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One-dimensional Analytical Methods for Full-scale Multilayer Viscoelastic Damper Considering Strain Sensitivity
Part 2. Experimental Validation: Accuracy and Efficiency Comparison

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One-dimensional modeling　Time-history analysis
Multilayer Viscoelastic (VE) damper　Strain sensitivity

1. INTRODUCTION

Part 1 proposed one-dimensional modeling methods applicable to multilayer VE dampers. Combining with the constitutive rule proposed in Ref. [3], one-dimensional time-history analysis methods (i.e., NL-1D and SN-1D methods) capable of considering the nonlinear effects of strain sensitivity on the behavior of VE dampers were proposed.

In this Part 2, the proposed methods are validated by considering a large deformation loading test on an eight-layered VE damper[5].

2. LARGE DEFORMATION LOADING TEST [5]

This current study utilizes the experimental result of VE damper test conducted by Kasai et al.[5]. Shown in Fig. 1 is the VE damper with VE material type of ISD111, thickness d_v = 8 mm. The harmonic loading conditions are as follows: initial temperature θ_0 = 21 ◦C, ambient temperature θ_a = 12.3 ◦C, frequency f_r = 0.25 Hz, damper strain level γ_d = 300% (= peak damper deformation u_{d0} / d_v), loading duration = 400 s (100 cycles).

3. VERIFICATION OF NL-1D METHOD: NL-1D ANALYSIS RESULTS VERSUS TEST

This chapter uses the same initial conditions as the test[5] to carry out time-history analysis by NL-1D method. Since the eight-layered damper is symmetrical in Z-direction, the 1D model is half of the damper (number of VE layers after symmetry L = 4). Each layer of VE and the steel plate is divided into 12 segments of 2/3 mm length. As for the parameters of constitutive rule and material characteristics (e.g., density and heat conductivity), they are the same with the study of Kasai et al.[2, 3].

Fig. 2 shows the time-history of damper reaction force F_d from the NL-1D method and test, respectively. Although the NL-1D method has slightly lower results than the test in the beginning of the loading, the rest results are very similar with test. As shown in Fig. 3, the cyclic behavior of VE damper, F_d – deformation u_d hysteresis loops (Cycles 1, 50 and 100) obtained from NL-1D method are fit well with the test.

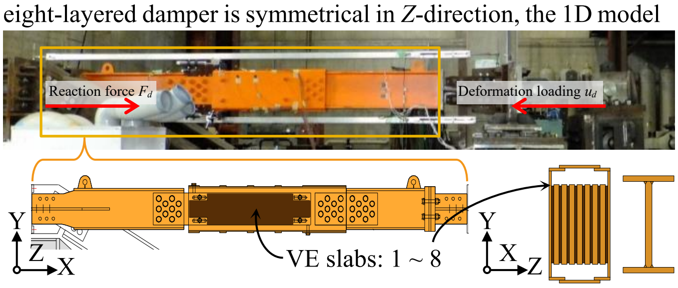


Fig. 1 Eight-layered VE damper of large deformation loading test

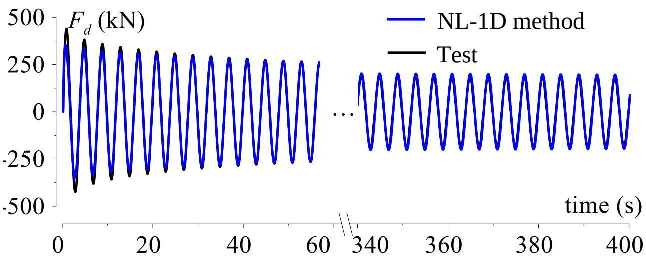


Fig. 2 Damper force F_d from NL-1D method vs. test [5]

