SOME ANALYSES OF MECHANISMS TO DECREASE EARTHQUAKE EFFECTS TO BUILDING STRUCTURES (PART 4)

STEEL DAMPERS

by
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SYNOPSIS

There are two fundamental methods in the aseismic design of buildings: one is to make structures strong enough to resist earthquake forces, and the other is to control input earthquake forces and minimize the effects to the structures. The authors have submitted papers concerning the latter at previous conferences.1)2)3) In this presentation the installation of a steel damper is proposed and the effect of earthquakes on structures so constructed is discussed. When this damper is installed in combination with a double column system in tall buildings of 15-20 stories, the shearing force produced by earthquakes is reduced by about 30% in comparison with ordinary structures of a similar height.

INTRODUCTION

Earthquake force-control-systems:

A. Avoid pseudo-resonance phenomenon.
B. Consume input-energy.

A. When the predominant periods of the input force are quite different from the natural periods of the structure, or the natural periods themselves vary from the ones before a pseudo-resonance state was produced, the response of the structure to the earthquake can be controlled to a certain extent. This method is quite effective when the input is of a narrow band characteristic.

B. Consuming input energy is effective in controlling major responses in structures. In the case of a building, energy is mainly consumed as damage to both structural and non-structural members, and repair costs after a strong earthquake are usually large, especially when the damage is scattered throughout the structure. If one wants to design the structure so that large amount of energy may be consumed without damage, a kind of damper should be used. However, installation of dampers is usually not thought to be effective because it is difficult to design and install dampers such that structural damage remains slight in cases of large relative displacement. Moreover, it is difficult to expend the relative displacement between the structure and the ground, except when the structure is not big and heavy (as in the case of gas tanks). Finally, the maintenance of damper for many years is generally troublesome and expensive. However, we believe that under the following conditions dampers will be effective:

(1) When there is a suitable structural component where a damper may be installed and where large relative displacements without structural-failure may be expected.
(2) Where the damper is maintenance free and renewable.

An example that satisfies the above conditions is a steel damper installed in a double column system.

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DOUBLE COLUMN SYSTEM[3)]

In order to vary the natural period of a building such that it will respond well to an input sorce of various frequencies, a double column system has been proposed. For waves of high frequency with small amplitude(displacement), the flexible inner columns resist the shearing force, and for low frequency waves of large amplitude, the inner and outer columns cooperate to support the structure against the force. At this moment the stiffness of the structure is increased. This system is easily adoptable when a building is supported by thick piles.(See Fig.1 A,B) When the expected difference between the relative-displacements of the outer and inner columns is large, in order to further stabilize the structure these two columns are connected by double beams. The gaps between these beams are exactly where dampers can be installed.
This system is efective when the building is not very flexible and when it is built on firm ground. Because of insufficient strength and because of additional forces and moments caused by the weight of the building, it is thought that the flexible inner column system will react undesirably in strong earthquakes. Therefore double columns of RC are not recommended. Instead steel columns of thick box or ring sections should be used especially for the inner columns.

STEEL DAMPER

Steel bars are not expensive and are easily maintained. The ductility of the steel bars may be utilized as a solid damper. The steel bars are curved so that they may easily bend and yield in small relative-dilplacement situations. After a simple calculation based on an idealized SS diagram of the steel, one obtains;

$$M = \int_0^S \frac{\sigma_y}{S} \sqrt{r^2-y^2}\, y^2 dy + 4\int_S^r \sigma_y \sqrt{r^2-y^2}\, y dy \qquad \text{Eq.(1)}$$

Where M: the bending moment
r: the radius of the bar
σ_y: the yield stress
S: the radius of the elastic range

$$\left.\begin{aligned} Q &= 2Ml_1/(h_2 l_1 - h_1 l_2) \\ N &= 2Mh_1/(h_2 l_1 - h_1 l_2) \end{aligned}\right\} \qquad \text{Eq.(2)}$$

(See Fig. 2)

From the Eq.(1) and (2), P-δ diagrams of bent steel bars of various diameters are calculated as in Fig. 3. By adjusting the length, curvature and diameter of the bar, one may get suitable P-δ relations for the structure. After simple calculations and test, ring-shaped and coil-shaped bars were adopted for static tests of the damper. Because of the non-elastic hysteresis of the input energy is converted to heat and consumed without accumulating strain energy. Fig. 4. A, illustrates the test-method and B shows the results. The P-δ diagrams obtained through the test shows that curved steel bars have preferable characteristics as solid dampers. Bent bars were joined to steel plates by welding. No cracks were produced in the bars or joined parts after more than twenty repeated loadings in possitive and negative directions. Considering that the bars were deformed in at least two directions, coiled bars appear to be more suitable than the ring-shaped bars.

SAMPLE ANALYSIS

A sample building was designed and earthquake resistance calculations of its structure were made using ordinary design steps as shown in Fig. 5. The building had 14 stories above ground and 2 below and was designed to be used as a hotel. It was supported by piers set on a solid gravel layer at 16.3 meters below GL. The building was symmetrical with respect to both axes, and the main frames are made of steel reinforce concrete(SRC). (See Fig. 6 A,B)

Double columns were used between B1 and the second floor. The dampers welded to steel plates were installed in the gap between the double beams by bolts, and they were covered with fire-proof materials. Both the upper and lower beams were connected to rigid strong RC walls such that part of the shearing force in the upper walls will be transmitted to the lower walls through the dampers when the relative displacement is small. For a large displacement, the damper works as a tension member, and a large portion of the shearing force can be transmitted from the upper walls to the lower walls.

