' of Damper A1 at various ambient temperatures.

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3. EFFECT OF DAMPER CONFIGURATION

As shown in Fig. 6, Damper A1 was geometrically modified to come up with Dampers A2~A6 that were used to investigate the effect of damper configuration.

Damper Properties. Other than the varying geometric configurations, the material properties remain the same for all six dampers.

Loading Conditions. All six dampers were subjected to harmonic displacement of ±50% peak strain level at a frequency of 0.33 Hz. Loading duration is 3000 seconds.

Heat Convection Rate. Table 1 indicates the $\alpha_{c,out}$ and $\alpha_{c,in}$ values for Dampers A1~A6 which were calculated by 3D finite element analysis$^{1)}$. Damper A4 has the least α_c values because it has the least steel surface area for convective transfer. Excluding Damper A4, the average value of $\alpha_{c,out}/\alpha_{c,in}$ ratio is 2.0 which indicates that the convective heat transfer rate at the outer plate is twice than that of the inner plate.

Results. Fig. 7 compares the temperature distribution in the six dampers. Dampers A1, A2 and A5 (with equal VE thickness) have similar behaviour. The (i) doubling of the inner plate and rib lengths for A2, and the (ii) removal of rib and extending the outer plate for A5 do not have significant effect. The same is observed for A3 vs A6 (both have equal VE thickness).

However, the removal of the ribs and shortening of the inner plates for A4 greatly slowed down the convective heat transfer, resulting to more heat accumulated in the VE material.

Except for A4, the temperature of all dampers from t = 1000 s becomes constant signifying that heat generation rate due to dissipated energy is equal to the convective heat transfer rate.

Worth noting, however, that for short duration loading ($t \leq 30$ s), the temperature distribution of the six dampers are similar. This is because for short duration loadings, such as typical earthquake, heat transfer does not have significant effect$^{2)}$. Therefore, the damper configuration does not affect the behaviour of VE damper.

The plots of the hysteresis loops at 1st, 50th and 1000th cycles (in Fig. 8) manifest similar behaviour of A1, A2 and A5, as well as, A3 and A6. During the early loading cycles, the dynamic properties of VE dampers decrease abruptly but become sluggish because of heat transfer.

Damper A4 has the maximum decrease of dynamic property after 1000 loadings cycles because large amount heat was accumulated in the VE material due to low convective heat transfer. Sufficient steel surface must be provided for dispersion of heat to the surrounding air.

4. CONCLUSION

This study investigated the effect of ambient temperature and damper configuration when a VE damper is subjected to long duration loading such as wind. It was found out that initial dynamic properties of viscoelastic dampers under long duration loadings significantly decreased when the ambient temperature is low. VE damper dissipates varied levels of energy under different ambient temperature, thus, it is vital to determine the environment at which the VE dampers are to be used.

Investigation of different damper configurations showed the importance of having sufficient steel surface for the dispersion of generated heat to the surrounding air, especially for long duration loadings that heat transfer has significant effect. However, for short duration loadings such as a typical earthquake, dampers of different configurations behave similarly.

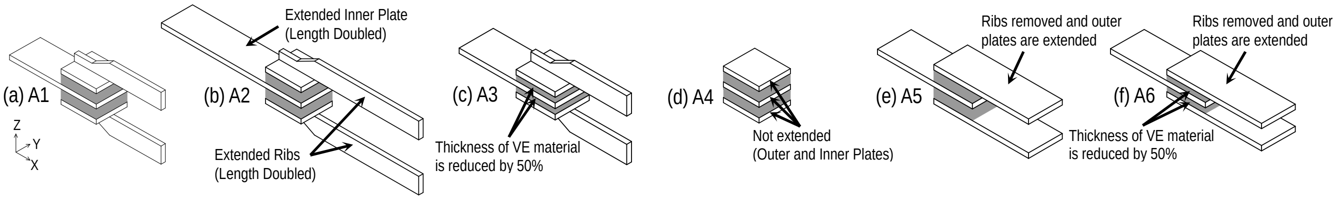

Fig. 6. Configurations of dampers A1 to A6.

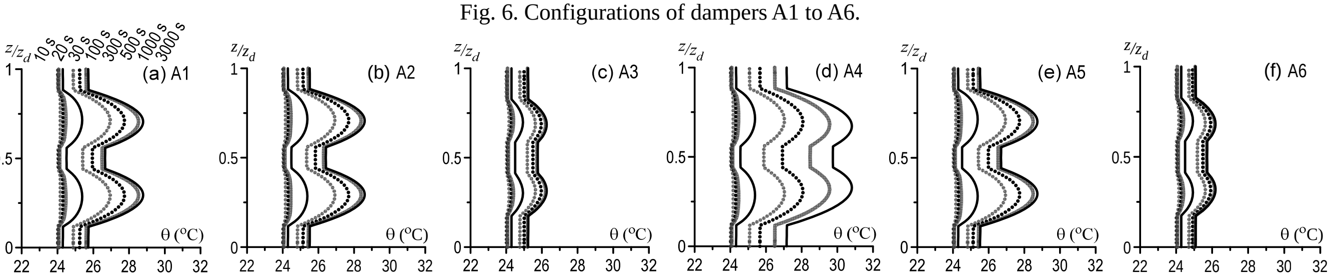

Fig. 7. Temperature distribution in dampers A1 to A6 at different time.

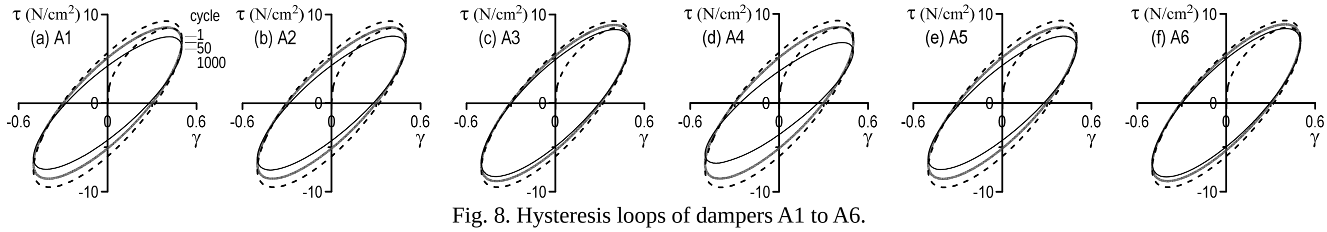

Fig. 8. Hysteresis loops of dampers A1 to A6.

Table 1. Heat Convection Rate of Different Dampers

Damper	$\alpha_{c,out}$ (N/s/cm/°C)	$\alpha_{c,in}$ (N/s/cm/°C)	$\alpha_{c,out}/\alpha_{c,in}$
A1	0.956	0.524	1.824
A2	1.104	0.589	1.874
A3	0.885	0.446	1.984
A4	0.517	0.160	3.231
A5	1.113	0.509	2.187
A6	1.041	0.446	2.334

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