16th World Conference on Earthquake Engineering, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 2419

Registration Code: S-C1464504907

DETERMINATION OF THE CHARACTERISTICS OF A NEW PRESTRESSED LEAD EXTRUSION DAMPER

C. Soydan(1), E. Yüksel(2), E.İrtem(3)

(1) Research Assistant, PhD, Namık Kemal University, csoydan@nku.edu.tr
(2) Associate Professor, Istanbul Technical University, yukselerc@itu.edu.tr
(3) Professor, Balıkesir University, eirtem@balikesir.edu.tr

Abstract

The energy released by an earthquake transforms into other forms of energies through the structural system i.e. recoverable and irrecoverable energies. The supplemental damping that is provided to a structural system via supplementary damping devices increases the irrecoverable energy extent so the displacement and acceleration demands of the structure decreases.

There are different types of devices which are utilizing in the diverse energy dissipating mechanisms. Lead extrusion damper (LED) is a passive energy dissipater utilizing the hysteretic energy dissipation properties of lead alloys. The LED developed in this study has not including lubricant layer and hydraulic seals. By means of its innovative design, the cap is employed to provide pre-stressing on lead core. The design aimed low-cost and more durable LEDs.

Force-displacement behavior of the new LED which owns pre-stressing on the lead core was obtained for sinusoidal displacement cycles with altered frequency and amplitude targets. The effects of frequency and amplitude of the excitation on the dissipated energy (E_D) and equivalent damping ratio (ξ_{eq}) are investigated within the existing laboratory circumstances.

The energy dissipation increases with the ascending displacement amplitudes and remains almost constant with a certain range of frequency that is adopted through the experimental program. The equivalent damping ratio is obtained as 58% on average where the minimum and maximum values are calculated as 53% and 62%, respectively.

Keywords: Energy dissipation; lead extrusion damper; force-displacement relationship.

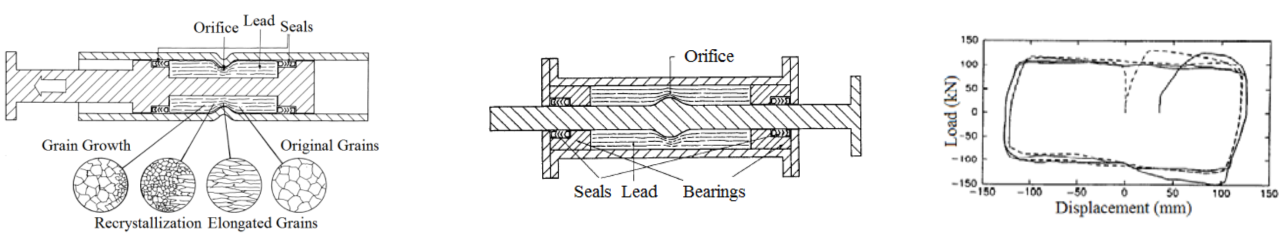
1. Introduction

Passive energy dissipation devices absorb and dissipate a significant portion of the energy imparted to a building by earthquake shaking. Energy dissipation devices are installed in a building to absorb the released energy as kinetic or strain energy [1]. The displacement and acceleration responses, and story shears can be significantly reduced with additional damping that will be provided in structures. The damage can be concentrated on the supplemental dampers which are easier to substitute with the new ones than to repair or strengthen the structural elements [2].

The LED studied here is a passive energy dissipation device. The energy dissipation is realized with the extrusion process of lead. The LED is designed excluding lubricant layer and hydraulic seals. Moreover, pre-stressing on lead is provided with the assembly of cap. Pre-stressing process allows to minimize the voids which occur during casting of lead into the LED. The voids may cause having low yield force with relatively unstable hysteresis loops. A low-cost and more durable LED excluding the risk of lubricant leakage is presented with the current design. The force-displacement relationships are obtained in the displacement controlled dynamic tests within a limited frequency and amplitude range by means of the specially designed loading frame existing in the Structural and Earthquake Engineering Laboratory (STEELab). The effects of considered frequency and displacement variables on the energy dissipation and damping characteristics of the LED are investigated.

2. Lead Extrusion Dampers

A material is forced through a hole or an orifice during the extrusion process, shape of the material is altered [2]. The pressure applied to the ram extrudes lead and it is produced a microstructure of elongated grains containing many crystal lattice defects. A proportion of the energy required to extrude the lead appears immediately as heat. On the other hand, some of the energy is stored in the deformed lead and it is the primary driving force for three interrelated processes which are called recovery, recrystallization and gain growth. These processes tend to restore the lead to its original condition [3, 4] (Fig. 1).



