Seismic Analysis of a 400-MWe Pool-type Fast Reactor*

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1 INTRODUCTION

This paper presents a seismic analysis of a 400-MWe pool-type fast reactor subjected to horizontal support excitation. Two types of analyses are performed -- the fluid-structure interaction analysis and the sloshing analysis. In the fluid-structure interaction analysis, the fluid coupling between various components are investigated. The maximum horizontal acceleration for the reactor core and the relative displacement between the reactor core and UIS (Upper Internal Structure) are examined. Seismic stresses at critical areas are calculated. In the sloshing analysis, the sloshing frequency and wave patterns are calculated. The maximum wave height and the sloshing forces exerted on the submerged components and the primary tank are evaluated.

The analyses are performed by a finite-element computer code, FLUSTR-ANL (i.e., FLUid-STRucture Interaction code, augmented by Argonne National Laboratory for seismic analysis of LMR reactor components). Only the results of fluid-structure interaction analysis are presented in this paper. The results of the sloshing analysis are reported in a companion paper [1].

Four sections are contained in this paper. The reactor system and the mathematical model are described in Section 2. The results of fluid-structure interaction analysis are presented in Section 3. The conclusions are given in Section 4.

2 REACTOR SYSTEM AND MATHEMATICAL MODEL

The 180° mathematical model used in the fluid-structure interaction analysis is shown in Figs 1 and 2. It represents half of the reactor system along the symmetry plane. The model consists of reactor vessel, UIS, cold trap, one pump, two IHXs, redan assembly, and core structures. The vessel has a diameter of 39 ft and a length of 47 ft

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6 in. The thickness is 2.5 in. in cylindrical shell and 4 in. in bottom head. The horizontal redan assembly structures separate the coolant into two pools: hot and cold. The sodium coolant above the redan, i.e., hot pool, has a large free surface and can undergo the sloshing motion. The sodium coolant in the cold pool, i.e., underneath the redan, is completely trapped and cannot participate in sloshing motion. The reactor core is enclosed by a core barrel and the shield barrel. It is supported laterally at the top by the redan assembly structures and vertically at the bottom core support plates, which in turn, are supported by the core support cylinders and the reactor bottom head.

The reactor vessel and redan plate are represented by shell elements, whereas the deck-mounted components and core structures are represented by beam elements. The beams representing the IHXs and UIS are suspended from the deck. The beams representing the shroud of the pump and cold trap are supported on the redan. The sodium coolant is simulated by the 8-node fluid continuum element. Thin-layer fluid elements are placed at fluid-structure interfaces to simulate the contact/sliding boundary condition. Four of the eight fluid nodes of the thin fluid element are moved together with the structure, whereas the other four are free to move.

The model consists of 3290 nodal points, 351 displacement-based fluid elements, 1331 pressure-based fluid elements, 463 shell elements, and 57 beam elements. It is a very sophisticated reactor system seismic model which considers fluid-structure interactions and sloshing.

In the analysis, the excitation motion is a 12-s acceleration time history at reactor support. The maximum acceleration level is 0.46 g, which occurs at t = 8.1 s. A linear transient time history analysis based on FLUSTR-ANL code is carried out with 0.005 s. of integration time step and three percent (3%) of the structural damping. The results of seismic fluid-structure interaction analysis are described in the following section.

3 RESULTS OF SEISMIC FLUID STRUCTURE INTERACTION ANALYSIS

The analysis indicates that there are three significant lateral modes. The first is the IHX lateral vibrational mode which has a frequency of 5.67 Hz. The second is the vessel-core-redan mode which has a frequency of 9 Hz. The third is the UIS lateral mode which has a frequency of 12.5 Hz.

The displacement time history and FFT at the bottom of the UIS and top of the core are shown in Figs. 3 and 4, respectively. They indicate that the maximum displacement of the UIS and the core is 0.047 in and 0.070 in, respectively. They occur at the same time, i.e., t = 8.15 s. The sum of the absolute value of the two displacements is only 0.117 in, which is well below the design limit of 2.2 in. The displacement time history and FFT of the UIS (see Fig. 3) indicate that the UIS has a vibrational frequency of 12.5 Hz. Also shown in Fig. 3 are the other significant modes. One has a frequency of 5.67 Hz and the other has a frequency of 0.23 Hz. The 5.67-Hz frequency is caused by the vibration of the IHX which is transmitted to the UIS by the fluid coupling effect. The 0.23-Hz frequency is the sloshing frequency transmitted to the UIS by the lateral sloshing force. The details of sloshing response can be found in [1]. The other peaks observed in the FFT plot belong to the input motion. The influence of the IHX on the core response can also be found in the FFT of the core (see Fig. 4).

