ENERGY ABSORBING DEVICES IN STRUCTURES UNDER EARTHQUAKE LOADING

by

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SYNOPSIS

Several different types of energy absorbing devices have been proposed for incorporation into structures designed to resist earthquake attack. The basic concept is that the energy dissipating, needed to absorb the kinetic energy imparted to the structure by earthquake loading, can be concentrated in devices specifically designed for that purpose. In previous work we have described a particular type of device which operates on the principle of large plastic deformation of mild steel in torsion. It has been shown that the device can provide substantial energy absorption over many cycles of plastic deformation, that the lifetime of the device and its absorption capacity are not decreased by increasing strain rates or by random loading.

In this paper we describe a series of tests in which a half scale three story single bay steel frame fitted with these torsion type energy absorbing devices was subjected to simulated earthquake loading on the 20 ft. square Earthquake Simulator Facility. The results of the tests are compared in this paper to those for two other series on the same frame when the devices were not used. The test series are taken as establishing the feasibility of the energy absorbing device concept.

INTRODUCTION

Many structures are currently designed for multiple load carrying and resisting capacities. Where earthquakes constitute a hazard, a serious problem may exist in that multi-functional structures may not only suffer damage to their seismic resistance capabilities but also to their normal load carrying capacities as well. All structural mechanisms for the absorption of seismic energy simultaneously diminish the capabilities of structures to carry loads under normal gravity and wind conditions. Even if repairs are effected after each earthquake attack there is always the possibility that some structural damage has accumulated in the structure.

The underlying theme of the work reported here concerns the separation of structural earthquake resistance from structural load carrying capacity; the structure is designed to resist gravity and wind loads and special energy absorbing mechanical devices are integrated into the structure to provide seismic resistance and thus to protect the major structure at the expanse of the replaceable energy absorbing devices. The effectiveness of such devices may be enhanced by incorporating them into a base isolation system which not only isolates the structure from seismic energy but channels such energy into the devices. Possible isolation systems include designs incorporating flexible first stories or stepping support foundations.

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The benefit/cost ratios of such designs are favorable. The major structure can be designed to be lighter and more economical since much of the damaging seismic energy can be absorbed by the devices. Low maintenance and replacement costs are possible. The devices can be designed to resist corrosion and require little monitoring and to be replaceable without disruption to the main structure. The cost of the devices would be a small percentage of the major structure cost.

A study of the feasibility of such devices has been reported by Kelly, Skinner, and Heine [1,2] in which various mechanisms of energy absorption were studied. The characteristics of these mechanisms which were of primary importance were the load displacement relationships, the energy absorption capacity and the low cycle fatigue resistance. It was shown that the plastic torsion of mild steel is an extremely efficient mechanism for the absorption of energy and that the mode of failure in torsion is a favorable one for use in an energy absorbing device in that it takes the form a a gradual decay.

The research to be reported in this paper is concerned with the experimental verification of the use of energy absorbing devices in earthquake resistant design. We have recently been able to carry out in a series of tests in which a three story model steel frame was fitted with energy absorbing devices and subjected to several earthquake loadings on the 20 ft. square shaking table at the Earthquake Simulator Laboratory of the Earthquake Engineering Research Center. The column bases of the frame were fitted with a special type of footing which provided full horizontal constraint but allowed the bases to move freely vertically. Roller bearings are incorporated to facilitate free vertical movement. The frame so fitted was subjected to a series of simulated earthquake loadings using the El Centro N-S 1940 record scaled up to a maximum intensity of .786g. The results of this series of tests on the free uplift frame has been reported by Huckelbridge and Clough [3].

Following these tests the column bases of the frame were modified to include torsion type energy absorbing devices with one device at each column base. The devices were located in such a way that they operated only when the column foot lifts off the foundation, in this case the shaking table. When the column foot lifts up the device produces a downward restraining force which is almost constant and when the foot moves back downwards the device produces an upward force, thus absorbing energy from the frame.

The results of the present series are compared in this report with previous El Centro tests on the frame with the feet tied down and the feet free as reported in [3].

TEST PROGRAM

The test structure is pictured in Fig. 1. A complete description of member sizes and connection details is given by Clough and Tang [4]. Details of the modifications needed to allow the column feet to uplift are given by Huckelbridge and Clough [3]. It should be noted that the feet although free to move vertically are constrained by the uplift mechanism to follow the horizontal displacement of the table. The modifications of the uplift mechanism to incorporate the energy absorbing device are shown in Fig. 2, and details of the design of the device are given in Fig. 3.

