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# A LEAD SHEAR DAMPER SUITABLE FOR REDUCING THE MOTION INDUCED BY WIND AND EARTHQUAKE

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## ABSTRACT

A compact efficient damping device has been developed by Penguin Engineering Ltd to be used as 'added damping' or 'suplementary damping' for tall and/or flexible structures. This device enables any amount of damping to be supplied to any structure. A standard device is sensitive to movements as small as ±2 microns such as expected in wind induced vibration, to ±10 mm as expected in a large earthquake. Larger devices have displacement capabilities of up to ±1 metre. Associated damping force ranges from 1 kN to 1000 kN. Six prototype lead-shear dampers have been successfully tested and Penguin Engineering Ltd. is preparing for production.

## INTRODUCTION

Lead based damping devices have been used successfully in many countries to counter the effects of earthquake on structures. This technology, originally developed in New Zealand by the DSIR Physics and Engineering Laboratory, has grown over the last twenty-eight years to become one of the most versatile damping systems. Many successful devices have been installed in several hundred structures throughout New Zealand, Japan, and the United States of America. As modern structures have grown, so too have the requirements placed on the materials from which they are constructed. Subsequently, new technology has been developed to counter the increasing problems presented by increasingly larger structures.

To damp the small and persistent vibrations encountered in the wind response of very tall structures, whilst also reducing the large deflections associated with earthquake motion, Penguin Engineering has developed a promising device; the lead-shear damper which accomplishes this via the concept of 'added damping'.

'Added damping' involves a uniform increase in damping of a structure by distributing many small damping devices throughout a structure, or by increasing the inherent damping in the materials used for construction.

One of the most successful earthquake motion damping devices developed, is the lead-rubber bearing (LRB). Relying on the principles of seismic isolation developed by Skinner *et al.*(1975), the LRB provides an isolation and damping system in a compact and simple device. The development and current usage of this device is detailed in Robinson 'Recent developments in Seismic Isolation'(1995).

As a science, seismic isolation has continued to develop at an accelerated pace in recent years and has been embraced by many engineers. Conceptually it involves increasing the natural period of a structure to outside the period of the exciting motion. This considerably reduces the forces transmitted into a structure through decoupling. The addition of a damping mechanism to dissipate the associated energy, thereby controlling the displacements and further reducing the accelerations transmitted to the structure, establishes a seismic protection system. This method of protection is suitable for structures with natural frequencies less than 1.5 seconds. Skinner et al. (1993).

The original lead based damping device, the lead extrusion damper, was also developed by PEL in the early seventies and first installed in the Aurora terrace and Bolton street bridges in Wellington, New Zealand, in 1974. Since its conception it has been installed in two major buildings, and two further bridges. This device relies on the energy absorbed during the mechanical process of extrusion of lead through an orifice. This process efficiently absorbs tremendous amounts of energy, and thus relatively small devices can be employed to damp very powerful motions.

## LEAD-SHEAR DAMPER

The lead-shear damper is a compact damping device, which is sensitive to very small displacements. Significant hysteretic damping can be achieved at displacements as low as ±2 micro metres. This device can be used as 'added damping' in flexible structures through the distribution of many small capacity devices throughout the structure. Suitable for vibration protection of structures with periods which fall outside the practical range of seismic isolation, this approach uniformly distributes damping throughout a structure. This effectively creates a highly damped structure. Scawthorn *et al.* (1995).

The practical range of this device is from ±2 micro metres to ±10 mm. Larger displacements come with larger devices, but the sensitivity decreases as size increases, to a maximum practical displacement of ±1 metre. For example a 100 mm displacement damper will begin to give appreciable hysteretic damping at 20 micro metres. eg. this device has a dynamic range of four orders of magnitude. The forces achievable with a small lead-shear damper range from 1 kN to 200 kN.

The lead-shear damper developed by Penguin Engineering, is now at pre-production prototype stage. An example of this self contained damper is pictured in Figure 1. It is capable of sustaining thousands of cycles at any amplitude within its design range, without deterioration or requiring maintenance.

The damping of this device is achieved through the plastic deformation of a lead core. This enables it to undergo many cycles, dissipating large amounts of plastic energy, while maintaining it mechanical properties. This is achieved through dynamic and meta-dynamic recrystallization of lead as described by Monti et al.(1995) and predicted by Robinson.(1976)

Principally designed to be included in a flexible structure at any point of flexure where displacement can be converted to damping, such as in cross bracing in a beam-column, moment resisting frame, in tie down spars on heavy pipe-work, or industrial plant.