The model for dynamic analysis is shown in Fig. 7 and the vibration characteristics are calculated in Fig. 8. Fig. 9 shows the calculated response of the model, illustrating controlled displacement and a decrease of shearing force. The dotted lines are the response of a similar building where dampers and double columns are not used. The P-δ diagram for the ground story where the mechanisms are installed is shown in Fig. 10. Fig. 11 shows the details of damper installation. The damper is designed so that it may be renewed after a severe earthquake.

Because of the decreased shearing force, the required quantity of reinforcement is reduced. And most of the structural members remain within their range of elasticity even when a very severe earthquake, max. 400gals, shakes the building.

CONCLUSION

The bending of coiled steel bars should be utilized as a solid damper. As this type of bar moves into its plastic range with only a small displacement, one may expect energy to be absorbed in a response of small amplitude. This damper is cheap, easily maintained and renewable, and it is effectively used when combined with the double column system of construction. In this sample calculatin the shearing force was decreased by more than 30% in comparison with ordinary buildings of the same scale, and the whole structure remained elastic during strong earthquakes of a max. 400gals. It seems that the increased cost of the double columns, beams and dampers can be compensated for by the decrease in shearing forces(damage) in upper stories. When the double column system is designed within the piers as shown in Fig. 1 B, then cost increases may be minimized, and it will certainly pay when one considers after-quake repair costs.

REFERENCE

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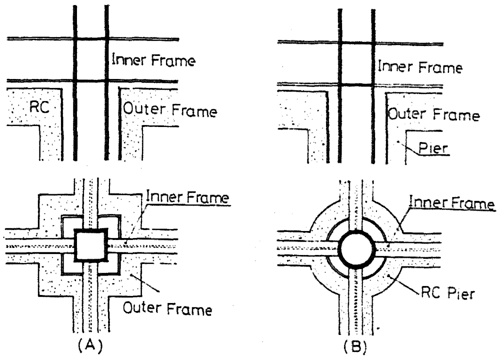
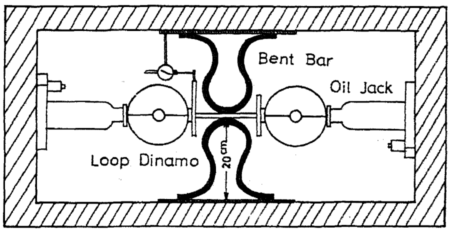
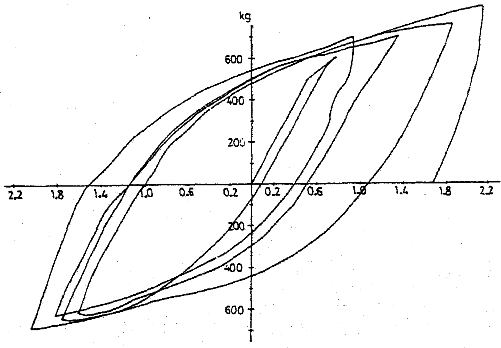


Fig.1. Double Column System



A. Instrumentation of Test



B. P-δ Diagram

Fig.4. P-δ Diagram of Damper Obtained from Test.

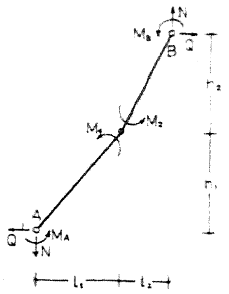


Fig.2. Bent Bar

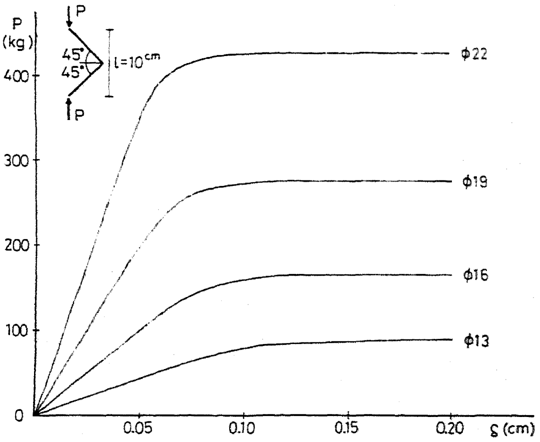


Fig.3. Calculated P-δ Relation of Steel Dampers

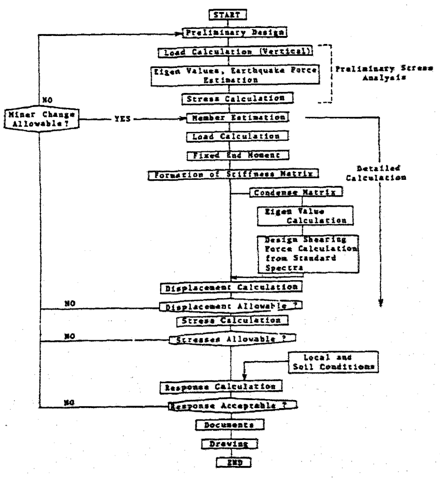


Fig.5. Structural Design Process