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Earthquake-resistant with hysteretic dampers

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Abstract

The earthquake resistance of buildings can increase by using of special ingredients which are working as hysteretic dampers. Within softly severe earthquakes these dampers are working as rigid members which reduce structural deformations, while during very severe earthquakes the dampers are working as energy absorbers which limit the quasi-resonant build-up of structural deformations and forces.

The hysteretic dampers are not necessary to bear the main structural loads, and therefore may be optimized for their needed stiffness and energy-absorbing traits. On the other hand, the main structural ingredients are not needed large energy-absorbing and they may therefore be optimized for their needed stiffnesses and load-bearing traits.

In many structures this segregation of ingredients functions leads to increased reliability at a lower primary cost. Under earthquake attack stractual loss should be reduced. Non- structural loss should have decreased within softly severe earthquakes, and for special types of structure it also should decreased for very severe earthquakes.

Different ways in which hysteretic dampers may be used in structures are discussed briefly.

The development of several kind of high-capacity, low-cost hysteretic damper, appropriate for use in structures, is described. The dampers use solid steel beams deformed plastically in different mixtures of torsional, sinuous and shear deformations.

The development of hysteretic dampers for the protection of structures against earthquake attack, carried out at the Physics and Engineering Laboratory over the past six years.

Keywords: Hysteretic dampers, earthquake resistance, unbonded brace

Introduction

The extension and testing of hysteretic dampers at the Physics and Engineering Laboratory was initiated in 1970 and has proceeded rapidly since 1973 in order to provide dampers for particular base isolated structures, which were at the same time investigated by the Laboratory, and were the subject of theoretical studies.

Earthquake ground rates offence structures with oscillatory inertia forces, the intensity is depending on the dynamic feature of the structure, and on the amplitude, feature and term of the ground rates. For big buildings there is a resonant build-up of motions and eneries over several cycles of vibration. Economy of design is attained by allowing the structure to change well into the inelastic range during severe earthquakes. This inelastic change increased structural flexibility and also a hysteretic absorption of energy, the two results of combining to limit the build-up of movements and forces.

The net result is a structure with less demands on its elastic ability, in exchange for which it must tolerate many cycles of severe inelastic changes. Recent earthquakes have showed some serious shortages in the techniques which used to prepare structures with earthquake resistance. These shortages have been verified by laboratory tests and analytical studies. Hysteretic dampers is intended to provide better and more reliable seismic performance than that of a conventional structure at the expense of the seismic input energy dissipation. There are five major groups of hysteretic dampers used for the purpose. During these earthquakes, many structures, designed in match with current methods, have toiled severe loss while undergoing inelastic changes. Widely reported earthquake loss happened at Anchorage 1964, Caracas 1967, Tokachi-oki 1968 and San Fernando 1971, while loss at Manila 1968 and 1970 has been explained in restricted-circulation reports. l. Many short columns did not change in inelastic joints, but failed in diametric stress with small absorption of energy. As a result of these failure systems many buildings absorbed small energy before the onset of severe loss. In addition, metamorphosis often caused severe non-structural loss, with the

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dangerous shedding of panel walls, facings and broken glass. tests show deterioration of structure ingredients under inelastic metamorphosis. At the Building Research Institute of the Ministry of Construction, Japan, cyclic inelastic changes have been used to several five-storey reinforced-concrete buildings. During the several metamorphosis cycles the structures suffered an oncoming damage of strength and rigidity. Tests by Bresler and Bertero3 on the cyclic loading of reinforced-concrete beams have also shown an oncoming loss of beam power and stiffness. Cyclic loading tests on beam-column connections for steel frames, explained by Popov *et d.,* 4 represented that flange inconsistency decreased the energy-absorbing valence of the members.

The difficulties intrinsic in preparing earthquake resistance by inelastic deformation can be decreased by accurate attention to detail. However, some structural systems, such as shells and pre-stressed concrete members, have a small capacity to absorb energy by hysteresis. All structural ingredients which support bars, in addition to absorbing energy, must be given a figure which is not optimum either for their energy absorbing or for their load-carring duties.

