VIBRATION OF A LARGE BOILER SUPPORTING STRUCTURE

T.Y. Yang[I], M.I. Baig[II], and J.L. Bogdanoff[I]

SYNOPSIS

Free vibration of the steam generator and its supporting structure of the TVA 1200 MW fossil plant (Unit 3) at Paradise, Kentucky, USA is studied. The steam generator is modeled by lumped masses connected by rigid bars. The hanger rods and ties are modeled by bar finite elements. The framing and floors are modeled by beam and plate finite elements, respectively. Fundamental frequencies and modes are first found for various versions of subsystems to check the computer program and the consistency of results. Three frequencies and modes are then found for the total system. Mode shapes are plotted. The torsional motion is found in the first mode.

INTRODUCTION

Literature on the study of free vibration of boiler structures is sparse. Because of the complexity involved in the system, computations have only been made for extremely simplified models (Refs. 1-3). In Ref. 1, three kinds of plane model, a Rahmen structure model, a truss model, and a shear-type frame model, were used to analyze two boiler supporting structures. In Ref. 2, a 600 MW boiler structure was studied by using a simple plane portal frame model. The portal frame included 22 lumped masses, 22 vertical shear members, and 3 horizontal flexural members. The 10-mass boiler model was connected to the frame by 3 ties and 2 hanger rods. In Ref. 3, a 1000 MW boiler structure was studied by a simple 3-D box frame model supporting 32 lumped boiler masses. The box model consisted of four vertical plane frames at the four sides. Thus far, no dynamic analysis has been made for the boiler structures with the following reality and complexity.

DESCRIPTION OF THE SYSTEM

The steam generator is described by a vertical plane view in Fig. 1. It is also described by a rough 3-D sketch (without the air heater) in Fig. 2. The walls are composed of closely spaced tubes which are held in place horizontally by buckstays. It is hung by 220 steel rods to the top girders. It is also supported horizontally by ties at the corner edges as shown in Fig. 2. Each tie is made of a pair of bars connecting the buckstay to the column. The air heater is connected to the steam generator by expansion joint that provides little bending or torsional rigidity. It is supported by columns and horizontal ties. The steam generator weighs 24,000 kips. The air heater weighs approximately 15% as the steam generator.

The frame structure is described in Fig. 3. There are two concrete floors at 42 and 169 feet above ground, respectively. The structure has a total of 1412 major beam and column members and 370 cross bracing members. There are 611 joints with 66 at the base. The largest girders have flange cross section of 30x4 in^2 and web depth of 20 ft. The heaviest columns are 14 WF 730 wide flange beams with two cover plates of 32x4-3/4 in^2. The total weight of the frame structure is over 13,000 kips.

I Professor, School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana, USA.

II Graduate Assistant

There are 23 coal silos extended from the level of 175 to 101 feet. They can carry 6000 tons of coal.

THE MODELINGS

Based on the distribution of the weight of each component and its location (Ref. 4), the steam generator is modeled by 48 lumped masses as shown in Fig. 4. Since the gross dynamic behavior of the steam generator and its supporting structure is of major interest, the flexibility of the steam generator is neglected. Thus the masses are assumed as connected by rigid-bars.

A balsa wood model with a scaling factor of 1/64 was built for the frame structure (Fig. 5). Each member in the model was labeled with its dimensions and mass per unit length. The finite element model is constructed exactly as the balsa wood model. All joints between columns and beams are assumed as rigid. All cross bracing members are assumed to have hinged ends.

The 220 hanger rods are modeled by 12 beam finite elements with equivalent masses and stiffnesses. The top ends of the 12 elements are hinged. The 11 ties are modeled by 11 bar finite elements with hinged ends.

RESULTS AND DISCUSSIONS

The present system is so complex that no previous computations on the natural frequencies have been made for the similar systems without severe simplifications. The results for comparative purpose are lacking. It appears that analyses of several subsystems are needed before the total system is considered. By selecting and neglecting certain portions of the total system, the effects of those portions on the frequencies and modes can be studied and the consistency among results can be checked. The subsystem analyses were performed with results presented in Table 1.

