

ASEISMIC ANALYSIS OF LARGE CAPACITY BOILER
FRAMINGS FOR COAL FIRED POWER STATION

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SUMMARY In order to perform design and analysis of framing structures for a large output power station, the authors developed a new analytical approach, wherein special considerations were taken into account on movements of structural portions subjected to earthquakes. By introducing effects of members perpendicular to the direction into a plain frame analysis computer code, torsional behaviour of the whole structure could be represented as well as local vibrations. As earthquake responses of the structure were also obtained within a proper computation time, rational dynamic design procedures became practicable for industrial structures as well as for tall ordinary buildings.

I. INTRODUCTION

Due to a necessity regarding the layout for plant equipments, structural framings for a coal fired power station differ from ordinary buildings in that rigid concrete slabs are seldom placed on some floor levels, and that horizontal rigidity of each plain frame is often constrained to be unproportional to the adjacent applied load. Hence, in conducting aseismic design of steel skeletons for the structure, an analysis with special consideration on the local movements of the framing's nodal points become indispensable. General computer codes for three dimensional frame analysis are, however, applicable only to static, or, at most, eigen value problems. Time history response analysis of the structure having large numbers of joints has scarcely been performed.

The object of this paper is to describe an analytical approach in aseismic analysis of the aforementioned structure. A dynamic frame analysis in which numbers of joints exceed 500 or more become capable and practicable. A boiler framing for a 700MW coal fired power station is analyzed as an example of a rational aseismic design for such structures.

II. METHOD OF ANALYSIS

1. Analytical Model Assumption

The structure, supposing that it is subjected to one-way earthquake excitation, is composed of plural plain framings parallel to earthquake direction. These plain framings are occasionally connected to each other by crossing members such as beams, horizontal and vertical braces and slabs which are all estimated to be equivalent springs as shown in Fig. 1.

Weights of structural elements and of equipments are assumed to be all concentrated in beam-column joining portions or to specified points on structural members. Vertical and/or horizontal forces in static analysis and inertia forces in dynamic analysis are applied thereto.

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2. Stiffness Matrix of Analytical Model

The stiffness matrix of the analytical model is composed of stiffness characteristics of each structural element. Bending, shearing and axial rigidities are all introduced for such line elements as column, beam, and brace, while steel walls for a coal bunker and reinforced concrete walls are considered as plain finite elements of which corners share the joints of columns and beams. Adding spring stiffness equivalent to crossing members, the equilibrium equation representing the relation between forces and deformations is finally expressed as follows:

$$[P] = [k]\{u\} \quad \text{-----} \quad (1)$$

where P and u denote the force and deformation of joints respectively and k is stiffness matrix. This equation is numerically solved in the same manner as in general frame analysis. Since numbers of degree of freedom per a nodal point are three in this analysis, computation time is much more decreased than in general purpose computer codes where 6 degrees of freedom are considered.

3. Vibration Model

When numbers of unknown in Eq. 1 usually exceed 500 or more, it is necessary to reduce matrix components for a dynamic analysis. Although some expertized considerations are needed on the effects of rigidity and mass on vibratory behavior of the total framing structure, reduction and consequent equation of motion should be obtained as shown in bottom of the Fig. 1. That is;

- (1) Dividing the building structure into several blocks in which individual joints are assumed to behave identically, the relations between the force and deformation of the center of the block in X direction are introduced.
- (2) Concentrated mass M_j and average displacement U_j in the j block is expressed as

$$\begin{aligned} M_j &= \sum_s^j m_{sj} \\ U_j &= \sum_s^j m_{sj} u_{sj} / \sum_s^j m_{sj} \end{aligned} \quad \text{-----} \quad (2)$$

where m_{sj} , and u_{sj} are mass and displacement of the s-th joint in the j block respectively.

- (3) Then, whole n blocks' equilibrium equations of motion for free vibration and forced vibration subjected to an earthquake acceleration α are expressed as follows:

$$\begin{aligned} [M]\{\ddot{U}\} + [K]\{U\} &= 0 \\ [M]\{\ddot{U}\} + (1 + \gamma \frac{\partial}{\partial t})[K]\{U\} &= -\alpha[M]i \end{aligned} \quad \text{-----} \quad (3)$$

where reduced matrix K denotes the inverse of flexibility matrix obtained by displacements of the centers of blocks.

