Development of the Three-Dimensional SHAPS Code Capabilities for Application to LMFBR Piping Systems*

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The interaction of pressure pulses with different piping components (elbows, valves, pumps, heat exchangers, etc.) and with one another, when they meet, can produce a variety of reflected pulses and pressures. The result is a complex system of pressure pulses that may cause plastic deformation, and possible structural damage to the piping system. To safely assess the adequacy of such a piping system, one should use realistic methods of modeling the hydrodynamic and structural aspects of the problem. One-dimensional analyses, typically employed, using the methods of characteristics is limited to using straight pipes and loss coefficients to simulate hydrodynamics in a pipe network. Furthermore, modeling deformable pipes as a series of disconnected rings subjected to the radial pressure of the internal fluid ignores bending and shear effects as well as the flexural interaction of the system. The SHAPS code[1,2] couples three-dimensional pipe elements and elbows with two-dimensional hydrodynamics in order to account for fluid-structure interaction, motion of fluid due to moving pipes, and deformation of the structure. Each pipe element is formulated with eight degrees of freedom per node to consider translation, rotation, and membrane bending and breathing modes of the structure in order to calculate the stresses arising from internal pressurization as well as the three-dimensional flexural motion of the piping system.

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Development of transient, three-dimensional, coupled, fluid-structure interaction computational methods has led to some important formulations within the SHAPS code. Methodology has been established to treat global elbow motion, internal baffle plates, and isolated flow regions. As a result, important effects of global structural motion and changes of flow area as well as flow direction can be properly included in the analysis. Elbow motion plays an important role in the propagation of pressure transients in piping systems. In previous analyses the global motion of the elbow was considered as a body force in the hydrodynamics, similar to the manner of treating the gravitational force. Recent test calculations have shown that this approach tends to over-attenuate the pressure peak as it passes through the elbow. To improve this situation, a new scheme has been developed to rigorously account for the global elbow motion.

As the elbow moves in three-dimensional space it carries the flowing fluid along with it. The hydrodynamic finite-difference mesh is, likewise, assumed to be carried along with the elbow without changing its shape or size. Nevertheless, the fluid remains free to slide along the elbow wall. Such motion of the finite-difference mesh must be considered in the hydrodynamic equations in the global coordinate system. To implement this, these equations are derived with respect to the moving elbow. Figure 1 shows a three-dimensional elbow junction and the control volumes for the derivation of the two-dimensional mass and momentum hydrodynamic equations.

The ability of the SHAPS code to rigorously account for three-dimensional structural response is equalled by its capability for handling internal hydrodynamics. A sample problem is presented, schematically, in Fig. 2 as a SHAPS model of a primary heat transport system (PHTS) in a loop-type LMFBR, complete with varying pipe diameters, elbows, and in-line components. A disruption within containment would propagate pressure pulses in both directions around the loop, simulated here by a 4 MPa pulse at the outlet and a 2 MPa pulse at the inlet.

A sequence of pressure profiles of the primary loop appears in Fig. 3, where the loop is stretched out linearly for graphical representation. Many aspects of pressure pulse interaction with components can be observed from this figure. Note that at 30 ms, the inlet and outlet pulses reach superposition and the peak pressure of 6.5 MPa is recorded between the pump and IHX.

The present form of the three-dimensional SHAPS code offers superior methodology and advanced modeling capabilities for the analysis of reactor piping systems.

REFERENCES

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2. C. Y. Wang, "A Three-Dimensional Method for Integrated Transient Analysis of Reactor-Piping Systems," Nucl. Eng. & Design, Vol. 68, No. 2, pp. 175-184 (March, 1982).