The data acquisition system of the University of California shaking table has been described by Rea and Penzien [5]. Up to 128 channels can be monitored in discrete sampling intervals, and the digital data stored on the disk of a mini-computer system. Subsequently the data is transferred to magnetic tape for detailed reduction. For the tests described here, 36 table functions and 90 transducer channels on the model were monitored, with a sampling frequency of approximately 50 points per second for each channel.

During the tests 5 types of electrical transducers were utilized to provide data: accelerometers, potentiometers, DC LVDT's, strain gages and half-bridge on-off contact switches. Accelerometers monitored the three horizontal floor accelerations and the table acceleration. Potentiometers and DC LVDT's monitored the three horizontal floor displacements relative to a fixed reference station off the table, the vertical displacements of the four column bases relative to the table surface, and selected frame member displacements. Strain gages were positioned on the various members to give the complete force distribution throughout the structure. The contact switches were placed between each column base and its impact pad to indicate the times of separation of the two elements during uplift.

The tests were carried out with six different intensities of the El Centro N-S 1940 record without vertical component with maximum intensity up to .786g. The intensities used here were the same as those of the tests reported in [3].

EXPERIMENTAL RESULTS

The results of the test series were very positive. At each intensity (from about 10% g max. to about 75% g max.) the uplift of the frame footings and the relative story displacements with devices was much less than when the frame was free to uplift as shown in Figs. 4 and 5. The column tension and base shear with devices were also much less than those experienced when the frame feet were rigidly fixed to the foundation as indicated by Figs. 6 and 7. Although not illustrated comparisons of base overturning moment produced the same results as the base shear. A summary of these results is given in Table 1.

CONCLUSIONS

Comparisons of the results for the case with energy absorbing devices with those for the base fixed and with those for the frame without any anchorages show that the use of the devices is generally beneficial. The devices offer enough base restraint to keep relative story displacements almost the same as in the fixed base case but substantially less than when the frame was uncoupled vertically from its foundation. Yet the devices absorb enough energy and allow partial base uncoupling to reduce column forces to levels much less than those for the fixed base case and to levels comparable for the unanchored case. Another notable fact is that the base shear and overturning moments were reduced by the devices to less than those experienced in both the fixed base and free base cases.

Thus it is believed that the tests have established the feasibility of the use of energy absorbing devices in seismic resistant design, at least in so far as El Centro type earthquakes are concerned. Work on the response to other types of earthquakes is continuing.

BIBLIOGRAPHY

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5. D. Rea and J. Penzien, "Dynamic Response of a 20 ft. x 20 ft. Shaking Table", Proceedings of 5th World Conference on Earthquake Engineering, Rome, 1973.

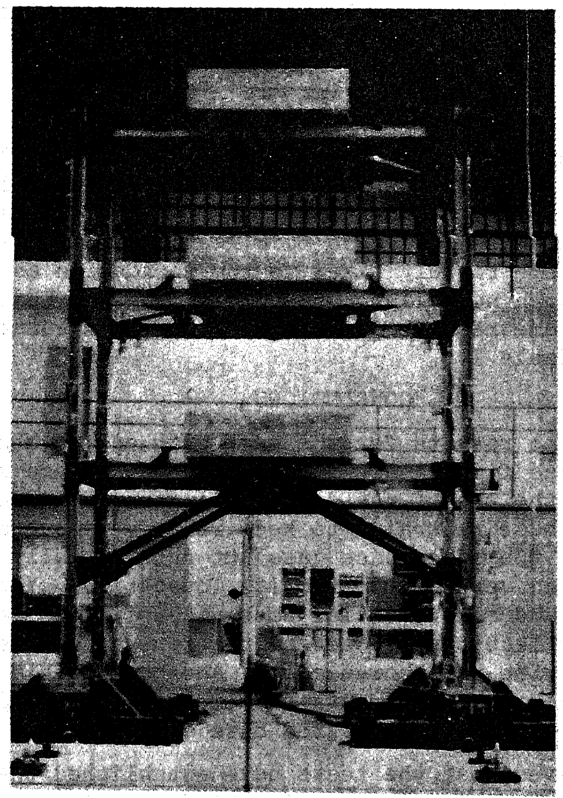

FIG. 1. TEST FRAME.