The central portion of the structure containing only 5 bays (Fig. 3) was first analyzed. The steam generator and the cross bracing members were neglected. The fundamental frequency was 0.43 Hz. The corresponding mode was dominated by side-sway motion with slight torsional motion (Ref. 4). The 147 cross bracing members were then included. The bracing members stiffened the structure and raised the fundamental frequency by 28% to 0.55 Hz. Due to the unsymmetrical arrangement of the bracings, slight but noticeable torsional motion was introduced (Ref. 4). The cross bracing members were then removed but the steam generator was included. The fundamental frequency was found to be 0.156 Hz which is 64% lower than the first case. The mode was found to be dominated by side-sway motion (Ref. 4). The second mode with frequency of 0.20 Hz was also found. The motion was perpendicular to the first mode motion. Both the 147 bracing mambers and the steam generator were then included. The fundamental frequency was found as 0.206 Hz, 32% higher than the previous case. The mode shapes for the structure and the steam generator are shown in Figs. 6 and 7, respectively. Slight torsional motion is seen.

Finally, the total system was analyzed. The first mode frequency was found to be 1.32 Hz. The corresponding mode shape is shown in Fig. 8. The side-sway motions in both orthogonal directions plus torsional motion are seen. A plane view is shown in Fig. 9. The motions of the front and the side elevations are shown in Figs. 10 and 11, respectively. Both plane frames show the first mode motion. The motion of the steam generator is shown in Fig. 12. The second and third mode frequencies were found approximately (without full convergence) as 2.1 and 3.6 Hz, respectively. The mode shapes were plotted in Ref. 4.

ACKNOWLEDGMENT

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BIBLIOGRAPHY

(1) Shiraki, K. and Nakazawa, S., "Study on the Aseismic Design of Boilers and Structural Steels - Considerations on the Vibration Characteristics and Design Criteria for Boilers and Structural Steels," Mitsubishi Technical Review, Sept. 1968, pp. 184-195.

(2) Anderson, J.C., Sirinivasan R., and Small, R.J., "Response of Suspended Boilers to Earthquake Motion," Electric Power and the Civil Engineer, ASCE Power Division Specialty Conf., Boulder, Colorado, Aug. 1974, pp. 363-387.

(3) Suehiro, T., "Vibration Analysis of a 1000 MW Boiler Frame Structure," Report KBD 19012, Ishikawajima-Harima Heavy Industries Co., March 1974.

(4) Yang, T.Y., Baig, M.I., and Bogdanoff, J.L., "Dynamic Behavior of the Steam Generator and Support Structures of the 1200 MW Fossil Fuel Plant, Unit 3, Paradise, Kentucky," School of Aeronautics and Astronautics Report, Purdue University, West Lafayette, Indiana, 1976.

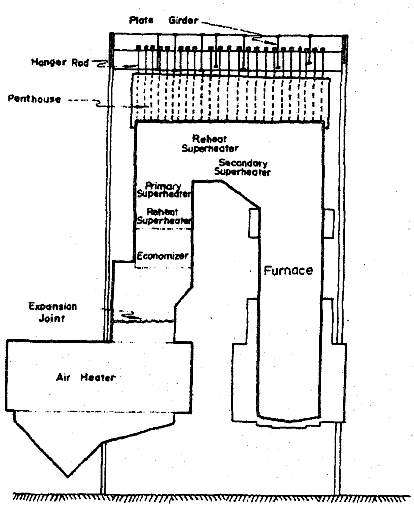

FIG. 1. AN ELEVATION VIEW OF THE STEAM GENERATOR.

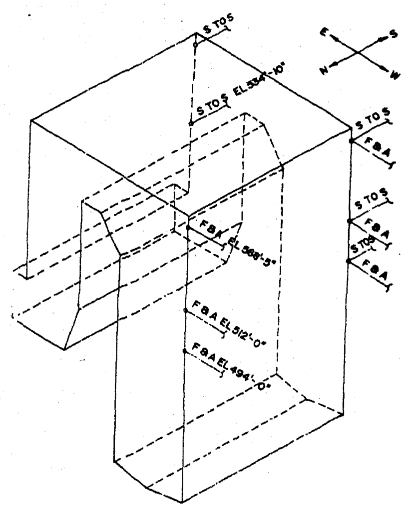

FIG. 2. A ROUGH 3-D SKETCH OF THE STEAM GENERATOR AND 11 TIES.

