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RESPONSE OF A VESSEL OF LMFBR SUBJECT TO HORIZONTAL EXCITATIONS

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SUMMARY

Coupled liquid-structure oscillations of a container of pool type LMFBR subject to horizontal excitations are studied for small motions. Ignoring pumps and IHX's the container is treated as an axisymmetric structure containing liquid sodium considered as a perfect fluid. Using structural data similar to Super Phenix, several natural frequencies and modes are computed. A modal analysis method is applied to give time history of the displacement of the coupled liquid structure system subject to horizontal excitations resonant to the first bulging mode. Deformations of an inner oblique wall (conical redan) are known to increase severely with time.

INTRODUCTION

A vessel of pool type LMFBR, which will be abbreviated as reactor vessel hereafter, is a complex structure consisting of several forms of shell and internals, such as pumps and IHX's. The complexity is enlarged by the fact the reactor vessel contains liquids in multi-connected regions. It is not easy that numerical analysis predicts accurately behaviors of the reactor vessel subject to earthquake excitations. But the importance of its safety claims for efforts of structural engineers and the like.

Progress on this subject are known from publications presented in the international conference on SMiRT held every two years. There are presented papers on free vibrations of axisymmertric structures which ignores internals (pumps and IHX's) (Ref.1), 3D free vibration analysis including the internals (Ref.2,3), model test (Ref.4) and model tests and their theoretical analysis (Ref.5,6).

It is thought to be beyond the capacity of the computer, at present, which calculates accurately the behavior of the reactor vessel under earthquakes using 3D FEM, and hence it may be meaningful to analyze effectively behaviors of the axisymmetric structure using axisymmetric shell element and BEM. The present paper treats free vibrations and responses of the axisymmetric structure subject to horizontal earthquake excitations, taking no accunt of the internals.

OUTLINE OF A THEORETICAL ANALYSIS

To deal with the coupled liquid-structure oscillations of reactor vessel, the following are assumed :

(1) Ignoring pumps and IHX's the reactor vessel is considered as an axisymmetric structure consisting of several forms of axisymmetric shells.
(2) The reactor vessel has small displacements that a linear shell theory is applicable for within an elastic limit.
(3) The liquid sodium contained in the vessel is regarded as a perfect fluid.
(4) The liquid has small free surface displacements and liquid pressure variations that the potential theory is applicable for.
(5) The liquid-structure interaction is described by a variational principle.

The flow of the theoretical analysis is as follows :

(1) A functional of a variational principle is introduced for liquid-structure interactions (Ref.7).
(2) The functional is discretized using FEM for the structure and BEM for the liquid.
(3) Stiffness and mass matrices of the structure are produced by axisymmetric shell element (Ref.8).
(4) Added stiffness and mass matrices of the liquid are produced by axisymmetric boundary element (Ref.9).
(5) The direct stiffness method is applied to construct discretized equations of motion, which have symmetric matrices easy to handle.
(6) Free vibration analysis is worked to obtain natural frequencies and modes.
(7) Rigid body displacement of the structure and uniform flow field of the liquid correspondent to horizontal excitations are specified, from which exciting forces of earthquakes are evaluated.
(8) A modal analysis method is employed to calculate time history of spatial distributions of the displacements.

NUMERICAL RESULTS

Based on the theory outlined above a computer program is specially developed for numerical calculations. Input data simulating Super Phenix are sketched in Fig.1 which indicates principal dimensions and joint numbers. The wall of the reactor vessel is made of steel and the liquid is taken as a water. The liquid is contained in compartments except for reactor core and its access. The liquid free surface has joint numbers 27, 76 through 89 and 65.

According to free vibration analysis, so called "sloshing modes" emerge in a lower frequency range, where displacements of the liquid free surface predominate. For this purpose, the displacement of the wall of the reactor vessel is constrained temporarily. The lower first to third natural frequencies and modes are shown in Fig.2. In a higher frequency range, there emerge so called "bulging modes", where displacements of the wall predominate. The lower first to third natural frequencies and modes are shown in Fig.3 to 5, respectively.

Taking as horizontal earthquakes sine-waves resonant to the first bulging mode (3.61HZ), response of the reactor vessel are computed. The deformation after three cycles of excitations are indicated in Fig.6, where deformations of an inner oblique wall(conical redan) are prominent. Figure 7 shows time history of the displacement of the joint number 48 belonging to the conical redan, from which a resonance characteristics is observed.

