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EFFECT OF DYNAMIC TUNED CONNECTOR ON REDUCTION OF SEISMIC RESPONSE -APPLICATION TO ADJACENT OFFICE BUILDINGS-

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SUMMARY

We conducted in attempt to reduce seismic structural response during earthquakes, by inserting dampers in-between two adjacent buildings. The device used is a hysteretic absorption type damper made of steel. It possesses both, stable hysteretic characteristic of high stiffness, and superior energy absorption efficiency. As this device has no directional element it is also effective for controlling building torsions. Static and dynamic loading tests were conducted to verify the efficiency of the damper. Also, seismic response analysis was conducted to confirm seismic response reduction effect of the system.

INTRODUCTION

The objective of aseismic design is to protect the human life and property from earthquake damages. The present aseismic design method of Japan is to prevent collapse of buildings by increasing the structural strength or by providing it with ductility. Furthermore, with the aim at higher quality of buildings, we are conducting research on establishing a seismic response control system. Among the seismic response control system under our research, there are two types. One is the 'active type' in which the vibration of the building is controlled by self-alteration of its own characteristics every moment against the earthquake. The other is the 'passive type' in which the damping function of the building is increased by effective distribution of the damping system. The system presented in this paper pertains to one of the passive types, which we call the joint damper system, in which the seismic response control of two adjacent buildings are achieved by inserting the dampers in-between the two buildings.

The foregoing system was applied to the Headquarters Building No.2 of Kajima Corporation to be built at Akasaka, Tokyo. For its application a damper device was developed which possessed both, stable hysteretic characteristic of high stiffness, and superior energy absorption efficiency. This was named the 'dynamic tuned connecter', moreover from the shape of the device, we gave it a nickname, 'bell damper'. In order to verify the efficiency of the bell damper, static and dynamic loading tests were conducted. Also, seismic response analysis was conducted to confirm the seismic response reduction effect of the system.

BELL DAMPER

The configuration is shown in Fig.1. The bell damper consists of; a) the damper part which was designed to plasticize as much portions as possible in order to increase the energy absorption capacity, b) the top part of the pin connection which transmits only the lateral load to the functional (atrium portion) structure, and c) the base part of fixed connection in which the bending and shear forces are transmitted to the subject (adjacent) structures. Also due to its near conical shape the directional tendency has been eliminated, so it is effective to any direction within a plane. The method of manufacturing this damper, is by forging a rod steel of Ø20 cm as close as possible to the the shape as shown in Fig.1. Then it is given a heat treatment so that the remnant influence of the forging is eradicated, and then processed to the final shape by a cutting machine.

OUTLINE OF SYSTEM

The exterior appearance of the building is shown in Photo 1. The layout plan and cross section is shown in Fig.2. This building has one basement floor and nine stories above ground. The layout of the building is complex with an 'L' shaped 5 story 'building A', and a 9 story 'building B', with an 'L' shaped atrium of 4 layers height above the second floor, in-between the two buildings. The two buildings are connected by passageways in 3 places, but are separated structurally by expansion joints. The bell dampers are installed in the roof portion (Fig.2) of the passageways. The weight of the passageway structure is sustained by separate roller supports so that the bell dampers will bear only the lateral load. When an earthquake occurs the bell dampers absorb the energy effectively and controls the seismic response of both sections. Moreover, the bell dampers suppress the torsional motion of the building. The basic performance of the bell damper, regarding such as, stiffness, resistance force and energy absorption ability was determined by parameter study.

LOADING TEST OF BELL DAMPER

Test Specimens Tests were conducted on test specimens of the same shape and same material property (SS41) as those of bell dampers actually installed in the building. The specimens are the 7 indicated in Table 1. Besides those shown therein, 7 more test dampers were made that were different in, shape, material property and manufacturing method, and were subjected to load tests. In consideration of these results we decided shape ,material and so on of the bell damper. The material test results are shown in Table 2. Their values are the obtained results of test pieces that were cut out from a bell damper test specimen that was manufactured identically with those used for testing.

Test Method

(a)Loading Method: The experimental setup is as shown in Fig.3. The load was applied with 2 units of 50tf actuator. The loading block which supported the loading plate had a mechanism which could move horizontally by link channels. The test pattern is as follows: Static monotonic loading (14 cm max.), Static cyclic loading (2 types), Dynamic cyclic loading (2 types), and Earthquake wave excitation. Excluding test specimens 150-1 and 150-7, the remaining were all applied with loads until failure. Also, for the earthquake wave excitation the forced deformation that the bell damper would be subjected to when an earthquake (El Centro NS 100 gal) vibrates the actual building, was applied intact.