The displacement response and FFT at the bottom of IHX-1 is shown in Fig. 5. The maximum lateral displacements of IHX-1 and IHX-2 are 0.32 in and 0.36 in, respectively. Both IHXs vibrate at a frequency of 5.67 Hz. It is noted that the in-air frequency of the IHX is 3.5 Hz. The increase in frequency is due to the influence of the vessel vibration on the IHXs. This influence can be seen from the plots of FFT of the IHX (see Fig. 5).

The displacement and FFT at the bottom of the vessel, the top of the pump well, and the top of the cold trap are shown in Figs. 6, 7, and 8, respectively. Basically, the vessel, core, pump well, and cold trap move in unison, having a frequency of 9 Hz. The effects of the IHX vibration of 5.67 Hz frequency are clearly shown in Figs. 6, 7, and 8. The maximum lateral displacement and the first (f_1) and second (f_2) dominant frequencies at various locations are summarized in Table 1. The second dominant frequency, f_2, represents the fluid coupling effects. The maximum acceleration at the core is 0.7 g. It is much smaller than the allowable core acceleration under SSE conditions, i.e., 3.5 g. The seismic stresses of the vessel and components are also very small.

4 CONCLUSIONS

Seismic fluid-structure interaction analysis has been performed for a 400-MWe pool-type advanced fast reactor with a diameter of 39 ft. Much valuable information has been obtained. The major conclusions drawn from this study are as follows.

(1) The most significant mode is the core-vessel lateral vibration mode which has a frequency of 9 Hz and which is considerably higher than that of a large-diameter (e.g., 70 ft) LMR reactor. The other two significant modes are the IHX lateral vibration mode, 5.6 Hz, and the UIS lateral vibration mode, 12.5 Hz. Because of high frequencies, the overall seismic response is small.

(2) Strong interaction (fluid coupling) exists between the IHXs and the vessel. As a result, the IHX frequency increases to 5.6 Hz. Note that the in-air IHX frequency is only 3.5 Hz. On the other hand, the vessel-core response has also been strongly influenced by the vibration of the IHXs. This is also true for the UIS. It is strongly influenced by the vibration of the IHX.

(3) Future analysis should also include the shrouds which are placed outside the components and the fluid which connects the shrouds and the components. The shroud can be treated by beam element. The fluid connecting the shroud and the components can be treated by the added mass based upon Fritz's equation [2].

REFERENCES

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Fritz, R. J. "The Effects of Liquids on the Dynamic Motions of Immersed Solids," Journal of Engineering for Industry, Transactions of the ASME, Vol. 94, February 1972, pp. 167-173.

Table 1. Maximum Lateral Displacement and Dominant Frequencies of the Components

	Maximum Disp. (in.)	f_1 (Hz)	f_2 (Hz)
Bottom of UIS	0.47	12.5	5.67
Top of Core	0.070	9.0	5.67
Bottom of Core	0.086	9.0	5.67
Bottom of IHX-1	0.32	5.67	9.0
Bottom of IHX-2	0.36	5.67	9.0
Top of Pump Well	0.078	9.0	5.67
Top of Cold Trap	0.083	9.0	5.67
Redan	0.068*	9.0	5.67