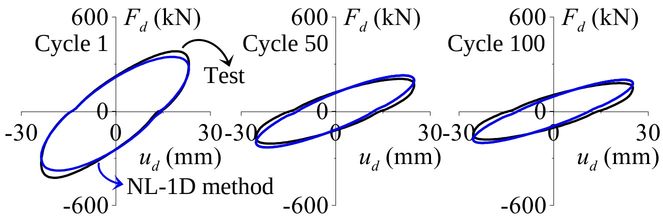


Fig. 3 F_d -u_d hysteresis loop from NL-1D method vs. test [5]

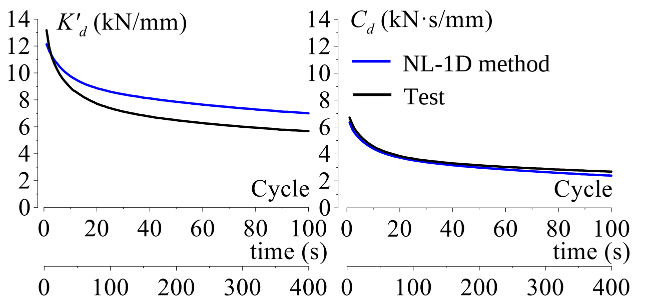
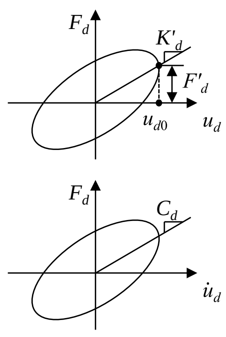


Fig. 4 Dynamic properties K'_d and C_d from NL-1D method



VE damper dynamic properties

Storage stiffness K'_d

$$K'_d = \frac{M\sum_{i=1}^{M}\left(u_d^{(i)} \cdot F_d^{(i)}\right) - \sum_{i=1}^{M} u_d^{(i)} \sum_{i=1}^{M} F_d^{(i)}}{M\sum_{i=1}^{M}\left(u_d^{(i)}\right)^2 - \left(\sum_{i=1}^{M} u_d^{(i)}\right)^2} \quad \text{--- (1)}$$

Damping coefficient C_d

$$C_d = \frac{M\sum_{i=1}^{M}\left(\dot{u}_d^{(i)} \cdot F_d^{(i)}\right) - \sum_{i=1}^{M} \dot{u}_d^{(i)} \sum_{i=1}^{M} F_d^{(i)}}{M\sum_{i=1}^{M}\left(\dot{u}_d^{(i)}\right)^2 - \left(\sum_{i=1}^{M} \dot{u}_d^{(i)}\right)^2} \quad \text{--- (2)}$$

M = number of data in one cycle I
u_d = deformation, $\dot{u}_d$ = velocity

Fig. 5 VE damper cyclic behavior and dynamic properties

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Moreover, Fig. 4 shows the VE damper dynamic properties (storage stiffness K'_d and damping coefficient C_d calculated from VE damper cyclic behavior using the least squares method as shown in Fig. 5) from the NL-1D method and test. NL-1D method can predict close results of K'_d and almost equal results of C_d as test. Based on these, the NL-1D method can be considered as having good accuracy on predicting multilayer VE damper's non-linear behavior under large strain level.

4. VERIFICATION OF SN-1D METHOD: SN-1D VERSUS NL-1D ANALYSIS RESULTS

In this chapter, the SN-1D method is carried out using the same element discretization as the NL-1D method. However, as mentioned in Part 1, the SN-1D method estimates VE material property by the weighted average temperature in each VE slab and idealizes the multilayer VE material as one element to have uniform shear strain. For this, the SN-1D method only took 0.10 times the computation time of the NL-1D method.

Moreover, as shown in Fig. 6, by dividing the SN-1D results (K'_d and C_d) with the NL-1D results, each ratio is very close to 1. With this, the SN-1D method can be considered to have almost equal accuracy with the NL-1D method on predicting the dynamic properties of multilayer VE damper. Fig. 7 shows the local nodal and element results within the outer and inner VE slabs at time $t = 400$ s, where the vertical axis is normalized to the thickness d_v. Although the SN-1D method idealized the uniform shear strain (left column of Fig. 7) and calculated VE material properties by weighted average temperature (e. g., storage shear modulus G', center of Fig. 7), the dissipated energy density W (right side of Fig. 7) from the SN-1D method has good agreement with those from the NL-1D method.

