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EARTHQUAKE RESISTANT DESIGN OF BOILER BUILDING OF THERMAL POWER PLANT

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SUMMARY

This paper describes an earthquake resistant design of a boiler building for a thermal power plant based on the dynamic analysis of a three dimensional steel braced frame. Since it is unavoidable that a building subjected to a severe earthquake motion enters into nonlinear range, all adopted structural elements should be ductile enough to resist large and repetitive deformations. Unlike column and beam, the brace element has been adopted on a rather more conservative selection by the structural engineers, because of the difficulty in estimating its post-buckling behaviors. In this paper, the developed analysis method, capable of considering nonlinearities due to not only buckling of the brace but also to the interaction between the boiler and adjacent frames, is applied to a practical design of the boiler building. Results of the dynamic analyses are discussed from the view point of damage control, which is essential in a rationalized earthquake resistant design of the boiler building.

INTRODUCTION

The boiler building of a thermal power plant has many openings and large hatches due to the requirements of the layout of the boiler and other appurtenant components. Consequently, as the structural steel frame possess different rigidities, the rigid floor assumption cannot be applied on the aseismic structural frame analysis. Moreover, the heavy weight boiler suspended from the top beam, and ordinarily isolated from adjacent frames, affects the entire building with nonlinear collisions when an earthquake induced motion occurs. The conventional design practice using the assumptions that a boiler has no rigidity and that only its weight is added to adjacent frames has already been reported as being unrational (Ref.1).

The authors had previously proposed the method of dynamic analysis for the earthquake resistant design of a turbine building with a flexible floor, where buckling of the braces is taken into account, as well as the yielding of the column and beam, supported by experimental verification (Ref.2). The method is then upgraded in order to further consider the nonlinear interaction between the boiler and the adjacent frames, and has been applied to the practical designs of two coal fired power plant facilities with 300MW and 1000MW electrical power generating capacity. The former is now in operation and the latter, which is mainly reported in this paper, is under construction.

OUTLINE OF BOILER BUILDING FOR 1000MW POWER GENERATION

As shown in the perspective view in Fig.1 and the cross section in Fig.2 the boiler building is functionally composed of the central boiler room, and the accompanying air-heater room and the coal bunker room placed in the upper tier, and of the coal mill and other equipment rooms on the basemat, while the turbine building is structurally isolated by expansion joints. In case of the earthquake loading in the direction shown in the figure by arrow mark, only four plane frames located on the external portion of the building among the eleven in total can be expected to resist the forces, as well as, the horizontal deformations induced by the earthquake. In each floor level the necessary horizontal rigidities are supplied by the horizontal braces and reinforced concrete slabs.

A boiler is suspended by numerous steel rods and is normally free from thermal expansion in all directions. When a horizontal movement occurs, however, the boiler structure will collide with the adjacent frames through the so called seismic tie as shown in Fig.3 and both structures will move affecting each other. Relationship between stress and deformation transferred by the seismic tie is illustrated in Fig.4, which has been formulated after a full scale testing.

MODELING FOR ANALYSIS

Fig.5 shows an analytical model of both the boiler and frames in accordance with the aforementioned concepts in the case of earthquake loading along the direction as marked in the figure. Regarding the boiler and adjacent frames, two neighboring plane frames are connected to each other by horizontal springs at column-beam joining portions equivalent with the horizontal braces and/or reinforced concrete slabs (if any), which subsequently express approximate three dimensional effects of the structure. The total weight of the building is 57800 ton including 10000 ton of the boiler, of which all are assumed as lumped masses located at the nodal points on the joining portion of the two members.

The largest number of nodal points of one plane frame is 73, which means that the total degrees of freedom of motion in this model are more than one thousand, since one nodal point is assigned to have horizontal and vertical translations and a rotation. In conducting a step by step integration for response calculation, the stiffness matrices of the column and beam based on a plastic hinge theory are modified from one second to the next, as well as the force vectors of brace and spring.