*Maximum displacement at base of pump well and cold trap

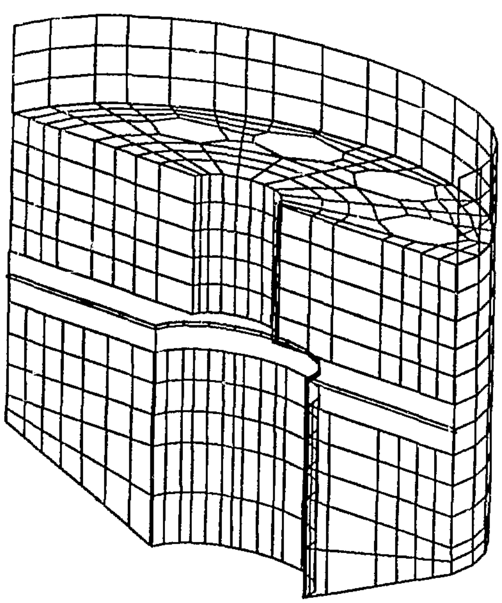

Fig. 1. Isoparametric View of the Reactor Model

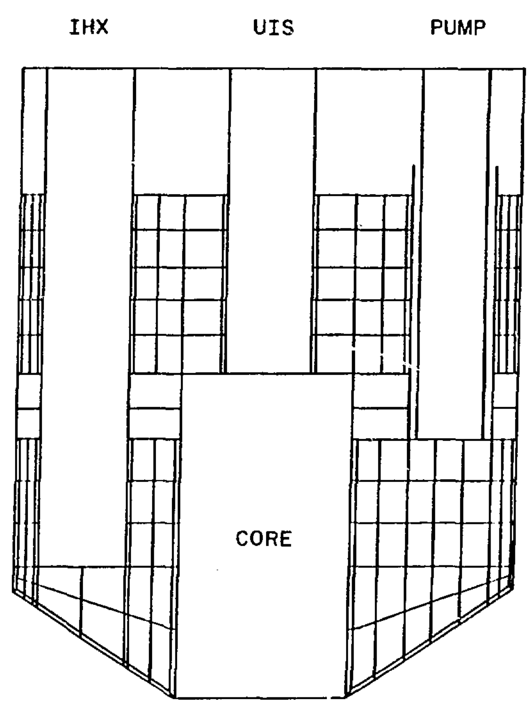

Fig. 2. Elevation View of the Reactor Model

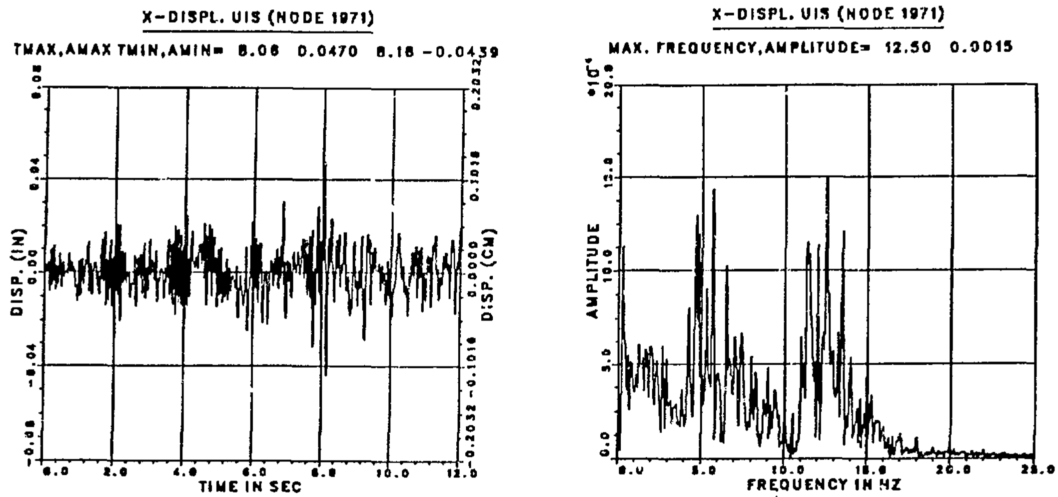

Fig. 3. Horizontal Displacement and FFT at the Bottom of the UIS

