THE SEISMIC PERFORMANCE OF ENERGY ABSORBING DAMPERS IN BUILDING STRUCTURES

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SUMMARY

A ten storey office building structure incorporating hysteretic dampers is studied by time history analysis, using five simulated earthquakes. Three different configurations are examined. The first uses a joint introduced between the shear wall and column-beam structure. The second and third involve the introduction of soft elements into the structure.

The effect of the three systems on shear and displacement is examined, showing substantial improvements in performance.

INTRODUCTION

By separating the stiff shear walls of the structural core of a building from the more flexible column/beam/slab structure, two independent structures with markedly different dynamic properties are formed. By introducing damping elements between the two, energy is absorbed during earthquakes, giving considerably improved response characteristics.

A structure designed to resist earthquake motion needs the capacity to dissipate energy. The inherent damping of typical structural materials is low while performing within the elastic range, so that most energy dissipation takes place in the form of inelastic material response. In a typical framed structure this is likely to be localised in the vicinity of beam to column connections and at the base of shear walls.

Non-linear behaviour of the connections presents a number of problems. In the first place, large displacements involve a high level of non-structural damage. Secondly, the reliability of the connections themselves is questionable. Steel connections suffer from local instabilities and reinforced concrete frames are subject to diagonal tension and bond failures.

Even in the best designed structures there is an inevitable consequence of strong ground motion i.e. heavy structural and non-structural damage. In consequence, the concept of an independent, replaceable, energy absorbing element is in principle an attractive one. The initial damping values of the system are increased and in a major earthquake when stuctural damage would normally be expected, energy dissipation would mainly take place in discrete elements with little damage taking place in the structure. The load carrying function of the structure and the energy absorbing function would thus be separated.

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Structural configurations

Building structures can generally be divided up, on plan, into:-

* "Usable" floor space.

* One or more core areas containing lifts, stairs, toilets and services.

* External wall.

The core and external wall may be used to provide stiff shear walls, or equivalent braced system, whereas the usable floor area is generally supported on a minimum of columns and is relatively flexible in response to lateral forces. Hence for structural modelling purposes the building structure can be divided up into two elements.

* The usable floor area will comprise most of the building mass, but will be relatively flexible laterally.

* The core and external wall will comprise a lesser proportion of the building mass, and their stiffness laterally is very much larger than that of the framed structure.

In this study the building structure is divided into two components, the P structure and the Q structure, both illustrated in Figure 1. The P structure consists of the ten storey reinforced concrete framed structure, and the Q structure the shear walls.

Three structural arrangements are examined. Distributed damping is shown in Figure 3 and comprises the basic structure, with a joint introduced between the shear wall core and the framed section. Discrete damping elements are introduced across this joint at each floor level.

Level 1 damping dispenses with dampers at all levels above the first, and introduces substantially lower lateral stiffness at level 1. This system is essentially the same as that of isolation, which can be regarded as a special case of the use of dampers. The general arrangement is shown in Figure 2.

The filter system uses two levels of damping. At the first level, damping is introduced as before but at the second level, the damping is added between the first and second levels of the flexible structure. This is illustrated in Figure 4. Such an arrangement acts as an effective filter to vibrations transmitted from the ground to the superstructure.

Dampers suitable for this type of application are described by Kelly (1) and Skinner (2,3).

Analysis

The structures examined here utilise hysteretic type dampers. These are located in a structural joint so that forces are developed in the damper from differential displacements across the joint.

Analysis is carried out in the time domain. A bilinear hysteresis response is used to represent the damper. The appropriate damper force vector is arrived at by iteration at each time step. The P structure is modelled as a shear type structure with a single translational degree of freedom for each floor.

The earthquake records used are computer simulated accelerograms, each of 20 seconds duration and scaled to a maximum acceleration of 0.3g. They are representative of strong ground motions in firm ground.

Distributed damping

Results for distributed damping are plotted in Figure 3. Displacement response is normalised as a ratio to the response of the free standing P structure. Damping is expressed as a ratio of total peak damper force to the mass of the structure. The structural properties are those shown in Figure 1.

