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EXPERIMENTAL INVESTIGATION OF HIGH-FORCE-TO-VOLUME EXTRUSION DAMPER SUBJECTED TO CYCLIC AND TIME HISTORY LOADING

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KEY WORDS: High force to volume, Damper, Cyclic load, Time history load

ABSTRACT:

The ability of energy dissipation from earthquake force in a controlled and iterative manner will play a vital role in maintaining structural reliability for various forces. High force-to-volume (HF2V) extrusion damper is a promising technology with simple designs, high damping force and achieving design requirements. This paper develops HF2V extrusion damper with multiple toothing configuration for seismic application. The experimental verification has been undertaken on lead extrusion dampers with various frequency range of 0.5 to 2 Hz. The maximum load-carrying capacity is 10.48 kN with strokes up to 5mm are observed with hysteresis loop with some recentering capability has a stiffness value up to 2*106 N/m, and force levels up to 2-10 kN. The maximum load carrying capacity for time history loading for Northridge earthquake is 11.57 kN. The overall findings suggest that silicone sealant may be employed to build and characterize extrusion dampers with maximum energy dissipation and high force/volume interactions. The suggested device may be a potentially effective way to provide additional energy dissipation to structures in seismic zones, according to the mechanical characteristics to the frequency. Additionally, the system can withstand for earthquake time histories, and ensuring maintenance-free operation even in the midst of frequent ground vibration.

1. INTRODUCTION

Seismic, wind and impact loads can cause significant structural damage, particularly beam column joint configuration and beam column connections. According to Barroso (2003), the smart extrusion device can considered as alternative to provide high force -to-volume extrusion damper with multiple toothing configuration for steel and RC frames. During seismic and wind loads the structure will damage, to resist damage these energy dissipation through dampers which can be easily repairable and cost effective (Barroso, 2003), (Chase, 2006), (Housner, 1997), So many technologies have been developed for response reduction of structural elements under seismic, wind and impact loads but many devices are large size, no proper fixtures, complicated designs, need skilled labor to install, improper load transfer etc. are occurred. The advancement of active, passive, semi-active and hybrid structural technologies has received noteworthy consideration in the recent scenarios and has been exposed to produce substantial reductions in seismic response. These control systems have numerous drawbacks when compared to each system (Cousins, 1993), (Robinson 1982). Though semi-active systems do not need more power supply of fully active systems, they still involve difficulty in detecting response and executing the preferred control law. The passive control system is economical with easy manufacturing and quick installation. Some passive system involves daily maintenance. Silicon extrusion damper was developed and currently used for energy absorption. They are one of the best structural control systems for structural designers. Previously lead extrusion damper is used with low internal pressure, but the silicon extrusion damper is very small with stable internal pressure with a lot of applications and considered for many structural applications (Robinson, 1995) (Pekcan, 1999).

The current technology a tight volume of silicon with a toothing extrusion damper can provide a load-carrying capacity and dissipate energy. The high force to volume multiple extrusion damper application is broader in the vibration control scenario. This can be attached with bridges, beam-column joints, precast beam-column joints which help to reduce damages in joints and in structure (Rodgers, 2006), (Chanchí, 2011), (Mander, 2009). The extrusion damper can be placed in both RC and steel frame with non-linear velocity-dependent elasto plastic hysteretic

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behavior enclosed with deformation and load constraints. Many researchers studied this device with extrusion and intrusion to have a response reduction during analysis using various ground acceleration.
This paper investigates the experimental testing and development of high force-to-volume dampers with multiple toothing configurations. Distinctive device design is also shown to enable non-symmetric hysteretic behavior that maximizes energy absorption but minimizes residual drift (Rodger, 2007), (Rodger, 2009), (Rodgers, 2012).