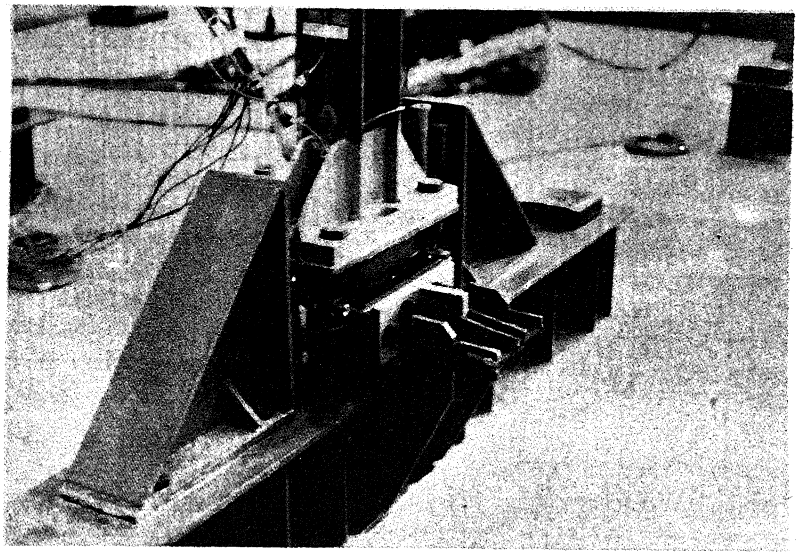

FIG. 2. COLUMN FOOT DETAIL.

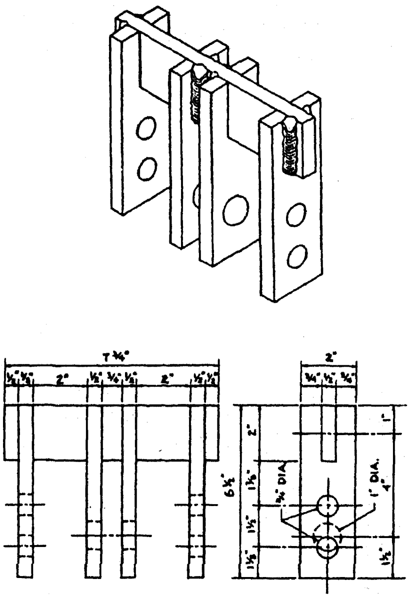

FIG. 3. TORSION DEVICE.

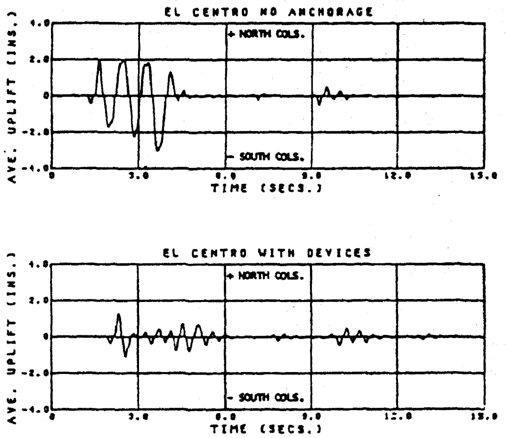

FIG. 4. VERT. UPLIFT DISPL. COMPARISON.

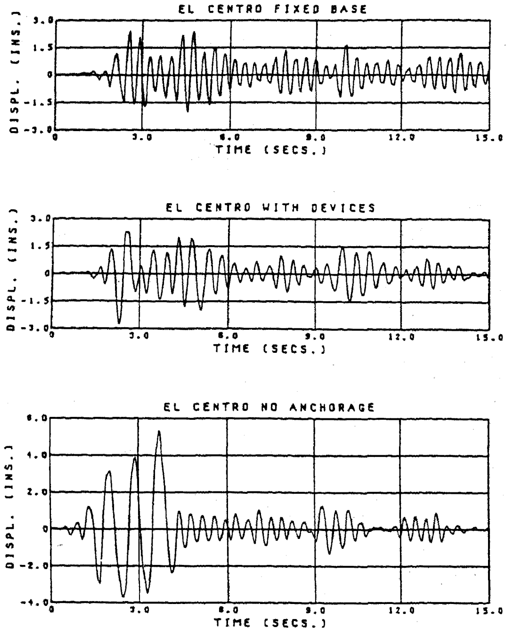

FIG. 5. REL. 3RD. FLR. HORT. DISPL. COMPARISONS.

