Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Application of joint damper to thermal power plant buildings

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ABSTRACT: The feasibility of a newly developed lead joint damper as a seismic-control device in a thermal power plant building has been clarified by means of both experimental and analytical approaches. The fundamental characteristics of lead and the shape and the size of the damper chiefly contribute to the energy-absorption capacity, which enables response reduction of buildings.

1 INTRODUCTION

In recent years, there has been remarkable development in technology relating to devices for reduction of structural response, and the fruitful achievements of this development have already been applied to various structures and structural members.

The authors have conducted an overall study on the application of seismic control systems to thermal power plant buildings and proved that the response of a turbine building can be reduced by utilizing joint dampers.

The mechanism of the seismic response reduction utilizing joint dampers is explained as follows: when two buildings with different fundamental periods are exposed to external forces such as an earthquake, the relative displacement between the two buildings causes a deformation of the joint damper set up between them. The damper absorbs the vibration energy by means of this deformation, and thus enables the response reduction of at least one of the two buildings.

The latest study shows that the newly developed lead joint damper possesses the best applicability for the purpose of response reduction among various seismic control devices. This paper discusses the effectiveness and the feasibility of the damper to a turbine building.

2 EXPERIMENTAL STUDY

2.1 Objective

In the first place, it must be noted that the selection of a material for the joint damper is the most important element in this study. We selected lead as a material having the required physical and mechanical damping properties. Lead has several advantageous properties. Its melting point (327K), which is lower than that of any other common metallic material, is advantageous in various ways such as ease of processing.

The mechanical properties of lead, however, are still unknown, although some of its characteristics such as recrystallization and energy-absorption capacity are worth noting. The recrystallization characteristic is expected to make the damper insusceptible to the hysteresis of the deformation. However, in order to apply the lead damper practically, it is indispensable to confirm its mechanical properties, especially its dynamic behavior under possible loading conditions. Thus, the experimental study was conducted to examine the dynamic behavior of the damper under horizontal loading.

2.2 Test Specimen

The form of the specimen was determined such that bending stress was minimized and it yielded by shearing deformation, and that it was axially symmetrical in the horizontal directions. The outline of the specimen is shown in Fig. 1. As shown, the portion in the middle is cylindrical.

The upper and lower portions of the damper are for attachment to the structural members. The dimensions of the specimen are assumed to be half those of the actual damper and its yield stress is about 5 tf.

2.3 Test Method

A displacement-control loading was made by an actuator controlled by a computer (VAX780). Loading patterns are classified into three groups:

1) unidirectional monotonic loading assuming considerably slow story drift of the building under temperature load (Case A: strain velocity: 10mm/12hours),

2) constant-amplitude sinusoidal loading for obtaining restoring force, energy absorption, and fatigue characteristics, and

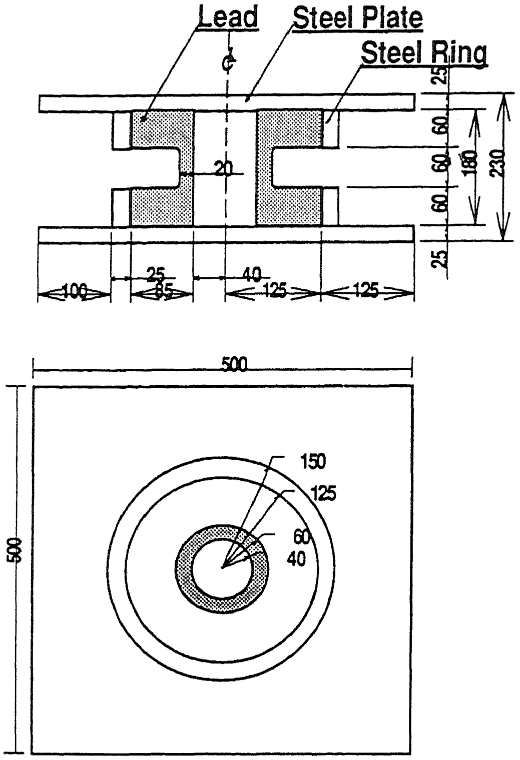


Fig. 1 Outline of Specimen

Table 1 Test Results

Case	Amplitude (cm)	Loading Pattern	Maximum Load (tf)	Strain Energy(tf*cm^2) until Cracking	until Collapse
A	-	Static	2.3	-	-
B	2.0	pseudo-dynamic	6.6	1100	2960
C	2.0	Dynamic	9.4	300	1250
D	4.0	pseudo-dynamic	7.2	550	1080
E	4.0	pseudo-dynamic	6.1	960	1330

3) varying-amplitude sinusoidal loading (Case E: 60 s/cycle, amplitude increment = 2mm/cycle).

