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Seismic Performance of Tall Wood Buildings with Fluid Viscous Dampers

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ABSTRACT

In recent years there have been significant initiatives towards design and construction of tall buildings with wood. For this type of buildings, the low modulus of elasticity of wood makes it challenging to meet code-specified drift limits under significant lateral loads. One possibility is to use seismic response modification devices to dissipate energy as well as reduce lateral drifts during seismic events. This paper investigates feasibility of using Fluid Viscous Dampers in high-rise wood buildings. Numerical model of a tall wood building with braced frames is used to simulate performance of the structure under a range of ground motions. The results indicate adoption of the dampers can effectively reduce peak lateral deflections under seismic load. Some limitations and practical considerations are discussed.

Keywords: Tall Wood Buildings, Seismic Performance; Supplemental Damping, Fluid Viscous Dampers, Braced Frames.

INTRODUCTION

This paper investigates seismic performance of tall wood buildings and applicability of Fluid Viscous Dampers to improve performance. A virtual structure located in Vancouver, British Columbia is used for analysis. The structure is subjected to seismic ground motion representing local seismicity as well as near-field and long-period motions to examine behavior of the building.

FLUID VISCOUS DAMPER IN WOOD BUILDINGS

The viscous dampers were originally developed for military applications. After the end of cold war the technology was adopted in civilian purpose since the early 1990s and has been used in structures, including in many seismic applications [1].

The first attempt to apply fluid viscous dampers in wood buildings was initiated by Symans et al. [2-4]. The dampers were incorporated as part of braces with light timber frame wall models. The behavior of the system was studied numerically with a nonlinear finite element model. The results showed significant reduction in drift ratio due to inclusion of damper, compared to same arrangement without damper. In addition, significant energy dissipation was observed due to hysteretic behavior of the damper. The arrangement (Figure 1) does not apply any additional bending moment to the corner connections and allows the damper to be conveniently placed within the sheathing panels.

After the initial study, further numerical investigation was undertaken by Symans et al [5]. Detailed finite element model of wood shear wall was developed and used to predict hysteretic response of the arrangement. Shear walls with different arrangement compared to the earlier setup (Figure 2) were used in the study. In addition, time history analyses of full building models were performed. The results confirmed energy dissipation ability of fluid viscous dampers in both and thereby reduce inelastic strain energy demand on wood framing system. Some additional considerations such as practical issues with implementation of fluid viscous dampers in light woodframe buildings were also examined.

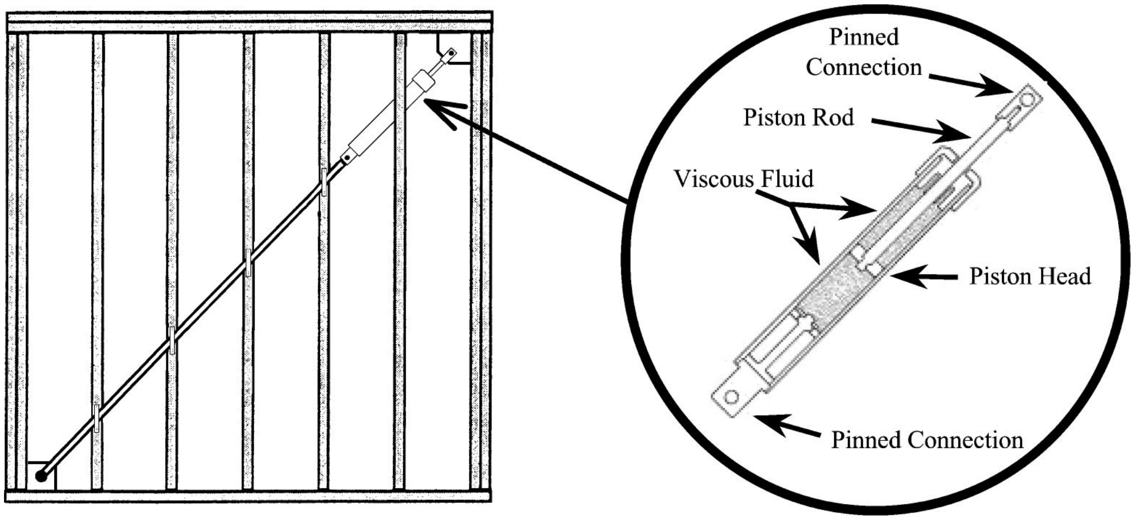

Figure 1. Light timber frame tested with viscous damper in diagonal [2]