The HF2V dampers has a compact design with increased damping capacity based on the density of material or the extrusion size. This device has enhanced stability and control to absorb energy and dissipate it, this will reduce the displacement and duration of vibration. This device generates large forces in quick response time (Rodgers, 2018). The objective of this paper is to provide an experimental investigation into the efficiency and execution of high force-to-volume multiple extrusion dampers. It also presents possible future consideration for innovative design with re-centering.

2. MATERIAL AND METHODS

2.1 Silicon Sealant

Silicone adhesive is a commonly utilized substance in home improvement industries. It is famous for its robust and pliable, characteristics, making it suitable for filling in connections in areas that are exposed to moisture or extreme temperatures. Some frequent applications of silicone adhesive include securing around bathtubs, basins, and shower enclosures, as well as for adhering glass, metal, and plastic surfaces. Silicone adhesive is usually produced from silicone polymer, a synthetic material that is impervious to water, heat, and UV radiation. Silicone adhesive can be used in a broad range of temperatures, from extremely cold to very hot, without compromising its bonding power. Based on the manufacturer direction 24 hours were allowed to the adhesive to cure (or harden) prior to testing. In the home renovation sector, silicone adhesive is frequently used. It is renowned for being strong and malleable, making it ideal for sealing connections in places that are subject to dampness or extremely high or low temperatures. The synthetic substance silicone polymer, which is resistant to heat, water, and UV rays, is typically used to make silicone adhesive. Extremely cold to extremely high temperatures are no match for silicone adhesive's ability to adhere materials together. Prior to testing, the glue was given 24 hours to cure (or harden) in accordance with the manufacturer's instructions. The figure 1 shows the silicone sealant filled cylinder after the testing.



Figure 1. Sealant filled with cylinder

2.2 High–Force–to–Volume Devices (HF2V)

High-force-to-volume (HF2V) devices are made up of a cylinder, two end caps, and a shaft with four poles on it. Pre-stress forces of 5–10 kN are applied to the end caps to restrict the silicon sealant that is cast in the area between the cylinder and the shaft. Dr. Fixit silicone sealant was used for the study. The sealant normally used for sealing the joints of ducts. The sealants available in clear, white and black colors. The solvent will be always ready to use. The silicon sealant will be durable and elastic in 2 hours. The silicon sealant has a less shrinkage properties. When the shaft is moving relative to the cylinder, the energy dissipation mechanism relies on compressing the silicon sealant via the gap between the bulge and the cylinder. As per the design requirement, the silicone material and 4 piston pole will generate 10 kN damping force. HF2V devices' hysteresis loops can be characterised as almost square (Abdeli Bisafar & Manafpour, 2022). Figure 2 shows the schematic representation of HF2V damper. Figure 3 shows the components of an HF2V device with constricted shaft. HF2V devices are less maintenance and small in size.