### *History*

Before the lead-shear damper was developed, extensive testing of the deformation characteristics of the lead plug was undertaken by Monti (1994). It was shown that the lead behaved reliably under cyclic plastic deformation, producing 'Coulombic damping'. This behaviour is exhibited in Figure 2. It was shown that the geometry of a lead specimen would degenerate over about twenty cycles. It was postulated that if the lead was suitably contained and held under a hydrostatic pressure, the cyclic lifetime of the lead specimen would be extended indefinitely. Monti *et al.* (1995).

It was shown that an unsupported lead specimen would sustain a strain of about 350%, before the load began to decrease, as shown in Figure 3. Accordingly, this device is designed to operate in the strain range of 0 to ±200%.

**Figure 1**. The self contained Lead-Shear Damper. Shown is a 200 kN damper with a stroke range of ±2 micro metres to ±10 mm.

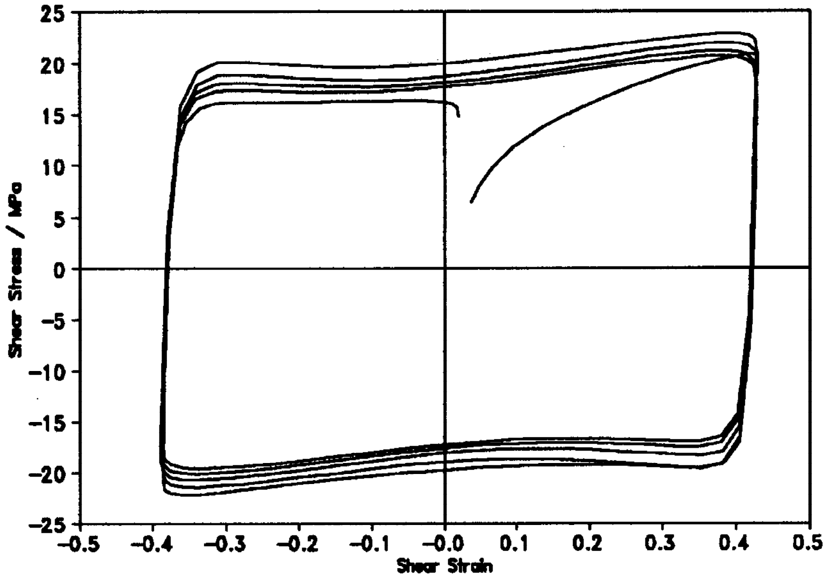

**Figure 2.** Stress-strain hysteresis diagram for uncontained lead shear specimens. Set two of five cycles of ± 10 mm at 0.5 Hz.

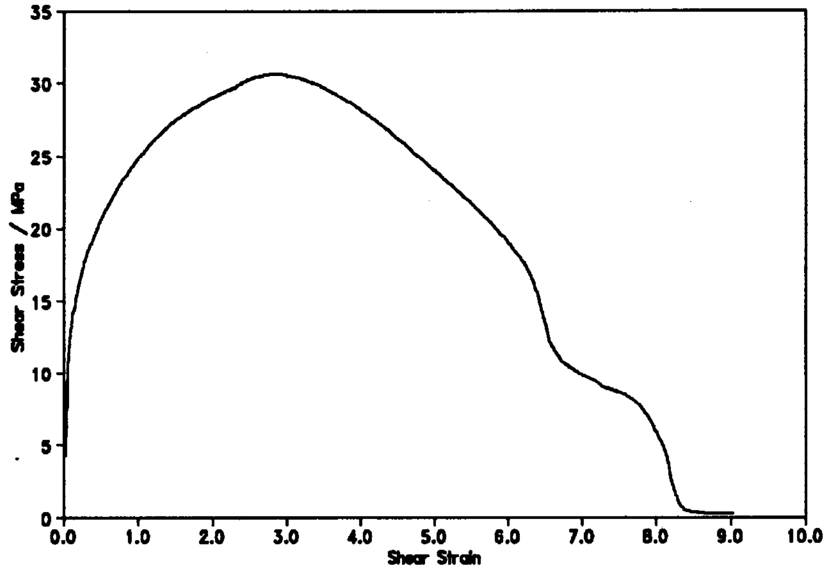

**Figure 3.** Stress-Strain curve for lead tested in uni-directional shear.

## DYNAMIC RECRYSTALLIZATION

Because lead at room temperature is above half of its absolute melting temperature, and the inherent metallurgical properties of lead, described in detail by Monti (1994), it has a tendency to recrystallize during deformation at room temperature.

New grains have been observed forming in high purity lead, when deformed at room temperature. Figure 4 shows two recrystallized scratches made during polishing and Figure 5 shows new grains which have formed in an intentional scratch.