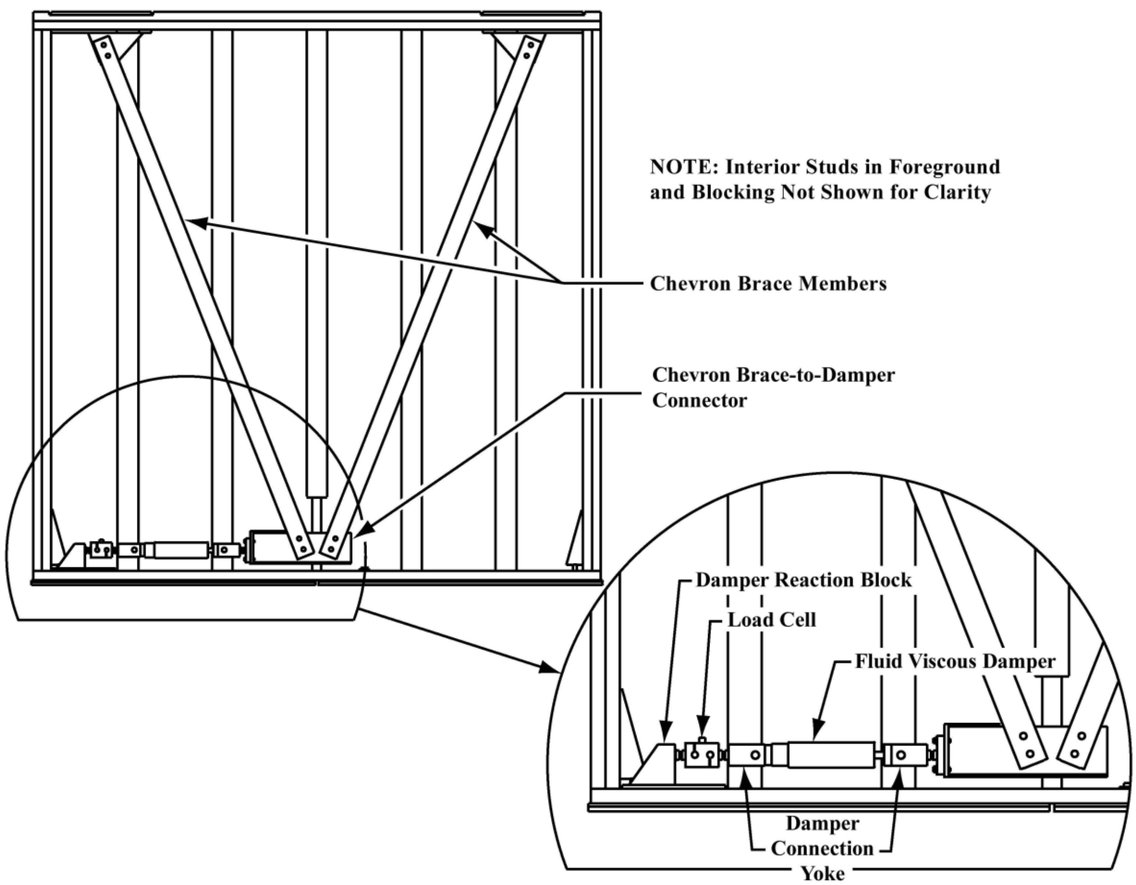

Figure 2. Viscous damper with chevron brace in light timber frame [5]

Following the earlier investigations van de Lindt et al. adopted fluid viscous dampers in their half-scale two-storied base-isolated building model (Figure 3) tested as part of NEESWood project [6-9]. Dampers were included within modular damper walls were also tested separately after they were retrofitted with toggle-braced dampers (Figure 4)

Figure 3. NEESWood building model and modular damper wall [6]

Figure 4. NEESWood model retrofitted wall and toggle-braced damper [6]

The dampers were implemented as part of Performance-Based Design Philosophy for mid-rise buildings. A direct displacement-based procedure [10-11] was developed to analyze and design buildings with such items included in consideration.

