HYSTERETIC DAMPERS TO PROVIDE STRUCTURES WITH INCREASED EARTHQUAKE RESISTANCE

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Hysteretic dampers are being used, in combination with special provisions which increase sidesway, to reduce earthquake forces and deformations throughout structures and to reduce or eliminate ductility requirements. Present or possible future applications to buildings, bridges, nuclear power plants and other structures are described, together with new developments in damper technology.

Introduction

Hysteretic dampers and their use in structures, together with flexible mounts, to provide increased earthquake resistance, have already been described[1,2,3,4,5]. An important application is the protection of nuclear power plants[6]. Their use imparts increased sidesway to the building, the building moving as a unit on the mounts with the dampers limiting the quasi resonant build-up of displacements and forces[5,6]. This paper outlines present applications in New Zealand, design studies for future applications, and new developments in damper technology.

Attenuation of Horizontal Earthquake Forces

Horizontal deformability may be provided by rocking with uplift, by shear of laminated rubber mounts, by sliding on low-friction surfaces, or by special highly deformable columns.

Damping may be provided by hydraulic pumping, by viscous materials, by surface friction, or by hysteretic deformation of solids. This paper describes the development and application of dampers based on the hysteretic deformation of solid steel elements, although lead extrusion has also been used for a similar purpose[5].

Steel Damper Characteristics

Damping is provided by the hysteresis of solid steel beams loaded cyclically into the plastic range in bending or torsion. The damper may be required for operation along a single axis or along any direction in a

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plane. Other important parameters are the effective damper force, the small-deformation stiffness, the yielded stiffness, the range of operating strokes and the cycles to failure.

A typical damper hysteresis loop is shown in Fig. 1, where Q_c is the effective damper force, approximately equal to the "yield force", while K_c and k_c are the initial and yielded damper stiffness. Typical cyclic strains of $\pm$ 0.02 to $\pm$ 0.03 allow a life of one hundred to several hundred cycles. Life can be increased by heat treating, by a low carbon content, and by the use of suitably detailed components for applying loads.

Typical simple damper elements are shown in Fig. 2, types (a) to (e). Two or more simple elements may be combined to provide the required damper characteristics economically, and to permit simple installation. Approximate formulae for the two most important parameters are given in the Table for damper types (a) to (e). The "effective" material constants "σ_o" and "τ_o" include the secondary factors neglected in developing the formulae, in addition to the material characteristics. For nominal maximum strains of 0.015 to 0.04, hot rolled mild steel gives average values of about 37 000 and 23 000 p.s.i. for σ_o and τ_o respectively. It is possible to provide a more compact hysteresis loop by the use of low-carbon steels or by annealing mild steels but at the expense of a reduction in damper force.

Table. Approximate damper forces and strains.
Damper types and dimensions are defined in Fig. 2.

Damper Type	Damper Force	Nominal Strain ε_m, γ_m, for deformation D
a	$\tau_o\ t^2(3b-t)/3r$	D 0.9 (b+0.6t)t/rlb
b	$\sigma_o\ bt^2/4l$	D t/l^2
c	$\tau_o\ bt^2/4r$	D t/2rl
d	$\tau_o\ d^3/6l$	Dd/l^2
e, axial	$\tau_o\ bt^2/4r$	Dt/4rl
e, transverse	$\tau_o\ t^2(3b-t)/6r$	D 0.45 (b+0.6t)t/rlb

Examples of Damper Applications

Rangitikei Railway Bridge (Fig. 4)

This bridge has 3 piers of height 200 feet and 2 piers of height 100 feet which are designed to rock with uplift at their bases under earthquake forces transverse to the bridge axis. Longitudinal earthquake forces are carried to the abutments by the continuous superstructure. Attached to the base of each pier are 4 dampers of type "a", Fig. 2, for which Q_c = 40 tons, K_c/Q_c = 2.8 in^{-1}, k_c/Q_c = 0.18 in^{-1}. Provision is made for an uplift of 4 inches.

Office Building, Wellington

It is proposed to provide this 4-storey reinforced-concrete frame building with horizontal flexibility, using laminated rubber mounts of the type commonly used under bridge superstructures. Pairs of type "d" dampers are to be connected end-to-end by cylindrical dry bearings which allow elongation, Fig. 3. An effective damper force of about 6 tons will be provided by each damper, with provision for displacements up to 6 inches.

Rocking Chimney

A 35 metre high reinforced-concrete chimney of cruciform section, with 4 inlaid steel flues, is to be constructed at Christchurch. It is designed to rock with uplift from 4 supporting pads of lead located under the extremities of the cruciform section. Vertical damping forces are provided by two dampers of type "b", Q_c = 12 tons, installed at a pair of opposite support locations.