It is to be noticed that the yield strength of the seismic tie is designed to support only 20 percent more or less of the gravity force of the boiler portion attached, which consequently makes it enter into nonlinear range even in the case of moderate intensity of earthquake excitation.

Design earthquake motions depend largely on the construction site and soil conditions. The subject plant is located in the western part of the Kyushu Island in Japan, known as a low seismic activity area. The maximum intensity of the ground motion was established at 150 gal for the moderate earthquake response and 350 gal for the severe response. The earthquake records at EL CENTRO 1940 NS, TAFT 1952 EW and SENDAI 1978 NS were applied with a fixed base assumption. Viscous damping was introduced in the form of invariable damping matrix proportional to stiffness matrix with critical damping ratio of 0.03 throughout the earthquake duration.

RESULTS OF DYNAMIC ANALYSIS

Fundamental period of the suspended boiler is calculated to be 4.0 seconds. From the large quantity of the computer output on 150 gal response, the time history of the acceleration that occurred in the 2A braced frame is shown, as an example, in Fig.6. The numbers of the figures denote the nodal point of the frame, and 2A-13 is connected through the seismic tie to the neighboring boiler portion. From the figure, it is understood that the frame is forced to move with a dominant period of 1.8 second and that a spike has appeared in the vibration at the location of seismic tie due to a small amount of gap therein. It is recognized that all the structural members remained elastic except the several seismic ties installed at the lower level than 2A-13.

Specific movements described in above paragraph are much more clearer in the case of 350 gal response as shown in Fig.7. Due to the increased earthquake acceleration, all the seismic ties enter into plastic region together as the consequence of the collisions. Fig.8 shows time histories of the stress and deformation which occurred in the seismic ties, where the lower level seismic tie is found to suffer worse deformation than that of the upper locations. This is caused by the design, in contrast with the actual behavior, that the yield strength of the seismic ties in the lower level location is determined to be lower than those of the higher level.

Fig.9 shows the displacement time histories of the steel frame with seismic tie and boiler, which indicates that the spikes in the acceleration did not affect the displacement, and that the vibration period has increased a little due to the overall plasticities. Several structural elements besides the seismic ties are recognized to enter the nonlinear range. As a result against the SENDAI earthquake, Fig.10 illustrates examples of the relationships between axial force and deformation of upper and lower braces. Although both braces have suffered repeated loadings after the buckling, abrupt deterioration in load bearing capacity was not recognized, while the relationships between shear force and deformation was regarded as wholesome.

All of the members that enter into plastic range due to yielding or buckling during the earthquake are expressed as shown in Fig.11. If the extent of plasticity of the buckled brace is quantified by largest deformation / buckling deformation, its maximum value is 1.34. As for the column and beam, six short members located at the boundary portion between the boiler room and the coal bunker room are found to have yielded. The extent of their plasticity defined by largest end rotation / yielding rotation is 3.86 at most. Considering the experimental and actual damage behaviors of the members, the building is found to be in a sound condition in general as responses against the other two earthquakes are not so severe.

CONCLUDING REMARKS

The response of the building and boiler is largely affected by not only the rigidity and strength of steel members but also by stiffness and strength of the seismic ties. Clearance in the tie must also be carefully considered as well as its deformability after yielding. Since the extents of the damage of all the members have been qualitatively and quantitatively expressed by the computer code developed, proper adoption of the structural members have become possible. Local damage are never overlooked through the rigorous modeling, which result in a more advanced and rationalized design practices.