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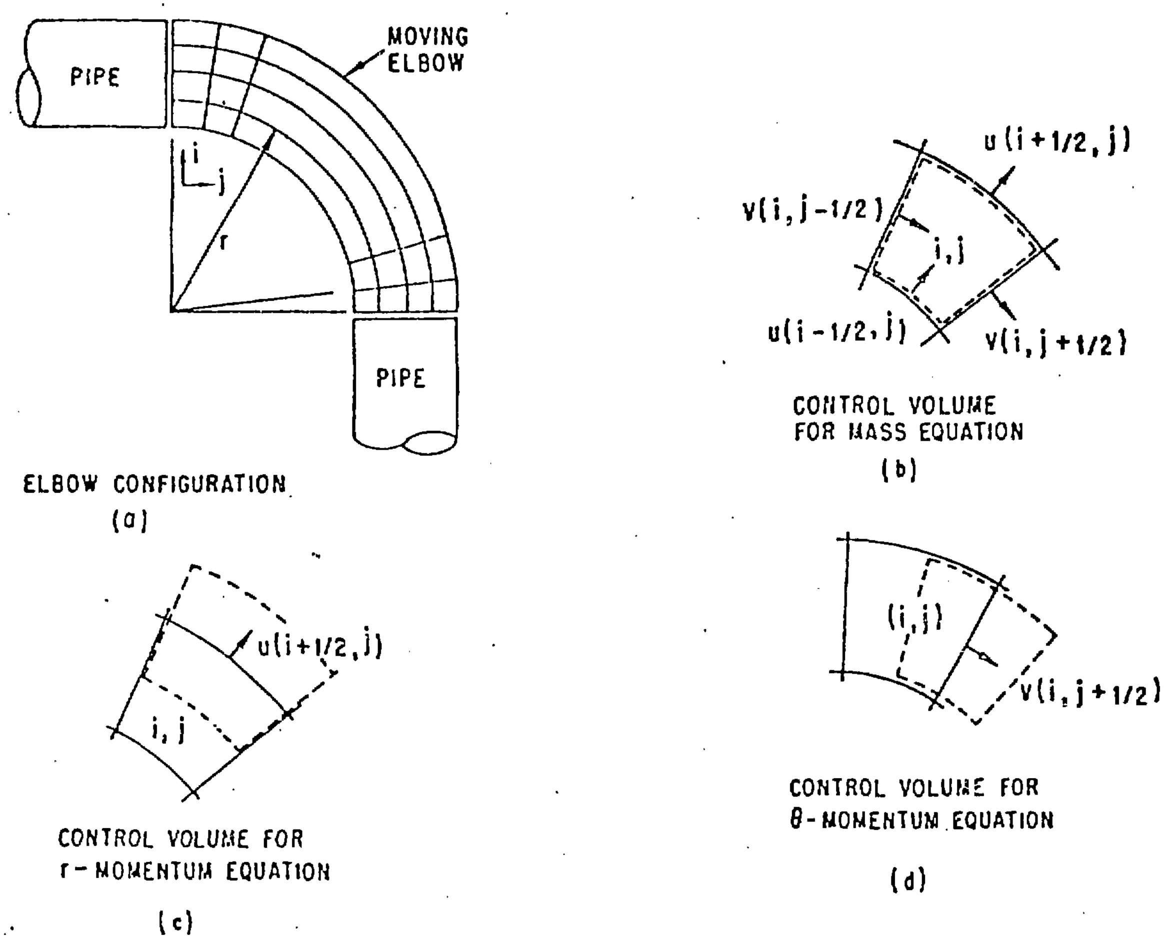

Fig. 1. Elbow Configuration and Control Volumes for Derivation of Hydrodynamic Equations