As the lead is deformed and recrystallizes, its mechanical properties return to those of the initial annealed state. This property of lead means that as long as the geometry of the lead component remains unchanged, the properties of the component will remain constant. As the elastomer deformation is predominantly elastic, there is no change in the properties of the device.

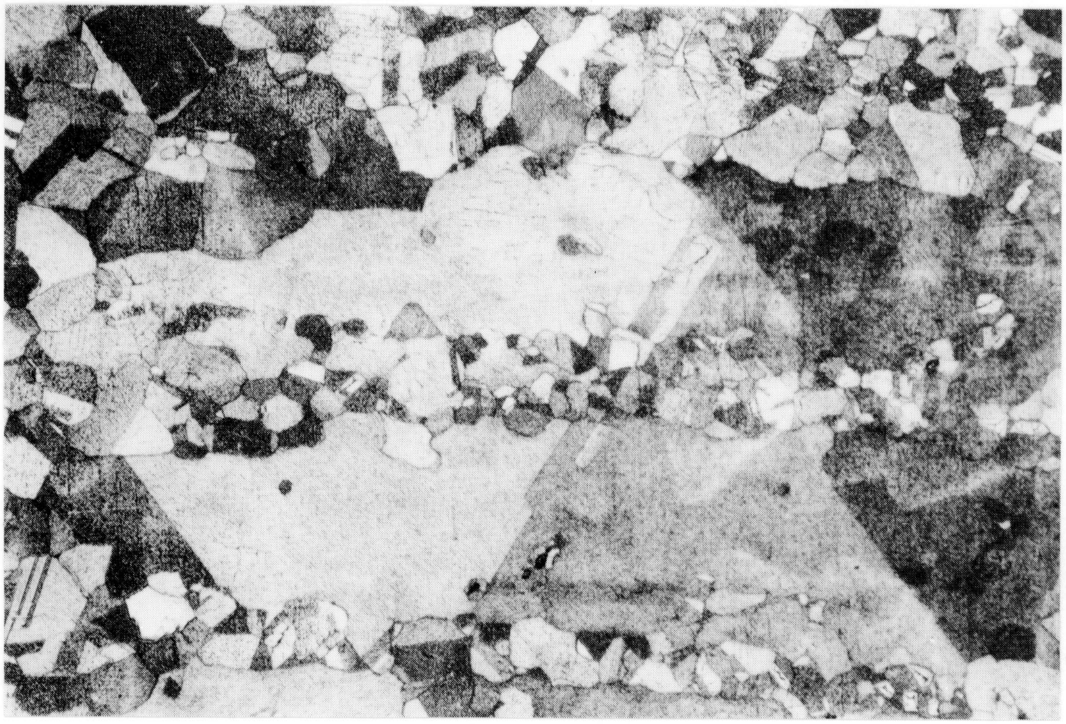

**Figure 4.** A polishing scratch in a lead specimen which has recrystallized at room temperature.

**Figure 5.** Recrystallized grains formed in an intentional scratch in a polished lead specimen.

## EXPERIMENTAL RESULTS

Six devices have been tested extensively at this stage. The design displacement range of all of the test devices was ±2 microns to ±10 mm. Successful tests with significant hysteresis loops have been achieved across the range of ± 2 microns to ±17 mm.

Figures 6 through to 8 show the hysteretic behaviour of this device at very small (±10 microns), medium (±1.1 mm) and large (±6.9 mm) displacements respectively.

## EXPERIMENTAL DISCUSSION

All the results obtained through the testing programme of this device have shown it to behave as an almost perfectly plastic device. It provides significant hysteretic damping at displacements as low as 2 microns and a reliable range of operating displacements of four orders of magnitude. It has exhibited constant and reliable properties, throughout extensive testing. After a large displacement at the top end of its working range, the device remains just as sensitive at the bottom end of its working range. At displacements of the order of twice the working range the device has shown to provide reliable damping for many cycles, however the elastomer was stretched beyond its elastic limit and fractured. It is not recommended that a device taken to such extreme displacements should remain in service.

The second device tested sustained 1226 cycles at various amplitudes across its working range, including a one thousand cycle test at ±0.7 mm, with negligible change in the hysteretic properties of the device. The device, of which the results are shown here, sustained 217 cycles at a range of displacements including three cycles at ±1.7 times the design displacement, with little change in the hysteretic properties of the device.