Design methods are being improved to compensate for the limitations of the techniques presently pursued to provide earthquake resistance. Major reviews have considered for the seismic provisions in the building codes for New Zealand, Japan and Los Ange l e~T.~he se proposed code changes take into account recent damaging earthquakes, building ingredient testing and analysis of structural systems.

These proposals provide for higher earthquake bars, smaller needs on the inelastic reserve of earthquake resistance and a bigger degree of simultaneity of the offence ahead the structure axes.

Features of Hysteretic Dampers

For generic frame structures, no damping, force waste is arrived via plastic metamorphosis of the flanges of beam-ends. The beam ends are essentially immolated to keep the entirety of the remains of the structure. This can be a negligible method to stand out earthquakes for two reasons. First, the small energy absorption could be anticipate from plastic metamorphosis of beam-ends. Once the beam-ends go into plastic deformation it will lead to a big deformation of the entire frame, thus failure the aim of deviation controlled plan. Secondly, the beam-ends require to be examined after an earthquake and fixed and or replaced if it got damage.

Hysteretic Dampers in Structures

The wrecking results of earthquakes which have ingredients of acceleration in the range 1 to 5 Hz, can be decreased by embellishment of the structure on a basis is isolation system in the type of ball bearings, sliding bearings, or more practically flexible rubber bearings.

Steel dampers progressed in the form of round and flat linchpin with and without tapers, round bars in the form of loops and flexural beams. With all of the steel systems the main problem is one of preventing setting welds at spots of high strength. In fact, the heavy welds needed contribute forcefully to the expense of the systems. However, steel dampers have been used in two bridges, one tall building and for one tall rocking chimney.

Many of the structural problems related with earthquake-induced inelastic metamorphosis may be decreased by limiting such deformations to special ingredients. These ingredients must have a big valence to absorb energy, and thereby ban structural resonances, when they are exposed to severe inelastic metamorphosis. These particular ingredients should have high stiffness under medium bars to inhibit repetitious extensive side-sway of the structure. The needed stiffness and energy-absorbing traits are exposed by recently developed dampers which apply severe hysteretic metamorphosis of solid steel beams.

Attention has gone to the production of soft steel systems of solid cross part, which will not be instable at high ranges of plastic strength. Black soft steel to BS 4360/43A or bright steels to a analogous combination have been found to be the most appropriate.

These big capacity low-cost hysteretic dampers are appropriate for apply in earthquake-resistant structures. Since normal structural bars would intervene with their function the dampers should be placed in laterally flexible buildings in a method that they are loaded only within side-sway. A check should be done to make sure that the dampers are unlikely to carry loss because of undergoing an extreme number of hysteretic cycles through wind storms.

While flexible buildings have hysteretic dampers which act during side-sway, the ingredients which help the normal bars and the decreased earthquake bars should keep elastic or suffer decreased inelastic metamorphosis. The hysteretic dampers could be optimized for their special actions, and they could be tested after a very special wind storm or earthquake and substitute to where it is necessary.

For many types of structure there are no appropriate places for the capacity of hysteretic dampers. However, it is often feasible to verify a structure to defeat against this problem. For the economic utilize of hysteretic dampers a structure should have pairs of nearby spot which undergo fundamental reated movement within severe earthquakes.

A building which merge a moment-resisting frame with a central tower may use hysteretic dampers if the tower is left separate from the floors and beams. Under peripheral bars there would be big motions among the tower and the frame, with mild interfloor translations. Hysteretic dampers may make connection between the tower and nearby floor beams (Figure l-b). The most suitable levels for the assembling of dampers is related on the dynamic feature of the tower and of the frame.

