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Full-Scale Viscoelastic Damper under Long-Duration Loading: Experiment and Performance Evaluation

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Abstract— **Viscoelastic (VE) dampers are known to be effective in mitigating structural vibrations of long-period tall buildings. Their dynamic mechanical properties (i.e., damping and stiffness) are highly dependent to the loading frequency and temperature. The co-authors had previously proposed a simplified performance evaluation method for full-scale brace-type VE dampers. However, the VE dampers they evaluated had almost the same ambient temperatures. For this, the authors of this current study conducted low ambient temperature tests and used the results to extend the original performance evaluation method mentioned above to cater wider range of initial temperatures.**

I. INTRODUCTION

A. *Viscoelastic Damper against Long-Duration Loadings*

Properly employing viscoelastic (VE) damper can effectively mitigate structural vibrations. Through the shear deformation of the steel-sandwiched VE materials, kinetic energy is dissipated and converted to small amount of heat within the VE material. Kasai *et al.* [1] defined the heat generated due to the dissipated energy as:

$$\Delta\theta = \frac{\int \tau d\gamma}{s\rho} \qquad (1)$$

where τ = shear stress, γ = shear strain, s and ρ are specific heat and density of the VE material, respectively.

Under long-duration loading, significant amount of heat can be accumulated within the low thermal conductive VE material, notably decreasing the dynamic mechanical properties of the VE damper.

Table 1. Harmonic Loading Conditions

Test	Period T (s)	Amplitude u_d (mm)	Duration t_0 (s)	Number of cycles	Ambient Temp. θ_0 (°C)	Specimen	Ref.
E-01	4.00	20.00	450	112	21	I	[3]
E-02	2.00	16.00	300	150	22	II	[4]
E-03	4.00	8.00	1200	300	22		
E-04	4.00	16.00	600	150	22		
E-05	4.00	24.00	400	100	22		
E-06	6.00	16.00	900	150	22		
E-07	2.00	16.00	300	150	22	III	
E-08	4.00	8.00	1200	300	22		
E-09	4.00	16.00	600	150	22		
E-10	4.00	24.00	280	70	22		
E-11	6.00	16.00	900	150	22		
E-12	4.00	16.00	600	150	22	IV	
E-13	2.86	24.96	66	23	22	V	[5]
E-14	3.61	5.66	22796	6314	26		[6]
E-15	3.61	5.66	25864	7164	30		
E-16	4.00	20.00	21600	5400	6	VI	Current study
E-17	2.00	10.00	10800	5400	5		

Table 2. Viscoelastic damper specimen specifications

Specimen	Length l (mm)	Total shear area A_s (cm^2)	Thickness of one VE lamination t (mm)	Number of laminations n	A_s/t (mm)
I	4628.7	26,000	9	10	28,889
II	3946.6	13,120	8	8	16,400
III	3946.6	18,112	8	8	22,640
IV	3848.9	26,000	8	10	32,500
V	4024.5	9,120	8	6	11,400
VI	4024.5	8,544	8	6	10,680

B. *VE Damper Performance Evaluation*

In 2017, Kasai et al. [2] proposed a simplified evaluation rule to predict the peak cyclic damper force variations. They showed a good correlation between the normalized peak damper force vs. normalized energy density Ω', which are calculated as:

$$Normalized\ Force = \frac{F_d^{[n]}}{F_d^{[1]}}\text{, and} \qquad (2)$$

$$Normalized\ Energy\ Density\ \Omega' = \frac{\sum W_d}{V}\cdot\frac{\gamma_{\max}}{T}. \qquad (3)$$

Here, $F_d^{[n]}$ and $F_d^{[1]}$ = peak damper forces at the n^{th} cycle and 1st cycle, respectively, W_d = energy dissipated in one cycle, V = volume of VE material, $\gamma_{\max}$ = peak shear strain, and T = excitation period.

C. *Objective of the Study*

However, the full-scale VE dampers considered in the above evaluation rule [2] had almost the same ambient temperature of 21~22°C [3-5], as in Tables 1 and 2. This motivated the authors to conduct full-scale VE damper experiment at low ambient temperatures of 5~6°C in order to incorporate the effect of the initial temperature to the simplified evaluation rule [2]. This cur-rent study also considers the tests at ambient temperatures of 26°C and 30°C from a previous study [6] (Tables 1 and 2).

II. LOW AMBIENT TEMPERATURE TEST

A. *Damper Specimen and Test Setup*

The low ambient temperature tests at 5°C and 6°C, herein designated as E-16 and E-17 (Table 1), respectively, were conducted in Tokyo Institute of Technology (Suzukakedai Campus), Japan. Fig. 1 shows the test setup for the full-scale viscoelastic damper. This setup is typical to all the previous studies. Harmonic damper deformation $u_d(t)$ is caused by the dynamic actuator on the right. Fig. 2