Above-mentioned reduction method is quite practicable, where, for instance, Eq. 2 can be eliminated if the blocks follow the rigid-floor

assumption.

III. EXAMPLES OF 700 MW POWER STATION

1. Structural Outline

Fig. 2 shows a boiler building for output generations of 700MW, which, as a coal fired power plant in Japan, will have the largest power unit at the time of operation in 1982. Building area is about 4,000 square meters and the highest eave's level is 73.6 meters above ground. The tall tower-like boiler room is set back to the lower control room with the coal bunker on one side. Inside this structure, steel gratings are used as floors, and lateral rigidity of the floor depends on the horizontal bracings. The structural void space is filled with a large boiler and an air heater which are suspended from the top beams and connected to floor members with special devices designed not to restrain thermal deformations. Lateral forces of these equipments due to earthquake are, then, shared by the connecting framings. Total weight of this building including 10,000 tons of equipments is 47,000 tons above the top of base mat. The base mat of 3 meter depth is placed on in-situ reinforced concrete pedestals.

In designing the structure, the conventional seismic forces defined in the Japanese Building Code are adopted in the preliminary design analysis, where appropriate and optimum size of structural members are selected. Dynamic response analyses are carried out until it is confirmed that stress and deformations are all within allowable limits.

2. Preliminary Design

Structural skeletons are shown as an analytical model in Figs. 3 & 4. Dotted lines in the Fig. 4 which is used for X direction are representing crossing members by which vertical and horizontal displacements are restrained. Selected members are all H-shaped steels which largest depth are 90 cm for column and 70 cm for beam and brace. The top beam suspending boiler is an exception of 600 cm depth. Steel walls for coal bunker is 0.9 cm thick.

Fig. 5 shows one of the results of preliminary design analysis in X direction. Floor displacement of framings subjected to code lateral forces are different from each other because of flexible floor rigidity. For checking the validity of this method, a general computer program "STRUDL-II" is also used and plotted as in the figure with dotted lines. Considering that some modifications of member placements are performed in order to reduce the number of joints even in the latter case, it is recognized that the method herein described is applicable as a pseudo-three dimensional frame analysis for the structure.

3. Dynamic Design

Free Vibration Fig. 6 shows the vibration mode shapes of the building structure. After Eigen Vector for each block is obtained, the mode deformation of all joints are calculated. In the fundamental mode with 1.0 second period, whole translational movement is predominant. In the second mode, whole torsion is remarkable, while local movement of coal bunker in addition to torsion is extraordinary in the third mode.

Earthquake Response By assuming that viscous damping factor is 0.03 for the first mode, earthquake responses are calculated against three earthquake waves of EL CENTRO 1940(NS), TAFT 1952(EW) and Sendai 1978(NS) with maximum intensity of 200 gals. Among them, Sendai 1978(NS) recorded during the MIYAGI-OKI Earthquake (M=7.4) on June 12, 1978, is the severest to the building structure.

Fig. 7.(a) and (b) show envelopes of maximum framing accelerations and displacements respectively in X direction subjected to Sendai 1978(NS) Wave. Frame J does not have much high rigidity so that it accelerated excessively at the location of 20 meters to 50 meters above ground, while frame G and M both include stiff bracings. Frame N involving coal bunker behaves rather differently. It is therefore, concluded that, owing to the balance between weights and rigidities of each framing, the individual building portions are forced to a complicated deformation.

It is possible to evaluate the seismic safety of the entire building structure in general by results shown in Fig. 8, although in actual design procedure, the individual member stresses and deformations during earthquakes are taken into consideration when estimating the cross section of the members. Fig. 8 shows the envelopes of maximum story shears subjected to three earthquake waves, where elastic limits of story shear and code story shears are also plotted for comparison. As shown in the figure, the upper part of the structure would be weak if designed by the Japanese Building Code. It is also recognized that, as dynamic effects are considered prior to the design of the actual building, the elastic limits of the structure are remarkably larger than those by the earthquake response.