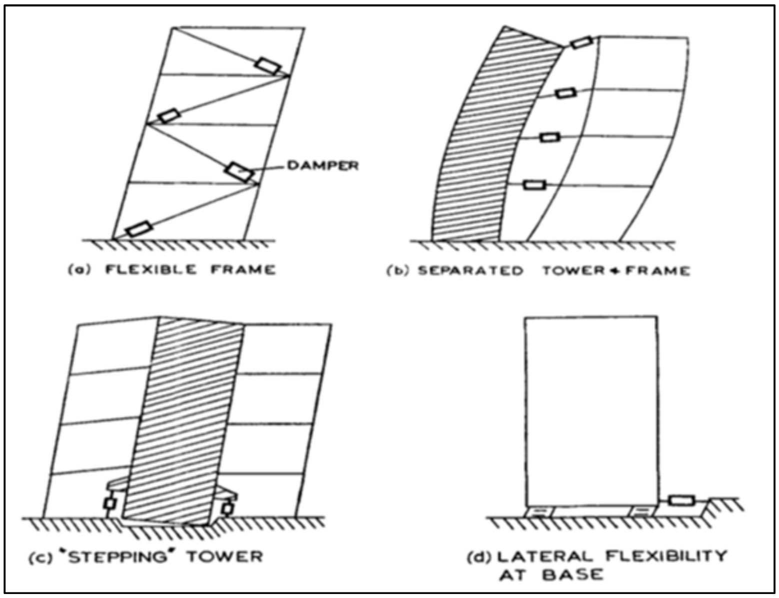

Fig 1: structural situation when Hysteretic Dampers are using

For generic buildings of 10-15 storeys, dampers located at 3 or 4 levels entirely the building height should prepare sufficient overall damping. However, a better bar repartition might be attained with dampers at all floor levels.

For narrow structures, an appropriate place for dampers may be used by allowing momentary uplift below the cyclic earthquake energies. The dampers could make connection between the vertically 'stepping' base and the foundations (Figure l(c)). This method has been accepted for the bridge piers of the 200-ft high South Rangitikei railway bridges with this system the stepping function restricts the peripheral energies, while the hysteretic dampers restrict the quasi-resonant build-up of stepping movement.

Hysteretic dampers are applied for special structural forms, may be used to provide earthquake insistence. A companion paper7 explained a particular structural form which has horizontally flexible mounts under the base of the structure and has hysteretic dampers contacted between the base and the foundations (Figure l (d)). Systems were examined for which the assemble were adequately flexible to have given an undamped term of 2-0 sec if the structural bulk had been assembled straightly on them. The total coulomb energy of the associated dampers (Qc in Figure (4) was 0.05 of the structure weight. This base seclusion restricts the base shears of a large range of structures to about 0.16 of the structural weight, with base movements of about 3 in, in plan earthquake defined in the paper.

When a set of hysteretic dampers are assembled among a frame building, as in Figure l (a), then the damper needs are more intense than they are for the base-isolated system of Figure l (d). An approximate analysis is used for a 10-storey frame structure exposed to the design earthquake defined in the companion paper.' The supposed structure had equal floor valence and free frame stiffnesses to give a triangular first style of 2.0 sec period. Hysteretic dampers were used in sets with oblique braces sloped at 45 degrees.

The damper valences and stiffnesses, for each inter-storey space, were built appropriate to the lateral stiffness of the unbraced frame for that space. A sufficient collection of dampers had a sum coulomb energy of 0.4 times the structure weight, which is 8 times the valence of the dampers which were suitable for a base-isolated structure. Again sufficient damper stiffnesses were 10 times as big as the stiffnesses for base-isolator dampers of the same valence. Under the plan earthquake the base shear was about 0.15 times of the weight of the building, with about half this shear grabbed by the columns and about half by the diagonal braces and associated dampers. The inter-storey deviation were about 0.5 in.

While it may be possible to extend the dampers for using for the provision of high stiffnesses and a big damper force would include fundamental expense. A more desirable structure frame would have stiffly braced upper storeys but vast peripheral flexibility for the lowest one or more storeys, and these would possess the hysteretic dampers.