Group 2 includes three cases: Case B, Case C, and Case D. Case B is a pseudo-dynamic loading of 20mm amplitude and the loading velocity of 60s/cycle, Case C is a dynamic loading of 20mm amplitude and loading velocity is 1.0s/cycle which corresponds to the 1st fundamental period of the boiler building, and Case D is pseudo-dynamic loading with twice the amplitude of Case B.

One specimen was used for each case, thus requiring a total of five specimens.

2.4 Results

The test results are summarized in Table 1. Two values of strain energy are given: the strain energy accumulated until initial cracking and the total energy accumulated until the specimen collapse.

The load-deflection relationships are shown in Figs. 2a-2c, and the transition of peak load and cumulative plastic strain energy against progress of the constant-amplitude sinusoidal loading are shown in Fig. 3 and Fig. 4, respectively. In Figs. 2, the vertical axes represent the horizontal load on the specimen in tf and the horizontal axes represent the horizontal displacement of the specimen. In Fig. 3 and Fig. 4, the vertical axes represent the absolute value of the peak load within each loading cycle, or the absorbed energy obtained by integrating the area of the load-displacement relationship until the end of each loading cycle, and the circles represent the time at which cracking occurred in each test case.

The progression of damage to the specimens under sinusoidal loading is summarized as follows. First, yielding occurred in the middle part of the specimen, then cracking took place, and finally the specimen ruptured. Under monotonic loading, elastic behavior was initially observed, then the stiffness began to deteriorate after 0.1mm deflection, and little load increase was observed after 0.3mm deflection. The final load level was much lower than those under sinusoidal loading cases.

Under sinusoidal loading (Cases B-D), the hysteretic loop was almost rectangular, which indicated high energy-absorption capacity. Although the maximum load in the dynamic loading case is greater than that in the pseudo-dynamic loading case by 30 percent, damage progressed faster, as shown by the fatigue characteristics. Since no decrease in load was observed in varying-amplitude sinusoidal loading until the displacement amplitude reached 40mm, it can be speculated that the deformation limit of the damper specimen is around 40mm. Case B showed the largest total energy-absorption capacity and this can be attributed to the fact that cracking occurred later than in any other case because there was a sufficient margin of deformation capacity.

2.5 Concluding Remarks for Experimental Study

From the observations described above, we can deduce the following:

a. The damper was fairly stable and the load was low when the strain velocity was very small. Thus, the damper will be sound when the building is exposed to a temperature load.

b. The rectangular hysteretic loop indicates high energy-absorption capacity. Thus, damper restoring force is guaranteed providing the displacement

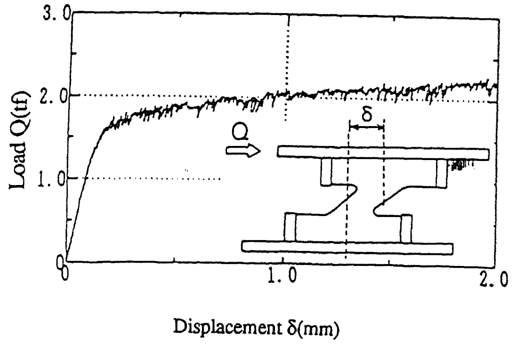


Fig. 2a Load-Deflection Relationship (Case A)

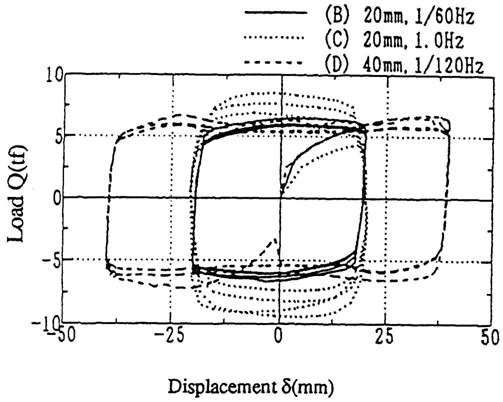


Fig. 2b Load-Deflection Relationship (Case B-D)

