TRANSSIENT ANALYSIS OF FLUID STRUCTURE INTERACTION IN STRAIGHT PIPE

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To my father, mother, brothers and sisters

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ABSTRACT

Water hammer phenomenon is a common problem for flows in pipes. Water hammer usually occurs when transfer of fluid is quickly started, stopped or is forced to make a rapid change in direction. The aim of this study is to use method of characteristics to study water hammer phenomenon. In this study, computational method is used to investigate the transient water hammer problem in a straight pipe. Method of characteristics is applied to constant density flow in a simple reservoir-pipeline-valve system. The water hammer effect is produced via suddenly closing the valve located at the upstream and downstream ends, respectively. Quasi steady shear stress is assumed for the flow. This study also considers steady and unsteady friction. Fluid structure interaction will also be analyzed. The results obtained show slightly higher pressure than that of published experimental data. This could be due to the Quasi steady shear stress assumption. Final results show that when fluid structure interaction is considered, more accurate answers were determined.

Abstrak

Fenomena ‘Water Hammer’ adalah satu masalah yang biasa dalam aliran dalam paip. ‘Water Hammer’ biasanya berlaku apabila perpindahan bendalir berlaku dengan cepat, berhenti atau dipaksa untuk melakukan perubahan arah dengan tiba-tiba. Tujuan kajian ini adalah untuk menggunakan ‘Method of characteristic’untuk mengkaji fenomena ‘Water Hammer’. Di dalam kajian ini, kaedah berkomputer digunakan untuk mengkaji masalah aliran peralihan “water hammer’ di dalam paip. ‘Method of characteristic’ di aplikasikan kepada ketumpatan malar di dalam takungan-paip-injap mudah. Kesan ‘Water hammer’ di hasilkan melalui penutupan injap yang berada di atas dan di bawah takungan secara tiba-tiba. Tegasan ricih di anggap tidak berubah dengan masa dalam kajian ini. Geseran tidak bergantung pada masa dan bergantung pada masa juga digunakan dalam kajian ini. Struktur interaksi bendalir juga akan di analisis. Hasil kajian menunjukan tekanan sedikit tinggi jika dibandingkan dengan kajian melalui eksperimen yang sudah di publikasikan. Ini mungkin kerana anggapan tegasan ricih tidak bergantung kepada masa. Keputusan akhir menunjukan apabila struktur interasi bendalir diambil kira dalam kajian akan menghasilkan keputusan yang lebih jitu.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Pipes installed in water supply systems, irrigation networks, hydropower stations, nuclear power stations and industrial plants are required to convey liquid reliably, safely and economically. Modern hydraulic systems operate over a broad range of operating regimes. Any change of flow velocity in the system induces a change in pressure. The sudden shut-down of a pump or closure of a valve causes a pressure wave develops which is transmitted in the pipe at a certain velocity that is determined by fluid properties and the pipe wall material. This phenomenon, called water hammer, can cause pipe and fittings rupture. The intermediate stage flow, when the flow conditions are changed from one steady state condition to another steady state, is called transient state flow or transient flow; water hammer is a transient condition caused by sudden changes in flow velocity or pressure.

The classical theory of water hammer [1, 2] describes the propagation of pressure waves in fully liquid filled pipe system. The theory correctly predicts extreme pressures and wave periods, but it usually fails in accurately calculating damping and dispersion [3] of wave fronts. In particular, field measurements usually show much more damping and dispersion than the corresponding standard water-hammer calculations. The reason is that a number of effects are not taken into account in the standard theory for example:

Generally friction losses in the simulation of transient pipe flow are estimated by using formulae derived for steady state flow conditions, this is known as the quasi-steady approximation. This assumption is satisfactory for slow transients where the wall shear stress has a quasi-steady behaviour. Experimental validation of steady friction models for rapid transients [4, 5, 6, 7] previously has shown significant discrepancies in attenuation and phase shift of pressure traces when the computational results are compared to the results of measurements. The discrepancies are introduced by a difference in velocity profile, turbulence and the transition from laminar to turbulent flow. The magnitude of the discrepancies is governed by flow conditions (fast or slow transients, laminar or turbulent flow) and liquid properties (viscosity) [7].

Also the waves have an acoustic pressure that acts against the surface of the pipe. Consequently, the fluid flow and the solid surface are coupled through the forces exerted on the wall by the fluid flow. The fluid forces cause the structure to deform, and as the structure deforms it then produces changes in the flow. As a result, feedback between the structure and flow occurs: action-reaction. This phenomenon what is call fluid structure interaction that can be attributed to three coupling mechanisms [8] Friction coupling is due to shear stresses resisting relative axial motion between the fluid and the pipe wall. These stresses act at the interface between the fluid and the pipe wall. Poisson coupling is due to normal stresses acting at this same interface. For example, an increase in fluid pressure causes an increase in pipe hoop stress and hence a change in axial wall stress.[8] The third coupling mechanism is junction coupling, which results from the reactions set up by unbalanced pressure forces and by changes in liquid momentum at discrete locations in the piping such as bends, tees, valves, and orifices. These include unsteady friction and fluid structure interaction which are taken into account in this study.

In addition the discrepancies between the computed and measured water hammer waves may originate from some other assumptions in standard water hammer, i.e. the flow in the pipe is considered to be one-dimensional (cross-sectional averaged velocity and pressure distributions), the pressure is greater than the liquid vapour pressure, the pipe wall and liquid behave linearly elastically, and the amount of free gas in the liquid is negligible. Also from discretization error in the numerical model, approximate description of boundary conditions and uncertainties in measurement and input data. In this study unsteady friction and fluid structure interaction are taken into account.

Because of the interaction between the fluid flow and the solid surface the equations of motions describing the dynamics are coupled. This makes the problem more challenging, and even worse when the flow is turbulent. In addition, this means that the Navier-Stokes equation and the structure equation for the solid surface must be solved simultaneously with their corresponding boundary conditions [9]. In this project Method of characteristics is used to solving classical water hammer with unsteady friction and fluid structure interaction which solved one-dimensional, four-coupled first- order, non-linear hyperbolic partial differential equation (PDE) model, which governs axial motion and includes Poisson, junction and friction coupling.

1.2 Objective

The objective of this project is to investigate the unsteady friction and fluid-structure interaction that may affect water hammer wave attenuation, shape and timing for single phase fluid in a simple reservoir-pipeline-valve system by using the method of characteristics which compared with experimental result [3, 10]

1.3 Scope

We consider cylindrical pipes of circular cross-section with thin linearly-elastic walls and filled with incompressible liquid, the flow velocities are small, the absolute pressures are above vapour pressure and the pipe is thin walled and linear, homogeneous and isotropic elastic.

The method of characteristics (MOC) is used to solve classical water hammer with quasi-steady shear stress, and with unsteady shear stress. To solving FSI, we used single procedure which treats the whole fluid–structure domain as a single entity and describes its behaviour by a single set of equations. these are solved using a single numerical method (MOC-MOC) The main focus will be in compare between water hammer with and without unsteady friction and FSI at different initial velocity and time closure and compare both with experimental results [3, 10]