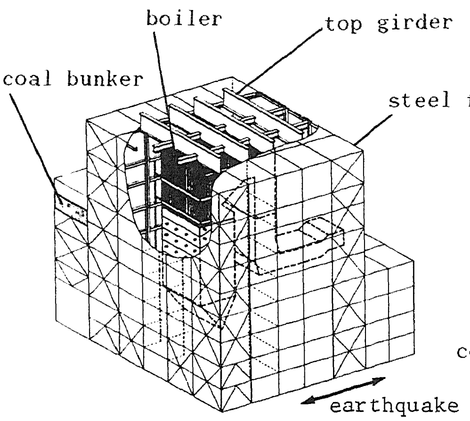


Fig.1 Perspective View of a Typical Boiler Building

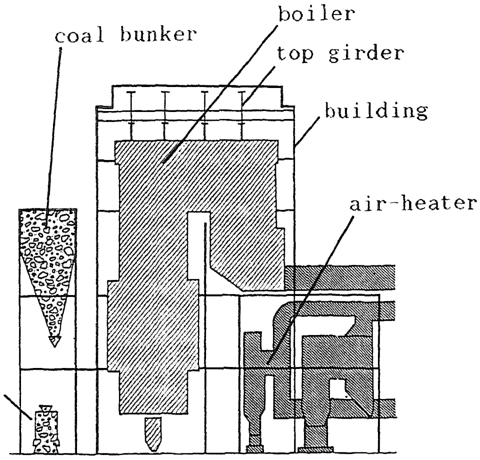


Fig.2 Cross Section of Building and Boiler

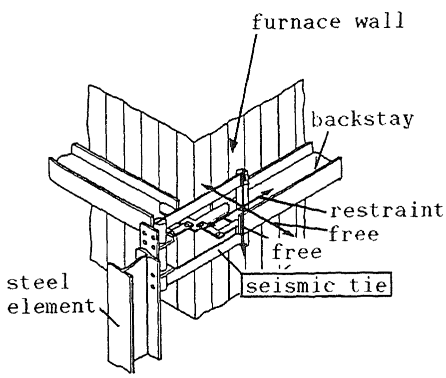


Fig.3 Details of a Seismic Tie

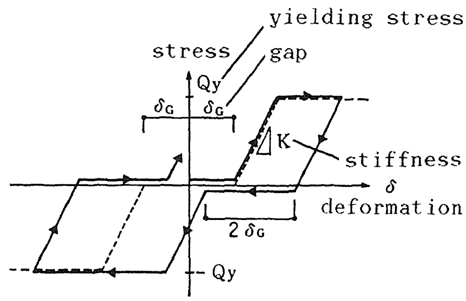


Fig.4 Relationship between Force and Deformation Transfered by Seismic Tie

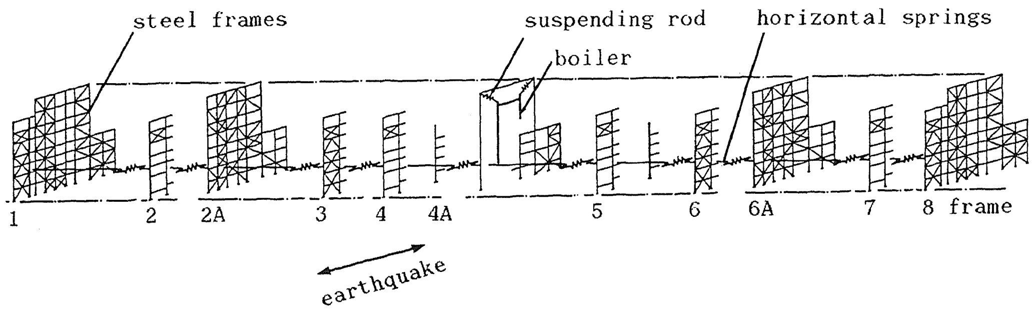
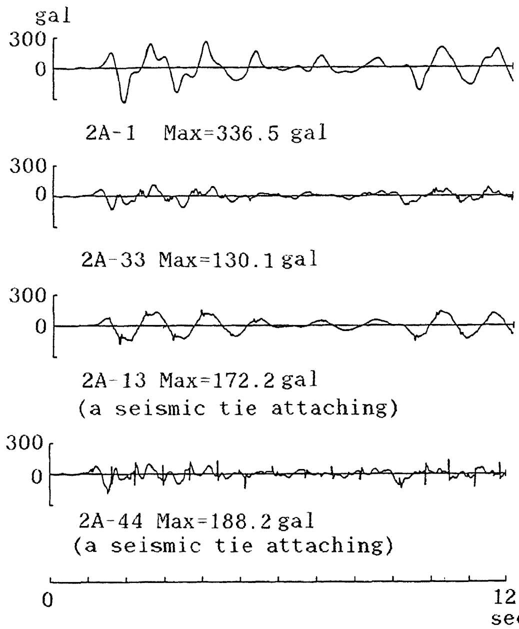