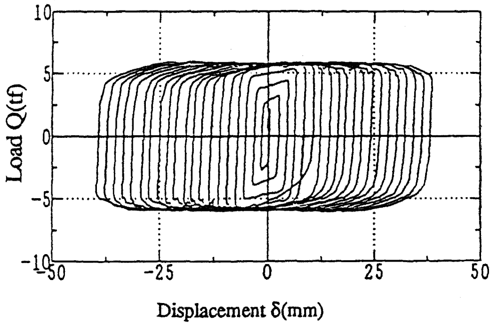


Fig. 2c Load-Deflection Relationship (Case E)

amplitude never exceeds 40mm.

c. The maximum load will increase with loading speed.

d. The damper will provide high energy-absorption capacity within the obtained deformation limit together with almost rectangular hysteretic loop and fairly stable behavior.

3 SEISMIC RESPONSE ANALYSIS

The previous chapter described the experimental study

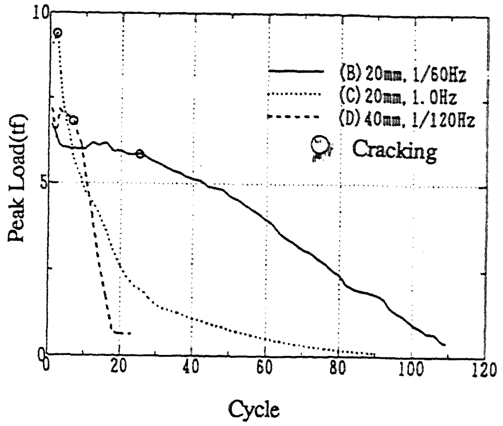


Fig. 3 Transition of the Peak Load

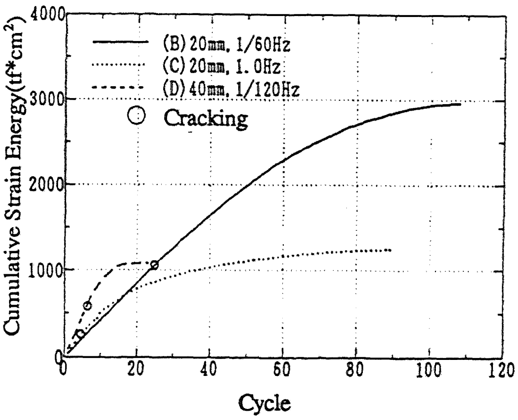


Fig. 4 Transition of Cumulative Plastic Strain Energy

carried out to confirm the fundamental mechanical characteristics of the newly developed lead joint damper.

This chapter describes seismic response analyses carried out utilizing the information obtained in the experimental study in order to examine the applicability of the developed leaden joint-damper to thermal power plant buildings.

3.1 Analytical Model and Seismic Control Device

The subject thermal power plant comprises a high-rise boiler building, a low-rise turbine building and a control building, as shown in Fig. 5. These buildings were originally independent each other. Hereafter, dampers are assumed to be installed only between the turbine and the boiler buildings, i.e., the control building can be ignored.

Seismic response is reduced by means of the energy absorption by the joint-dampers. The damper can absorb the vibration energy because the two buildings