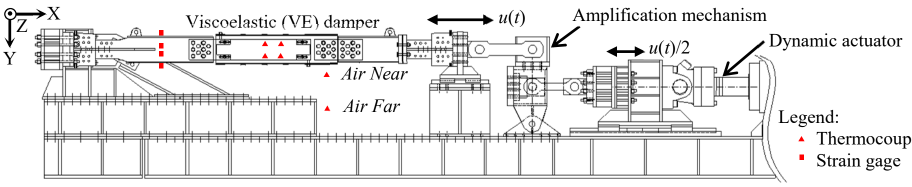


Figure 1. Viscoelastic (VE) damper test setup

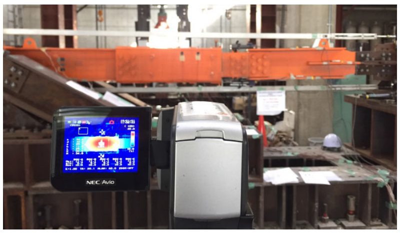
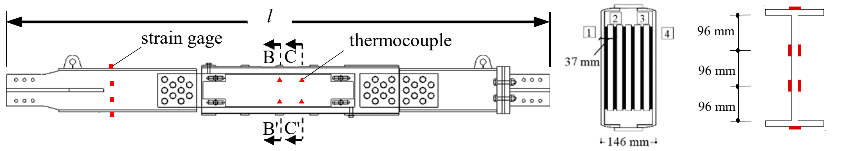


Figure 3. Thermal imaging device capturing the damper temperature.



(a) VE damper side view

(b) Positions of thermocouples and strain gages

Figure 2. Measurement locations for the test setup [unit: mm]

shows the locations of the thermocouples and strain gages. The measured strains at the bracing were used to calculate the damper reaction. Loading conditions are indicated in Table 1, and VE damper specimen specifications in Table 2.

B. Test Results

Fig. 3 shows the thermal imaging device capturing the temperature distribution of the VE damper test specimen when subjected to long-duration loading.

Fig. 4a shows that from an initial temperature of 6°C, the temperature of E-16 increases when loaded. Despite being in a low ambient temperature, VE material temperature increased to about 60°C. With the rise of temperature, the dynamic mechanical properties of VE damper decrease. As seen in Fig. 4b, the storage stiffness K'_d decreases to about 2.50 kN/mm from an initial value of 31.28 kN/mm, i.e., more than 90% decrease.

III. PERFORMANCE EVALUATION

The original simplified performance evaluation (Equations 2 and 3) [2] is applied to the current tests above and then compared to those from the previous tests indicated in Table 1. As shown in Fig. 5, only E-01~E-13 tests with ambient temperature of 21~22°C have good correlation. It is clear that the initial temperature has significant effect, thus, must be considered in modifying the simplified performance evaluation method. Preliminary investigation showed that it is possible to modify Equations 2 and 3 into

$$\text{Modified Normalized Force} = \left(\frac{F_d^{[n]}}{F_d^{[1]}}\right)^{A}, \text{ and} \tag{4}$$

$$\text{Mod. Normalized Energy Density } \Omega'^{*} = \frac{\sum W_d}{V}\cdot\left(\frac{\gamma_{\max}}{T}\right)^{0.50} \tag{5}$$

to have a better correlation of all the tests with varying ambient temperatures. Here, A is a function of the ambient temperature which is currently being investigated. Fig. 6 shows an improved correlation of all the tests using the Equations 4 and 5. This is achieved by setting A to different values.

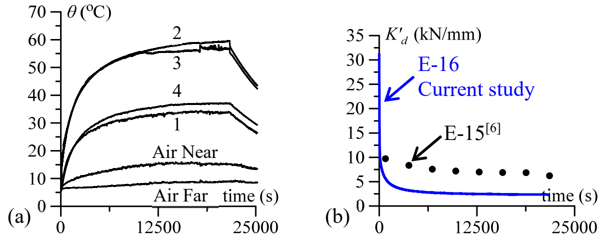


Figure 4. (a) Temperature time-history, and (b) storage stiffness K'_d.

IV. CONCLUSIONS

This study showed that the ambient temperature of a full-scale VE damper has a considerable effect on how the device behaves when subjected to long-duration loading. As such, it was considered in modifying the previously proposed performance evaluation of the co-authors. However, the findings in this report are just preliminary and proposed equations can be modified in the future.

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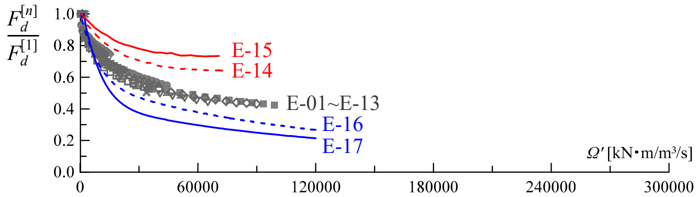

Figure 5. Using the original performance evaluation method [2].

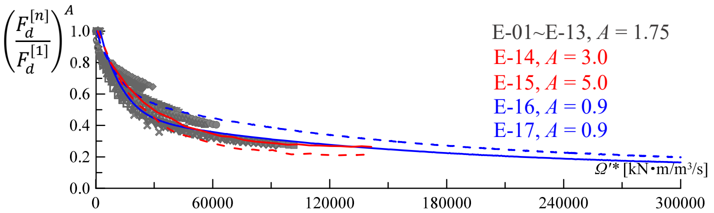

Figure 6. Modifying the original evaluation method by considering the effect of ambient temperature.