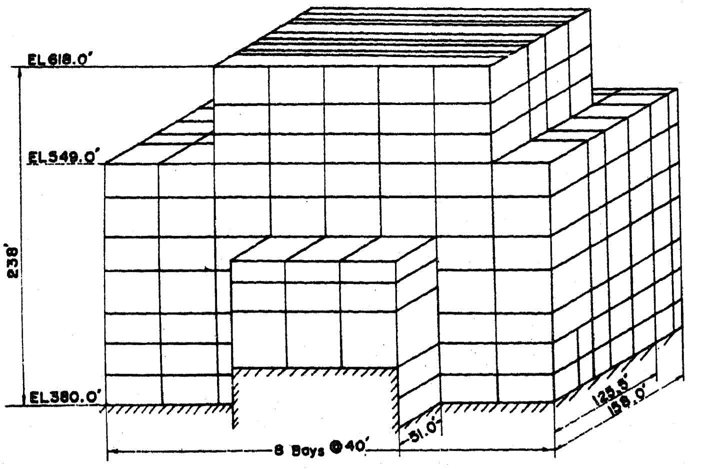

FIG. 3. A THREE-DIMENSIONAL OUTSIDE VIEW OF THE STEEL FRAME STRUCTURE.

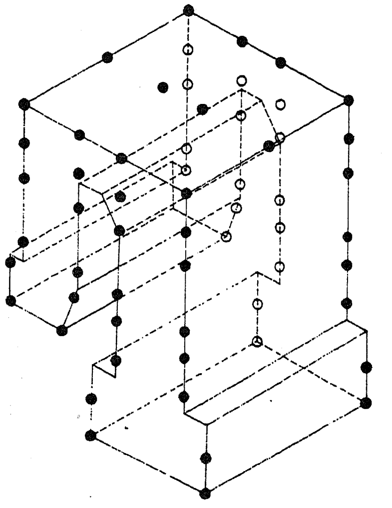

FIG. 4. THE LUMPED MASS AND RIGID BAR MODEL FOR THE STEAM GENERATOR.

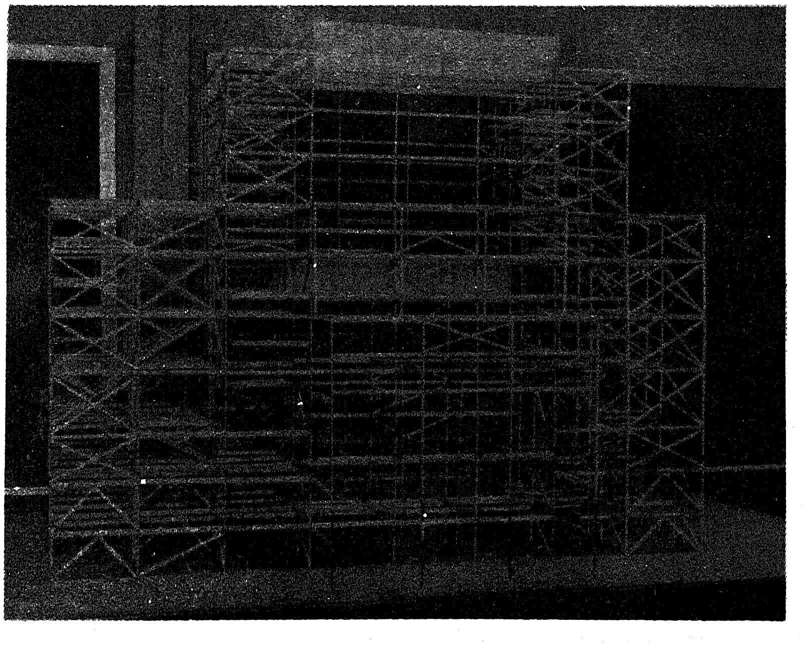

FIG. 5. THE BALSA WOOD MODEL FOR THE SUPPORTING FRAME STRUCTURE.

