STEEL-BEAM DAMPERS FOR INCREASING THE EARTHQUAKE RESISTANCE OF STRUCTURES

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SUMMARY

During the past 6 years the Physics and Engineering Laboratory has continued the development of steel-beam hysteretic dampers. These are installed to reduce the earthquake forces and deformations in structures which have been adapted for their use. The adaption provides a high degree of horizontal flexibility at the base or at an intermediate level in a structure. Steel-beam dampers are connected across the flexible components or parts of the structures which separate to provide increased damping during earthquake induced motions. The use of steel-beam dampers complements other methods for providing structural damping.

1. INTRODUCTION

The development and testing of steel-beam hysteretic dampers was initiated at the Physics and Engineering Laboratory in 1970, and has proceeded rapidly since 1973 in order to provide dampers for particular "base-isolated" structures, which were the subject of investigation and theoretical studies at the Laboratory[1,2]. Details of various types of damper have been published[3-7] and this paper updates the information on steel-beam dampers and their applications. A more general survey of the use of special components in providing earthquake resistance was published recently[8].

The Physics and Engineering Laboratory has used lead inserts in laminated rubber bearings to provide a flexible mount and a hysteretic damper in a single easily-installed unit. These mounts have been installed under a 4-storey building and the superstructures of several bridges. Other promising systems for providing structural damping include the frictional forces of sliding mounts utilizing unlubricated PTFE or lead-bronze. Mounts with rubber formulated to give high internal damping are also under development.

2. STEEL BEAM HYSTERETIC DAMPERS

Attention has been directed towards the production of mild steel devices of solid cross-section, which do not become unstable at high levels of plastic strain. Black mild steel to BS 4360/43A or bright steels to a similar composition have been found to be the most suitable, preferably heat-treated for 5 hours at 620°C following fabrication. In design, welding is kept well away from highly strained zones otherwise earlier failure results.

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2.1 Torsion Beam Device

The first hysteretic damper developed by the laboratory was of the torsional beam type (Plate 1) for the Rangitikei Bridge project[9] (Plate 2 and Fig. 1). This bridge was given transverse flexibility by allowing rocking with uplift at locations A, Fig. 1. The uplift deformed the dampers using the connections shown in detail A. In the device the short sections of the beam between the loading arms are overstrained in torsion and bending. The initial testing of models was followed by the testing of the full scale device of 450 kN capacity with a range of movement of up to 80 mm (Plate 1).

The device offered a means of providing a compartively large dissipating force from a welded fabrication using 60 mm plate. However, it is likely now that, for large forces, the flexural beam device (Section 2.4) would be preferred in any future application requiring a steel device, as this can be fabricated with a minimum of welding using cast steel arms.

2.2 Round Steel Cantilever

The tapered round steel cantiliver was developed to provide damping in a horizontal plane when used in conjunction with rubber bearings in base isolated buildings. The taper is designed to yield over its whole length. Damping forces up to about 100 kN for a movement of ± 75 mm can be provided using steel rounds commercially available, but above this size fabrication of the base becomes inconvenient.

This type of device was originally considered for the base-isolated 4-storey William Clayton Building in Wellington[10], but was later abandoned in favour of the more recently developed lead-rubber bearing (Section 3) which was simpler to fabricate and less expensive to install.

2.3 Taper plate cantiliver

The taper plate device (Plate 3) was originally suggested as a simple alternative to the torsion beam type when space permitted the use of a cantilever arm and a test programme was carried out to establish the design parameters[8]. In practice however, it was found that the fabrication of the welded base, necessary to keep welding well away from the taper, proved difficult. This was, however, overcome by a special welding and machining procedure for the fabrication of a 240 kN device for a motorway overbridge in Dunedin.

The taper plate design also found application in a chimney at Christchurch designed to rock on its base (Fig. 2 and Plate 4) for which application the fixity for the device was provided by extending the plate, which was produced economically mainly by profile cutting.

The most practical form of the taper plate damper, which can also be scaled up for large displacements and damping forces, is a double taper which is fixed at the centre and loaded at both ends[11].

2.4 Flexural Beam Damper

The flexural beam damper has loading arms with pinned ends at which loads are applied along the direction of the beam axis (Fig. 3 and Plate 5). Hence beam loads are predominately bending with an additional moderate axial load. The arms are cranked to give a pin spacing of 7/8 of the beam length to offset the effect of geometrical changes on the load deflection relationships. This results in polar symmetry for the hysteresis loops under cyclic loading (Fig. 4(a)). The geometrical changes under deformation reduce the "second" slope of the hysteresis loops below that associated with the moment-curvature relationship of the beam. This is in contrast with the torsion beam and cantilever dampers in which geometrical changes increase the second slope. Hence of the steel dampers described the flexural beam gives the greatest effective damping for a given maximum damping force.