(b) Measurement Method: The test measuring was conducted, for the loadings by load cells installed inside the actuators, and the horizontal displacements by two transducers. Other measurings were conducted such as, various surface strain distributions and temperature rise of the specimens.

Test Results The main test results are shown in Table 3. The examples of load and deformation curves are shown in Fig.4.

a) In the static and dynamic cyclic tests, some slippages are observed when the loading is zero (0). This is due to occurrence of plastic deformation at top pressure bearing part.

b) Due to the stroke limitation of the loading apparatus the monotonic load test was stopped at 14 cm deformation (Photo 2).

c) Although the earthquake wave excitation was conducted 3 times, decrease in resisting strength was not found.

d) The ruptures of the test specimens T150-2 to 6 occurred about 5 cm above the damper base.

e) In the dynamic cyclic loading tests the temperature rose by about 40°C in maximum. The functions of bell dampers were not influenced by temperature-rise.

From the tests, it was confirmed that the function of bell dampers practically satisfied the requirements.

PREDICTION DYNAMIC ANALYSIS

Analysis Method A comparison was made of the response properties of subject buildings, provided with and without bell dampers during earthquakes.

(a) Building model: The analysis model is shown in Fig.5. The subject buildings were modelled as three-dimensional model with lumped masses, shear springs and tortional springs. The damping established for the natural vibration period of primary mode was 3% for buildings A and B in accordance with Rayleigh damping.

(b) Bell damper model: Because the damper may be subjected to forces simultaneously in 2 directions of X and Y within a plane, it was considered as biaxial non-linear element. The foregoing element was expansion of unidirectional bi-linear load/deformation curve to two directional characteristics (See Fig.6) under assumptions as follows: The damper element and the building model were jointed by rigid elements.: (1)Initial yield surface Φ_1 was assumed as a circle. (2)Prager's Hardening Rule (= Ziegler's Rule) was used. (3)Von Mises's Flow Rule was used.

(c) Analysis case: For the input earthquake wave, El Centro 1940 (NS) was applied. The maximum acceleration was 100 gal and was input in either X or Y direction.

Analysis Results

(a) The results of eigen value analysis: The results of eigen value analysis on the building model are shown in Table 4.

(b) The results of earthquake response analysis:

a) When maximum response acceleration (Fig.7) is viewed, regarding building A, the response has decreased by 40% - 50% due to application of the dampers in both X and Y directions, indicating about the same response value with building B. Because the seismic response of building A was higher than that of building B, building A was influenced by dampers.

b) When maximum response story shear force (Fig.8) is viewed, because of application of dampers the decrease is 20 - 40% for building A and 10 - 30% for building B, in both X and Y directions.

c) The maximum response story drift at the corners of those buildings (Fig.9) are viewed. For the L shaped building A, the action was toward suppressing torsion, but for rectangular building B, there was little effect of torsion in relation with installation of the dampers.

d) The maximum energy absorbed by one damper was 700 tf cm, and is able to resist earthquakes more than 10 times.

e) The maximum deformation of the dampers was about 1.4cm.

CONCLUDING REMARKS

When the joint damper system using the bell damper was applied to the expansion joint of the building, it had the effect of decreasing the seismic response during an earthquake, and indicated its value in increasing the structural function of the building. The described system is economical, greatly effective and has bright prospects as a simplified earthquake control technology.