Fig.5 Analytical Model of a Boiler Building for 1000 MW Power Generation



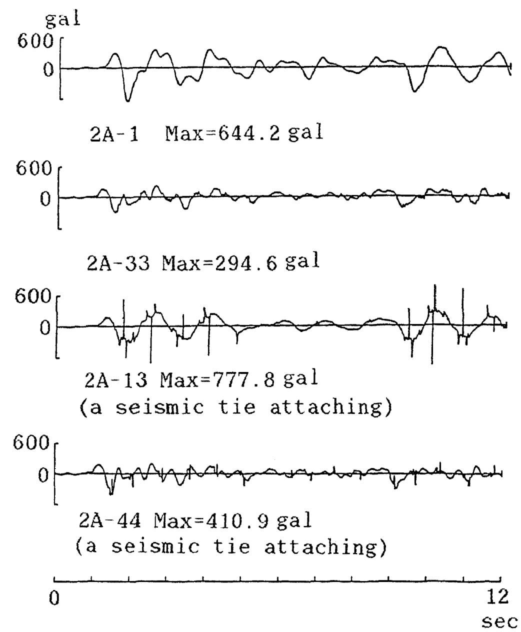


Fig.6 Acceleration Time Histories in the 2A frame on SENDAI 150 gal Response

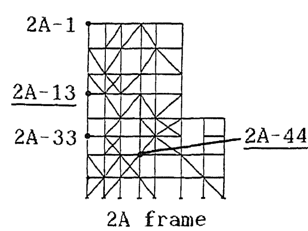
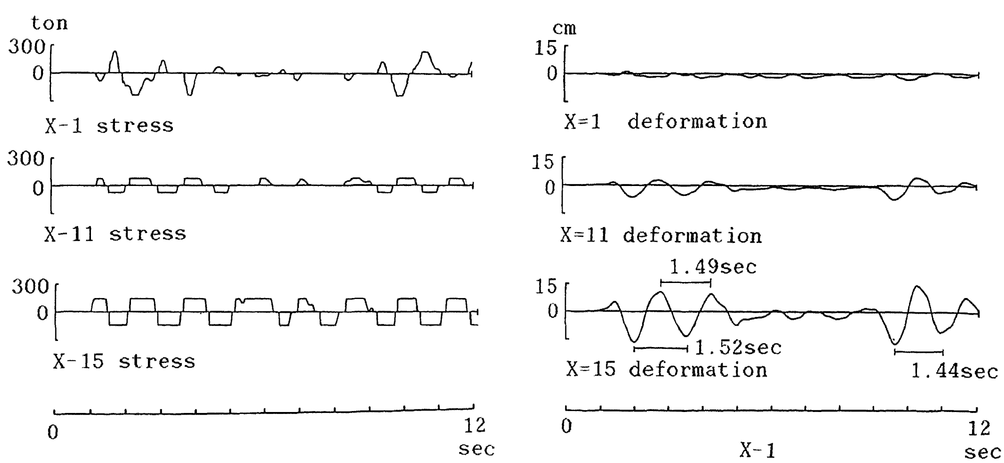


Fig.7 Acceleration Time Histories in the 2A frame on SENDAI 350 gal Response



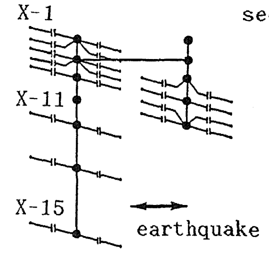


Fig.8 Time Histories of the Stress and Deformation in Seismic Ties on SENDAI 350 gal Response