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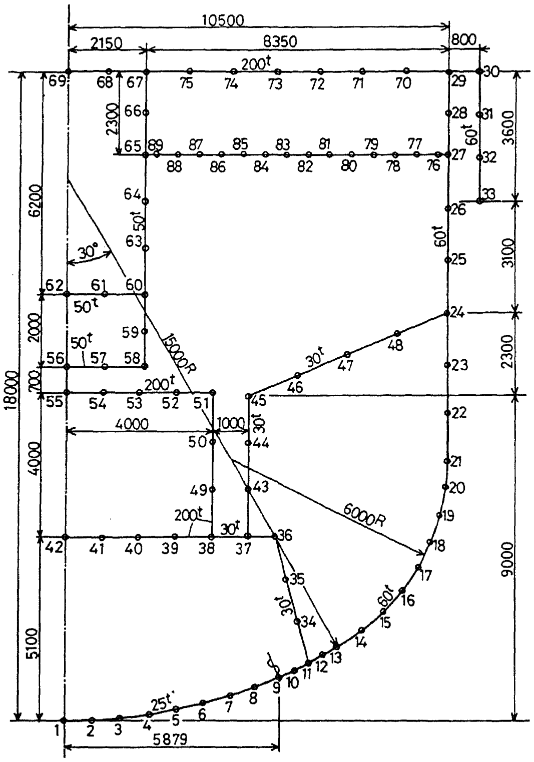

Fig. 1 Principal Dimensions and Joint Numbers

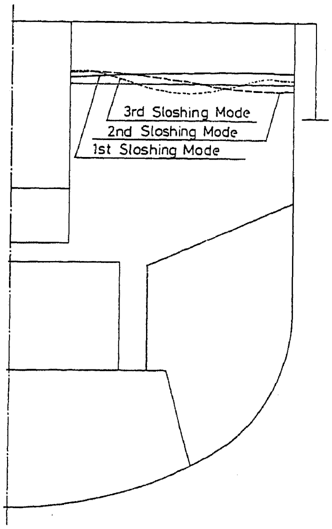

Fig. 2 Lower Sloshing Modes
(1st to 3rd)

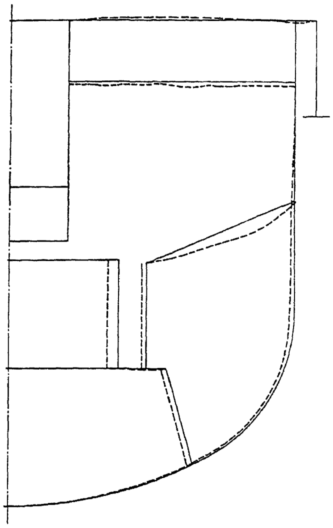

Fig. 3 1st Bulging Mode (3.61 HZ)

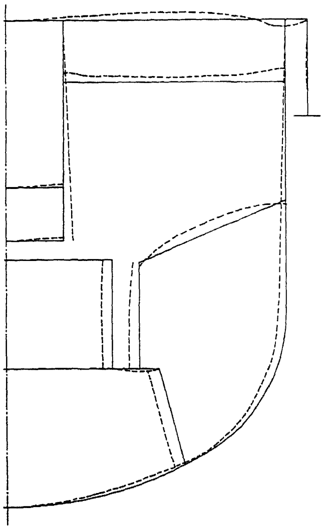

Fig. 4 2nd Bulging Mode (5.85 HZ)

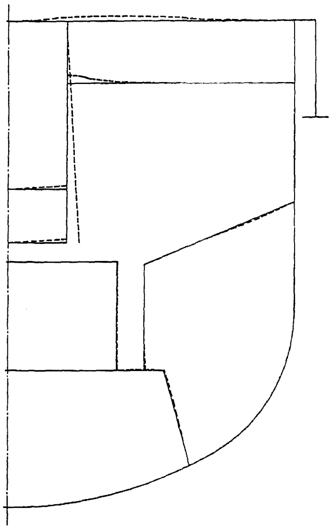

Fig. 5 3rd Bulging Mode (8.16 HZ)

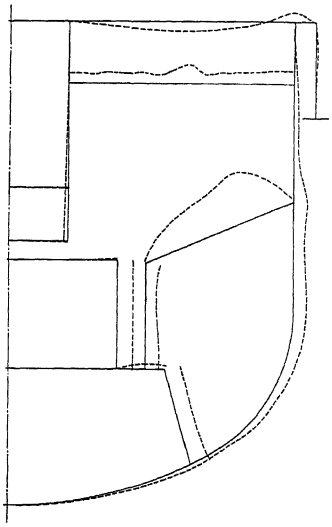

Fig. 6 Displacement of the Profile after the Three Cycles of Excitation

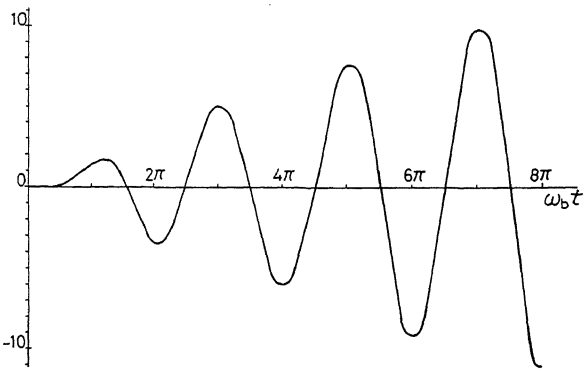

Fig. 7 Time History of the Displacement of Joint Number 48