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WOOD AND STEEL VISCOELASTIC DAMPERS: SHORT AND LONG-TERM PERFORMANCE

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ABSTRACT: The objective of this study is to characterize the performance and quantify the short-term and long-term differences between viscoelastic dampers constructed with steel and wood. Static and cyclic tests were conducted on steel and wood dampers utilizing 3M ISD-111 viscoelastic polymer. Initially, twelve specimens, six wood and six steel, were loaded statically to failure. Six dampers, three wood and three steel, were subjected to ten fully reversed cycles of sinusoidal displacement at various strains and frequencies. Twenty years later two of the dampers were retested under identical conditions to confirm material integrity and structural performance. For all dampers, the shear area of the VE was held constant, while the thickness varied. The initial static investigation demonstrated that the failure mode for all wood specimens was a shearing of the material at strains over 500%. There was no debonding of the VE material from the wood. After twenty years, the failure mode was delaminating from the wood at a strain of greater than 300%. The results of the cyclic tests showed good agreement between the stiffness and energy dissipations for the wood and steel dampers immediately after construction and twenty years later.

KEYWORDS: viscoelastic dampers, wood, energy dissipation, supplemental damping, polymer bond, time dependent

1 INTRODUCTION

Historically, viscoelastic (VE) dampers have been used exclusively in steel and reinforced concrete structures. Conventional VE dampers are constructed with the polymer bonded to steel plates which connect the dampers to the structure. With the recent increase in mid and high-rise structures constructed from wood, there exists a need to provide supplemental damping to wood structures.

2 BACKGROUND

When first implemented into the design of civil structures, viscoelastic dampers were aimed at decreasing the motion that the structure underwent because of wind. The original World Trade Center Towers in New York City, constructed in 1969, were the first applications of VE dampers in a tall building (Mahmoodi, 1969). The two towers used a combined 20,000 dampers made with VE material located between the lower chord of the floor system and the outside wall column at lateral bracing. VE dampers were utilized in the Columbia Center Building, located in Seattle, Washington, to reduce its acceleration levels (Keel and Mahmoodi, et. al. 1990; Samali and Kwok, 1995). The decision to use viscoelastic dampers in this structure was partially the result of how economic this material was for the overall cost.

The success of viscoelastic dampers in response to wind loading has led to the investigation of this material with respect to seismic activity. Research has shown that steel and reinforced concrete structures have seen improved performance through use of viscoelastic dampers. While wood structures are currently designed such that structural collapse is not a concern, they still experience considerable damage, both structural and nonstructural. A study conducted by Dinehart et. al. (1999a, 1999b) analyzed the performance of conventional shear walls to those constructed with viscoelastic dampers. This research concluded that there was significantly higher stiffness and energy dissipation ability displayed from the tests with viscoelastic dampers than the conventional shear walls.

The research previously conducted into the performance of viscoelastic material in wood structures has been promising, but not enough to fully justify implementation in wood structures. This paper discusses the performance of wood dampers made with viscoelastic material in both the short term and long term, as well as compares its performance to that of a similarly designed steel damper. The utilization of viscoelastic material in the design of wood dampers is an effective way to provide sufficient stiffness and energy dissipation capacity, while maintaining structural integrity. This VE design proves to

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be successful in improving the performance of wood dampers not only in the short term, but it maintains its performance when investigated twenty years later. Furthermore, the evaluation of the steel damper confirms the durability of the viscoelastic material over time and its ability to withstand variable dynamic loading. Structures designed with viscoelastic dampers will not only have improved performance, but also decreased economic cost associated with maintaining these structures following seismic events.

3 TEST SPECIMENS

3.1 Polymer

This study utilized two specimens that were constructed and tested in 2000 and then tested again in 2021. The VE material used to construct these dampers was an ISD-111 VE polymer which was manufactured by 3M Corporation. It is important to note that this material is self-adhering. One damper, which will be referred to as "the wood damper", was constructed by adhering the VE material to a wood surface. The second damper, "the steel damper", had the VE material adhered to a steel surface. A double-lap configuration was used to create these dampers so they could resist load in pure shear when loaded axially.

