THEORETICAL AND EXPERIMENTAL STUDIES OF EARTHQUAKE RESPONSE OF A CHIMNEY

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SYNOPSIS

A tall chimney is modeled using Bernoulli-Euler beam finite elements and its time-history dynamic responses are analyzed using the method of modal superposition. The chimney includes two reinforced concrete shells, each with two flue openings. The full-scale measurement provides three natural frequencies which agree well with the computed values. The horizontal and vertical components of the 1940 El Centro earthquake are used as input in the analysis. Various damping coefficients are considered. The stresses around the flue openings at the most critical instant are computed using 3-D quadrilateral plate elements. Results are discussed.

DESCRIPTION OF THE SYSTEM

The chimney of the TVA 1200 MW fossil steam generating power plant, Unit 3, at Paradise, Kentucky, USA is shown in Fig. 1. The 822 feet tall chimney includes two reinforced concrete shells. The inner shell serves as a liner and has 2 inches of fiber glass insulation on its outer surface. The inner shell also has a stainless steel cap at the top covering the gap between the inner and outer shells. However, there is no significant structural connection between them. There is a 4 ft and 6 inches mimimum air space between the two shells.

The foundation of the chimney is buried in excavated limestone rock. Thus in this study the chimney is assumed as rigidly fixed at the base.

Each shell has a pair of rectangular flue openings with dimensions of 28x14 ft^2. The base lines of the openings are 73.5 feet above the foundation. The circumferential distances between the center lines of the two openings are 50 feet for the outer shell and 38 feet for the inner shell, respectively. Each inner shell opening is connected to an outer shell opening by steel frame duct. The duct provides no significant structural connection.

THEORETICAL MODELINGS

Each of the two shells is modeled by eight Bernoulli-Euler beam finite elements. The stiffness coefficients for the first beam finite element that contains the two flue openings are obtained by using 70 3-D quadrilateral plate finite elements. After the dynamic responses to an earthquake are obtained, 244 quadrilateral plate elements are used to analyze the stress distributions in the first beam element that contains openings. In the

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horizontal earthquake response analysis, the chimney is oriented such that the earthquake direction coincides with the diameter that passes through the midpoint between the two openings.

EXPERIMENTAL SET-UP

Accelerometer assemblies are installed on the inner surface of the outer shell at the foundation level and three upper levels. Accelerations in the three space coordinate directions are measured. The set-up includes 9 units, 17 transducers, and 14 data recording channels. Primary excitation is due to wind and the blasting of a nearby coal mine. A detail description of the experimental set-up is given in reference 1.

RESULTS AND DISCUSSION

The natural frequencies were first found for both the outer and inner shells. The results are shown in Table 1. For the outer shell, the 5th, 8th, and 11th modes are longitudinal. For the inner shell, the 5th, 9th, and 11th modes are longitudinal. All other modes are flexural. The first three natural frequencies for the outer shell were also obtained from experiment and shown in Table 2. In Table 2, the theoretical results are seen to be in close agreement with the experimental data.

The N-S component of the 1940 El Centro earthquake was chosen to analyze the dynamic response of the chimney. The record of the first 30 seconds was broken down into 1500 equal time intervals. The first six flexural modes were used in the modal method. The time-history responses were obtained for tip deflection, base bending moment, and base shearing force for both shells, with or without flue openings. The deflection shapes, distributions of moment and shear were also found for several critical instants. Various values of viscous damping coefficients were considered. All results were given in reference 2. Figs. 2 and 3 show the time-history response of the tip-deflection for the outer shell and inner shell, respectively. Since the two shells share a common rigid foundation, the distances between their tips can be found from Figs. 2 and 3 and are shown in Fig. 4. The two tips are very close at 22.6 seconds. However, the tip distances become very far apart when small damping coefficients are included (reference 2). The time history responses of bending moment and shearing force at the base of the outer shell are shown in Figs. 5 and 6, respectively.

The record of the vertical component of the same earthquake was then used. Two modes were used in the modal analysis. The results for time-history responses for both shells are given in reference 2. Figs. 7 and 8 show the vertical displacement at the top and axial force at the base of outer shell, respectively.

By using 244 quadrilateral plate elements to model the first beam element that contains two openings, the stress distributions around the openings can be computed. Fig. 9 shows the distribution of vertical stress (ksi) in the outer surface of the outer shell around one opening at the most critical instant (25.2 seconds) with bending moment = $32x10^6$ kip-in, shearing force = 11,800 kips, and axial compression = 218 kips at the base.

Fig. 10 shows the effect of viscous damping on the tip deflection for both shells. The effect on the base bending moment and shearing force is similar (reference 2). Such figure may provide an estimate basis for the effect of various values of damping coefficient.

ACKNOWLEDGMENT

The study is conducted under a grant from the U.S. National Science Foundation (GI 41897).

