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# Experimental testing of damage-resistant rocking glulam walls with lead extrusion dampers

Daniela Wrzesniak [a,*], Geoffrey W. Rodgers [b], Massimo Fragiacomo [c], J. Geoffrey Chase [b]

[a] Am Bahnhof Westend 6, 14059 Berlin, Germany
[b] University of Canterbury, Private Bag 4800, 8140 Christchurch, New Zealand
[c] University of Sassari, Piazza Duomo 6, 07041 Alghero (SS), Italy

## HIGHLIGHTS

- We proof the potential for highly damage resistant wood frame working structures.
- We provide first information on the behaviour of HF2V dampers in timber structures.
- HF2V dampers represent a feasible solution for rocking timber structures.

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## ABSTRACT

When rocking structures are designed, dampers may be required to substitute conventional connections to provide load resistance and dissipate the rocking motion. This study investigates the applicability of High-Force-to-Volume (HF2V) damping devices in rocking timber structures. HF2V devices present an attractive solution since the device does not suffer stiffness or strength degradation and can be reused after an earthquake. Laboratory tests on loaded and unloaded timber walls using two HF2V devices per wall were carried out. The applicability of the devices in timber walls was investigated focusing on damper functioning, the influence of the vertical load on the self-centering behaviour of the dampers, and possible slip in all connections. The results show that the devices functioned as intended and no significant damage occurred in the devices or the timber walls. HF2V devices present a feasible solution for rocking timber walls when a damage free structural behaviour is aimed for.



## 1. Introduction

Recent earthquakes in Christchurch, New Zealand highlighted the need for a conceptual change in designing and detailing seismic resistant structures. More than 70% of the buildings in the central business district were demolished in the wake of the February 2011 earthquake, due to high repair costs making restoration unfeasible. Current design principles aim to save lives at the expense of structural damage. This sacrificial damage design approach has also been shown to incur high costs associated with damage and economic disruption in other earthquakes such as in Northridge (1994) and Kobe (1995). The objective of new design approaches is to minimise damage with no loss of life and therefore minimise the cost of repair and economic loss from business downtime.

The application of damping devices offer a possible solution. The feasibility and behaviour of various seismic protection systems in timber structures have been numerically and experimentally studied [21,3,23]. Some of these systems use passive base isolation to reduce the seismic demand, while other systems use natural rubber or sacrificial steel fuses, hysteresis or viscous damping devices. Passive base isolators are very common in steel and concrete structures and the additional costs are negligible in comparison to the repair cost for traditional fixed-base structure [8,19]. However, the application of passive base isolation is only possible when the design is governed by seismic actions and not by wind actions. Another option is the incorporation of hysteretic energy dissipation devices at selected positions of the building while designing the remaining connections as rigid [14,2].

A different approach is the rocking wall system first introduced by Ajrab [1] based on [9] investigation on free vibration of rocking blocks. In a rocking structure, the load reactions are entirely taken up by the connections. Thus, structural elements, designed to rock, remain elastic. In rocking systems the application of damping

* Corresponding author.
*E-mail address:* dani_wrz@yahoo.de (D. Wrzesniak).

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devices is essential to provide the required energy dissipation and avoid excessive displacement response.

Mild steel dampers attached externally to a rocking wall in combination with pre-stressed tendons [12,22] or flexural U-shaped steel plates positioned between two adjacent timber walls together with hysteresis or viscous damping devices and pre-stressed tendons [20], represent possible solutions. Major drawbacks of these damping systems are the dissipation of energy through irreversible yielding of the steel parts. Yielding means these elements must be replaced after an earthquake, which may be difficult due to their position within the structure and also can reduce the energy dissipation delivered on subsequent cycles after initial yielding.

A new type of damper has been developed at the University of Canterbury, New Zealand (Rodgers et al. 2006). These devices dissipate significant energy, but can fit into small architectural spaces. They offer a damage-free and thus repeatable form of energy dissipation. This dissipator was tested in rocking beam-column moment connections made of reinforced concrete elements [17] and steel members [11], showing promising behaviour. This paper investigates the use of these devices in solid cantilevered timber walls. More specifically in the wall-foundation connection.

Cantilevered timber walls are a possible solution to brace low and medium rise residential and office buildings. Laminated veneer lumber (LVL) [4], glue-laminated heavy frames sheathed with LVL [13], cross-laminated panels [5], and glue-laminated deep members arranged vertically [25] can be used for the walls. The connection between the wall and the foundation is subjected to high bending moment, particularly when few walls are used like in open space buildings. This connection must be stiff to control interstory drifts and, in seismic region, dissipative to ensure satisfactory performance at ultimate limit state. Therefore, the use of innovative dampers is of great interest as a possible solution for the issues related with the design of the wall-foundation connection.