IV. CONCLUDING REMARKS

In the MIYAGI-OKI Earthquake, several tall buildings in the Tohoku district in Japan were reported to be excited by base accelerations with the maximum intensity of 200 gals or more. Amplified accelerations at the top of the structure were 3 - 4 times, which are quite reasonable on view of the analytical results in this paper. It is also concluded that dynamic forces induced by the earthquake largely exceed those of the conventional seismic regulations. In the past, dynamic analyses have been seldom carried out, much less considering three dimensional movements for industrial facilities such as power stations and factories. Considering the importance of these facilities, the authors sincerely hope that, by the wide spread of analyzing and designing method described in this paper, the safety and economy would be vested to the industrial structures as well.

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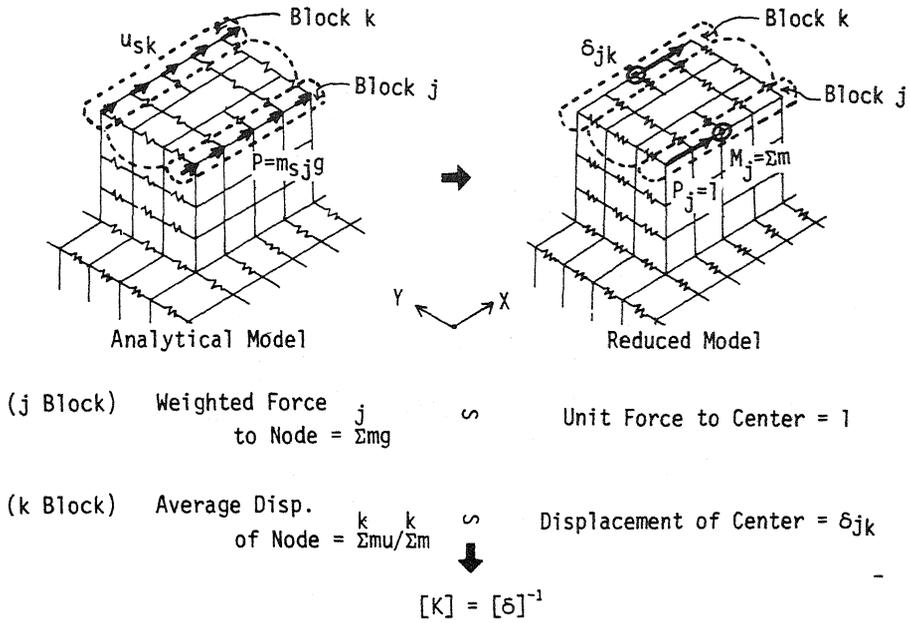