The combined effect of bending and axial loads gives a progressive buckling of the beam, away from the line of the applied loads. This results in a progressive concentration of plastic deformations towards the central part of the beam and away from arm connections (Fig. 4(b)), with their locally raised stresses. The final failure of the beam is near its centre, after its energy absorbing potential has been almost fully utilized. Six such dampers, of 300 kN capacity, are to be installed at one abutment of the Cromwell bridge, Fig. 5.

3. LEAD-RUBBER BEARING

The lead-rubber bearing[7] is the most practical mount for the base isolation of many structures. For this device a laminated elastomeric bridge bearing is modified by placing a lead plug down its centre. The bearing carries the weight of the structure and supplies a horizontal restoring force while the plastic deformation of the lead plug produces damping. A 356 x 356 x 140 mm lead-rubber bearing, containing seven 3 mm thick steel plates, six 16 mm rubber plates and a lead plug of 100 mm diameter has been tested at 0.9 Hz with vertical loads and strokes of up to 450 kN and $\pm$ 68 mm respectively. This bearing completed a total of 340 cycles and operated satisfactorily at temperature of - 35 $\pm$ 5°C and 45 $\pm$ 5°C. The results of these tests together with the tests now in progress on the lead-rubber bearings for the Scamperdown, Toe Toe and Waiotukupuna Bridges and the William Clayton Building are being used to prepare a design procedure for the lead-rubber bearings.

4. PTFE SLIDING BEARINGS

Testing of PTFE sliding bearings was initiated at the Laboratory because of the possibility of using them in base isolation systems in buildings, while at the same time providing data to bridge designers, as PTFE sliding bearings have been used in long-span bridges for about two decades to accommodate temperature movements. For this application, the coefficient of friction of pure dry PTFE sliding on stainless steel is usually taken to be about 0.03.

Dynamic tests have been reported in the literature but usually these have been carried out at quite slow speeds, when coefficients of friction of about 0.03, or slightly greater were obtained. For conditions equivalent to a moderate to severe earthquake, viz. a travel of 150 mm and simple harmonic motion at frequencies up to 0.83 Hz, giving a maximum velocity of 38 cm/sec, frictional coefficients up to 17% were obtained, for the pressures normally employed in bridge bearings.

A promising development for base-isolated structures is in the field of lubricated PTFE bearings. For the conditions given above a frictional coefficient of less than 2% was obtained for a type of greased lubricated bearing which has been employed by one manufacturer of bridge bearings for more than a decade. This opens up the possibility of using a combination of lubricated PTFE and rubber or lead-rubber bearings in a base-isolation system to reduce the transmitted horizontal shear to a minimum. There may be a cost restriction however as PTFE bridge bearings tend to be more expensive than rubber bearings of the same capacity.

5. DISCUSSION

When laminated rubber mounts are used, and when it is appropriate to provide hysteretic damping at the locations of the mounts, then it is simple and economic to use lead-rubber bearings, since the functions of bearing and damping are contained in one unit, reducing both the unit cost and the installation cost. For bridges, this use of the same bearing is a natural development, as plain unmodified laminated rubber bearings have been used to allow temperature movement in bridge decks for about two decades. With steel devices, repetitive movement into the plastic range needs to be taken into account and preferably eliminated by using them as a connection to a normally fixed point as in the case of the Cromwell Bridge, where expansion occurs at the other end of the structure. For stepping structures, where damping only is required, steel devices are appropriate. Again if lubricated PTFE mounts are used it would be appropriate to use steel-beam dampers.

Some structural steel bars, subjected to severe plastic deformation and then allowed to age, have suffered brittle failure during later deformation. No such embrittlement has been found in a range of steel-beam dampers which have been retested after earlier severe plastic deformation followed by a storage period of several years. This is attributed to the low-carbon steel used for the yielding beams and to the methods used when fixing loading members to them.

When initiating the development of dampers for structures, plastically-deforming steel was chosen since the fabrication and maintenance of such dampers posed no problems unfamiliar to structural designers. Moreover it was hoped that the development of steel dampers would provide new information related to the behaviour of steel in structures during earthquake deformations. Information obtained includes steel properties under severe cyclic bending, and the connection techniques required to give structural hinges of very high ductility.