## 2. High Force to Volume viscous dampers

High-Force-to-Volume (HF2V) damping devices dissipate energy by a reversible plastic extrusion of lead. The recrystallization temperature of lead is approximately −25 °C, so the lead working material dynamically recovers during the extrusion process. This unique rheological property of lead means that the device exhibits no change in strength or stiffness under cyclic loading. A cross-sectional schematic view and a photograph of the device used in this research is presented in Fig. 1, along with the corresponding hysteresis loop in Fig. 2.

The damper can be mounted within a beam-column connection or between a wall and a foundation. Due to the plastic deformation of the lead, HF2V dampers can absorb a larger amount of energy in an extremely small package [16]. In contrast to conventional viscous dampers, HF2V devices have a low velocity dependency, which means that the damping force exhibited does not vary significantly under different ground motions.

This aspect makes them applicable for earthquakes with both near and far field effects. Based on [15] the damper force can be calculated as:

$$F_d = C_\alpha \cdot \upsilon^{0.11} \quad (1)$$

where $F_d$ = damping force, $C_\alpha$ = damping coefficient, $\upsilon$ = velocity. The velocity exponent of 0.11 is derived from experimental testing of these devices. The damping coefficient of the devices used for testing was $C_\alpha$ = 167 kN mm/s.

The cost of device varies based on their size. However, the cost is in the range of US$500–1000 per device, which is broadly comparable to the cost of sacrificial steel fuse components and sub-

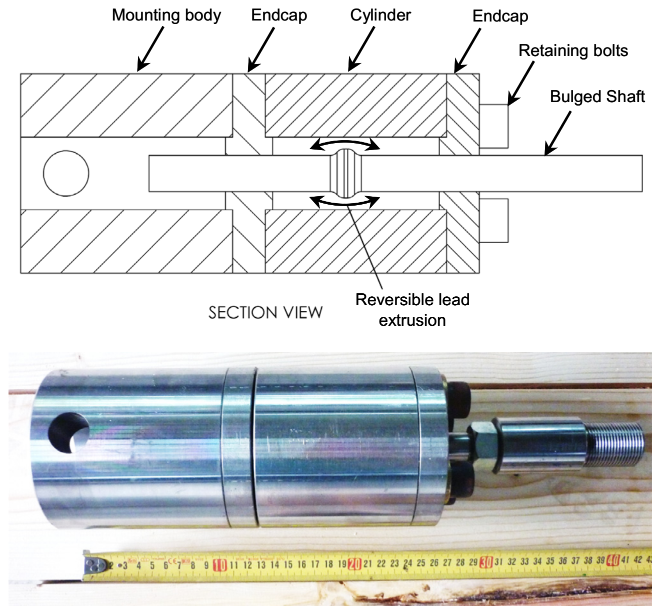


**Fig. 1.** Damping device used for experimental tests.

stantially cheaper than typical commercial viscous dampers. Recently, 96 HF2V devices were built into a new hospital complex in Christchurch, New Zealand [10] with the total costs of the dampers being approximately equal to 0.25% of the overall building cost. Considering the cost for repair or possible demolition due to an earthquake, this is a relatively low investment.

Reversed cyclic tests on steel and concrete structures using HF2V devices achieved high, repeatable and stable energy dissipation without damage at drift amplitudes up to 4% [18]. However, the HF2V dampers are not self-centring. Thus, the devices do not return to their neutral position after an earthquake. Consequently, a restoring force or mass is needed to achieve self-centring. Furthermore, a minimum uplift of 5 mm is required to obtain high forces from the devices. Although minor shear forces can be accommodated by the damper shaft, the devices work mainly in compression and tension. To limit shear forces acting on the damper shaft, additional elements are required to provide shear resistance.

These damping devices have so far only been implemented in steel and concrete structures. Timber, due to its anisotropy and its light weight, behaves significantly different than these other materials. Currently, no information exists, experimental or analytical, on the interaction between HF2V damping devices and timber elements. To achieve an overall damage-resistant design methodology, careful attention must be given to the development of concentrated point loads from rocking reactions and damping/energy dissipation elements to avoid crushing or localised damage in the timber walls.

## 3. Quasi static laboratory tests on timber walls with HF2V devices

Experimental tests were carried out on a glulam timber wall with HF2V damping devices. The aims were to: (i) study the magnitude of the damper response in relation to the horizontal wall displacement; (ii) gain information on the magnitude of prestressing force or vertical load necessary to achieve re-centring of the wall; and (iii) investigate the applicability of the selected connecting solution between damper and wall. One test with vertical loading and one test without vertical loading were conducted at the