FIG. 1 REDUCED MASS & STIFFNESS

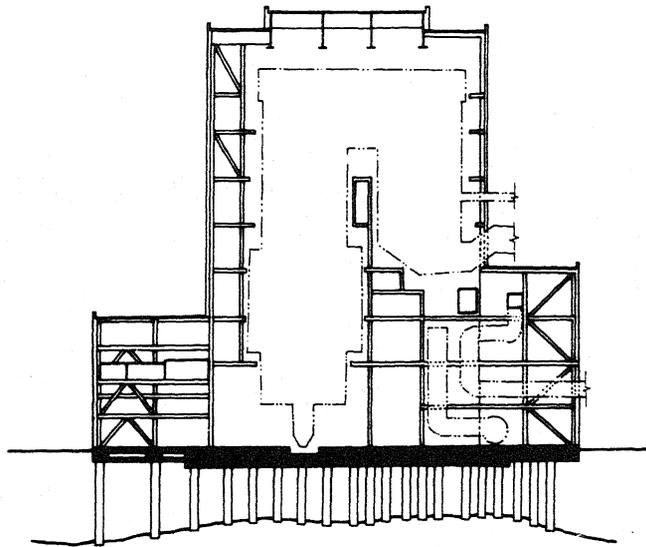


FIG. 2 SECTION OF A 700 MW COAL FIRED BOILER BUILDING

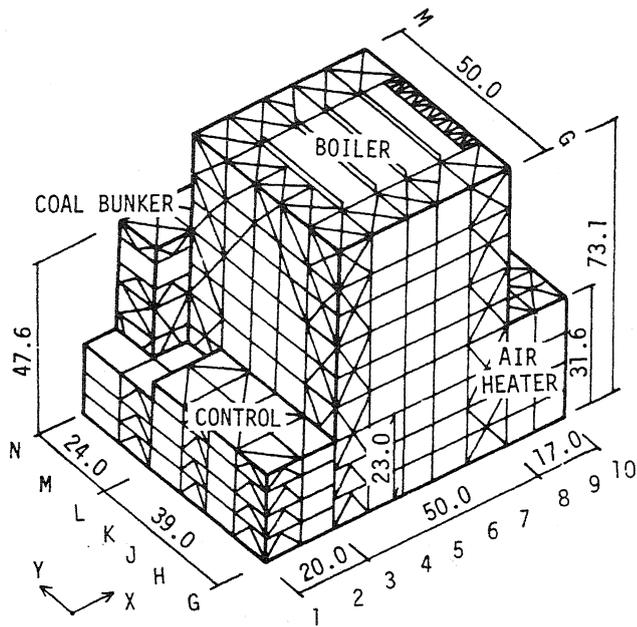


FIG. 3 STRUCTURAL FRAMING (UNIT:METER)