The damper valence and stiffness which are needs for the types of usage demonstrated in Figures l (b) and l (c) lie between the needs for base-isolated structures and the needs for flexible-frame structures. These middle needs could be reach by the hysteretic dampers are expanded recently.

In time of an earthquake, building ingredients are replacing in two dimensions, since the loading is cyclic in nature. Also, a typical bracing scheme places the brace at 45^0 in a frame consisting of columns and beams. Because of the cyclic motion of the structure, the brace will go into tension and compression.

Therefore, the hysteretic damper should have planned so as to prepare similar tensile and compressive properties. Figure 2 demonstrates a bracing ingredient, which includes of a yielding steel core and a stiff jacket with little to no friction between the two elements. Such a part is called an unbonded brace.

The "unbonding material" lets the yielding core element to act apart of the jacket, while the jacket prepares the cross partial motion of inertia to stand out buckling under pressure. The brace treats elastically with a natural stiffness when the usage force is less than the material yield force. In the idealized situation, one time this force is arrived the brace will hang on movement without an enhancement in usage force, which is based on the elastic-perfectly plastic model. Once the force is returned the brace prepare the equal elastic stiffness until the yield force is attained in compression. This process will hold on under cyclic loading and is known as a hysteresis loop. See Figure 3.

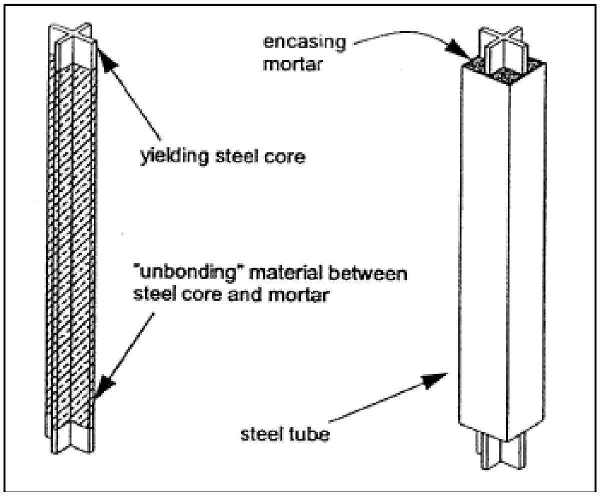

Fig 2: Hysteretic Dampers (unbonded brace)

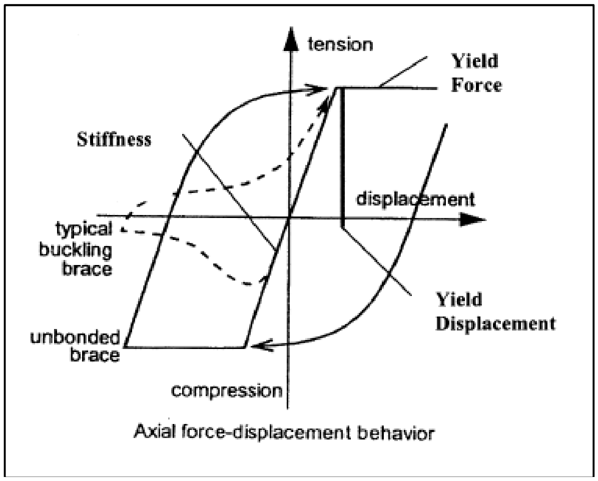

Fig 3: Hysteretic Behavior of Unbonded Brace

Hysteretic Dampers and Using In Structures

Slit-wall amplified concrete panels have been assembled among the height of a number of tall steel-frame structures in Japan. The main action of these panels is to operate as hysteretic dampers which decrease inter-storey deviations under mild lateral forces and operate as energy absorbers under drastic cyclic forces. Though these hysteretic panels are a significant progress, but they enhance the structure weight and they will destroy under periodic metamorphosis which increase lot into the inelastic area.

Hysteretic dampers which founded on the plastic metamorphosis of steel beams are expanded and their usage to earthquake-resistant structures, and to structural ingredients, is being examined. Beams with square, rectangular or circular parts have changed inelastically, with different composition of torsional, flexural and shearing metamorphosis. In each special damper ingredient, the inelastic metamorphosis was either mostly torsional or flexural.