It is seen that the level 1 displacement response reaches a minimum of 0.45, while the level 10 value shows a steady reduction to approximately 0.2. The optimum value of damping is 0.6. Interstorey response values generally range between those at levels 1 and 10.

Shear response values are normalised to those for the structures rigidly connected. The base shear response for the combined, damped structure shows a pronounced minimum of 0.35 at damping of 0.3, while the Q structure shear shows a progressive increase over the area of concern, being 0.24 at a damping of 0.6. The shear response values approach a value of 1 as the damping is increased but show local departures from the asymptote line, which accounts for the local peak shown between damping values of 2.0 and 2.5.

Level 1 damping

Results for level 1 damping are shown in Figure 2. Normalisation of damping is the same as that for distributed damping but the base shear response is the ratio to the response with level 1 rigid. In this way the effect of modifying level 1 on the upper nine storeys is seen. Displacements shown are actual values as it was felt that this was critical in assessing the system.

The structural model used is that of the P structure shown in Figure 1, with the level 1 stiffness modified as shown. The shear wall is assumed to be effectively rigid.

For the three values of main structure natural damping, which cover the area of practical interest, similar type results are obtained. For the two lower values of k_1 the mimima are outside the range examined, but for the two higher values pronounced minima are shown in the region of damping of 0.1. However, in order to avoid excessive displacements at level 1, higher design values would probably be used.

Comparison of the three plots clearly illustrates the effect of natural damping. As natural damping is increased the effect of added damping is reduced. However, it must be borne in mind that the datum values are reduced with increased damping, so that the errors in estimating natural damping have very little effect on response.

Filter system

Figure 4 shows the filter system configuration and response plot. An important difference from the previous two arrangements is that the mass at level 1 is increased by a factor of five. This would be in accordance with a podium type building for which this arrangement is particularly suitable.

Base shear is taken at level two, following the reasoning used for level 1 damping, the response being the ratio to base shear with the lower two levels rigid. Actual values of displacement are given. The analysis is made for the following values:-

$k_1 = k_2 = 12.5$ MN/m

$pd_1 = 0.52$ N/Kg

The plot shows level 1 displacement to be more or less constant at 25 mm, and level 2 displacement decreasing with increased damping. The minimum base shear response ratio is 0.06 with damping of 0.18, at which point level 1 displacement is 80 mm.

Design implications

The distributed damping system shows substantial benefits in reducing shears and displacements. In particular, it enables a shear wall system to be used without paying the penalty of the wall taking very high shears. For the normal, rigidly connected system the shear wall is required to resist almost the whole of the lateral force under elastic conditions, leading to problems with member design and stability. The damped system offers a solution to this by very substantially reducing forces on the shear walls.

With level 1 damping, improved shear response is achieved with less damping but some penalty is paid in increased displacements at the lowest level.

The filter system shows the most impressive results, again with some penalty being paid in increased lower level displacements. Its use is not limited to cases where the lowest floor mass is larger than the upper levels, but this arrangement brings out its maximum potential.

Conclusions

The study carried out suggests considerable potential in design application for this system.

Initial studies suggest that the savings in structural cost will be larger than the additional costs involved in providing for both the dampers and the structural jointing. However, other benefits arise in the form of improved response to moderate earthquakes and reduced risk.

References

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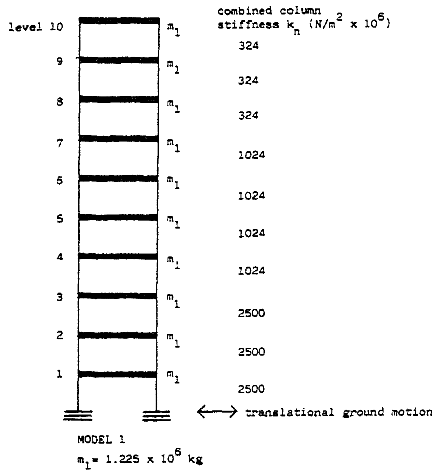
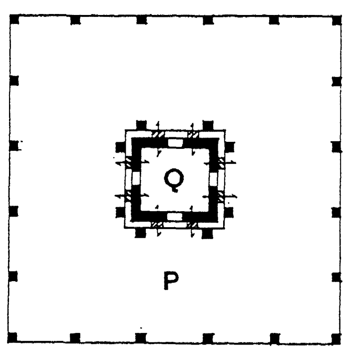