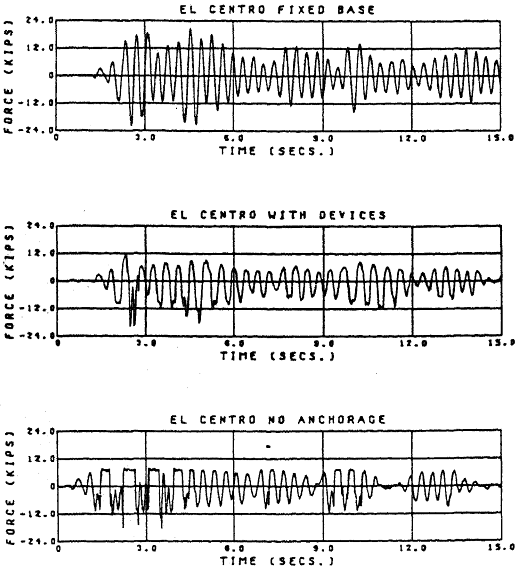

FIG. 6. 1ST. FLR. NORTH COL. AXIAL FORCE COMPARISONS.

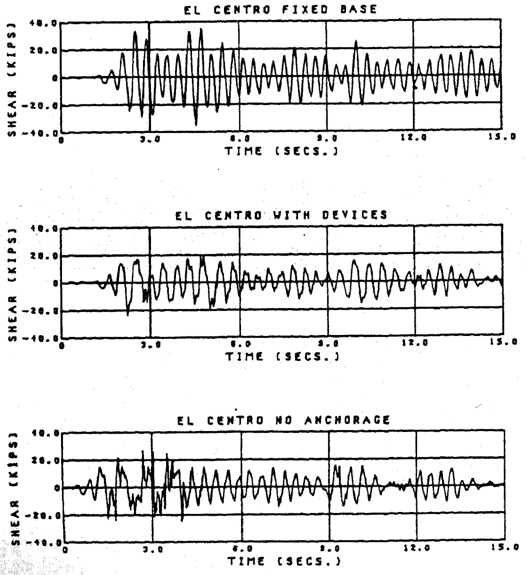

FIG. 7. BASE SHEAR COMPARISONS.

SUMMARY OF EL CENTRO PEAK RESPONSES

	FIXED BASE	WITH DEVICES	WITHOUT ANCHORAGES
AVE. UPLIFT			
NORTH COLS.	0"	1.26"	1.99"
SOUTH COLS.	0"	1.10"	3.03"
REL. 3RD. FLR. DISPL.	+2.43" -2.02"	+2.29" -2.74"	+5.34" -3.72"
1ST. FLR. COL. AXIAL FORCE			
NORTH COL.	+20.76 K -22.14 K	+11.64 K -19.93 K	+7.85 K -18.44 K
SOUTH COL.	+22.10 K -18.93 K	+14.42 K -13.33 K	+8.99 K -20.50 K
BASE SHEAR	+35.21 K -35.53 K	+19.57 K -24.11 K	+26.90 K -25.25 K
BASE OVERTURNING MOMENT	+471.3 K-FT -434.3 K-FT	+278.7 K-FT -297.7 K-FT	+323.2 K-FT -296.1 K-FT

TABLE 1

DISCUSSION

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For electrical equipments like circuit-breakers should the dampers be used between equipment and foundation to make them suitable for earthquake conditions. But this will increase displacement of equipment in case of earthquake which may not be desirable in some cases. Further this will also bring the frequency response of the equipment within critical zone of say 1 Hz to 15 Hz which may cause resonance. Other method may be to make the equipment rigid such that first mode of frequency is out of critical zone, but the equipment is made strong enough to withstand the full seismic acceleration. In this case displacement will be very small. In the opinion of authors what is preferable design phylosophy for electrical equipment.

Author's Closure

Authors thanks Mr. Bansal for his interest in their paper.

The paper itself will not give an answer to his question because the paper is not concerned with the use of damper between equipment and foundation which he asked about.

Apart from the paper, author's basic way of thinking in the control of vibration is to make best use of all possible ways under given condition. Therefore the way to take will differ from case to case. It would be wiser not to stick to either the use of damper or the rigid construction.