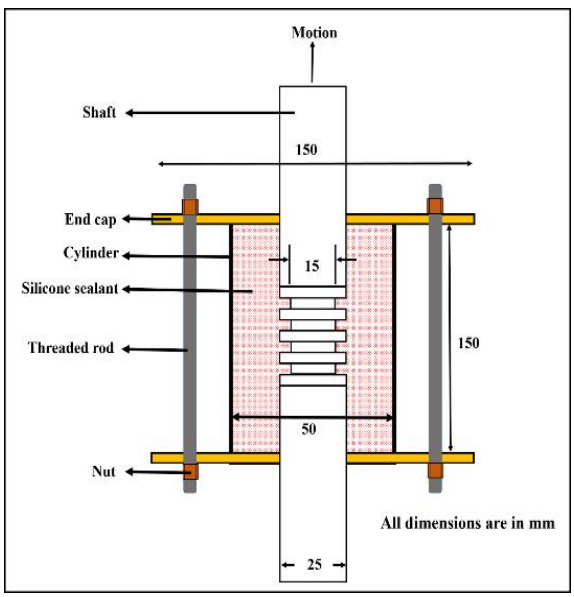


Figure 2. Schematic representation of HF2V Damper with toothing configuration

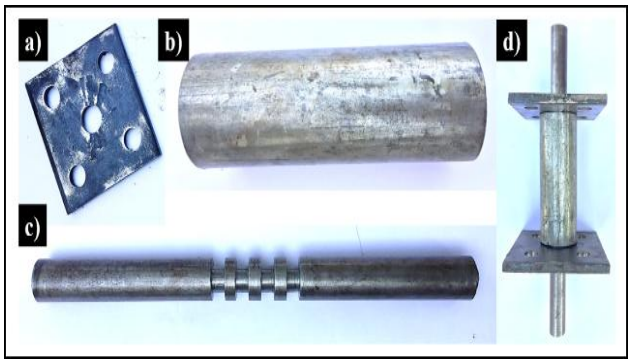


Figure 3. Fabricated parts of HF2V Damper with toothing configuration a) End cap b) Cylinder c) shaft d) HF2V damper

3. EXPERIMENTAL METHODS

3.1 Cyclic Loading

The HF2V device with constricted shaft configurations were designed and fabricated. Devices were assembled using shaft diameters of 25mm and internal cylinder diameters of 50mm. Constricted configurations were built by respectively reducing the shaft diameter by 5mm in the machining. The piston has a stroke length of 25mm. Testing was carried out on a MTS fatigue testing machine of 1000 kN actuator. Devices were subjected to a cyclic loading with amplitude of 5mm and frequency range from 0.5 Hz to 2 Hz. Fig. 4 presents testing setup and typical displacement regime applied at each frequency level. The difference of damping force in cyclic load test is 2.5-2.8 kN, approximately. Two cycles for each frequency with 5mm amplitude were applied.



