Dominant Seismic Sloshing Mode in a Pool-type Reactor Tank*

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1 INTRODUCTION

Large-diameter LMR (liquid Metal Reactor) tanks contain a large volume of sodium coolant and many in-tank components. A reactor tank of 70 ft. in diameter contains 5,000,000 of sodium coolant. Under seismic events, the sloshing wave may easily reach several feet. If sufficient free board is not provided to accommodate the wave height, several safety problems may occur such as damage to tank cover due to sloshing impact and thermal shocks due to hot sodium, etc. Therefore, the sloshing response should be properly considered in the reactor design.

~~Seismically induced sloshing response of a 70 ft-diameter pool type LMR was reported in [1].~~ This paper presents the results of the sloshing analysis of a pool-type reactor tank with a diameter of 39 ft. The results of the fluid-structure interaction analysis are presented in a companion paper [2]. Five sections are contained in this paper. The reactor system and mathematical model are described ~~in Section 2~~. The dominant sloshing mode and the calculated maximum wave heights are presented ~~in Section 3~~. The sloshing pressures and sloshing forces acting on the submerged components are described ~~in Section 4~~. The conclusions are given ~~in Section 5~~.

2 DESCRIPTION OF THE SLOSHING MODEL

The sloshing model shown in Fig. 1 represents the hot pool of the coolant above the horizontal redan. The cold pool below redan is completely trapped. Therefore, it is omitted. It is a 180° model representing half of the reactor. The component at the center represents the UIS; the other four off-center components represent two IHXs, one pump, and one cold trap. The detailed description of the reactor system can be found in [2]. The components and the tank are assumed to be rigid in the analysis. The input motion at reactor support has a duration of 20 s and a maximum acceleration of 0.46 g. A linear transient time history analysis is carried out. The results of the analysis are described in the following sections.

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3 THE DOMINANT SLOSHING MODE AND MAXIMUM WAVE HEIGHT

The analysis indicates that there are three significant sloshing modes at frequency of 0.23 Hz, 0.5 Hz, and 0.9 Hz, respectively. The fundamental mode of 0.23 Hz belongs to cosθ tangential mode in which the coolant sloshes along the circumferential direction of the tank. The wave pattern of cosθ tangential mode is shown in Fig. 2 in which H and L indicates the high and low lines of the wave, and 0 represents a zero line. The second sloshing mode at frequency of 0.5 Hz belongs to the radial mode in which coolant sloshes antisymmetrically between the UIS and the tank as shown in Fig. 3. The third mode is more complicated. It has a cosnθ up-and-down type wave along the circumferential direction of the tank. The number of waves is somewhat related with the number of the off-center components (i.e., IHXs and pump). The up-and-down type mode of a 70 ft diameter pool-type reactor tank with six off-center components in half of the tank [1] is shown in Fig. 4. The cos6θ wave can be clearly observed. The up-and-down sloshing mode occurs mainly in the fluid region bounded by the off-center components and the reactor tank.

The analysis also indicates that the fundamental mode (i.e., cosθ tangential mode) completely dominates the sloshing wave height with exception at the 0° of the UIS where the wave height is dominated by the radial mode at 0.5 Hz (see Fig. 5). The results based on a different set of input motion (i.e., 1940 El Centro record) also indicate that cosθ sloshing mode is the dominant mode of the wave height. A typical sloshing wave height history is shown in Fig. 6. It clearly indicates that the cosθ sloshing mode is the dominant mode. Figure 7 shows the maximum wave height at various locations on the free surface. The maximum wave height is 29 in. and occurs at IHX-2. It is noted the maximum wave height in the 70-ft-diametered tank [1] is 40 in.

4 SLOSHING PRESSURES AND FORCES EXERTED ON THE COMPONENTS

In addition to the maximum wave height, the sloshing pressures and forces exerted on the components and the reactor tank are also of importance to the reactor design. The calculated sloshing pressure consists of two components: a convective pressure component which has a longer period and an impulsive pressure component which varies synchronously with the input acceleration history. When the input motion stops, the impulsive pressure component vanishes and only the convective pressure component exists.