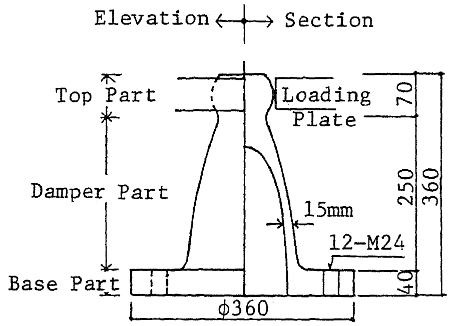


Fig.1 Bell Damper

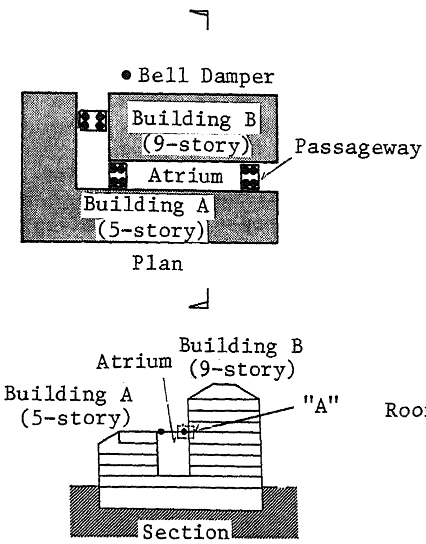


Fig.2 Shape of the Building

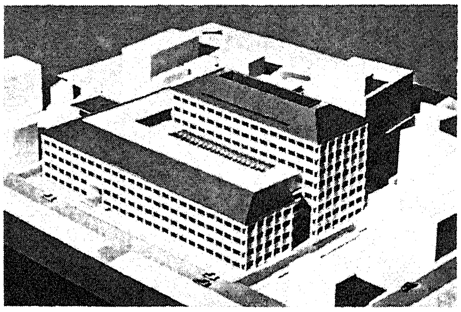
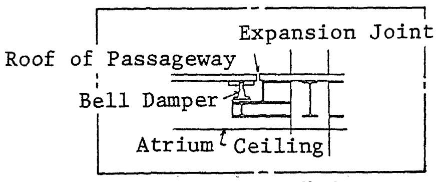


Photo 1 View of the Building



Detail of "A"

Table 1 Test specimens

Specimen	Loading Condition	Amplitude(cm)	Note
T150-1	Static Monotonic Loading	———	
T150-2	Static Cyclic Loading	0.65,1.0,3.0	
T150-3	Static Cyclic Loading	0.65~6.5	
T150-4	Static Cyclic Loading	0.65~5.2	
T150-5	Dynamic Cyclic Loading	1.0	Frequency 1Hz
T150-6	Dynamic Cyclic Loading	3.0	Ditto
T150-7	Seismic Loading	———	El Centro(NS) 100Gal

Table 2 Material Test

	T150-1~3	T150-4~7
Yielding Stress (tf/cm^2)	2.56	2.28
Tensile Stress (tf/cm^2)	4.93	4.42
Elongation (%)	35.2	37.8
Reduction of Area(%)	59.8	62.0

JIS No.4 Test Piece was used

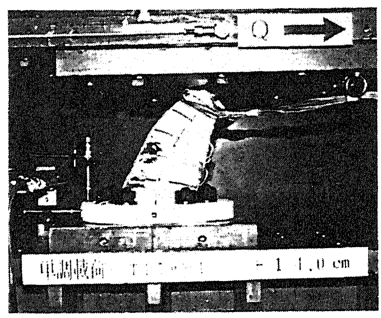


Photo 2 Monotonic Loading Test (T150-1) (Deformation 14cm)

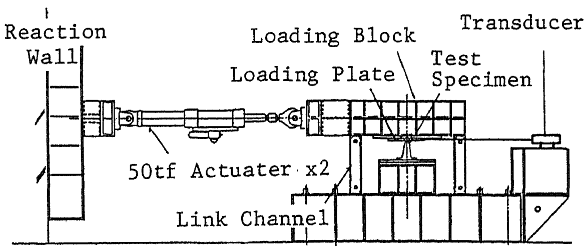


Fig.3 Experimental Setup

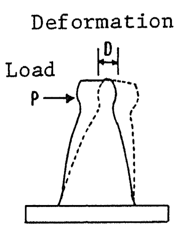


Table 3 Test Results

Initial Spring	172tf/cm	*1
Yielding Force	40tf	*1
Maximum Deformation	Over 14cm	*2
Energy Absorption Capacity	14600tf cm(Amplitude 1cm) 7400tf cm(Amplitude 3cm)	

*1 Average Value
*2 Monotonic Loading

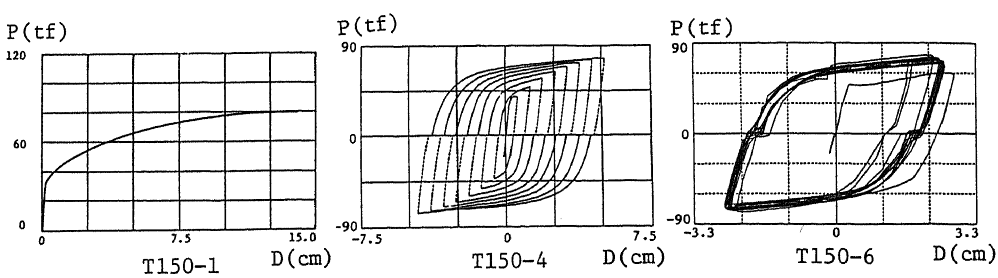
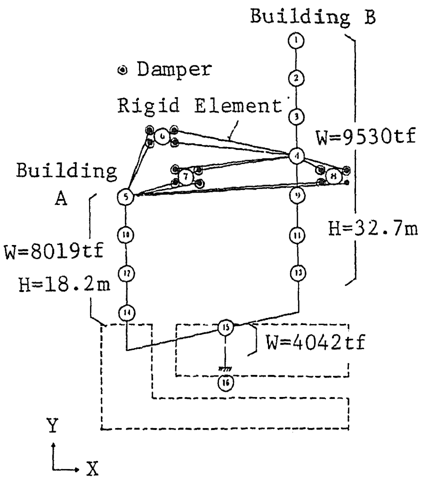