(a) (b) (c)

Fig. 1 – LED; (a) Constricted tube LED design [5] (b) Bulged shaft LED design [6] (c) Hysteresis loops [7]

The LED consists of a thick-walled tube having an assembly, on either side of which two pistons are connected by a tie rod. The space between the pistons is filled with lead. A thin layer of lubricant separates the lead from the cylinder wall. The layer of lubricant is kept in place by hydraulic seals which are located around the pistons. One of the pistons extends beyond the cylinder and is fixed to a structural element, while the opposite end of the tube is fixed to another structural element. When the structural elements oscillate relative to each other the lead is extruded back and forth through the orifice [5].

LEDs were first suggested by Robinson as a passive energy dissipation device for base isolated structures in New Zealand [8]. Fig. 1a and Fig. 1b presents two devices introduced by Robinson [5, 6]. The first device consists of a thick-walled tube with a construction and co-axial shaft with a piston (Fig. 1.a). The difference is the formation of extrusion orifice in the second device. The orifice is created by a bulge which is constructed on the central shaft. The shaft is supported by bearings which also serve to hold the lead in place (Fig 1.b). The hysteretic behaviour of LEDs is essentially rectangular (Fig. 1.c) [2].

3. Experimental Study

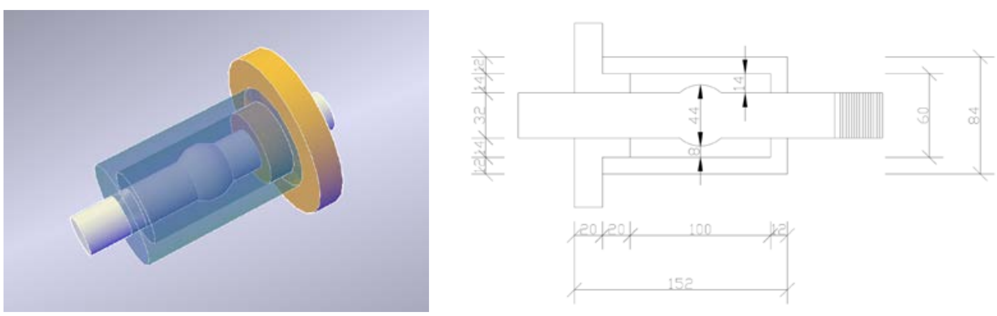
Loading frame, adaptor elements and out-of-plane retainers were designed originally in the testing set-up. The loading frame (black frame in Fig. 2a) was fixed into an existing frame (yellow frame in Fig. 2a). A servo controlled DARTEC hydraulic actuator was used in the testing system (Fig. 2).

(a) General view of the testing system (b) LED and measuring system

Fig. 2 – Experimental set-up

3.1 LED

Bulged-shaft type LED design is adopted in this study (Fig. 3a). LED comprises bulged shaft, tube and cap. The void between those parts is filled by lead alloy. Diameters of the shaft and the bulge are 32 mm and 44 mm, respectively. Inner diameter of the tube which has a 12 mm thickness is 60 mm. Gap between the bulge and the tube is 8 mm (Fig. 3b). Displacement capacity of the LED is ±33 mm. Pre-stressing was applied through the assembly of the cap. The average axial strain on the lead was calculated as 0.015.



(a) (b)

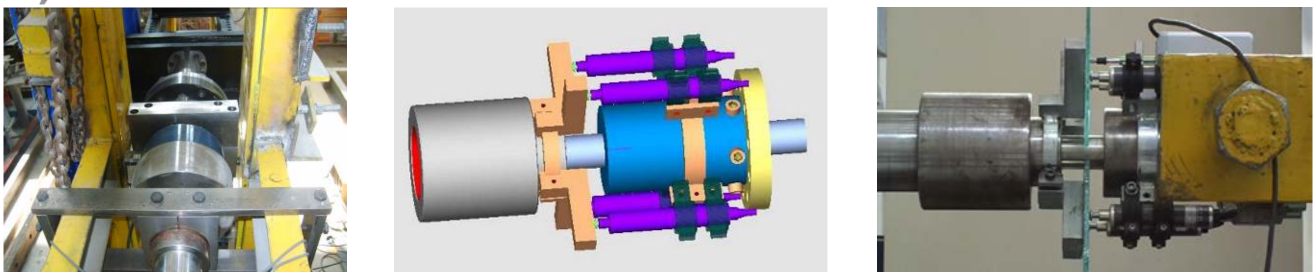
Fig. 3 – 3D view and dimensions of LED

Unlike from [5], [6] and [9], the layer of lubricant is not used between the tube and the lead in the adopted LED. Consequently, hydraulic seals are not required for the design. The device lubrication was not found to be necessary in [10] and [11] either. The tube and the cap are designed to be used as bearings, so the LED doesn't have additional bearings.