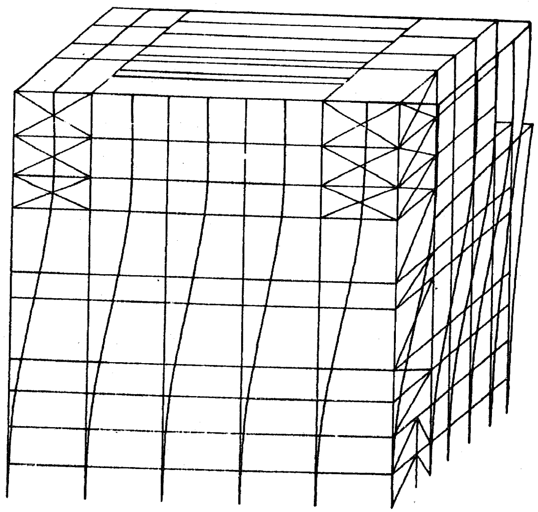

Fig. 6. The first mode shape of the central system.

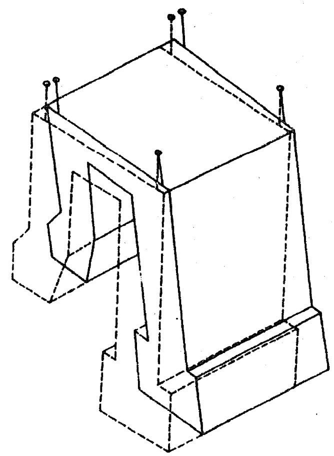

Fig. 7. The first mode shape of the steam generator supported by central structure.

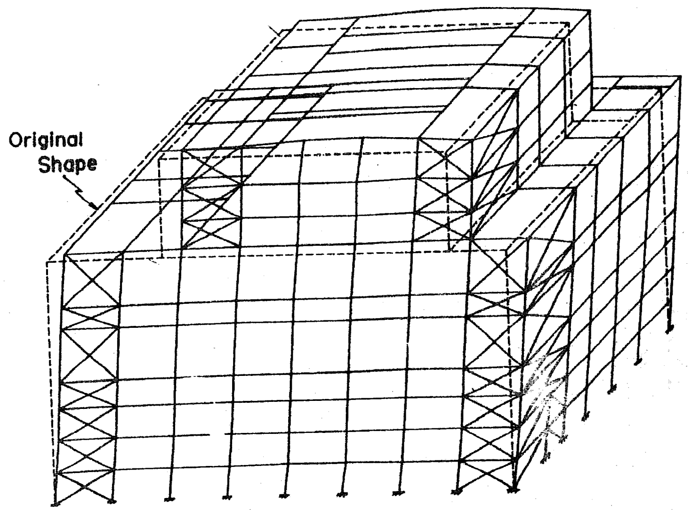

Fig. 8. The first mode shape of the total system.

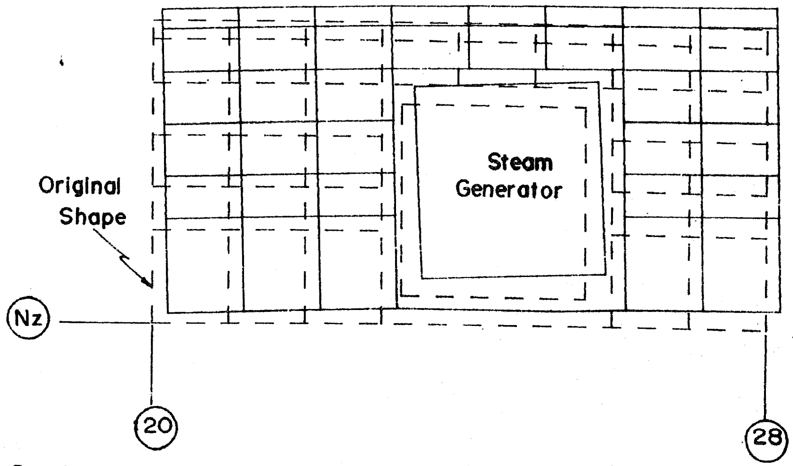

Fig. 9. The first mode shape of the plane at 169 feet above ground.