Figure 4. Experimental setup for cyclic load test and time history test

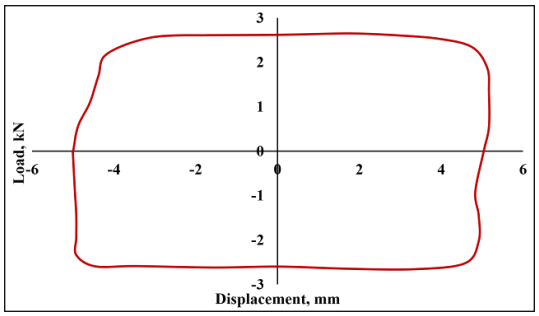


Figure 5. Load vs. Displacement of Frequency – 0.5 Hz

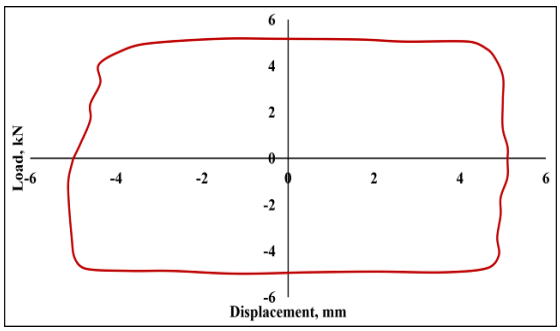


Figure 6. Load vs. Displacement of Frequency – 1 Hz

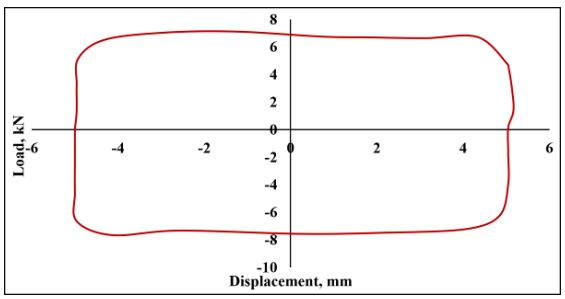


Figure 7. Load vs. Displacement of Frequency – 1.5 Hz

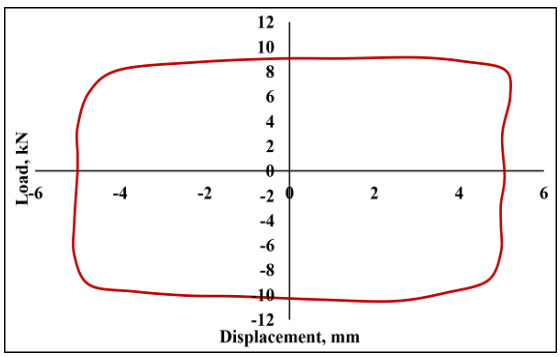


Figure 8. Load vs. Displacement of Frequency – 2 Hz

Figure 5-8 depicts the force-displacement behaviour of the HF2V prototype as shown in a fully reversed cycle with a maximum deflection of 5mm. When working material's breakaway friction resistance is exceeded, the entire damper first exhibits an elastic deflection before eventually engaging in sliding of the shaft relative to the silicone core.

The maximum load carrying capacity of HF2V device during cyclic loading is tabulated in table 1.

Frequency, Hz	Amplitude, mm	No of cycles	Maximum load, kN	Difference in load, kN	% increase in damping force with respect to 0.5 Hz
0.5	5	2	2.66	-	
1	5	2	5.16	2.5	93.98
1.5	5	2	7.65	2.49	187.59
2	5	2	10.48	2.83	293.23

Table 1. Maximum Load carrying capacity of HF2V

3.2 Time history loading test for HF2V

Elcentro and Northridge history loading is used to experimentally investigate the HF2V performance and behaviour. Utilizing a 100 Tonne Universal Testing Machine (UTM) from Material Testing System (MTS), the experiment is conducted. To carry out experiments, the ground acceleration of time history is transformed to displacement.

Figure 9 displays the input displacement of two-time histories. Due to strain hardening, the pinching effect developed in the zero-force zone; due to an increase in rapid displacement in the time history, the hardening effect developed in the maximum force region.

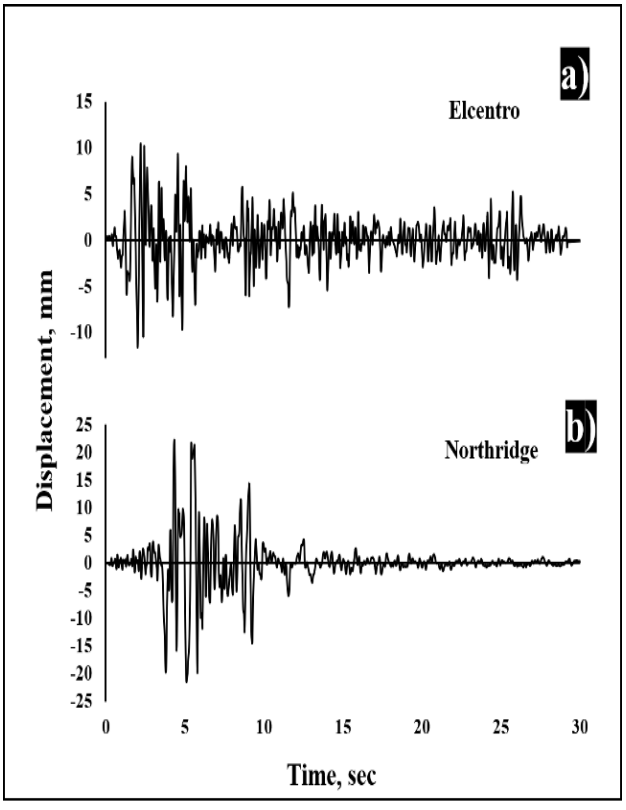


Figure 9. Input time history

Figure 10 depicted the load carrying capacity during two-time histories test. When the Northridge time history is employed, the HF2V damper produces the maximum damping force of 11.57 kN. The maximum damping force for Elcentro is 11.04 kN. The HF2V met the design specifications.

Table 2 shows the maximum load carrying capacity for two time histories recorded.