3.2 Wood Damper

The wood damper was constructed by utilizing four-ply American Plywood Associated (APA) rated, 11.9 mm (15/32 in.) thick, plywood and Standard Spruce-Pine Fir (SPF) 50.8 mm by 101.6 mm (2 in. by 4 in.), to model the sheathing to stud connection. ISD-111 VE polymer with a thickness of 15.2 mm (0.6 in.) and a width of 50.8 mm (2 in.) was used to manufacture the wood damper and Grade 8 hex bolts were used opposite the VE material to fasten the damper to an A36 steel plate. Elevation and plan views of the wood damper can be seen in **Figure 1**.

Figure 1: *Wood Damper*

3.3 Steel Damper

The steel damper was created in a manner consistent to that of the wood damper. The specimen utilized 9.5 mm (0.375 in.) thick, A36 steel and ISD-111 VE polymer with a thickness of 5.08 mm (0.2 in.) and a width of 50.8 mm (2 in.). Adjacent to the viscoelastic material, this damper was also fastened using four Grade 8 hex bolts. An example of a steel damper in the testing machine is presented in **Figure 2**. For both specimens, after the VE material was self-adhered, it was compressed to 20% of its initial thickness for 24 hours to ensure complete bonding, as instructed by the manufacturer.

Figure 2: *Steel Damper in test machine.*

3.4 Specimen Modifications

The wood damper was modified, as described in the following section, to allow for attachment to the test apparatus as. Two 6.35 mm (0.25 in.) thick A36 steel plates were added to the SPF Stud and then a third A36 steel plate was placed in between to allow for the damper to be gripped by the test apparatus. The same modifications were made on the opposite side of the damper to the existing 9.5 mm (0.375 in.) A36 Steel Plate. These modifications did not impact the integrity of the specimen, nor alter the results in a way that would make them incomparable to the results collected in 2000.

4 EXPERIMENTAL SETUP AND PROCEDURE

4.1 Testing Apparatus

All the tests conducted on the two dampers were done by an MTS TestStar Materials Testing Workstation. This apparatus has two hydraulic wedge grips that can handle a maximum load of 24.9 tons. The bottom grip functions as the actuator, which is controlled by both the load unit control panel and a multi-tasked TestWare SX program. It is powered by the hydraulic power supply, which provides pressure to the servovalves that then regulate the flow of fluid between the hydraulic power supply and the actuator in a closed loop control mode. An image of the test apparatus that was used in 2000 can be seen in **Figure 3**. A similar test apparatus was utilized again in 2021 for testing consistency.

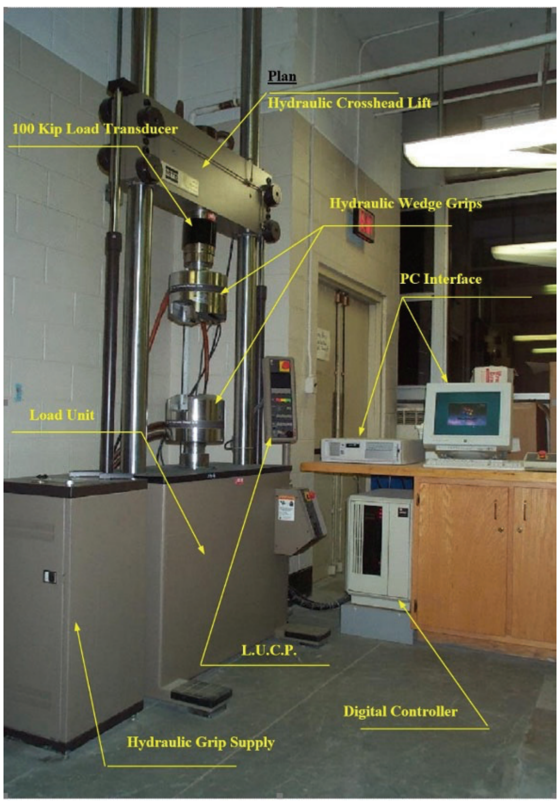

Figure 3: *MTS Workstation*

4.2 Displacement Protocol

The two dampers were subjected to 10 cycles under various frequencies and strains in 2000 and then retested in 2021 under similar frequencies and strains to evaluate their behavior and response. Temperature conditions for 2021 were chosen to ensure that the data would be comparable to the results obtained in 2000.

The wood damper was tested under the following conditions in both 2000 and 2021: 1.0 Hz at 10% strain, 0.5 Hz and 1.0 Hz at 20% strain, and 0.5 Hz at 80% strain. This produced four sets of data to be compared over time. The steel damper was tested at 1.0 Hz at 10% strain and 0.5 Hz at 80% strain in 2000 and then tested at the same strains and frequencies as the wood damper was in 2021. **Figure 4** shows the displacement protocol for the wood damper tested at 1.0Hz and 10% strain.