Figure 5. NEES-Soft model and toggle-braced dampers at first story [12]

Toggle-braced fluid viscous dampers were one of the retrofit options for the NEES-Soft project aimed at seismic performance improvement of soft-story wood buildings [12-16]. The project experimentally validated retrofit options for those type of buildings through series of shake table tests on a full-scale four-story wood building (Figure 5). Metal frames with dampers were fixed at the base and top of the first story to prevent soft-story mechanism and dissipate energy to minimize damage. Anchor plates were used to minimize slippage between the frames and wooden structural members. The added stiffness and energy dissipation properties of the dampers significantly altered displacement profile of the building, transferring more forces to the upper stories with higher capacities.

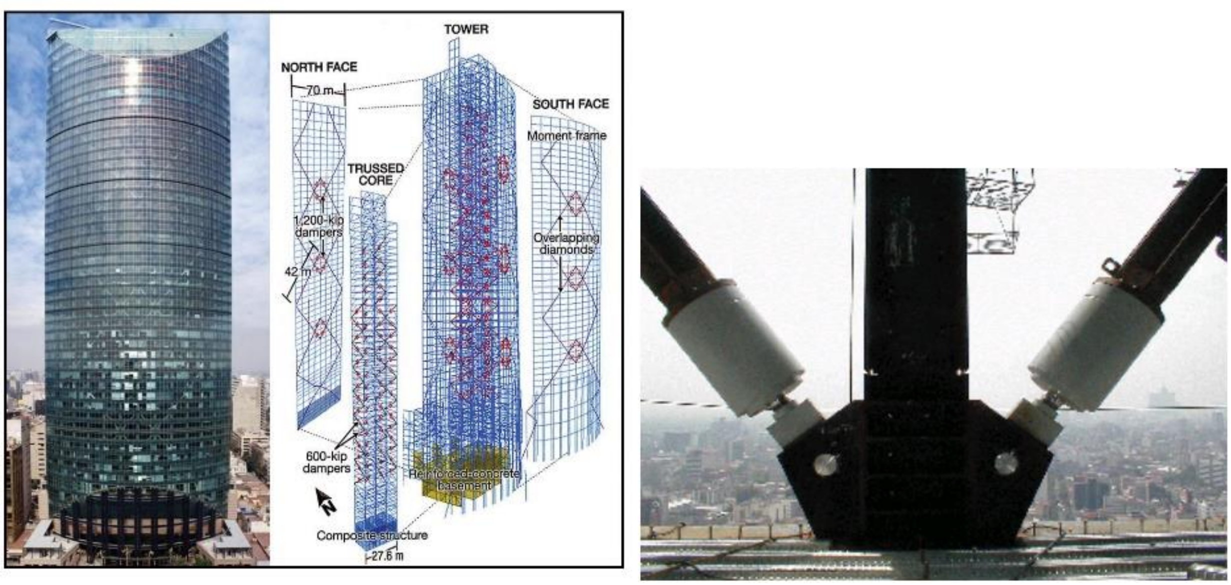

Figure 6. Torre Mayor structure and damper in bracing system [17]

Although applications of fluid viscous dampers in buildings have increased steadily since the 1990s and particularly over the last two decades, the number of tall buildings with them is still limited. One of the most prominent examples of fluid viscous dampers used as the primary means of seismic energy dissipation is the Torre Mayor, a 55-story steel building in Mexico City

(Figure 6), completed in 2002 [17-18]. It has since been through numerous earthquakes, including one in 2003 with a magnitude of 7.6, with no damage confirming effectiveness of the bracing system with fluid viscous dampers.

MODEL BUILDING: MJØSTÅRNET

For this study, a real tall wood building with braced frame is chosen as a model structure. Mjøstårnet is a 18-story, 83m tall building in Blumanddal, Norway (Figure 7). Construction completed in 2019 and it is currently world's tallest timber braced frame building [19-20]. The building is next to a lake and subject to high wind loading. It faced challenges in meeting code-specified drift limits, even with the braces. The building is chosen as a case study to evaluate feasibility of improving seismic performance by adding fluid viscous dampers to the braces. The virtual building is assumed to be located in Vancouver, British Columbia to apply appropriate seismic demands. Effectiveness is measured through observation of structural response with viscous damper in comparison to structure without any supplemental damping.