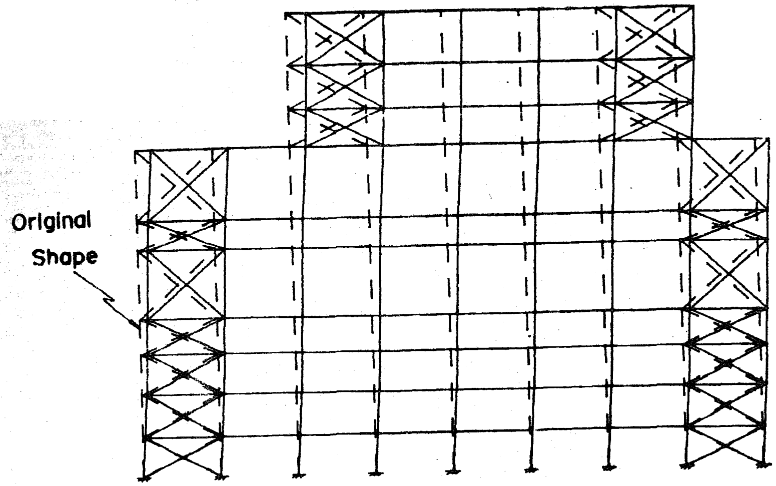

FIG. 10. THE FIRST MODE SHAPE OF THE VERTICAL FRAME ALONG NZ LINE.

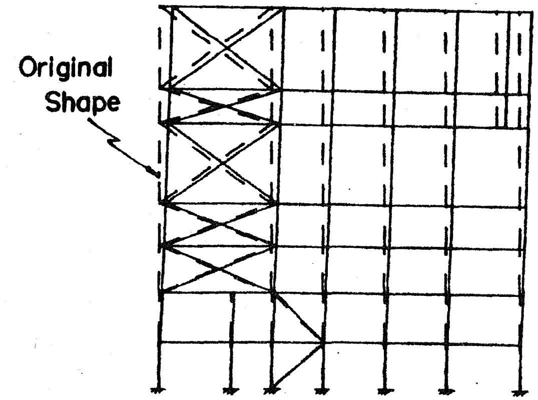

FIG. 11. THE FIRST MODE SHAPE OF THE VERTICAL FRAME ALONG LINE 20.

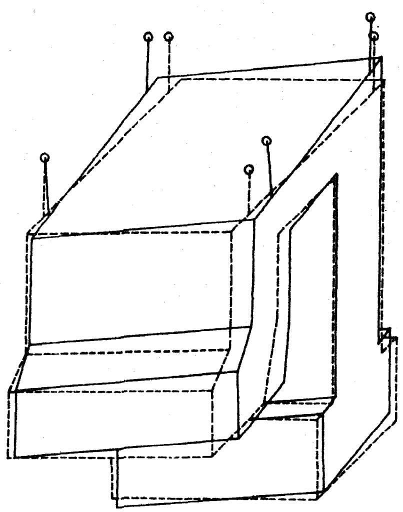

FIG. 12. THE FIRST MODE SHAPE OF THE STEAM GENERATOR SUPPORTED BY TOTAL STRUCTURE.

TABLE 1. THE FIRST MODE FREQUENCIES FOR THE VARIOUS FORMS OF CENTRAL SYSTEM

Subsystem	Steam Generator	147 Bracing Members	Number of Degrees of Freedom	Band Width	CDC 6500 CP Time (Minutes)	Frequency
1	No	No	1968	426	50	0.430 Hz
2	No	Yes	1968	426	52	0.552 Hz
3	Yes	No	2328	474	96	0.156 Hz
4	Yes	Yes	2328	474	101	0.206 Hz