The research presented in [5], [6], [9] and [12] did not mention about pre-stressing of lead. However, pre-stressing was used to minimize void formation and to improve LED behaviour in [10], [11] and [13]. In the current study, the cap is designed originally to make available pre-stressing on lead with the assembly of LED (Fig. 3).

3.2 Experimental setup

LED is fixed between the actuator and the loading frame. Out of plane retainers are utilized to keep the actuator in its original alignment (Fig. 4).



(a) (b) (c)

Fig. 4 – Out-of-plane restraints and LED displacement monitoring

In the tests, the displacement controlling was conducted with a Heidenhain MT2571 length measurement gauge. Axial displacement was monitored by four CDP10 displacement transducers which are radially positioned around the specimen. The transducers were measured relative displacement of the shaft (Fig. 4). The average of four transducers measurements was accepted as axial displacement of LED. The restoring force of LED was traced with a HC-30 type load cell having a 300 kN load capacity. The loading frame’s in-plane and out of plane movements were monitored with ten displacement transducers. The data was monitored with a TML DRA-101C DIGITAL dynamic strain meter that has a capability of 2.5 kHz frequency response.

3.3 Loading function

The cyclic displacement amplitudes applied to the specimen are 0.5, 1.0, 1.5, 2.0 mm. Force-displacement relationships of the LED are determined within 0.1-0.5 Hz frequency band where frequency is ascended by 0.1 Hz steps. The limited ranges selected for the displacement and frequency are related with laboratory restrictions.

The experimental study was conducted with ascending displacement amplitudes while frequency was kept constant. Each displacement target was repeated 20 times, hence totally 80 cycles were produced for each frequency (Fig. 5).

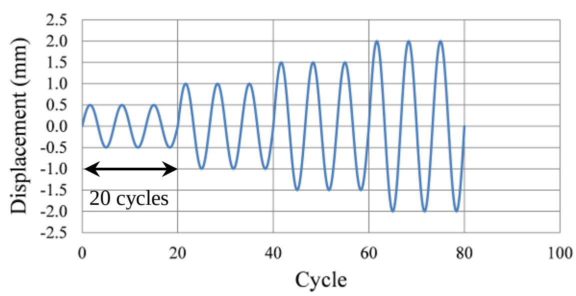


Fig. 5 – Displacement function

3.4 Load-displacement relationships

Force-displacement relationships of the LED are almost in rectangular form for the evaluated frequency ranges excluding the inclined loading and unloading paths. General shape of them is quite similar each other and yield force is almost persistent for the displacement targets (Fig. 6).