The tests were originally conducted at a temperature of 26.7°C, a condition that was recreated in 2021 to ensure testing consistency since the VE material is temperature dependent. Both specimens were removed from the testing apparatus between tests and allowed to rest for a predetermined time of thirty minutes to allow the damper to set before undergoing more testing, thus maintaining the integrity of each test's individual results.

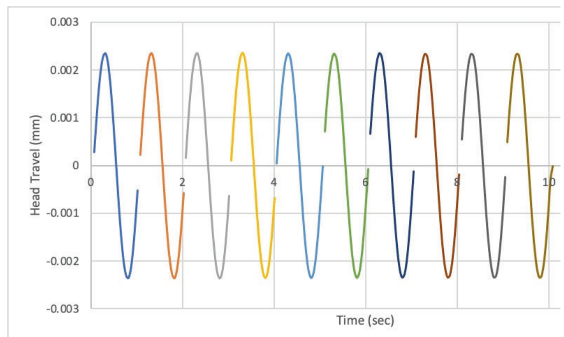

Figure 4: *Displacement versus time test input.*

5 EXPERIMENTAL RESULTS

The data collected from the tests were used to generate hysteresis loops, which display the cyclic response of the damper. **Figure 5** shows a hysteresis loop obtained for a single cycle.

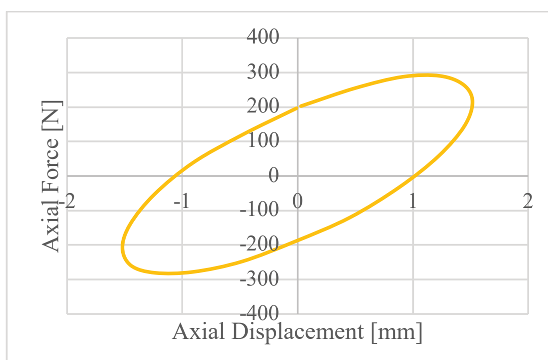

Figure 5: *Example hysteresis loop*

Hysteresis loops were created for each of the tests that were run on the dampers. The hysteresis loops produced from tests conducted at a frequency of 1.0Hz and 10%

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strain are shown for the wood and steel dampers in **Figures 6 and 7**, respectively.

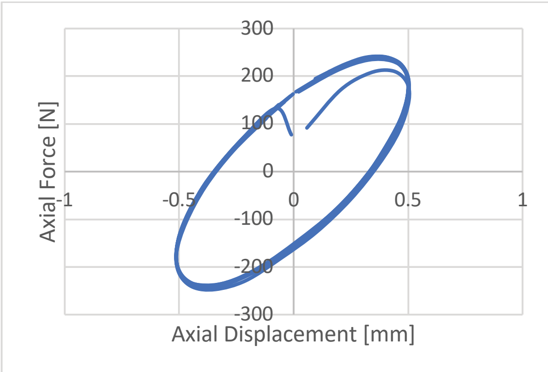

Figure 6: *Wood damper results from tests at a frequency of 1.0Hz and 10% strain*

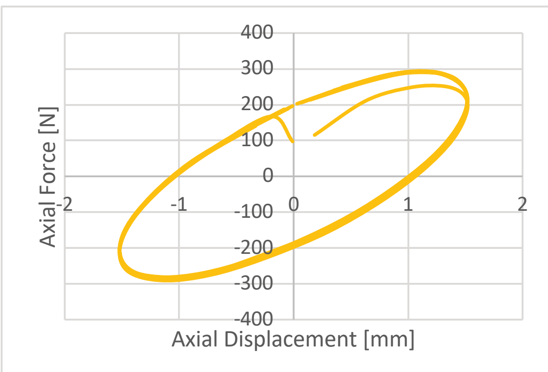

Figure 7: *Steel damper results from tests at a frequency of 1.0Hz and 10% strain*

The slope of the diagonal of the hysteresis loop is equal to the effective stiffness of that cycle. This was calculated using Equation (1):

$$K_{effective} = \frac{P_{x_o} - {}^{-}P_{x_o}}{x_o - {}^{-}x_o} \quad (1)$$

where P_{xo} = load correlating to the maximum displacement, $^{-}P_{xo}$ = load correlating to the minimum displacement, x_o = maximum displacement, and $^{-}x_o$ = minimum displacement.