Isolation of Bridge Superstructures

A study is being made of proposals to isolate the superstructures of a number of New Zealand motorway bridges from their piers and abutments. For the two-pier bridges it is proposed to provide dampers for transverse superstructure motion at the tops of the piers and dampers for longitudinal motion at the abutments. The dampers will be of type "b" or type "c", with Q_c at about 25 tons.

Base Isolation of Nuclear Power Plants

When a nuclear power plant is integrated within a single structure base isolation may be applied readily[6]. It is practical to provide for earthquakes with a severity (maximum ground velocity) of 6 or more times that recorded at El Cantro 1940, NS component. The proposed base isolator reduces overall earthquake forces and deformation by 10 times while it eliminates the large force increases which occur when appendages resonate with major substructures. The published work[6] describes the use of a large number of dampers of type "a". A present study is investigating the use of dampers of type "c" or of dampers which contain 2 pairs of type "b" units. It is practical to construct such dampers for forces of about 1 000 tons, a size appropriate to nuclear power plant isolation. The compound type "b" damper would require the forging of very large tapered mild steel beams, while type "c" dampers would employ uniform mild steel beams and cast steel loading arms.

Discussion

If dampers of each of the types "a" to "d" are cycled with the same maximum strain they will withstand a comparable number of cycles. Hence each damper type requires about the same weight of yielding steel to absorb the same amount of energy. The choice of type depends on the loading requirements and the ease with which they can be met by the various dampers.

Special provisions for structural flexibility and damping give the greatest reduction in earthquake attack for structures of fundamental periods between 0.2 and 1.0 seconds since such structures would otherwise suffer a quasi-resonant magnification of earthquake loads.

Earthquake attenuation is particularly important for structures which are inherently low in ductility or when the consequences of earthquake loads and deformations may be very serious.

References

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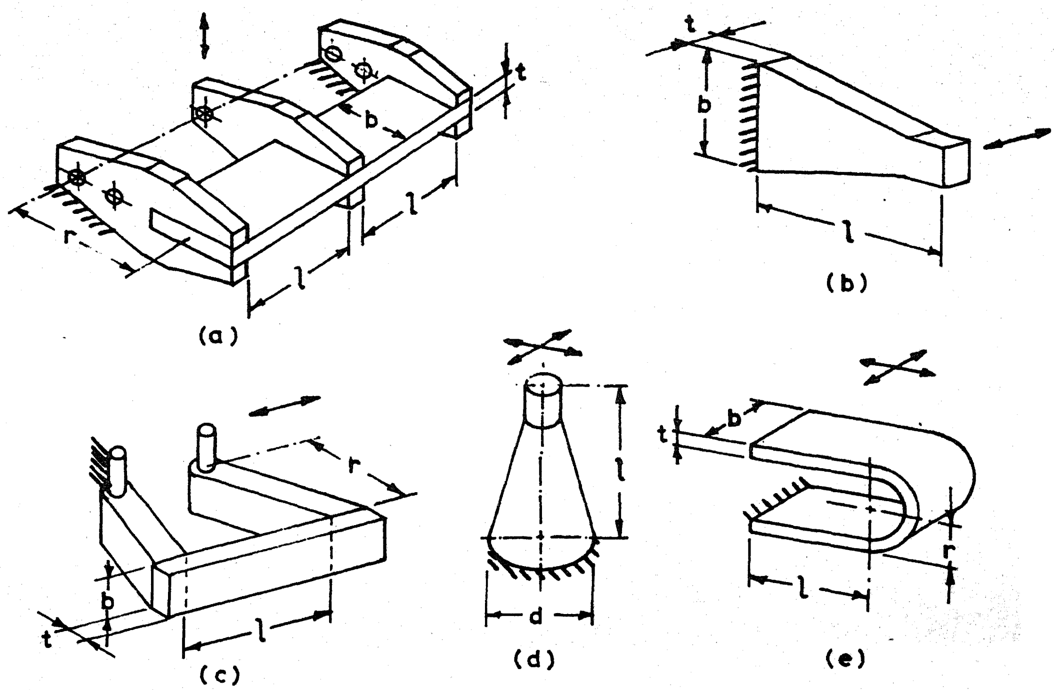

Fig.2. Steel beam dampers, types (a) to (e). The end of damper (e) is moved without rotation.