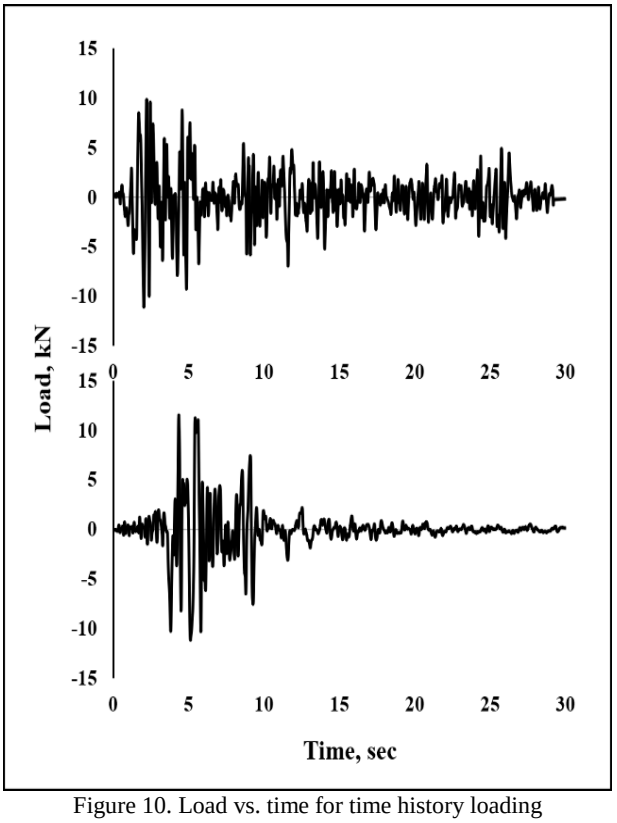


Figure 10. Load vs. time for time history loading

Earthquake	Maximum input displacement, mm	Maximum load, kN
Elcentro	11	11.04
Northridge	22	11.57

Table 2. Results of HF2V damper subjected to time history loading

4. DISCUSSION

The damping force generated by HF2V damper generates10.48 kN at 2Hz for an amplitude of 5 mm is observed in cyclic load test. The square shape behaviour observed in the hysteresis loop. After the experiments, the silicone material is slightly damages, in real time application, it will be better if the whole silicone material is replaced after the earthquake is over. The rheological and hysteretic behaviour of potential working materials must be carefully considered when choosing materials for the design of such devices. 11.57 kN is the maximum load for Northridge earthquake.

5. CONCLUSION

The 10 kN designed HF2V damper investigated experimentally using cyclic load test for various frequency range from 0.5 Hz to 2 Hz. Less compressive residual stress is provided by the silicon material. The outcome in the hysteresis loop is more "square" and excellent. The damping system generates more resistive forces and dissipates more energy.

The maximum load of 10.48 kN at 2Hz for an amplitude of 5 mm is observed in cyclic load test. After the experiments, the silicone material is slightly damages, in real time application, it will be better if the whole silicone material is replaced after the earthquake is over. A novel model of the device process is also offered as a result of this finding. The compact high force/volume dampers that are now being shown are a significant first step towards a wide range of innovative applications, notably in structural connections, and increased structural robustness. During the design phase, a restricted shaft with four poles was offered. The potential for further structural applications, such as reducing residual drift, is demonstrated by the extension of this technique to produce dampers with recentering capabilities.

The rheological and hysteretic behaviour of potential working materials must be carefully considered when choosing materials for the design of such devices. 11.57 kN is the maximum load bearing capability throughout time in studying the two times histories namely Elcentro and Northridge.

Two important requirements—robustness and stability—are met by the damper, demonstrating its capacity to do so. It is a viable technology for the construction of long-lasting structural solutions because of its mechanical behaviour and maintenance-free operation even in the face of repeating excitations occurring quickly, as may happen, for example, in the occurrence of aftershock sequences.