The basic damper components may demonstrate in four systems

A. This type is a flexural-beam damper which uses a U-shaped steel tape rolled between two faces in parallel comparative move Figure 4[a]. It is comparatively flexible in the elastic range and can act in very big movements in the inelastic range. In the flexural beam damper, bars used to the ends of the cranked arms (Figure 6 & 7) for the spherical beam element to act staggering as a necessary loaded strut or tie pertaining on the bar orientation.

B. These type of hysteretic dampers will change square or rectangular loads in torsion and flexure, with torsion conquering Figure 4[b]. In the system the small part of the beam between the loading arms are overstrained in torsion and bending (Figure 8). They can be made handily to prepare a big damper energy valence. A feasible usage is assembling at the base of a tower or building in which uplift is happening, or a big base translation happens, in time of a drastic earthquake.

C. This is a flexural-beam damper; the fundamental figure is a simple linchpin of square or spherical part Figure 4[c]. in this situation damper may planned to act for bars along any vertical orientation to the beam axis. Thus it is appropriate for utilize in a structure with a flexibly help base on assembling between the latter and the foundation to prepare a damping energy for any horizontal orientation of base move. This horizontal damping force is used via a connection which prepares for some comparative spin and vertical move of the beam end.

D. This hysteretic damper is a particular figure of type of system of C which is using a vast beam which prepares a big valence for loading along a single axis Figure 4[d]. Two or more pairs of this type can mix to figure a dense damper, Figure 5**,** suitable for use as a diagonal element in a flexible structural frame.

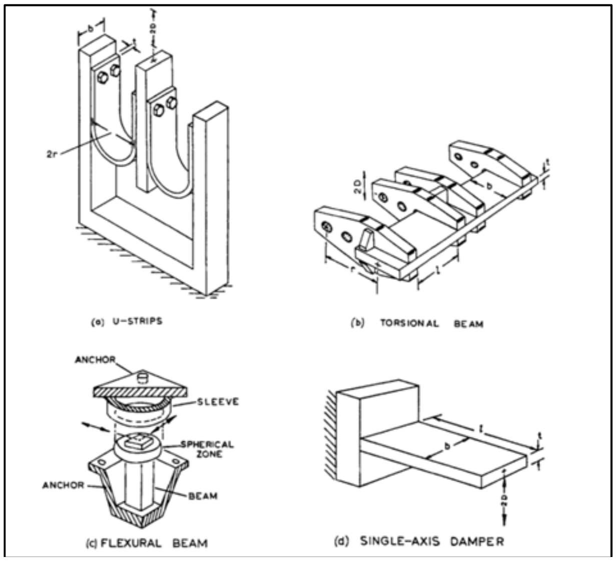

Fig 4: Four basic types of hysteretic damper, based on the inelastic deformation of solid steel beams

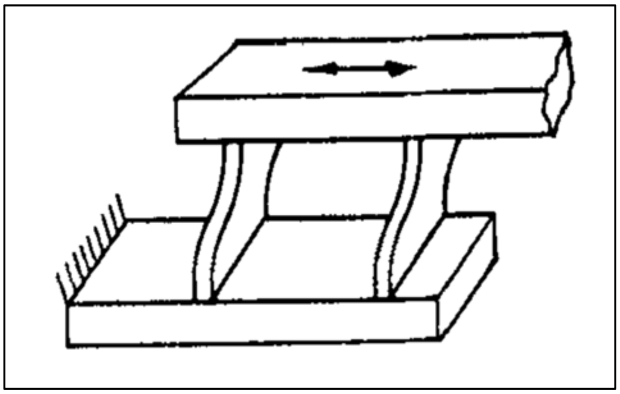

Fig 5: Hysteretic damper based on a set of four flexural-beam dampers of the type shown in Figure 4[d]