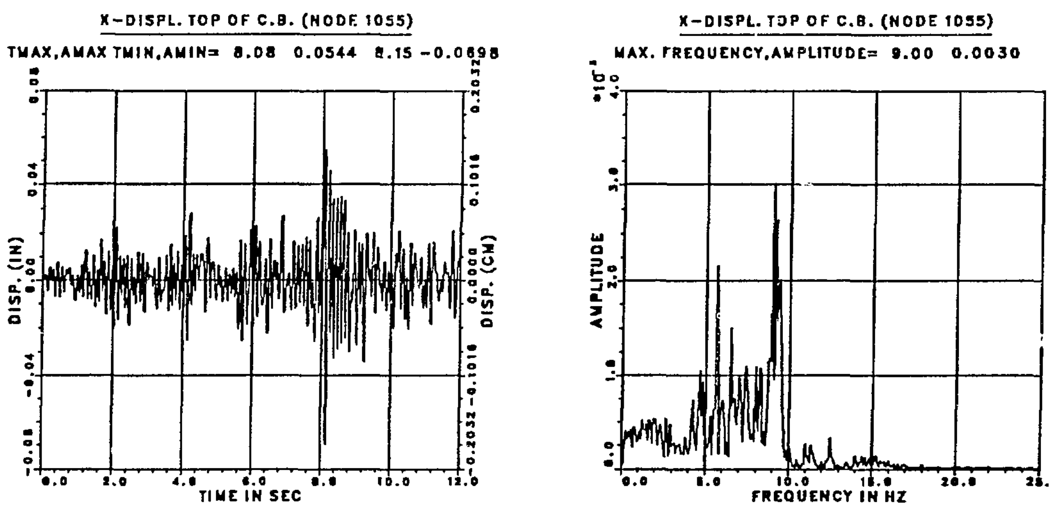

Fig. 4. Horizontal Displacement and FFT at the Top of the Reactor Core

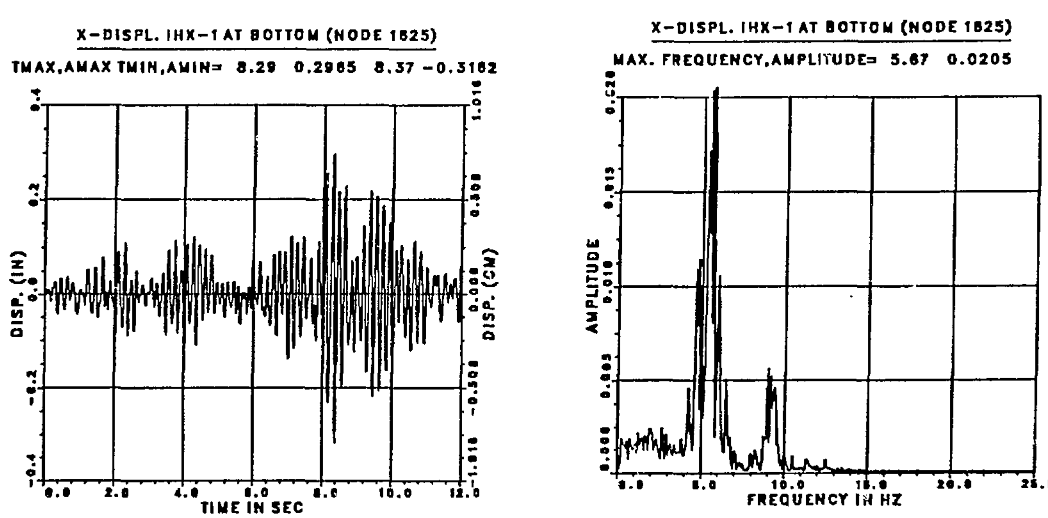

Fig. 5. Horizontal Displacement and FFT at the Bottom of the IHX-1

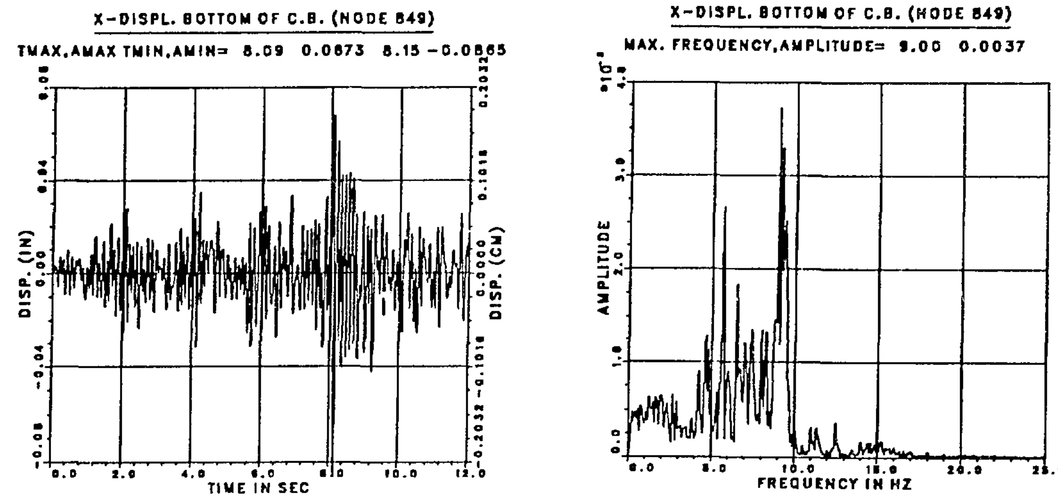