The maximum sloshing pressure exerted on the components and tank wall at top, middle, and bottom fluid-element layers (see Fig. 1) are shown in Figs. 8, 9, and 10, respectively. It should be noted that they do not occur at the same time. The maximum sloshing pressure is 1.3 psi for the reactor tank, 0.50 psi for the UIS, 0.75 psi for the cold trap, 0.66 psi for the pump, 0.92 psi for the IHX-1, and 0.96 psi for IHX-2. They all occur at the bottom fluid layer. It is noted that the maximum sloshing pressure exerted on the component can reach to 5 psi for a 70-ft-diametered pool-type reactor [1].

On the top fluid-element layer, the most important mode in the sloshing pressure is the cosθ tangential mode at frequency of 0.23

Hz. As the fluid depth increases from top layer to bottom layer, the intensity of the impulsive pressure increases. The 0.23 Hz of cosθ sloshing mode is no longer the dominant frequency. It is interesting to note that the pressure magnitude of the 0.9-Hz cosnθ sloshing mode also increases with the fluid depth. As a result, the sloshing pressures at the bottom of the tank are larger than those near the surface.

On the off-center components, there are two types of sloshing modes: cosθ tangential mode at 0.23 Hz and cosnθ tangential mode at 0.9 Hz. It is reasonable to assume that at certain instances, the sloshing pressure acting on the component has a cosθ distribution as shown in Fig. 11. It is the worst loading case that a component can be subjected to under seismic sloshing. The resultant sloshing force, f, acting on unit length of the component (see Fig. 12) can be obtained from

$$f = \int_0^{2\pi} P \cdot \cos^2\theta r d\theta \qquad (1)$$

or

$$f = \pi p r \qquad (2)$$

where P is the maximum sloshing pressure acting on the component. For this case, P is 0.96 psi for IHX-2. As a conservative estimate, the sloshing force can be assumed to be uniformly distributed along the submerged length of the component. The base shears and moments induced by the sloshing force at top support should be considered in the design of the components.

6 CONCLUSION

Sloshing analysis of a pool-type reactor tank with a diameter of 39 ft is performed. The maximum wave height is 29 in. The maximum sloshing pressure on components is 0.96 psi. They are smaller than those in the large-diametered (e.g., 70 ft) pool-type LMRs.

Three sloshing modes have been identified. They are the cosθ tangential sloshing mode (i.e., fundamental sloshing mode) at a frequency of 0.23 Hz, the radial sloshing mode at a frequency of 0.5 Hz and the up-and-down tangential sloshing mode frequency of 0.9 Hz. The free surface wave height is mainly caused by the cosθ tangential mode in which the fluid flows in the circumferential direction of the tank. The radial sloshing mode is confined in the fluid region between the UIS and the vessel along the excitation direction. The up-and-down mode is a higher order tangential mode in which the wave height has a cosnθ distribution along the circumferential direction of the tank. It is believed that this cosnθ mode is somewhat related to the number of the off-center components (i.e., IHXs and pump).

The sloshing pressure near free surface is also dominated by the cosθ tangential mode. As the fluid depth increases from the free surface, the pressures induced by the cosnθ tangential mode also increase. The cosnθ mode becomes the dominant mode for sloshing pressure at the bottom of the tank.

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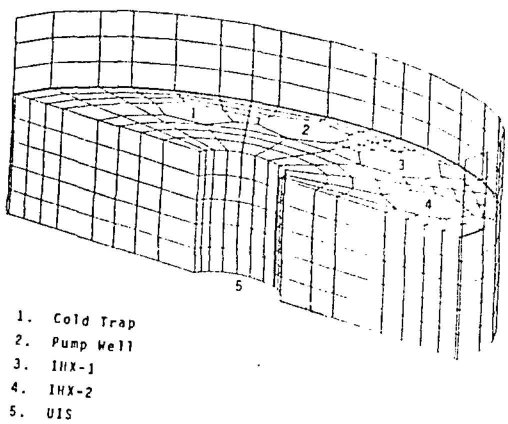