6. REFERENCES

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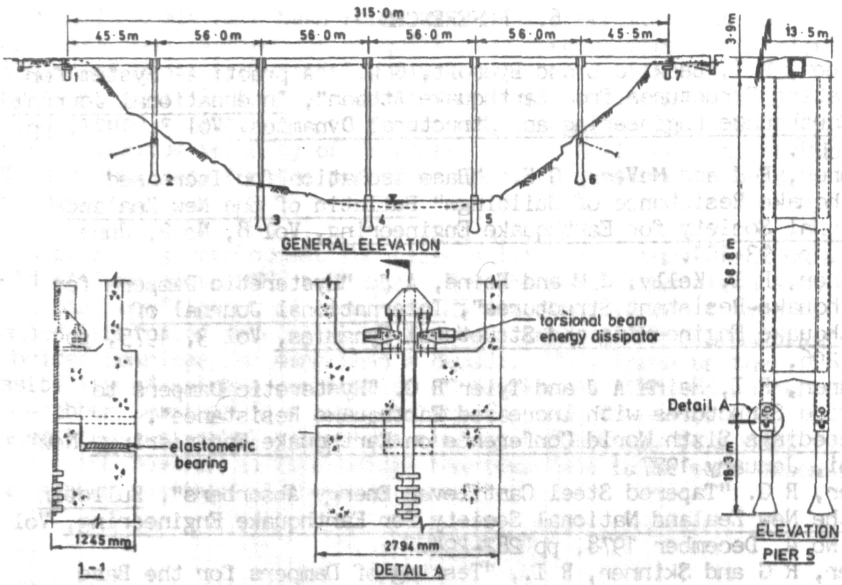


Fig. 1: Details of Rangitikei Rail Bridge

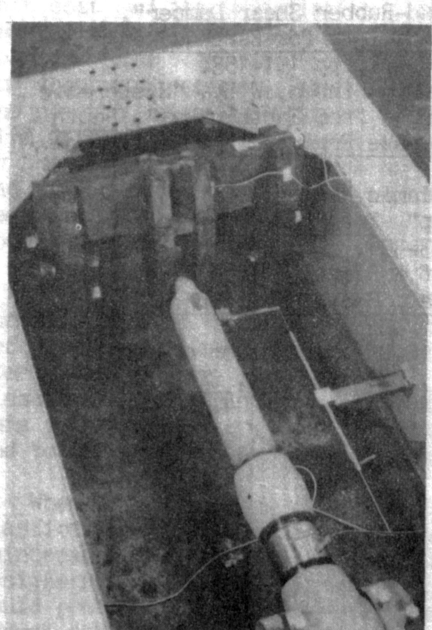


Plate 1: Torsion beam hystere tic damper in test machine

Plate 2: Rangitikei Rail Bridge under construction

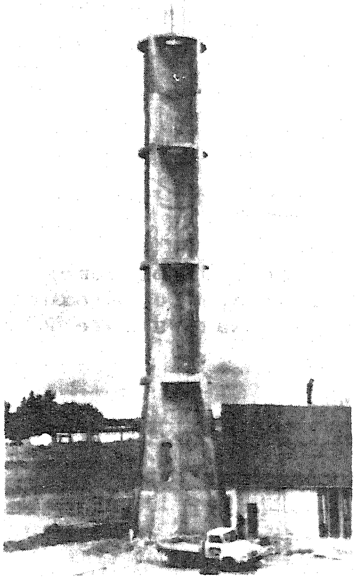


Plate 4: Chimney at Christchurch
designed to step
(From Beca, Carter, Hollings & Ferner)