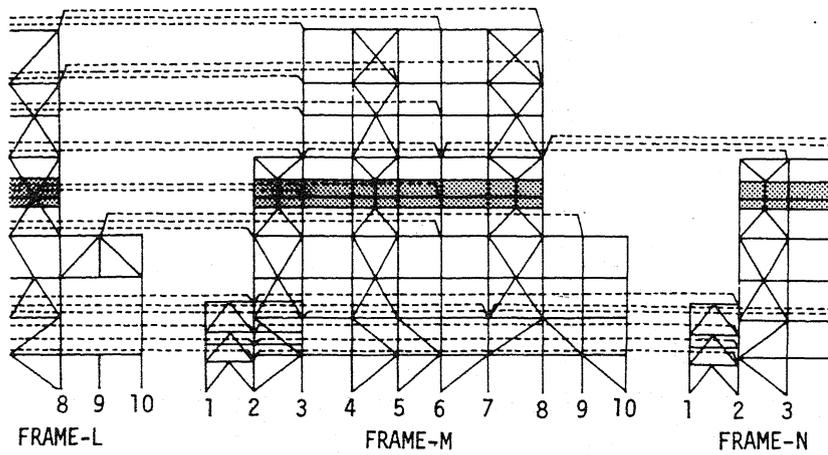


FIG. 4 ANALITICAL MODEL IN X DIRECTION

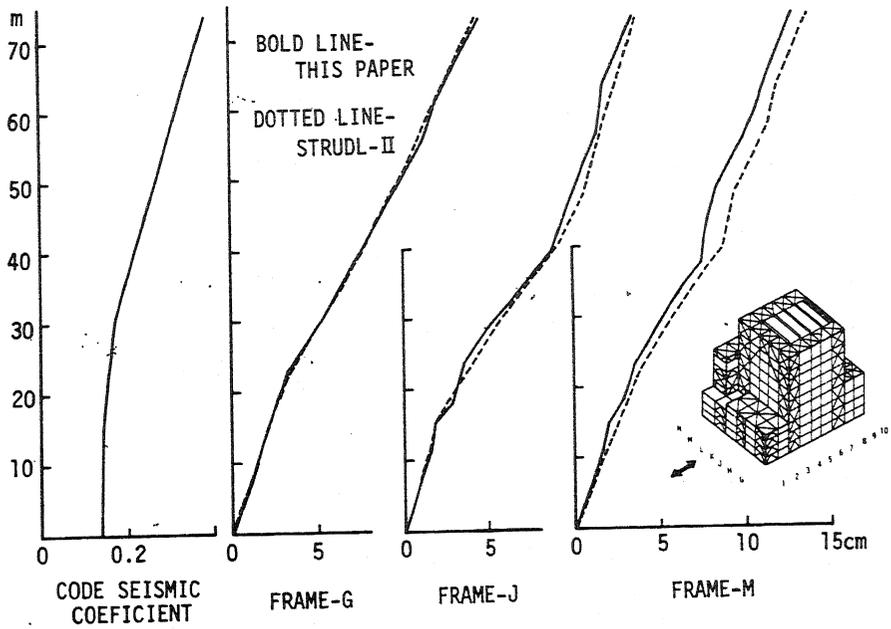


FIG. 5 HORIZONTAL DISPLACEMENT BY STATIC FORCE

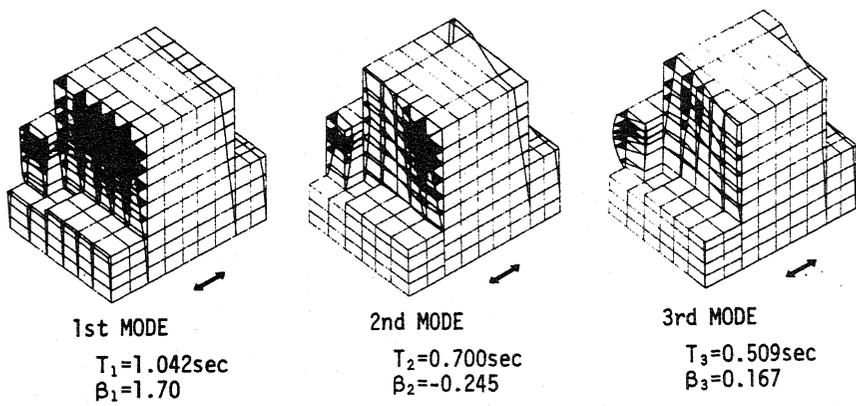
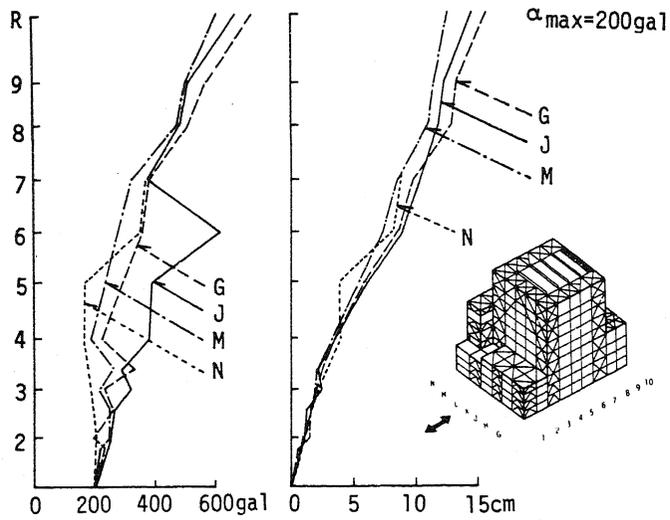


FIG. 6 MODE SHAPES IN FREE VIBRATION



(a) MAX. ACCELERATION (b) MAX. DISPLACEMENT

FIG. 7 MAX. RESPONSE ENVELOPES BY SENDAI EARTHQUAKE

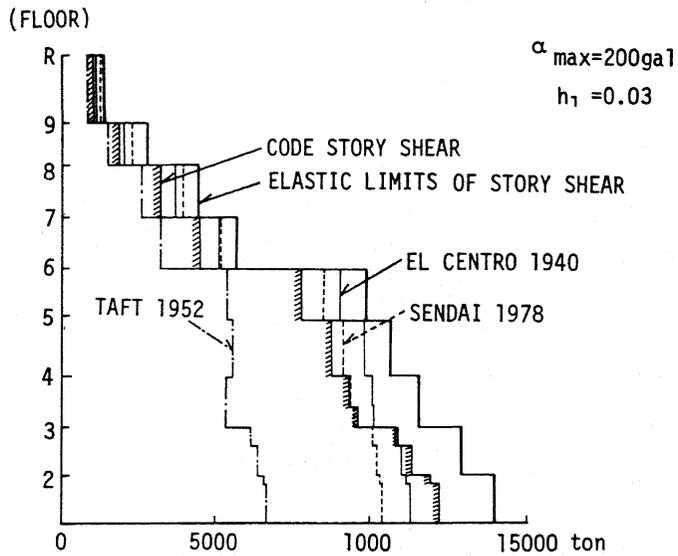


FIG. 8 MAX. STORY SHEAR ENVELOPES