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Study of Full-Scale Multi-Layered Viscoelastic Dampers under Long-Duration Harmonic Loading (Part 3: Characteristics of a Viscoelastic Damper under Different Loading Conditions)

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Full-Scale Viscoelastic Damper Long Duration Loadings 3D-FEM Analysis Different Loading Conditions

1. INTRODUCTION

In Part 1, past experimental studies on full-scale multi-layered viscoelastic (VE) dampers under long-period ground motions and long-duration loadings were briefly introduced, and an experiment on low ambient temperature was also presented.

Part 2 addressed the lack of analytical investigation on long-duration loading. The proposed model of Kasai *et al.*[1)] was used in the analysis. The said model combines the elastic-static analysis and three-dimensional transient-state heat transfer analysis using 3D finite element method (3D-FEM model). The analysis predicted the temperature and the dynamic mechanical properties with high accuracy. However, major drawbacks of this technique are the high computational time and non-thermo-physical nature of the heat transfer coefficient which requires several trials to matching results with tests. Despite these drawbacks, the 3D-FEM model is a good tool to thoroughly investigate a full-scale VE damper behavior under long-duration loadings.

To better understand the nature of the heat transfer in full-scale VE dampers, particularly the convective heat transfer and value of heat transfer coefficient, this paper carried-out analyses of the same damper specimen in Part 2 but under different loading conditions.

2. DAMPER SPECIMEN AND LOADING CONDITIONS

For consistency, the indexing for the damper specimen in Part 1 and the indexing for the test number in Part 1are used in this report. For convenience, excerpts of are shown below in Tables 1 and 2, respectively. Damper specimen VE05 under loading conditions of Tests 14, 15 and 16 are analyzed in the report[2)], herein referred as Conditions 14, 15 and 16, respectively. Each of the three loading conditions has peak amplitude of ±5.66 mm. Loading period for Conditions 14 and 15 is 3.61 seconds while that for Condition 16 is 7.01 seconds. Ambient temperatures range from 26°C to 30°C.

Please refer to Part 2 for the material properties of VE05.

3. 3D-MODEL OF THE VE DAMPER

The same 3D-FEM model (Figure 3 of Part 2) is used in this report.

Damper Properties for Heat Transfer Analysis.

Please refer to Table 1 of Part 2.

Heat Convection Rate.

Analysis of Condition 14 had been reported in Part 2 and the adopted value for the heat transfer coefficient $\alpha_c = 2.60$ N/s/m/°C.

From several trials, the adopted α_c for all air-exposed surfaces for Condition 15 is 2.60 N/s/m/°C.

From several trials, the adopted α_c for air-exposed surfaces for Condition 16 vary from is 0.60 N/s/m/°C to 2.20 N/s/m/°C with the innermost air-exposed surfaces having the lowest values and the outermost air-exposed surfaces having the highest values.

Ambient temperature. The recorded or measured ambient temperatures θ_c are used in the analyses.

4. ANALYSIS RESULTS

Locations of the thermocouples at the mid-section of VE05 are shown in Figure 1. Point 1 is on the surface of the steel, Points 3 and 5 are on the innermost VE lamination, and Points 2 and 4 on the VE lamination next to Points 3 and 5.

Figure 2 compares the analysis results with those from the tests. It is verified that the adopted α_c values for the different loading conditions are reasonable. The predicted steel surface temperatures (Point 1) for all three conditions match well with the recorded test data. Meanwhile, for the temperature at the VE laminations, those predicted at Points 4 and 5 have better match with the test than Points 2 and 3 do. Considering the relatively large volume of VE lamination, this difference has insignificant variation to the dynamic characteristics of the full-scale VE damper.

As seen in the lowermost row in Figure 2, the storage stiffness for all the three conditions are predicted with high accuracy. By incorporating heat transfer analysis, the real behavior of the full-scale VE damper is simulated, i.e., the steady-state response.

Different Ambient Temperature.

Except for the ambient temperature θ_c and the loading duration, Conditions 14 and 15 have the same loading conditions. It is found that the ambient temperature plays vital role in the initial the performance of the VE damper.