Figure 7. View of Mjøstårnet and building structure [21]

Viscous dampers are added to the bracing of structures as shown in Figure 8 to absorb the energy from the seismic load. In total, 20 dampers are used in X axis, 14 dampers are used in Y axis. The viscous damper damping coefficient is based on the product catalogue of damper manufacturer [22]. Rest of the structure in the model has been kept the same as the original structure.

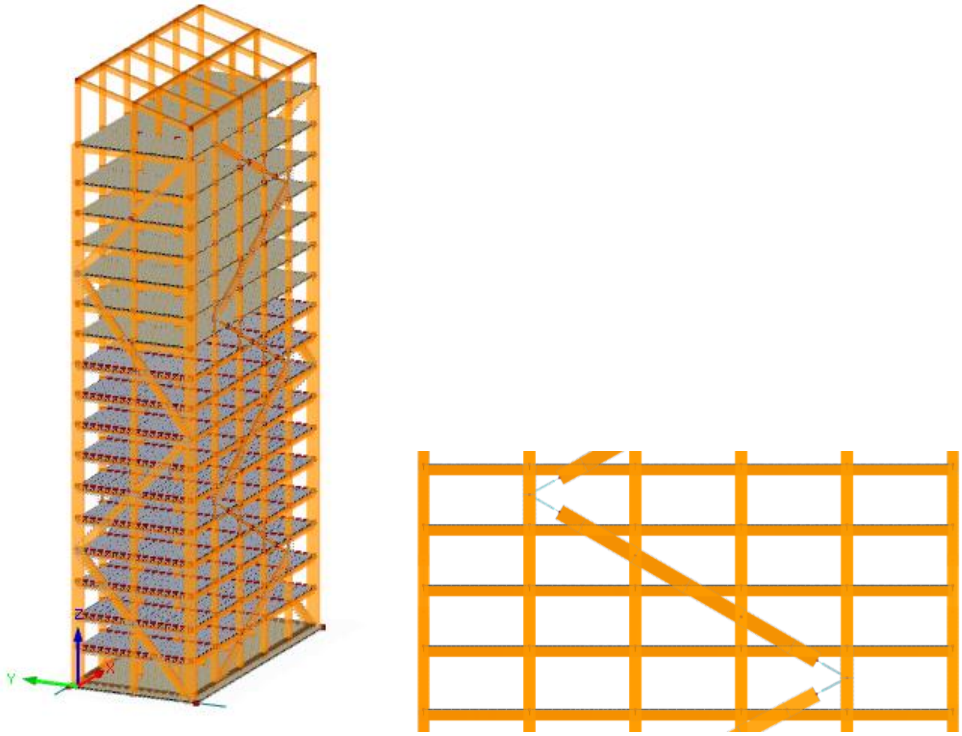

Figure 8. Building model with view of viscous dampers in bracing

The structure is modelled with finite element analysis software RFEM [23]. Wood structure can be easily modeled using the wood element in the RFEM database, which works for modeling requirement of the structure in consideration.

BUILDING ANALYSIS

Time history analysis of the add-on module RF-DYNAM pro in RFEM is used for dynamic wind load analysis and dynamic seismic load analysis. The damping ratio of wood structure used is 1.9%. Historical seismic acceleration data is collected from Strong-Motion Virtual Data Center [24] and GeoNet [25] and imported to RFEM acceleration analysis under time history analysis, RF-DYNAM pro.

Three earthquakes' acceleration data are chosen for seismic analysis. They are 2001 Nisqually earthquake, 1985 Mexico City earthquake and 2011 Christchurch earthquake. Details of the ground motions are presented in Table 1 below.

Table 1 Details of ground motions used.