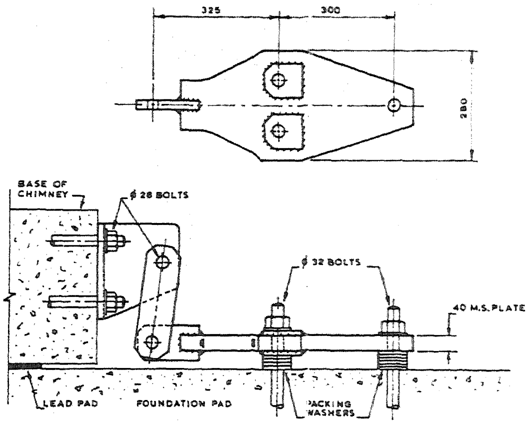


Fig. 2: Detail of cantilever
damper at chimney base

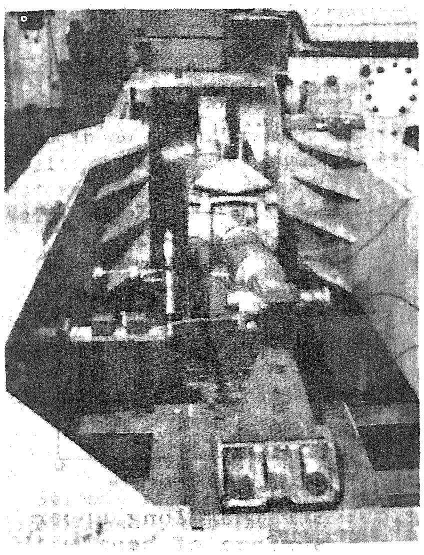


Plate 3: Cantilever plate
damper in test
machine

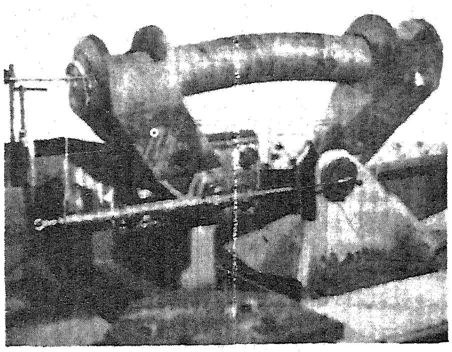


Plate 5: Flexural beam damper
under compression in
test machine

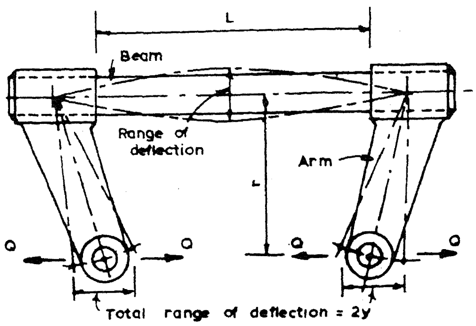


Fig. 3: Flexural beam damper

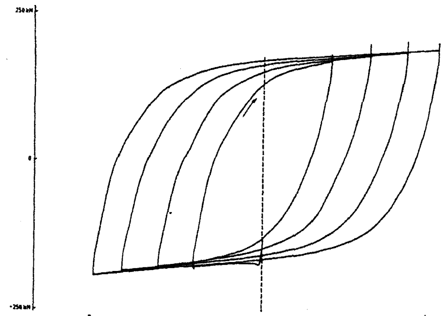
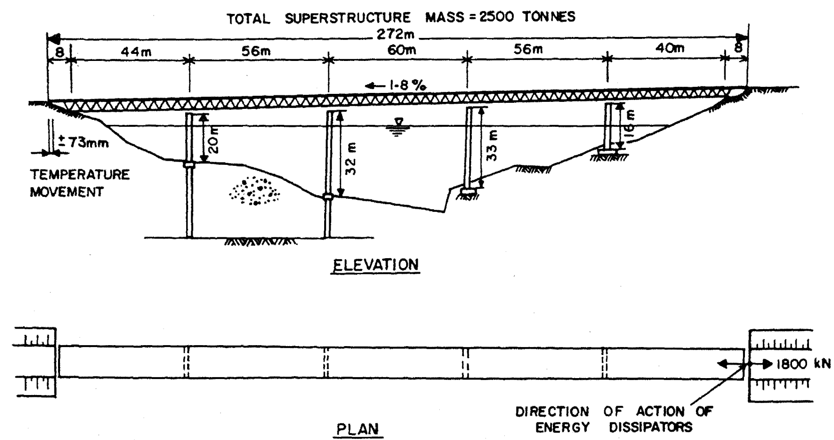


Fig. 4a: Force-displacement hysteresis loops for flexural beam damper Max. stroke 28cm. Cycles 83 - 86



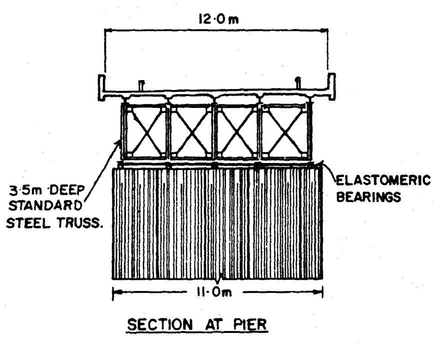


Fig.5: Flexural beam dampers in Cromwell Bridge (From Park and Blakeley)

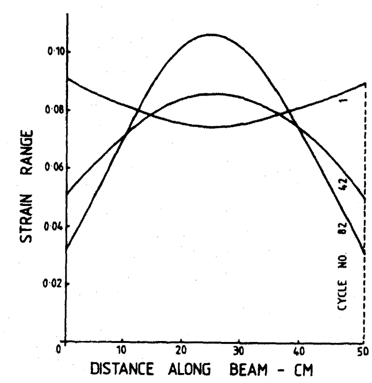


Fig.4b: Strains along upper surface of beam with a compressive displacement of 14 cm