Fig.4 Load Deformation Curves(T150-1,4,6)



Building: Lumped Mass Model
Damping Coefficient 3%
Damper : Non-linear Biaxial Model

Fig.5 Analysis Model

Table 4 Results of Eigen Value Analysis

Mode	1st	2nd	3rd	4th	5th	6th
Natural Period(s)	0.884	0.869	0.726	0.532	0.528	0.494
Participation Coefficient	1.28	1.29	0.00	1.16	0.99	0.00
Note	Y_1	X_1	Φ_1	X_2	Y_2	Φ_2

Building B (1st–3rd modes) Building A (4th–6th modes)

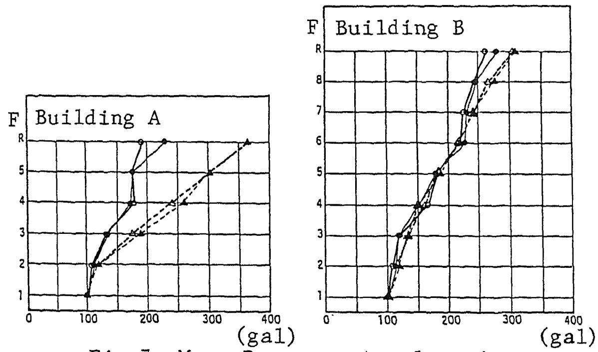
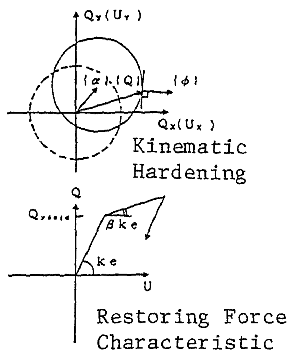


Fig.7 Max. Response Acceleration



Stiffness Matrix

(1) Elastic Stiffness

$$Ke=\begin{bmatrix} ke & 0 \\ 0 & ke \end{bmatrix}$$

(2) Plastic Stiffness

$$Kp=Ke\left\{I-(1-\beta)\frac{\phi\ \phi^T}{\phi^T\phi}\right\}$$

Fig.6 Non-linear Biaxial Element

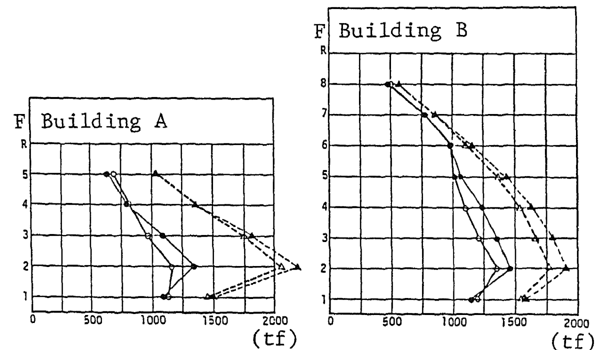
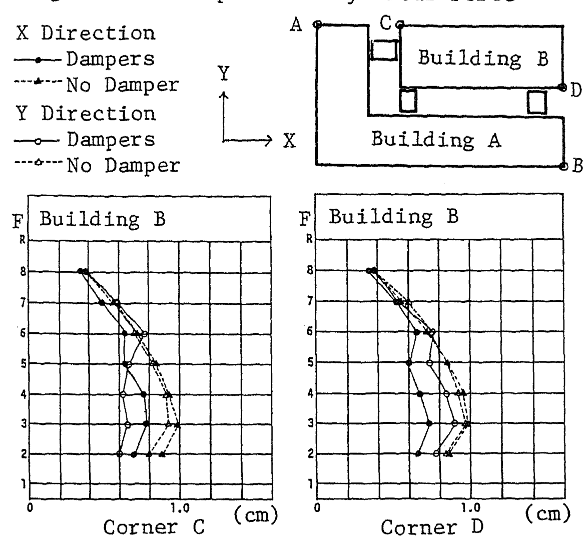


Fig.8 Max. Response Story Shear Force



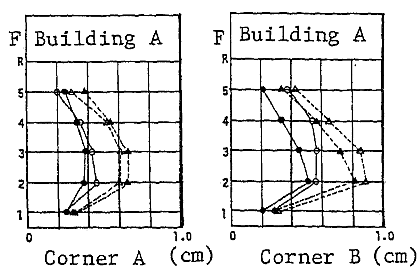


Fig.9 Max. Response Story Drift