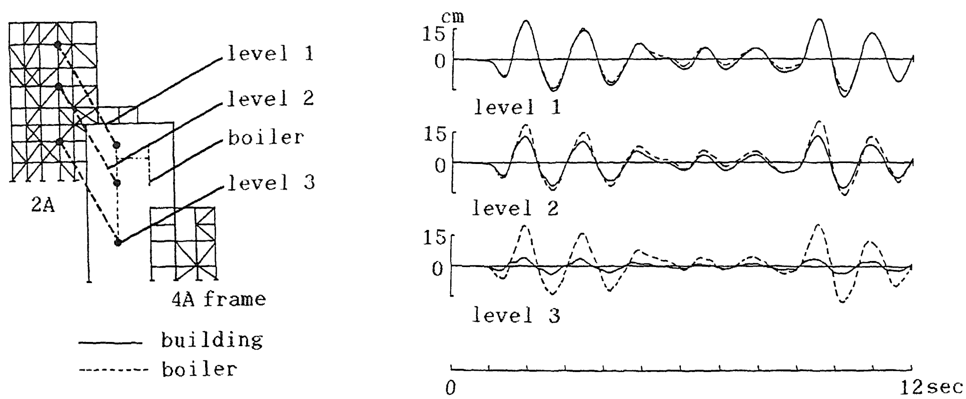


Fig.9 Displacement Time Histories of the Steel Frame with Seismic Tie and Boiler on SENDAI 350 gal Response

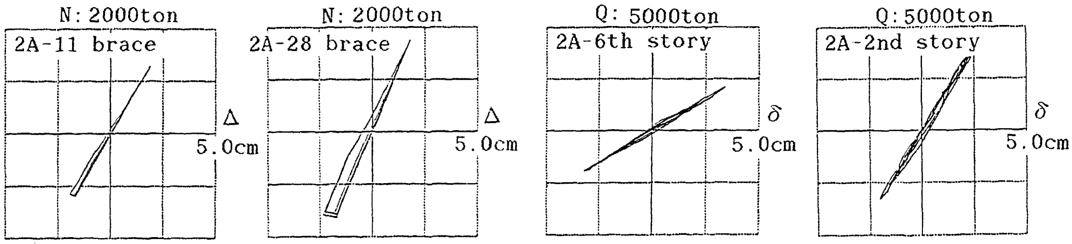
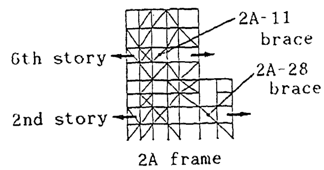


Fig.10 Relationship between Axial Force and Axial Deformation (N-Δ) and Relationship between Story Shear and Deformation (Q-δ) on SENDAI 350gal Response



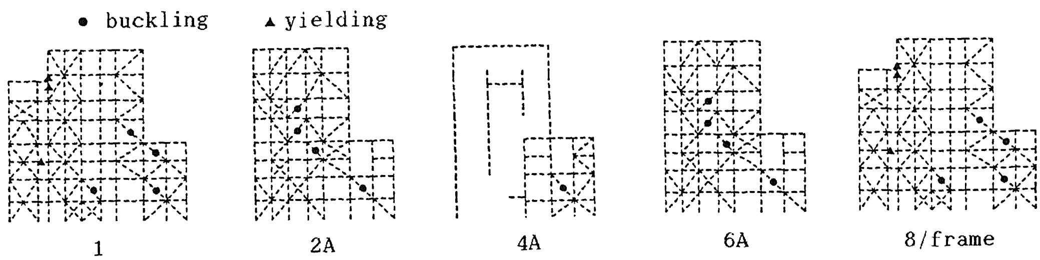


Fig.11 Whole Members Entering Plastic Range on SENDAI 350gal Response

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