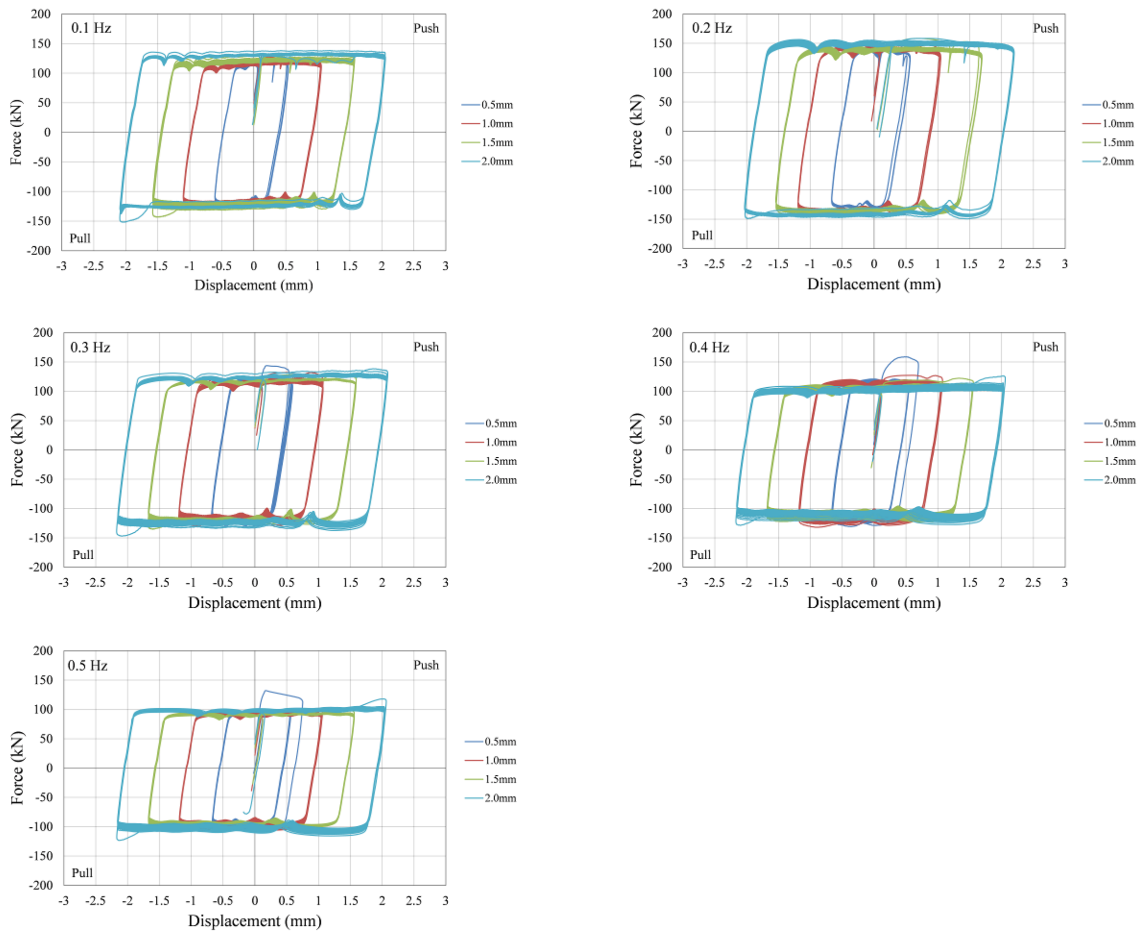


Fig. 6 – Force-displacement relationships of the LED

4. Energy Dissipation and Equivalent Damping Ratio

Typical force-displacement loop obtained from a cyclic excitation with the displacement amplitude u_o is shown in Fig. 7. Dissipated energy E_D is determined as the area enclosed by the hysteresis loop. E_{So} represents the maximum strain energy corresponding to the cycle. Damping ratio is determined by making equal the maximum strain energy with the energy dissipated by viscous damping Eq. (1), [14].

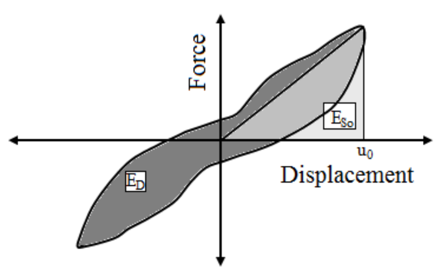


Fig. 7 – Energy rate method [14]

$$\xi_{eq} = \frac{1}{4\pi}\frac{E_D}{E_{So}} \tag{1}$$

The relation between loading frequency, displacement and energy dissipation capacity is depicted in Fig 8. One can conclude that dissipated energy is invariable against the altered frequencies.

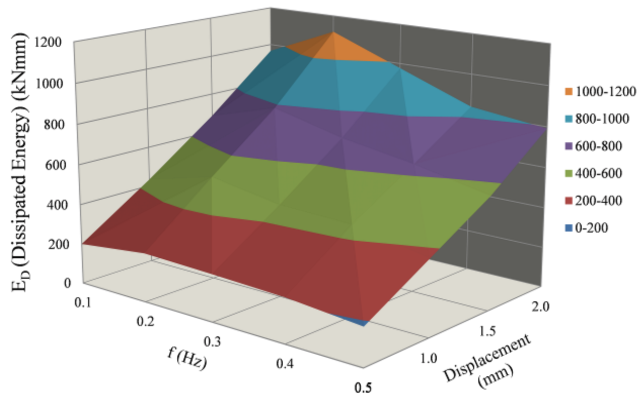


Fig. 8 – Dissipated energy vs. loading frequency and displacement

Equivalent damping ratio versus loading frequency and displacement relation is presented in Fig 9. Equivalent damping ratio is varied in the range of 0.53-0.62. It is obtained 0.58 as an average value for the considered frequency and displacement targets.