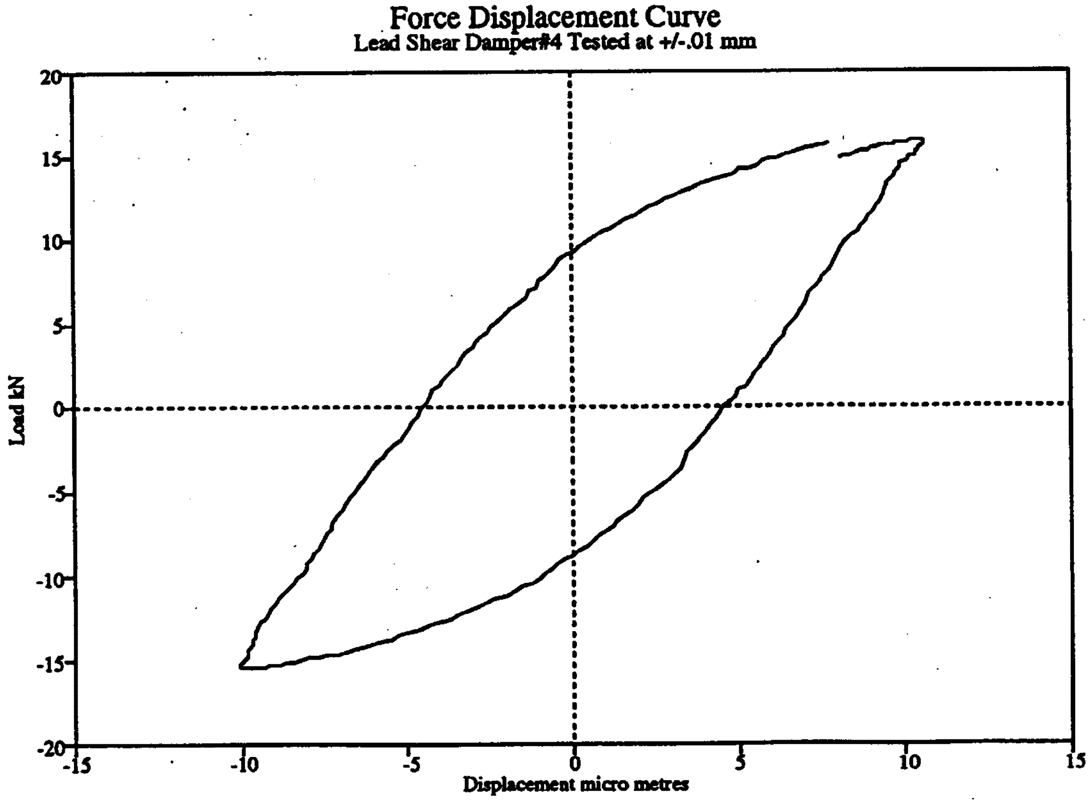

**Figure 6.** Hysteretic force-displacement curve for the fourth prototype lead-shear device. Tested at ± 0.01 mm.

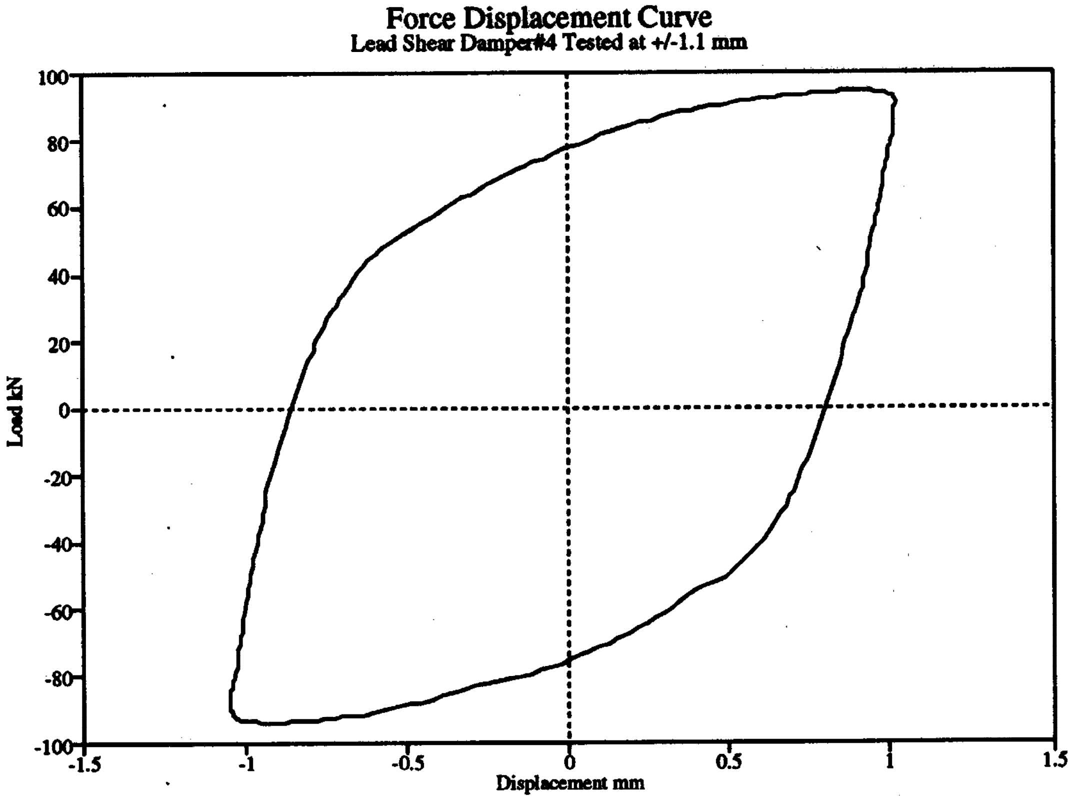

Figure 7. Hysteretic force-displacement curve for the fourth prototype lead-shear device. Tested at ± 1.1 mm.

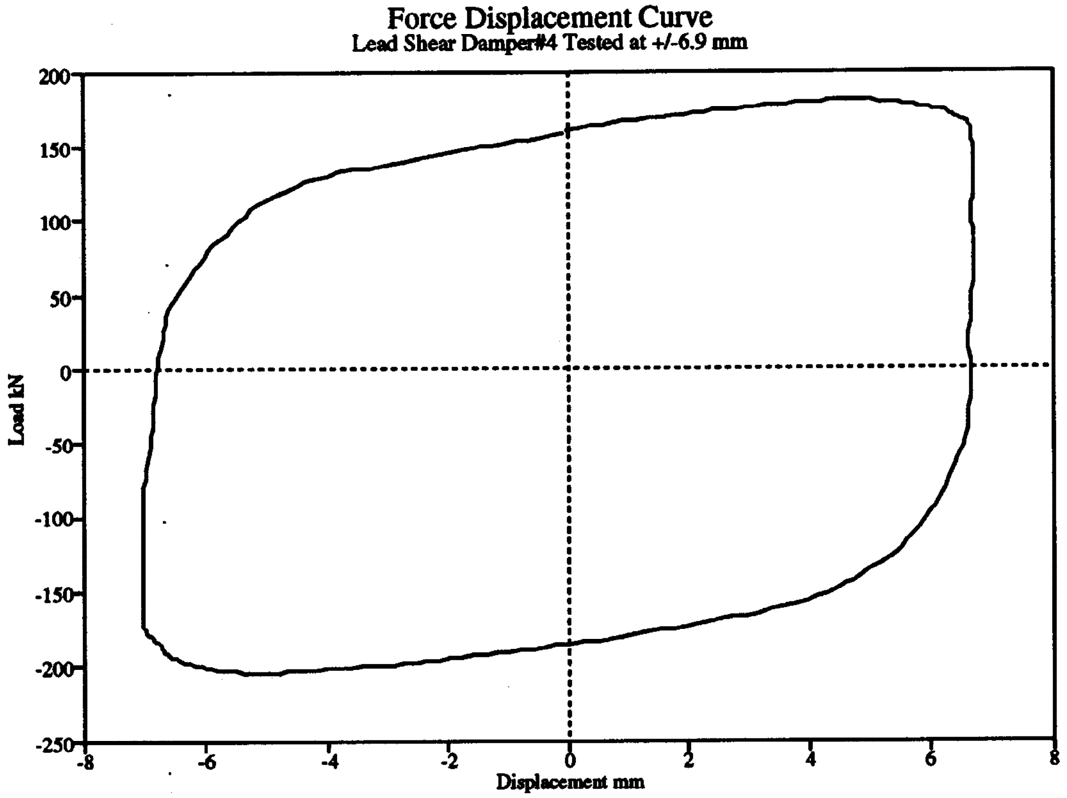

Figure 8. Hysteretic force-displacement curve for the fourth prototype lead-shear device. Tested at ± 6.9 mm.

## CONCLUSIONS

1. This new lead-shear damper behaves as a plastic damping device capable of working at displacements of one micron to 10 mm or any range of four orders of magnitude, up to a maximum displacement of 1 metre.

2. The lead-shear damper provides the following:
   a) Unlimited life.
   b) Reliable damping.
   c) Maintenance-free operation.
   d) Simple and compact design.
   e) An economic solution to the problems encountered in flexible structures.

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