Fig. 1. Sloshing Model

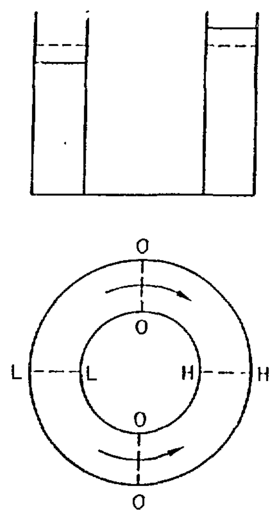


Fig. 2. Cosθ Tangential Mode

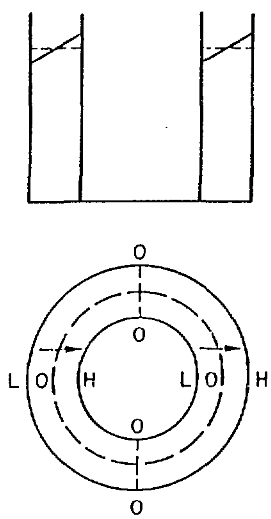


Fig. 3. Radial Mode

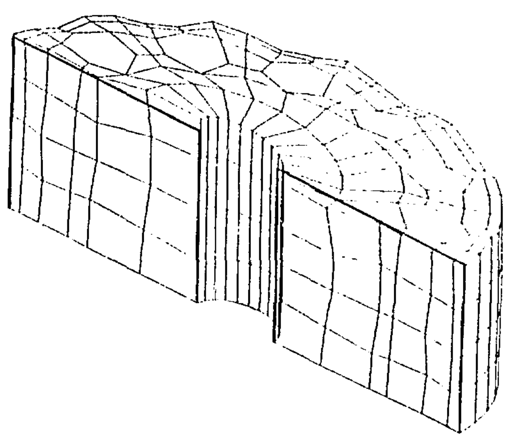
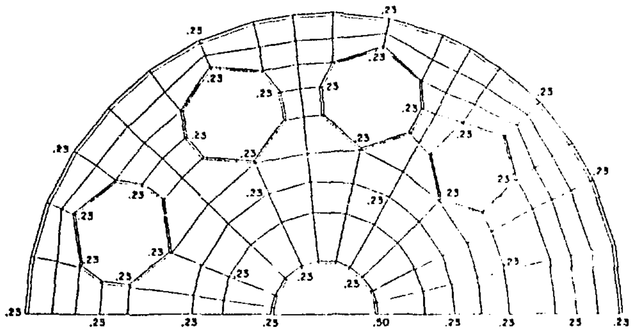


Fig. 4. Cosnθ Tangential Mode



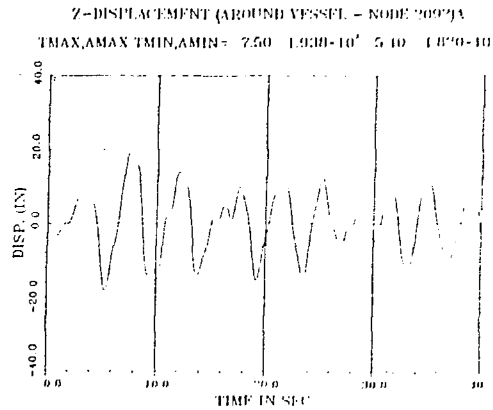


Fig. 5. Dominant Wave Frequency

Fig. 6. Typical Wave History

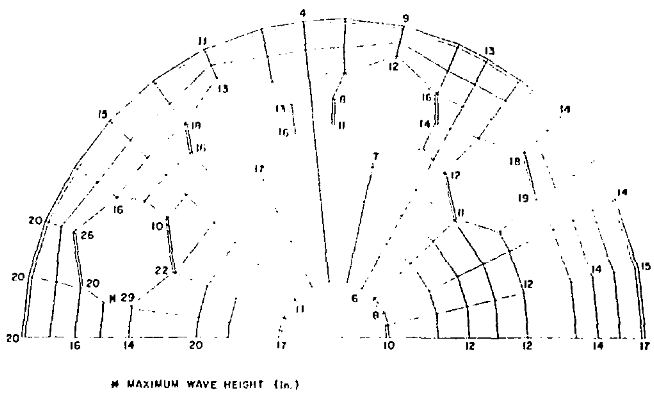


Fig. 7. Maximum Wave Height (in.)