With such great advantage in computation time, and good accuracy as that of the NL-1D method, the SN-1D method can be effectively used to analyze multilayer VE damper non-linear behavior under large strain level.

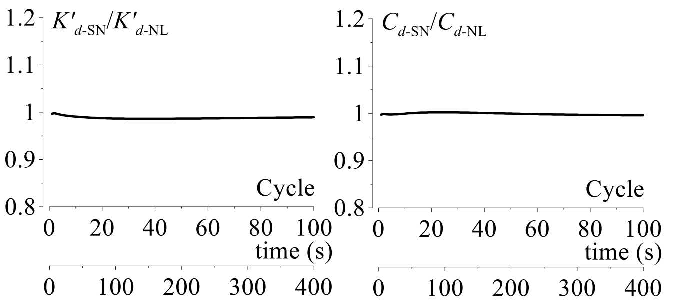

Fig. 6 Accuracy of dynamic properties: SN-1D / NL-1D

5. CONCLUSION

The analytical results obtained from the NL-1D and SN-1D methods were compared with experimental results[5] of a large deformation loading test on an eight-layered VE damper. The NL-1D method demonstrated to have good accuracy, enabling precise prediction of the nonlinear behavior of stiffness, and damping from the multilayer VE damper under large strain level. Moreover, SN-1D method has almost equal accuracy with, but has greater computational-efficient than, the NL-1D method.

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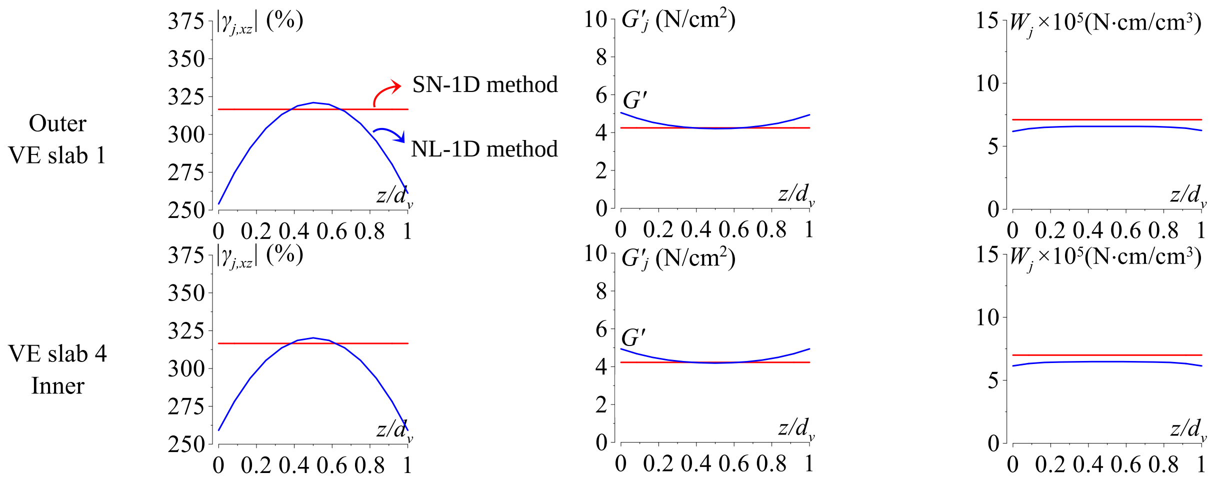

Fig. 7 (left) Nodal strain, (center) G_j and (right) dissipated energy density W_j in VE slab 1 and slab 4 at 400s from SN-1D method versus NL-1D method

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