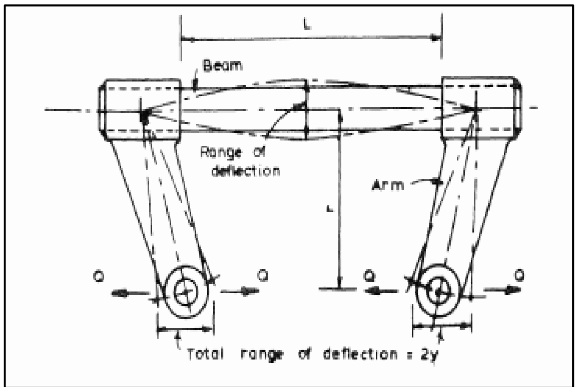

Fig 6: Flexural beam damper

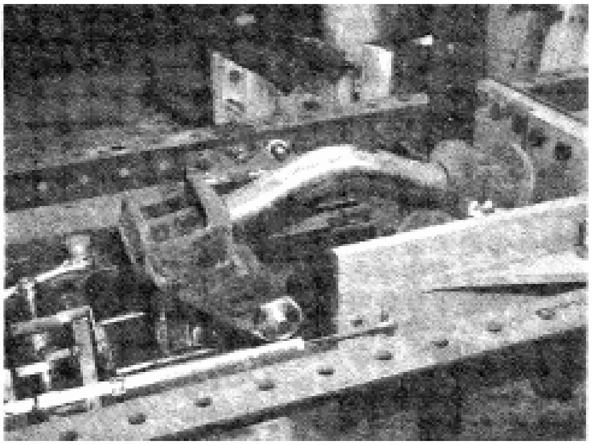

Fig 7: Flexural beam damper at extreme of travel in test frame

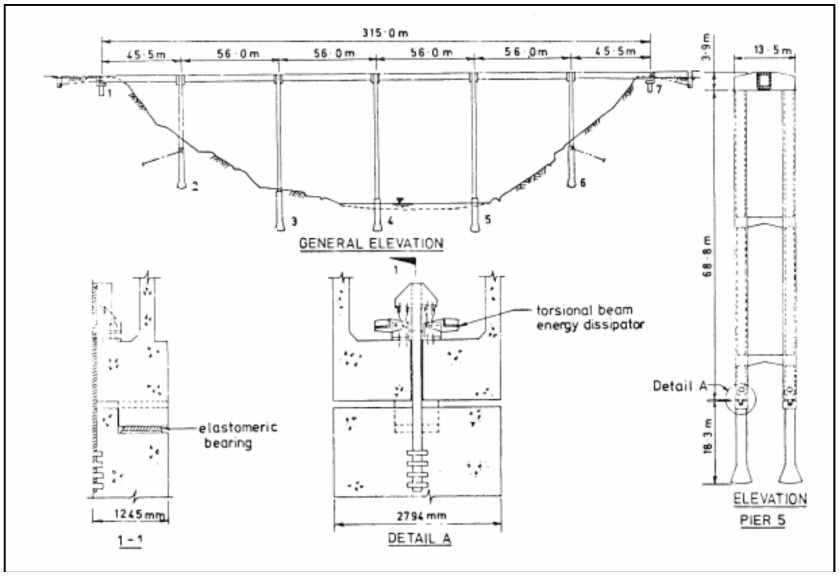

Fig 8: Details of Rangitikei Bridge

Hysteretic Dampers: Tests and Development

The main goal is the development of a range of large-capacity, low-cost hysteretic dampers which are appropriate for its application in earthquake-resistant structures. These dampers should have a trustworthy life up to multiple hundred cycles.

Many researches carry out regarding to development of earthquake control system. The aim of using these system is decreasing the reaction of structure which are using hysteretic dampers. The aim of using these system is protecting of steel weight and concrete content in order to keep seismic safe and human tranquility of building in time of earthquake. In tall buildings, the honeycomb dampers are using a new system of steel plates with a honeycomb-shaped opening (Figure 9).