The area bound by each of the hysteresis loops determines the energy dissipation of that cycle. This was determined utilizing Equation (2):

$$E_D = \pi \gamma_o^2 G'' A h \quad (2)$$

where γ_o = peak shear strain amplitude, G" = the loss modulus, A = shear area, and h = thickness of the VE material.

The hysteresis loops shown for the first cycle of the tests have lower values initially than the rest of the cycles which is the result of this being the initiation cycle for the test. At the completion of the final cycle, the hysteresis loop can be seen decreasing away from the other cycles', which is a result of the test ending and is not necessarily representative of a decrease in material performance. These trends were observed for all the tests conducted on the two dampers.

Average effective stiffness values were obtained for each of the tests conducted in 2000 and 2021 for the two dampers. The average effective stiffness was determined by calculating the mean effective stiffness over all ten cycles of a given test. The values obtained for the wood and steel dampers are shown in **Table 1** and **2**, respectively. A positive percent change value denotes an increase in the effective stiffness between the results obtained in 2000 and 2021.

Table 1: *Average Effective Stiffness (N/mm) for the Wood Damper*

Frequency	Strain	2000	2021	Percent Change
1.0 Hz	10%	115	141	22%
0.5 Hz	20%	93	105	13%
1.0 Hz	20%	119	133	12%
0.5 Hz	80%	81	92	14%

Table 2: *Average Effective Stiffness (N/mm) for the Steel Damper*

Frequency	Strain	2000	2021	Percent Change
1.0 Hz	10%	417	356	-15%
0.5 Hz	80%	283	240	-15%

The wood damper (**Table 1**) shows a relatively consistent increase in average effective stiffness from the tests conducted in 2000 to those conducted in 2021. The steel damper (**Table 2**) saw a 15% decrease in average effective stiffness for the two tests being compared.

The average energy dissipation capacity of the dampers was determined by calculating the area bound by the load-displacement ellipse using Equation (2) for each cycle and taking the mean over the ten cycles of each test. Average energy dissipation values for the wood and steel dampers from each of the tests conducted in 2000 and 2021 can be seen in **Table 3** and **4**, respectively.

Table 3: *Average Energy Dissipation (N-mm) for the Wood Damper*

Frequency	Strain	2000	2021	Percent Change
1.0 Hz	10%	746	786	5%
0.5 Hz	20%	2203	1919	-13%
1.0 Hz	20%	3141	2826	-10%
0.5 Hz	80%	30054	25137	-16%

Table 4: *Average Energy Dissipation (N-mm) for the Steel Damper*

Frequency	Strain	2000	2021	Percent Change
1.0 Hz	10%	316	114	-64%
0.5 Hz	80%	12685	10247	-19%

All the tests, with one exception, experienced a decrease in average energy dissipation from the results obtained in 2000 when retested in 2021. The exception to this trend was the wood damper when tested at a frequency of 1.0Hz and 10% strain, which saw a minor increase of 5%. The steel damper saw a decrease of 64% between 2000 and 2021 when tested at a frequency of 1.0Hz and 10% strain. This appreciable difference in performance is a byproduct of the low energy dissipation capacity of the steel damper under these testing conditions.

6 CONCLUSIONS

From these tests, the following conclusions can be drawn:
1. There was minimal change in the average effective stiffness of the two dampers over twenty years. The wood damper saw an average increase of approximately 15%, while the steel damper saw an average decrease of 15%.
2. The wood damper displayed consistent energy dissipation over time, only experiencing a decrease of about 10%, on average, when tested in 2021. Comparatively, the steel damper had minimal energy dissipation abilities when originally tested, which held true when the tests were conducted again in 2021.
3. The structural integrity of the two dampers held up well between tests and over time, with minimal damage observed between the two dampers.

The results from this research display the promise of using viscoelastic polymers more prominently in structural design of wood structures. These results show that there was no appreciable difference in performance between the steel and wood specimens. Based on this study, engineers can now investigate innovative applications of VE material in mid and high-rise wood frame structures without concern for the long-term effects of connecting VE material directly to wood. The next step in evaluating the performance of this material is to test it on a larger scale within a shear wall and compare the data to traditional shear walls.

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