Earthquake Name	Location, Country	Date	Magnitude (Mw)	PGA (g)
Nisqually	WA, USA	Feb 28, 2001	6.8	0.3
Christchurch	Christchurch, New Zealand	Feb 22, 2011	6.1	1.51
Mexico City	Mexico City, Mexico	Sep 19, 1985	8.0	0.15

2001 Nisqually earthquake is chosen because of its proximity to Vancouver, assumed site location. The Christchurch earthquake of 2011 has strong near field effect. The 1985 Mexico City earthquake is of special interest with the long-period motion due to soil condition at the location.

The three seismic acceleration records are used for the structure with and without viscous dampers to evaluate effectiveness of viscous dampers in reducing the lateral deflection under seismic loads. Maximum lateral deflections, maximum inter-story drifts and maximum base shear of one column are collected.

RESULTS AND DISCUSSION

As shown in the table below, with 100% of seismic acceleration applied to Y axis and 30% of seismic acceleration applied to X axis, the structure without any damper has a maximum deflection of 76.1 mm in Y direction and a maximum deflection of 16.6 mm in X direction. The deflection is reduced to 41.60 mm in Y with a 45.34% reduction efficiency. However, the deflection increased to 33.50 mm in X.

Table 2 Nisqually earthquake results

	Without Damper		With Damper	
	EW (X) Dir	NS (Y) Dir	EW (X) Dir	NS (Y) Dir
Displacement (mm)	16.6	76.1	33.5	41.6
Inter-Story Drift (mm)	1.3	6.3	3.1	3.9
Base Shear (kN)	17.1	54.6	42.7	102.8

The results showed that the viscous damper is helpful in reducing lateral deflection on the weak direction (Y direction) of the structure which is useful. Even though, the deflection in X direction increased, X direction is the strong direction of structure, and the deflection is quite small which does not have a significant effect on structure or occupants.

With 100% of seismic acceleration applied to Y axis and 30% of seismic acceleration applied to X axis, the structure without any damper has a maximum deflection of 141.10 mm in Y direction and a maximum deflection of 14.80 mm in X direction. The deflection increases to 200.40 mm in Y and the deflection increased to 27.80 mm in X. Furthermore, the base shear in both directions is amplified.

Table 3 Mexico City earthquake results

	Without Damper		With Damper	
	EW (X) Dir	NS (Y) Dir	EW (X) Dir	NS (Y) Dir
Displacement (mm)	14.8	141.1	27.8	200.4
Inter-tory Drift (mm)	1.3	12.6	2.7	17.7
Base Shear (kN)	15.9	103.2	34.0	388.7

As mentioned earlier, 1985 Mexico City earthquake is very special because the soil condition. The results showed that the viscous damper is not helpful in reducing lateral deflection in both directions for such special earthquake case. Thus, viscous damper is not recommended to be used on high-rise wood structure for such earthquake.

With 100% of seismic acceleration applied to Y axis and 30% of seismic acceleration applied to X axis, the structure without any damper has a maximum deflection of 271.50 mm in Y direction and a maximum deflection of 120.60 mm in X direction. The deflection is reduced to 234.10 mm in Y with a 13.78% reduction efficiency. The deflection is reduced to 68.60 mm in X with a 43.12% reduction efficiency. The base shear in both directions is amplified.

Table 4 Christchurch earthquake results

	Without Damper		With Damper	
	EW (X) Dir	NS (Y) Dir	EW (X) Dir	NS (Y) Dir
Displacement (mm)	120.6	271.5	68.6	234.1
Inter-Story Drift (mm)	11.0	32.3	6.5	29.7
Base Shear (kN)	100.7	530.2	115.8	1309.0

Christchurch earthquake is very strong earthquake with high acceleration because it is near the source. The results showed that the viscous damper is helpful in reducing lateral deflection in both directions for high-rise wood structure under strong near field ground motion.

CONCLUSIONS

Based on the result and discussion, fluid viscous dampers solution is effective in reducing deflection and inter-story drift. However, base shear increases with adoption of viscous dampers. Fluid viscous dampers are found helpful in reducing the deflection and inter-story drift when high-rise wood structure is under strong near field ground motion. When it experiences moderate acceleration, the maximum deflection might be very small, and the viscous damper doesn't have a significant performance. For long-period earthquake such as 1985 Mexico City, adoption viscous damper lead to amplification of response and higher drift values.

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