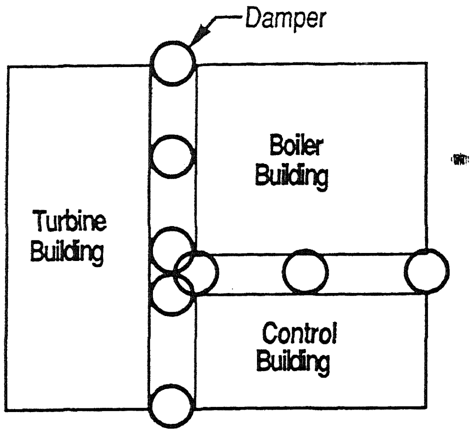


Fig. 5 Outline of the Thermal Power Plant Buildings

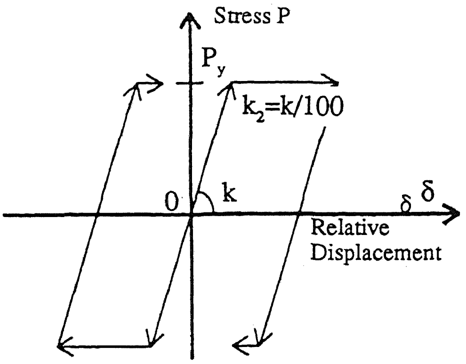


Fig. 6 Restoring Force Characteristic of the Damper

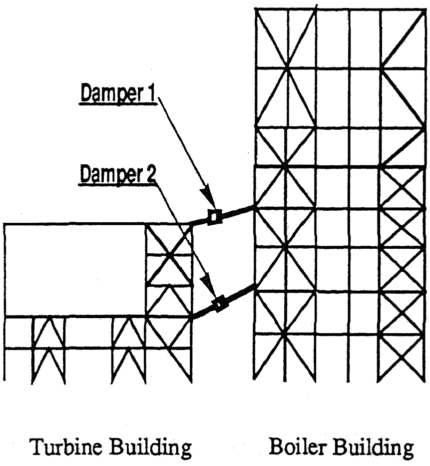


Fig. 7 Analytical Model

Table 2 Cases in Parametric Analysis

	Yield Stress of Each Damper	
Case	$_1P_y$	$_2P_y$
(a)	0	0
(b)	40	0
(c)	80	0
(d)	40	5

have different vibration characteristics, i.e., fundamental periods. The joint damper is chiefly effective for response reduction of the turbine building when the dampers are located at the position which corresponds to the peak point of the vibration mode shape of either one of the buildings. In analyses, dampers must be installed in each structural frame, because there are many openings and well-holes in the buildings. Therefore, a rigid-floor assumption cannot be made for the buildings of this plant.

3.2 The Lead Joint Damper

As described in Section 2, the developed damper shows appropriate characteristics both physically and mechanically, for instance, recrystallization which enables the damper to be used after experiencing forced deflection caused by temperature load on the boiler building. It has been reported that a lead damper retrieves its initial state after experiencing a plastic deformation and its energy absorption characteristics are not affected at all$^{1)}$.

However, under cyclic loading, which emulated seismic response, a high load level in the initial state was confirmed. In order to grasp the seismic response of buildings with dampers, restoring force characteristic of the damper is assumed to be bilinear, which is very close to an elasto-plastic hysteretic rule, as shown in Fig. 6. In the seismic response analyses, the ratio of plastic to elastic stiffness (k_2/k) was assumed to be 1/100. The yielding stress and the elastic stiffness were determined on the basis of the results of the pseudo-dynamic tests in order to avoid overestimating the energy-absorption capacity of the damper.

3.3 Seismic Response Analysis of the Buildings

By choosing the typical frame structures of both turbine and boiler building, a simplified analytical model was made as shown in Fig. 7. The buildings are assumed to be fixed at the bottom. The effectiveness of the damper was examined through conducting parametric studies considering its size, as shown in Table 2. In Table 2, $_1P_y$ and $_2P_y$ represent the yield stress in tf of Damper 1 and Damper 2, respectively. Four cases have been carried out for the response analyses as shown in Table 2.

Case (a) is without dampers, case (b) is with Damper 1 only assuming a yield stress to be 40tf, case (c) is also with Damper 1 only but assuming a yield stress twice that for case (b), and case (d) is with both Damper 1 and Damper 2, assuming the yield stress to be 40tf for Damper 1 and 5tf for Damper 2.

Fig. 8 shows the vibration mode shapes of the independent buildings obtained by computation without dampers, and the first and the second natural periods of each building are given below the figures.

Two kinds of recorded ground motions, EL CENTRO (NS) and TAFT (EW) were used in conducting response analyses according to a method developed especially for an inelastic seismic response analysis of the buildings of a thermal power plant[2].

The buildings were assumed to remain elastic even when exposed to 40cm/sec input motion. Results of the response analyses are shown in Fig. 9 and Fig. 10, and the hysteretic behavior is shown in Fig. 11.

3.4 Effect of the Joint Damper

As illustrated in Figs. 11, the decrease in response especially in the lower stories varies for different input motions and, as expected at the beginning, the response reduction is more significant in the turbine building than in the boiler building.

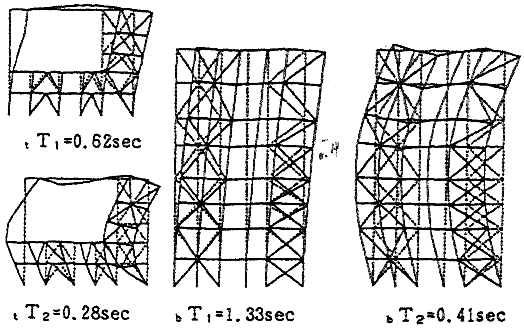
Although the effectiveness of damping differs for each ground motion, the shear force response of the turbine building decreases when the joint dampers are installed. It must be noted that dampers with excessive yielding stress cause an increase in the shear force response of the boiler building, while the response of the turbine building is reduced more significantly than for any of the other cases (Case C).