P STRUCTURE
ARRANGEMENT

FIRST FIVE UNDAMPED NATURAL FRQUENCIES

MODE	1	2	3	4	5
ω (rads/sec)	4.66	10.92	18.99	23.68	29.21

P STRUCTURE
MODAL DATA



P & Q STRUCTURES
PLAN ARRANGEMENT

UNIDIRECTIONAL DAMPER

FIGURE 1 DETAILS OF REINFORCED CONCRETE STRUCTURES

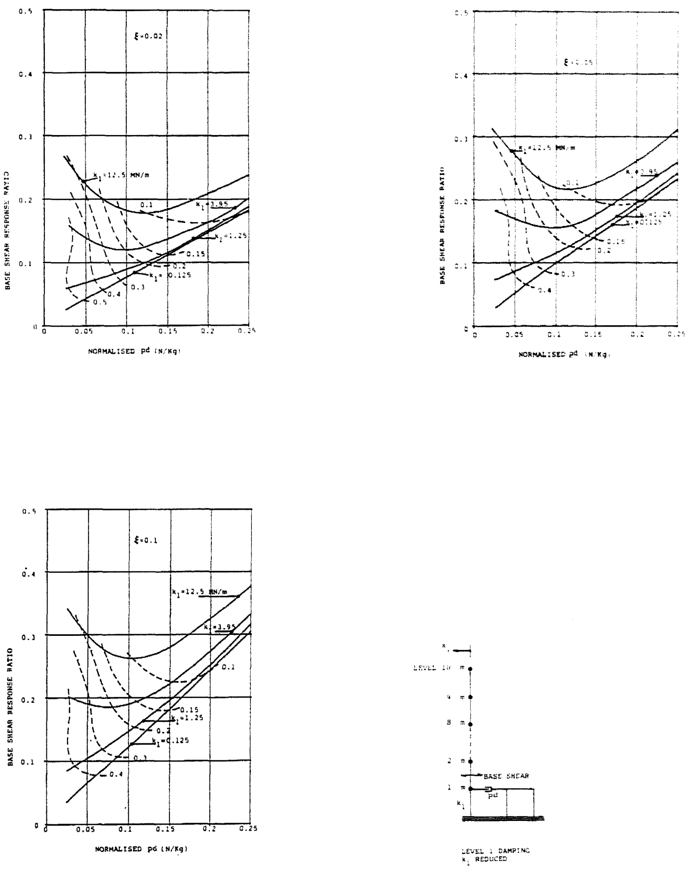


FIGURE 2   LEVEL 1 DAMPING

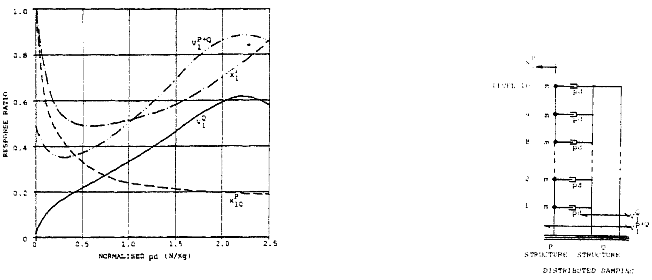


FIGURE 3   DISTRIBUTED DAMPING

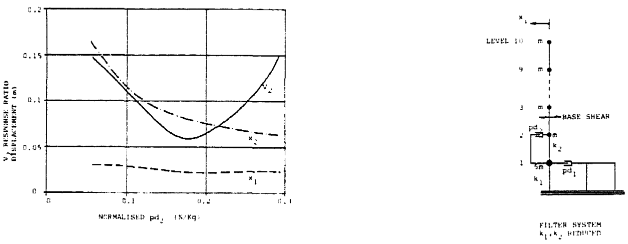


FIGURE 4   FILTER SYSTEM