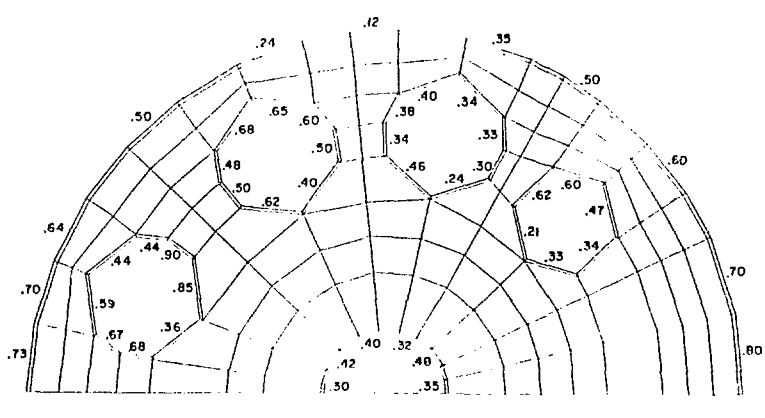


Fig. 8. Maximum Pressures (psi) on Top Layer

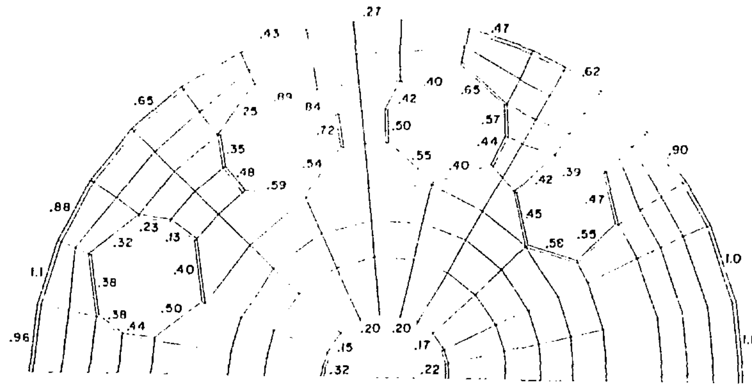


Fig. 9. Maximum Pressures (psi) on Middle Layer

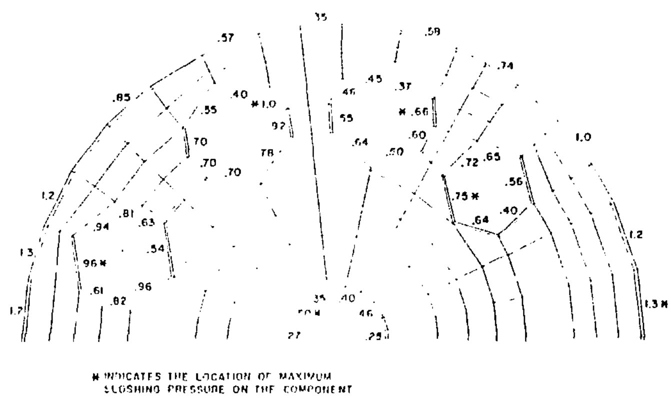


Fig. 10. Maximum Pressures (psi) on Bottom Layer

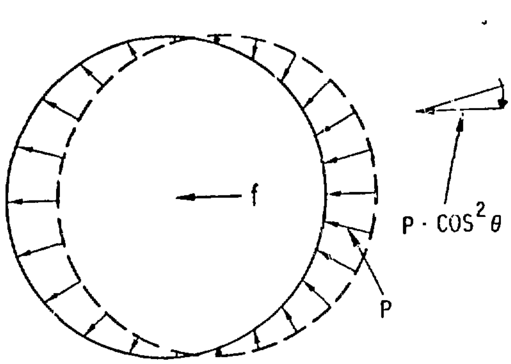


Fig. 11. Cosθ Pressure Distribution

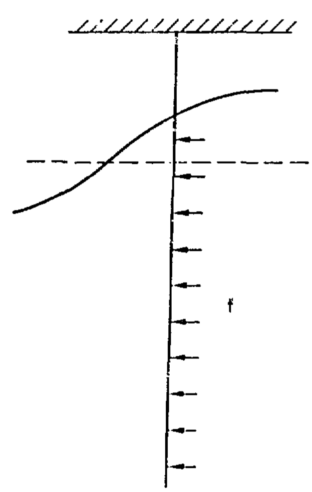


Fig. 12. Sloshing Force Distribution