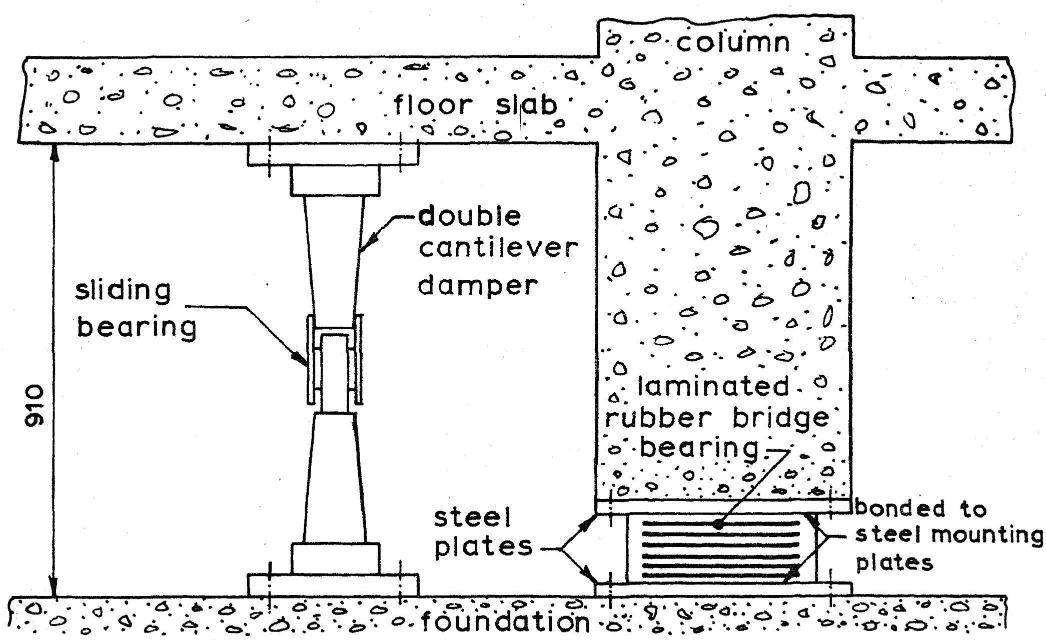

Fig.3. Column detail for base isolated building.

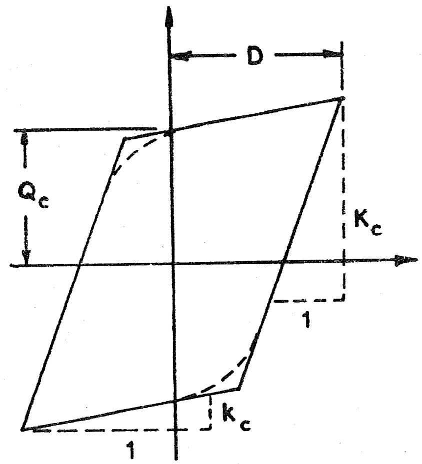

Fig.1. Damper hysteresis loop and bilinear representation.

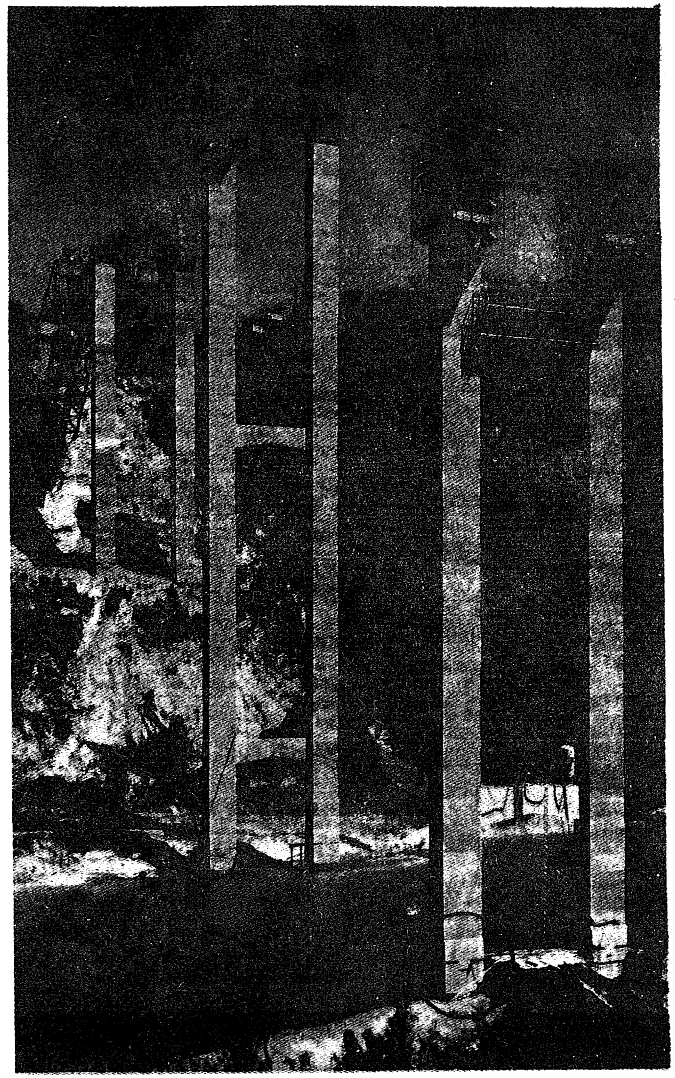

Fig.4. Photograph of rocking piers of the Rangitikei River railway bridge.