The high initial K'_d of Condition 15 is due to low initial damper temperature since θ_c is low. Consequently, the amounts of energy dissipated and heat generated are higher than those in Condition 14, therefore the amount of storage stiffness decrement is predicted to be larger as well.

Different Loading Frequency.

Although Condition 16 has lower θ_c than Condition 14, its initial storage stiffness is predicted to be lower than the latter. This is due to the fact that the former has a low-period loading of 7.01 s than the latter which has 3.61 s.

Furthermore, the temperature distributions for Conditions 14 and 15 are shown in Figure 4. Only the mid-portions near the VE laminations differ for both conditions, the supporting steel (I-sections) are very similar. The innermost VE laminations manifest high temperature since the transfer of heat to the surrounding air is limited, whereas, the outermost VE laminations have low temperature due to effective dispersion of heat to the surrounding air.

Table 1. Viscoelastic damper specimens from past studies

Specimen	Length l (mm)	Total shear area A_s (cm^2)	Thickness of one VE lamination t (mm)	No. of laminations n	A_s/t (mm)
VE05	4024.5	9,120	8	6	11,400

Table 2. Harmonic loading conditions from past studies

Test No.	Period T (s)	Amplitude u_d (mm)	Duration t_0 (s)	No. of cycles	Ambient Temp. θ_c (°C)	Damper Specimen	Ref.
14	3.61	5.66	25,864	7,172	30	VE05	2
15	3.61	5.66	22,796	6,321	26		
16	7.01	5.66	24,942	3,559	28		

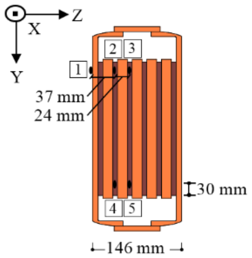

Figure 1. Temperature measurement positions

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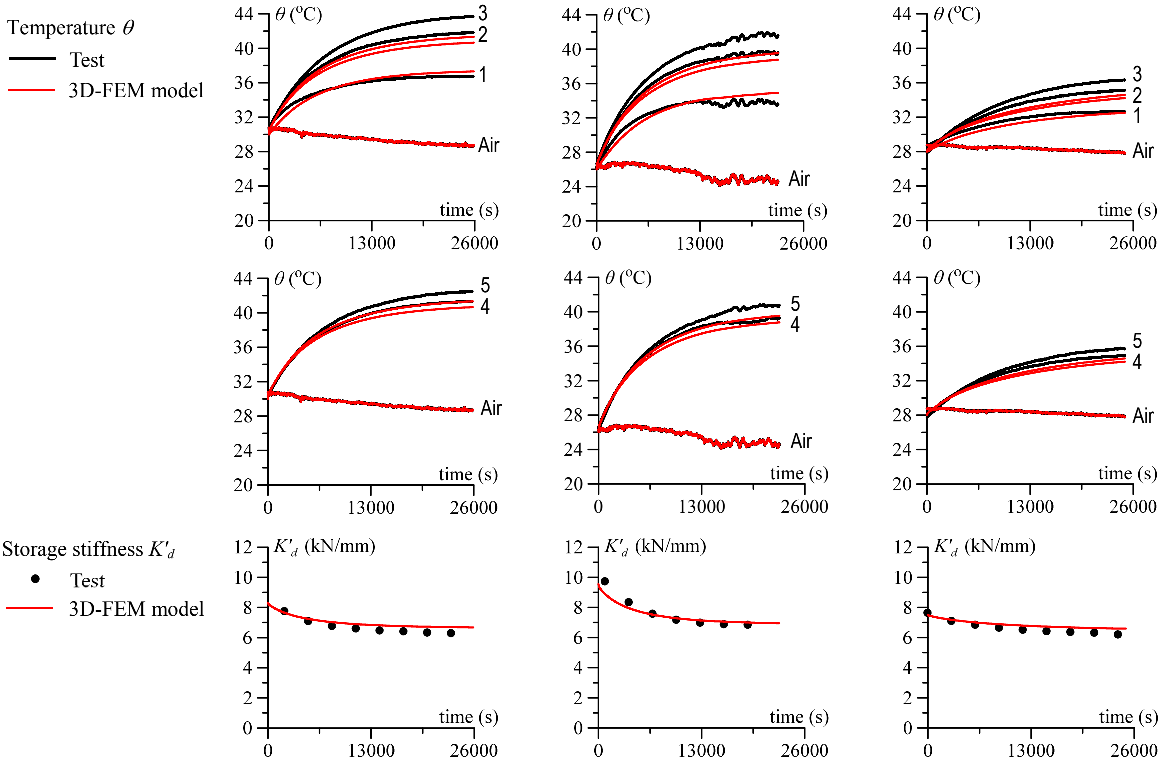

