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Fluid-structure interaction in thin laminated cylindrical pipes during water hammer

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Abstract

Composite pipes with unidirectional fiber-reinforced layers at different fiber orientations are used in many industrial applications. When they carry pressurized fluids, water hammer may occur during any rapid change in the momentum of the fluid flow. Water hammer produces a travelling pressure wave and causes pipe vibration. This vibration, in turn, affects the water hammer so that fluid-structure interaction may play an important role in the pipe design calculations. In this paper, governing equations for the fluid-structure interaction of water hammer in thin laminated pipes were derived by assuming longitudinal vibration of the pipe. The resulting system of partial differential equations (PDEs) was solved numerically using an implicit least squares technique. The method uses radial basis functions locally in function approximations leading to a sparse and symmetric coefficient matrix. Two problems were solved using the proposed numerical method and the effect of the number of layers on the travelling pressure wave characteristics was investigated.

Keywords: Transient flow, Laminated deep shell, Least squares technique, Radial basis functions

1. Introduction

Any rapid change in the momentum of a pressurized fluid flow in a pipe produces a rising pressure that travels through the pipe. This phenomenon, which is called water hammer, may damage hydraulic accessories. Vibration during water hammer affects fluid flow and should be taken into account in pipe design procedures. Fluid-structure interaction (FSI) during water hammer was investigated experimentally [1-3] and numerically mostly for elastic pipes. Considering full degree of freedom for the elastic pipe requires fourteen equations to describe fluid-structure interaction properly [4], however, if just longitudinal motion is taken into account, the four-equation model is good enough for mathematical modeling [5]. The numerical models for solving the governing equations mainly are based on the method of characteristics (MOC) [3, 4] and MOC–FEM scheme [6] which consists of the MOC for the fluid and the finite element method (FEM) for the structure. Beside these methods, transfer matrix method (TMM) [7], spectral element method [8], and Godunov's method [9] also were applied for numerical solution of water hammer with FSI in cylindrical elastic pipes. Laminated composite thin walled pipes, which composed of unidirectional fiber-reinforced layers with different orientations, are used in the pipeline systems. The lamination also is used in the reinforcement of an existing pipe to enhance its performance using fiber-reinforced polymers (FRP). Pavlou derived a mathematical model for simulating undamped vibration of thin-walled multilayered filament wound FRP pipes subjected to water hammer [10]. The derived fourth-order PDEs governing the wall radial motion was solved analytically with the aid of integral transforms and generalized functions