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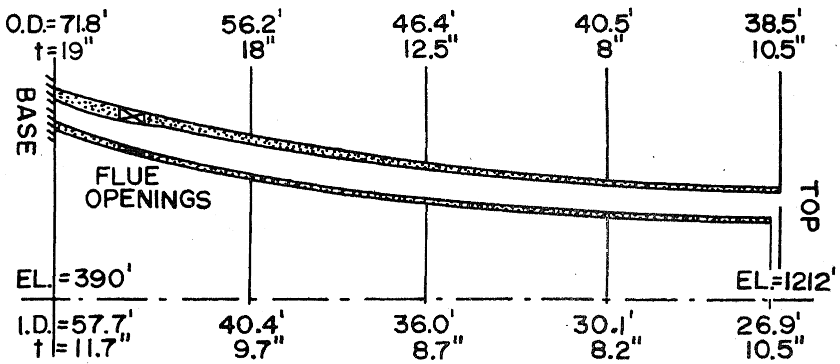

Fig. 1. Description of the chimney in the TVA fossil plant at Paradise, Kentucky, USA.

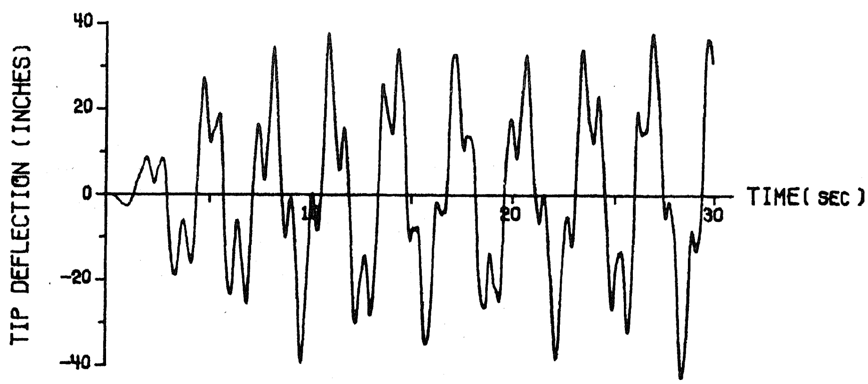

Fig. 2. Tip deflection vs. time curve for the outer shell.

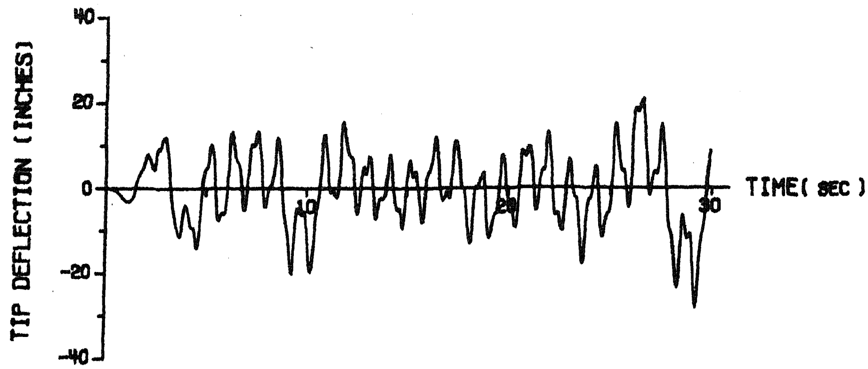

Fig. 3. Tip deflection vs. time curve for the inner shell.

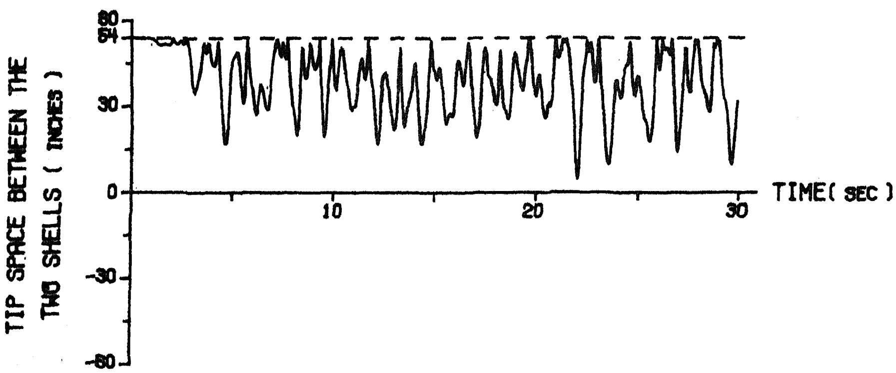

Fig. 4. Time-history curve for the spacing between the tip of two shells.