These observations suggest that there is an optimum damper size (here the size of the damper is referred to because the yield stress can be adjusted by varying the size of the damper), which enables reduction of the design shear force without needing to augment the response of the boiler building. Moreover, the positions where the damper is located can also affect the response reduction, and the position assumed in the analyses seems to be the best.

The assumed yielding stress is sufficient to satisfy the purpose, i.e., seismic response reduction, if the actual damper is twice as large size as the test specimen and if two dampers of this size are installed at the top of the turbine building. In that case, the maximum deflection remains within the deflection limit obtained from the test results, and the energy-absorption capacity of the dampers is sufficient even for the 40cm/sec input level.

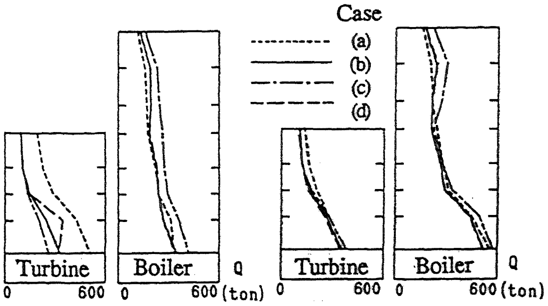
4 CONCLUDING REMARKS

The fundamental mechanical properties of the lead joint damper which are prerequisite for realization of seismic response reduction were obtained from experimental studies on various loading patterns.



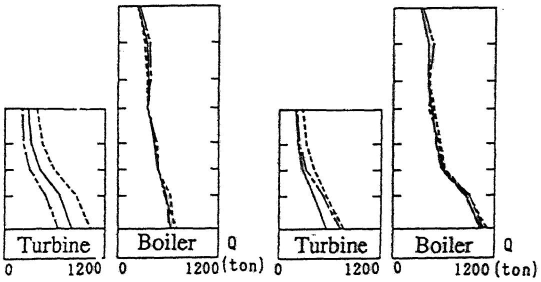
Turbine Building Boiler Building

Fig. 8 Results of Eigenvalue Analysis



El Centro Taft

Fig. 9 Comparison of Maximum Shear Force Response (input level: 20cm/sec)

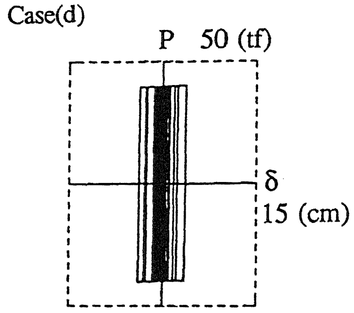


El Centro Taft

Fig. 10 Comparison of Maximum Shear Force Response (input level: 40cm/sec)

The expected material characteristics of lead seemed to play a great role in the obtained mechanical properties of the damper, and a nearly rectangular hysteretic loop together with the fairly stable behavior under cyclic loading guarantee high energy-absorption capacity within a certain deformation limit.

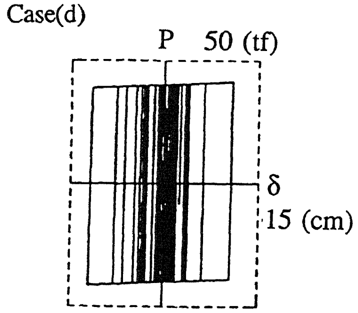
Results of the seismic response analyses using the



Cumulative Strain Energy : 2209tf*cm^2

input: El Centro 40cm/sec

Fig. 11a Hysteretic Behavior of a Damper



Cumulative Strain Energy : 8890tf*cm^2

input: El Centro 40cm/sec

Fig. 11b Hysteretic Behavior of a Damper

information obtained from the experimental study show that the maximum interstory deflection can be considerably reduced by the dampers.

It is indicated that the lead joint damper chosen and developed has the greatest feasibility among the seismic-control devices examined so far in the past studies. It has a large energy-absorption capacity and therefore greatly contributes to reduce the seismic response of the buildings of a thermal power plant.

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