Fig. 6. Horizontal Displacement and FFT at the Bottom of the Vessel

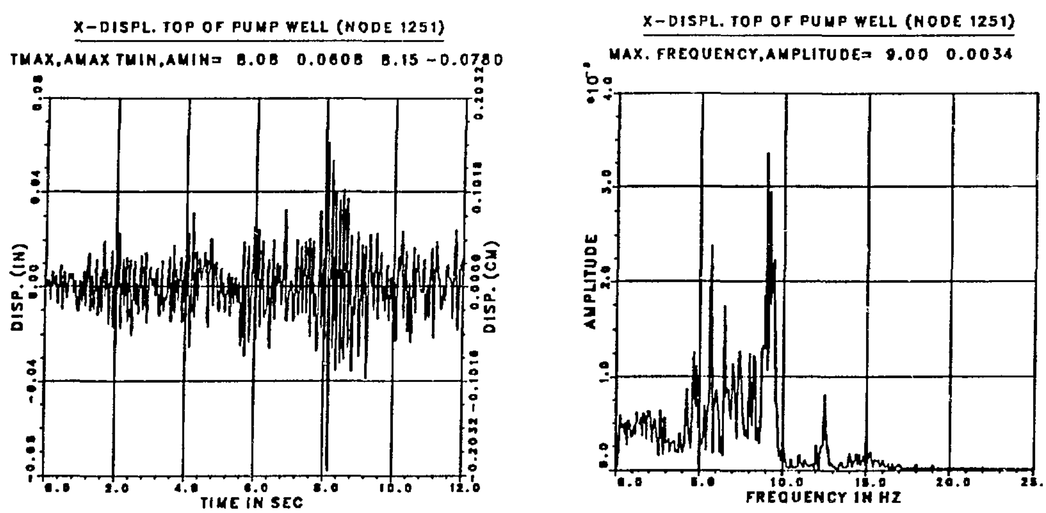

Fig. 7. Horizontal Displaclement and FFT at the Top of the Pump Well

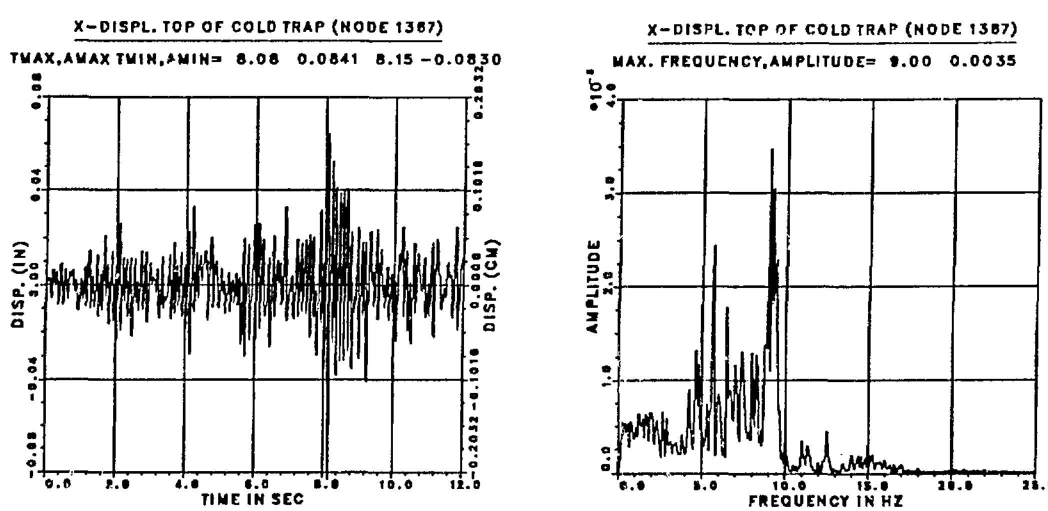

Fig. 8. Horizontal Displacement and FFT at the Top of the Cold Trap

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