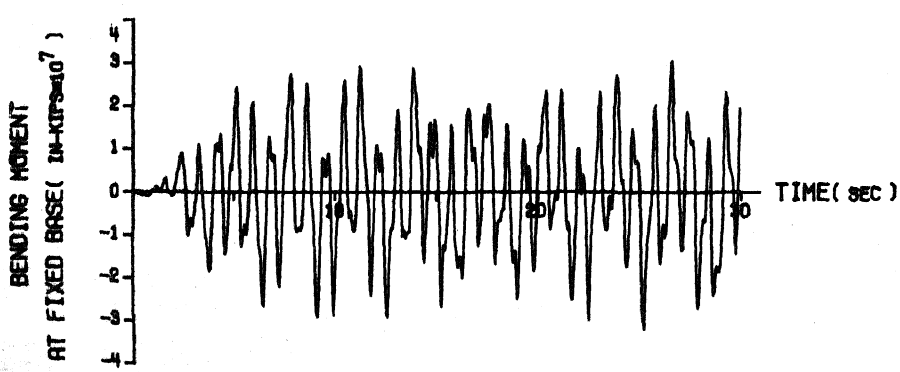

Fig. 5. Bending moment at base vs. time curve for the outer shell.

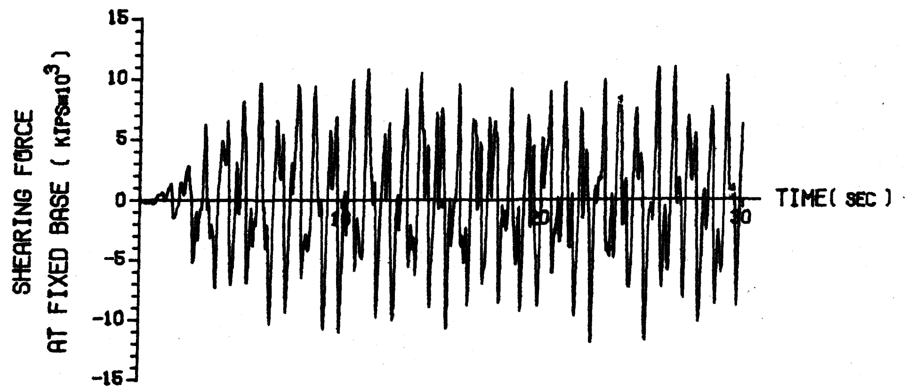

Fig. 6. Shear force at base vs. time curve for the outer shell.

Fig. 7. Vertical tip deflection vs. time curve for outer shell.

Fig. 8. Axial force at base vs. time curve for outer shell.

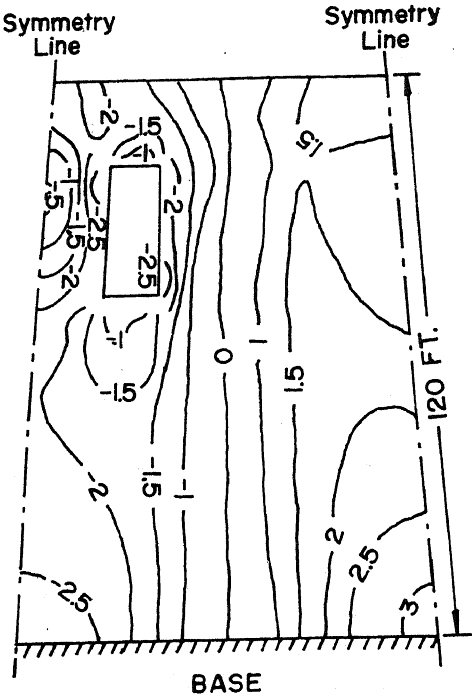

Fig. 9. Iso-stress (ksi) plot around hole of outer surface of outer shell at 25.2 seconds.

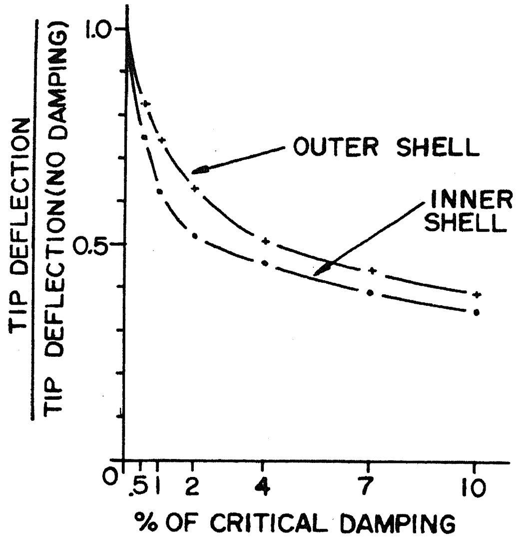

Fig. 10. Effect of damping in horizontal earthquake.

Table 1. Natural Frequencies (rad./sec.) for the Chimney

Mode Number	Outer Shell	Inner Shell
1	1.97	1.28
2	7.01	5.62
3	16.57	13.57
4	29.02	24.32
5	31.39	28.03
6	43.43	36.98
7	58.12	50.25
8	65.28	61.98
9	71.44	70.37
10	81.81	73.00
11	109.30	110.90
12	145.80	148.90

Table 2. Comparison of the First Three Natural Frequencies (rad./sec.) for the Outer Shell

Mode Number	1	2	3
8-Finite Elements	1.97	7.01	16.6
Full Scale Measurement	1.82	6.35	15.1