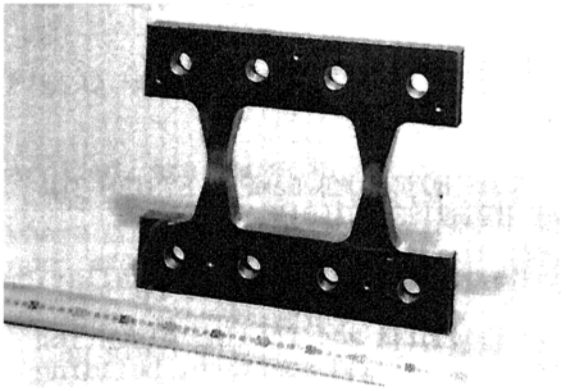

Fig 9: Honeycomb damper plate

In this system, energy-absorbance valence is good usage by assembling steel plates between stories which are consecutively along the tall building, but this system is only operate when bars are acting on their surface.

For big size structures, the joint damper is applying in order to control reply of building by putting dampers between two or more neighbor buildings with various inherent frequencies. In this type of dampers, energy-absorbance valence is best usage by focusing on set of dampers at the place where a big movement is happening. In old use of these dampers, the bell-shape dampers were used for real building, but now, the joint dampers are utilizing for big structure of interior ski slope, which is using hourglass-shape dampers (Figure 10).

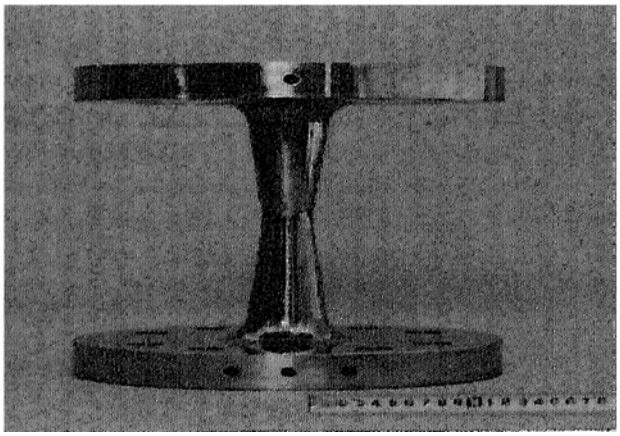

Fig 10: Hourglass shape damper

Cyclic change tests were executed on a big number of dampers of each basic type. The measure and shape of the damper ingredients was different from a broad range to expand useful dampers, and to clear the method in which these factors control the damper efficiency. The tests were doing on an Instron machine which could locate to cycle automatically. Bar-deviation relationships are drawing below and it's result to a loops that gave the stiffness, force and energy-absorbing traits of the dampers. The damper expansion program includes the determination of design criteria for each damper. A suitable explain of the efficiency of a damper is specified by the bilinear loops which approximate its hysteresis loops. The factors which is used here to explain hysteresis loop have demonstrated in Figure 11 that are outcomes of restriction of tests on torsional and flexural dampers.

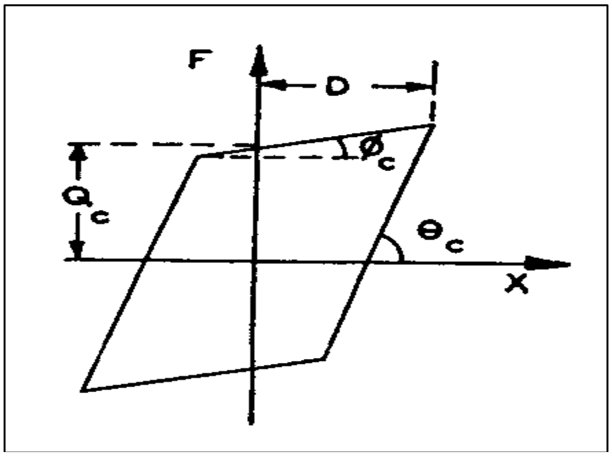

Fig 11: parameters used to define a bilinear loop which appropriate for hysteretic dampers