(a) Condition 14 (b) Condition 15 (c) Condition 16

Figure 3. Results: Test vs. 3D-FEM Analyses

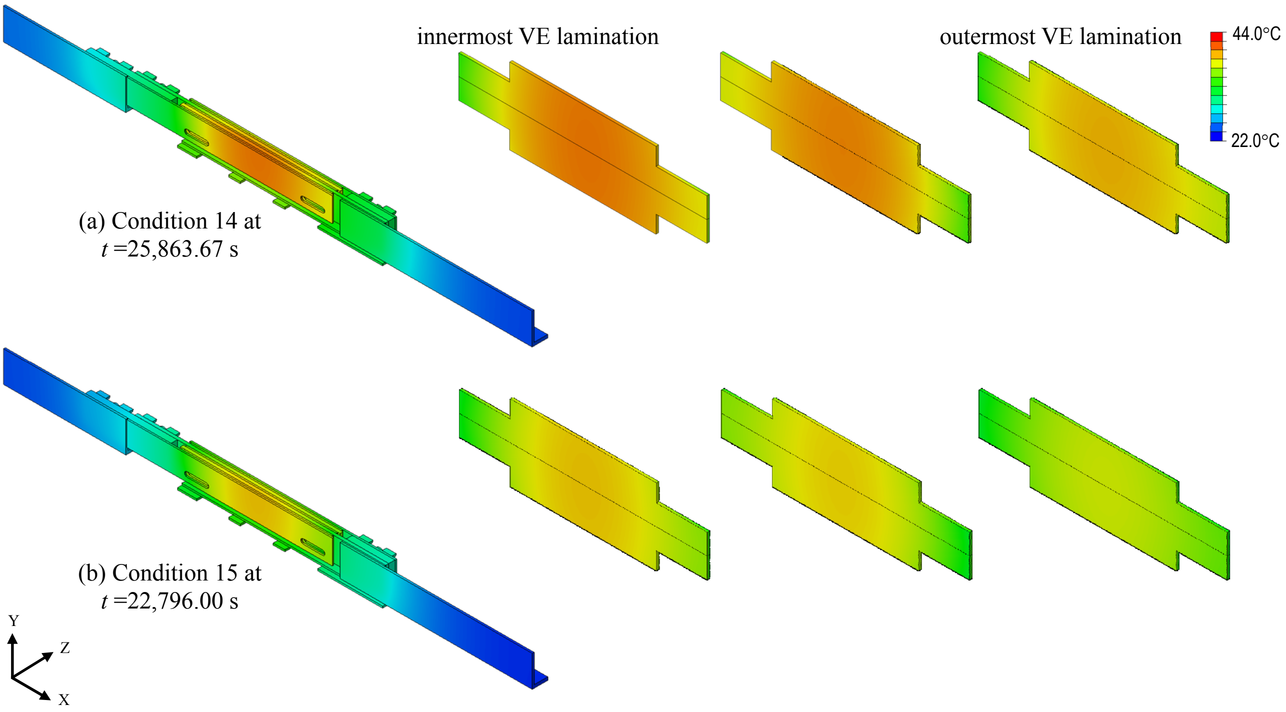

Figure 4. Temperature distributions for Conditions 14 and 15.

5. CONCLUSIONS

Despite the complex nature of a full-scale multi-layered VE damper, it is possible to carry-out analytical investigation. The only major issue encountered for this technique is determining the appropriate value of the heat transfer coefficient α_c since this is not a thermo-physical property of the VE damper.

For the damper specimen in this paper, it was found that the α_c value ranging from 0.60 N/s/m/°C to 2.60 N/s/m/°C is reasonable, although it can still be improved by subdividing the VE damper into more segments and assigning more detailed α_c.

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