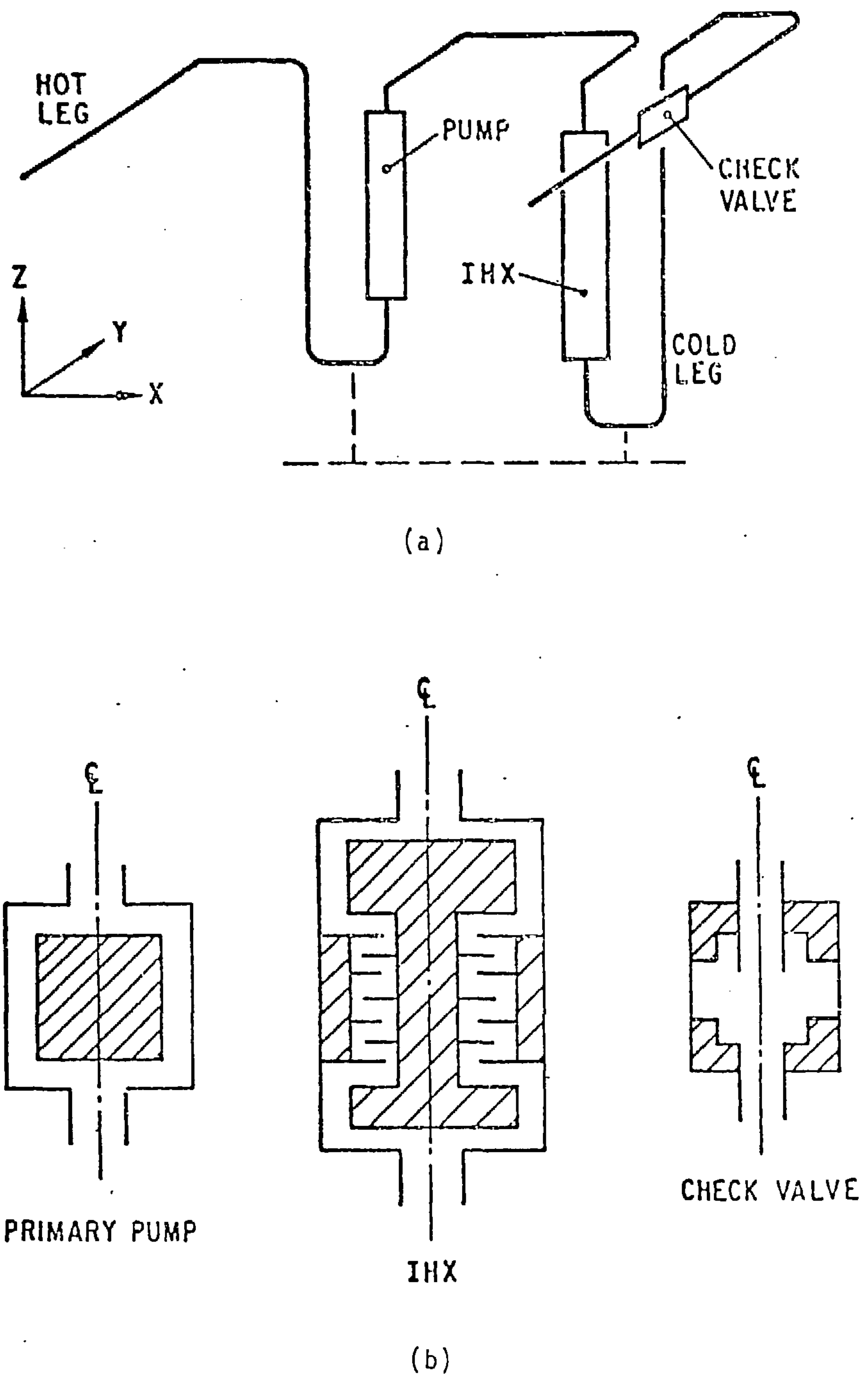

Fig. 2 a) Schematic of SHAPS Mathematical Model of LMFBR Primary Coolant Loop; b) Detail of SHAPS Model of the Components of the Primary Coolant Loop