The damper's major shortcoming is its inability to revive the structure's recentering capabilities following a seismic event. In future, the potential for coupling the HF2V with a spring system will be investigated to increase more damping force.

References

Barroso, L.R., Chase, J.G. and Hunt, S., 2003. Resettable smart dampers for multi-level seismic hazard mitigation of steel moment frames. *Journal of Structural Control*, 10(1), pp.41-58.

Chase, J.G., Mulligan, K.J., Gue, A., Alnot, T., Rodgers, G., Mander, J.B., Elliott, R., Deam, B., Cleeve, L. and Heaton, D., 2006. Re-shaping hysteretic behaviour using semi-active resettable device dampers. *Engineering Structures*, 28(10), pp.1418-1429.

Housner et al., 1997. Structural Control: Past, Present, and Future. Journal of Engineering Mechanics September 1997, pp 897-971. Pearsons, C. E. & Parkins, R. N., The Extrusion of Metals. pp. 201-221, 1960.

Cousins, W. J. & Porritt, T. E., 1993. Improvements to lead-extrusion damper technology. Bulletin of the New Zealand National Society for Earthquake Engineering, vol. 26, pp. 342-348.

Robinson W. H., Lead-Rubber Hysteretic Bearings Suitable For Protecting Structures during Earthquakes. Earthquake Engineering and Structural Dynamics, vol. 10, pp. 593- 604, 1982.

Robinson W. H., Recent research and applications of seismic isolation in New Zealand. Bulletin of the New Zealand National Society for Earthquake Engineering, vol. 28, pp. 253-264, 1995.

Pekcan G., Mander J. B., & Chen S. S., Fundamental Considerations for The Design of Non-linear Viscous Dampers. Earthquake Engineering and Structural Dynamics, vol. 28, pp. 1405-1425, 1999.

Rodgers, GW, Leach, N, Denmead, C, Chase, JG, & Mander, JB. Spectral evaluation of high force-volume lead dampers for structural response reductions. Proc. New Zealand Society for Earthquake Engineering Annual Conference, Napier, New Zealand, March 10-12, 2006.

Chanchí, J. C., MacRae, G.A., Chase, J.G., Rodgers, G.W., and Clifton, G.C. (2011). Behaviour of HF2V devices and possible applications on steel structures. STESSA 2012, Santiago de Chile, Chile.

Mander T.J., Rodgers G.W., Chase J.G., Mander J.B., MacRae G. A. & Dhakal R. (2009). A Damage Avoidance Design Steel Beam-Column Moment Connection Using High-Force-To-Volume Dissipators. American Society of Civil Engineering – Journal of Structural Engineering. Vol. 135 (11), pp 1390 – 1397.

Rodgers, G.W., Chase, J.G., Mander, J.B., Leach, N. C., and Denmead, C.S. (2007). Experimental Development, Tradeoff Analysis and Design Implementation of High Force- To Volume Damping Technology. Bulletin of the New Zealand Society for Earthquake Engineering. Vol.40 (2), pp. 35 – 48.

Rodgers, G. W. (2009). Next Generation Structural Technologies: Implementing High Force-to-Volume Energy Absorbers. PhD Thesis, Dept. of Mechanical Engineering, University of Canterbury, Christchurch, New Zealand.

Rodgers, G.W., Solberg, K.M., Mander, J.B., Chase, J.G., Bradley, B.A., and Dhakal, R.P. (2012). High-Force-to-Volume Seismic Dissipators Embedded in a Jointed Pre-Cast Concrete.

Rodgers, G. W., Mander, J. B., & Chase, J. G. (2018, June). Precision design modelling of HF2V devices. In Structures. Vol. 14, pp. 243-250.

Abdeli Bisafar, M., & Manafpour, A. (2022). Development and experimental validation of a new self-centering HF2V

damper with disc springs. Bulletin of Earthquake Engineering, Vol. 20 (13), pp .7417-7440.