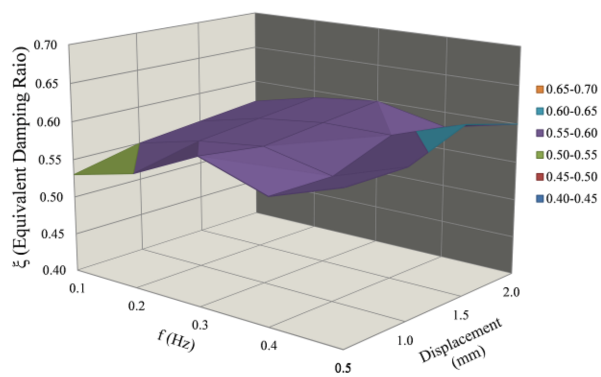


Fig. 9 – Equivalent damping ratio

5. Conclusions

The results of experimental study conducted on the LED, which has different design aspects from the traditional LEDs, are presented here. The LED is designed without a lubricant layer and hydraulic seals. The tube and cap are functioning as bearings; hence it is not essential to use additional bearings. Furthermore, the design may provide pre-stressing on the lead.

Force-displacement relations are determined for the specific frequency and displacement targets which were selected in the range of laboratory equipment. Henceforth energy dissipation capacity and equivalent damping ratio are determined for the LED.

Energy dissipation capacity rises with the increment of displacement intensity while it remains persistent for the altering frequencies. Comparatively high dissipated energy is obtained for 0.2 Hz where relatively high yield forces are retrieved.

The average equivalent damping ratio is determined as 58% for the considered frequency and displacement targets.

6. Acknowledgements

Funding for this research was provided by ITU Department of Scientific Research Projects (34285, 34014, 35057 and 35065). Researchers are gratefully thankful to staff of STEELab. The contributions of Irmak Cagdas and Pet-Mak Companies are also gratefully acknowledged.

7. References

[1] Aiken I (1996): Passive energy dissipation-hardware and applications. *Proceedings of the Los Angeles County and SEAOSC Symposium on Passive Energy Dissipation Systems for New and Existing Buildings*, Los Angeles.

[2] Sadek F, Mohraz B, Taylor AW, Chung RM (1996): Passive energy dissipating devices for sesismic applications. *Report NISTIR 5923*, Building and Fire Research Laboratory, National Institute of Standarts and Technology, Gaithersburg, Maryland, USA.

[3] Wulf J, Taylor JF, Shaler AJ (1956): *Metallurgy for Engineers*, John Wiley and Sons, New York.

[4] Birchenall CE (1959): *Physical Metallurgy*, McGraw-Hill, London.

[5] Robinson WH, Greenbank LR (1975): Properties of an extrusion energy absorber. *Bulletin of the New Zealand Society for Earthquake Engineering*, 8(3), 187-191.

[6] Robinson WH, Greenbank LR (1976): Extrusion energy absorber suitable for the protection of structures during an earthquake. *Earthquake Engineering & Structural Dynamics*, 4(3), 251-259.

[7] Robinson WH, Cousins WJ (1987): Recent developments in lead dampers for base isolation. *Proceedings of the Pacific Conference On Earthquake Engineering*, 2, 279-283.

[8] Skinner RI, Robinson WH, McVerry GH (1993): *An Introduction to Seismic Isolation*. John Wiley and Sons, New York.

[9] Cousins WJ, Porritt TE (1993): Improvements to lead-extrusion damper technology. *Bulletin of the New Zealand National Society for Earthquake Engineering*. 26(3), 342-348.

[10] Rodgers GW, Chase JG, Mander JB, Leach NC, Denmead CS (2006): Experimental development, tradeoff analysis and design implemention of high force-to-volume extrusion damper technology. *Bulletin of the New Zealand National Society for Earthquake Engineering*, 40(2), 35-48.

[11] Rodgers GW (2009): *Next Generation Structural Technologies: Implementing High Force-to-Volume Energy Absorbers*. PhD Thesis, University of Canterbury, New Zealand.

[12] Tsai CS, Lai WS, Chang CW, Li MC (2002): Testing and analysis of a new lead-extrusion damper. *Pressure Vessels and Piping Conference*, August 5-9, Vancouver, BC, Canada.

[13] Rodgers GW, Chase JG, Mander JB, Leach NC, Denmead CS, Cleeve D, Heaton D (2006): High force-to-volume extrusion dampers and shock absorbers for civil infrastructure. *19th Australasian Conference on Mechanics of Structures and Materials*, Christchurch, New Zealand.

[14] Chopra AK (2001): *Dynamics of Structures: Theory and Applications to Earthquake Engineering*, 2nd Ed., Pearson Prentice Hall, Pearson Education Inc., Upper Saddle River, NJ 07458.