Simplified samples for dampers

When expanding explains for the bilinear loop factors of the dampers, in case of their geometries and effective features, simplified samples applied. Only the changes were assumed, rolling as a shaft for dampers of type A, torsion only for type B and flexure only for types *C* and D. For the big-stiffness bilinear factor, tan θ_c, elastic beam theory, for the less-stiffness factor, tanΦ_c, and for the useful coulomb damper force Q_c, it was considered that an elastic beam of low stiffness coefficient in parallel with a tough plastic beam. For type C and D dampers the flexible inelastic area was limited to a small duration neighbor the beam harbor. The substantive utmost force*,* was based on elastic beam theory. The useful features were inferred from a measurement between scale of hysteresis loops and the bilinear loops attained from the simple samples.

Rolling-bending of thin U-shaped strips

The test included of two U-shaped strips, assembled on both side of a loading beam. After a few period of inelastic change, the bent part of the strips set asymmetric, non-circular shapes which enhanced the maximum flexion by 50 per cent or more. After multiple tens of cycles, twits to form in the strips, especially when the first bent gave a less inelastic strain. The simplified sample explained is utilized to deduced for statements for the maximum bar *F,* the energy which is absorbed per unit volume e and the substantival maximum strain E, which give some sign of the result of geometrical parameters on the properties of these dampers

$F = \sigma bt2/2R$, $e = 2FcD/(nRbt)$, $E, = t/2R$ (1)

Where

σ = effective cyclic yield stress

= 60,000 Ib/in2, for 10 per cent strain in mild steel

b, t, R = width and thickness of strip, and mean radius

D = displacement of the loading beam

c = (hysteresis area)/ (circumscribed rectangle area)

= 0.65 for large *D*

To restriction of the formation of kinks suitable strain ranges are 0.05 to 0.1, and for these strains the life, a damper with *b* = 3 in, *t* = 0.5 in, *R* = 2.75 in and *D* = *2* in gave area from about 150 cycles down to 70 cycles.

F = 9,000 lb, *e* = 1,800 in-lb/cycle/in3, *c* = 0.65 and *E,* = 9 per cent

The cycles to failure were 80 and the force *F* had fallen only a few per cent after 75 cycles.

Torsional-beam dampers

An easy figure of damper is torsional-beam, this damper gives a big energy absorption per unit valence of shaped beam, and it has a life of multiple hundreds of period if appropriate contacts are made between the loading arms and the inelastically changed beam.

Flexural-beam dampers

A range of flexural beams tested and it was demonstrating that the energy-absorbing valence, per unit content of beam, was around two-thirds of the absorbing valence of torsional-beam dampers. With suitable anchorages for the linchpin their life was multiple hundred cycles.

Conclusion

The simple damper, and the combined dampers which may be create from them, is different in their geometry and in their efficiency properties. Torsional dampers cannot be built much dense since the beam, the lever arm and the loading axis are bilateral vertical. It would possible to measure these dampers easily for damper energies to around 2 x 105 lb. When a flexural beam is applied for forces through a single axis it can be a big valence. A flexural damper in the figure of a simple based beam, with suitable focal anchorages, should prepare damper energies to above of 10^6 lb.

structures with dampers between different towers and frames should be middle in expense and be more less responsibility to structural loss. The responsibility to non-structural loss is same for more typical structures with central towers. If properly stiff dampers are expanded the same properties that could be attained with dampers on frame braces.

For structures which includes steps, damping only is needed, using steel devices are better from view of cost and simplicity. The research has not shown any sign of age frangibility of the steel beam dampers while the recent trend is to prepare for the feasible movement of systems that are important.

Structures with a base system may made easily by applying torsional-beam dampers or flexural-beam dampers. Combination of base systems, which involves both flexural-beam dampers and laminated rubber bearings, are studied. As combination isolators might involve ingredients which stand out against uplift of the structure. With base structures it is feasible to make highly trusty conservation from both structural and non-structural loss.

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