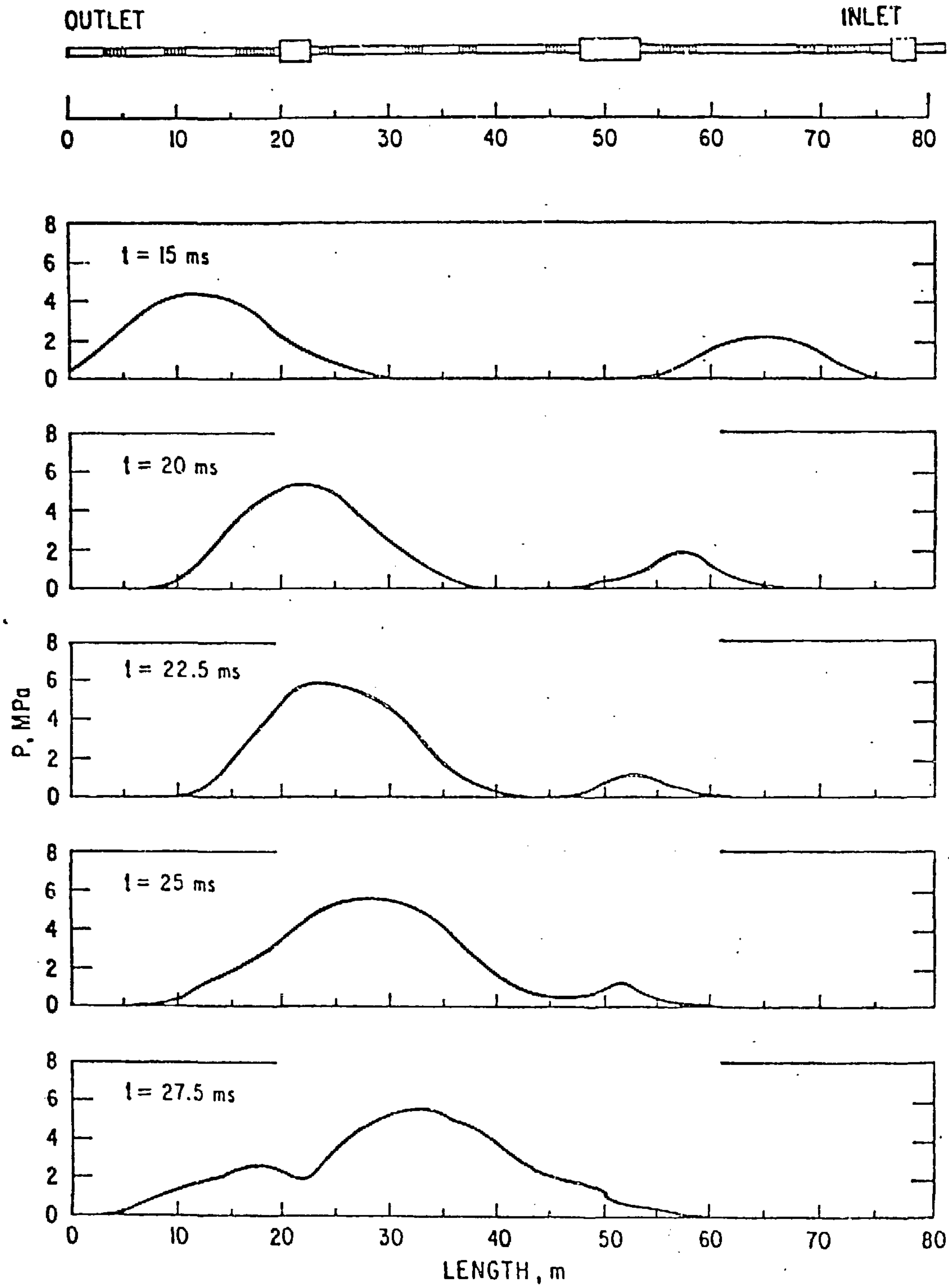

Fig. 3 Pressure Profiles at Various Times Along the Length of the SHAPS Model of the Primary Coolant Loop

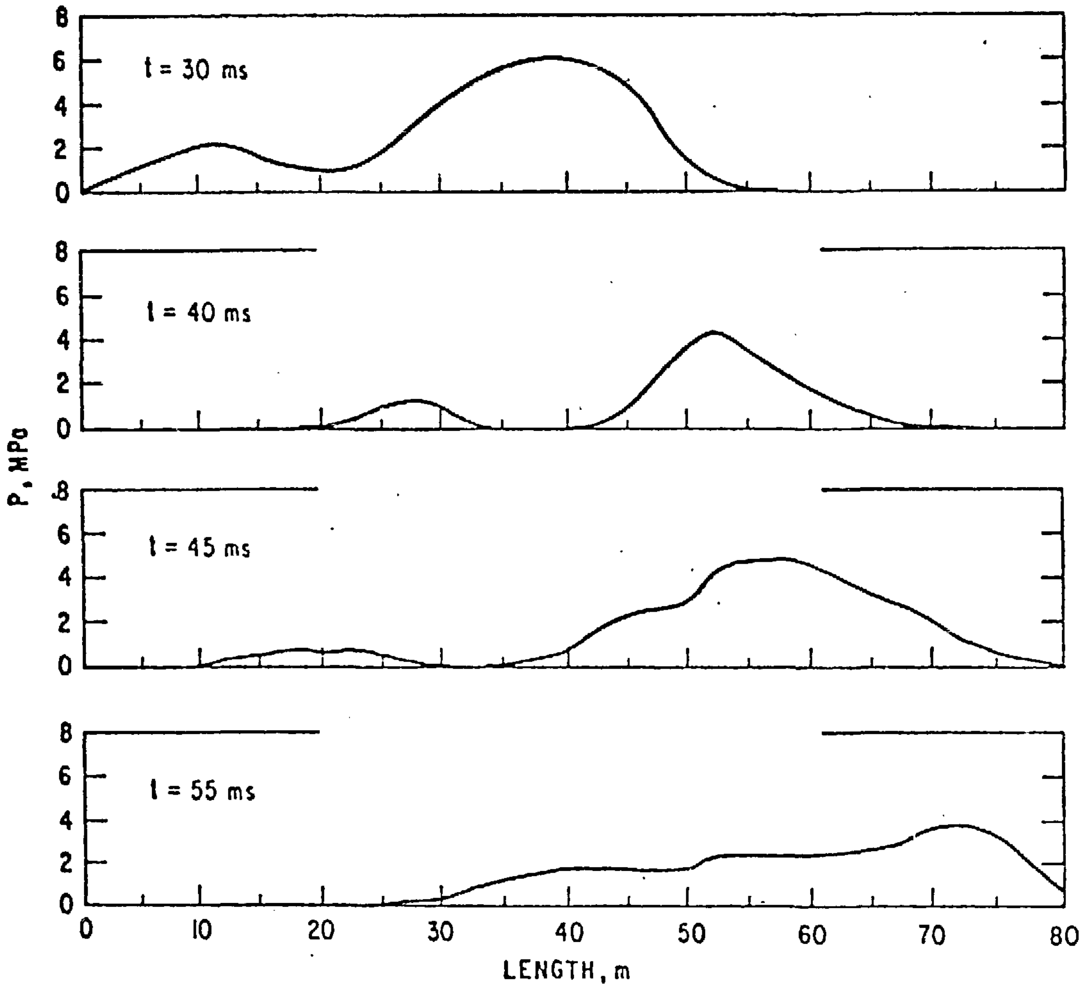

Fig. 3 Pressure Profiles Along Primary Coolant Loop (cont'd)