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Comparison between Hydrodynamic Forces Derived from a Force-Balanced Method and a Momentum-Balanced Method

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1. Introduction

The analyses of piping systems under dynamic conditions such as pipe ruptures and abnormal valve operations are important to a safety evaluation. Hydrodynamic forces in the piping system can be computed by using the hydraulic output from the RELAP5/MOD3.1. In this study, hydrodynamic forces were computed by two different methods. One is a force-balaced method and the other is a momentum-balanced mehod. The purpose of this study is to compare hydrodynamic forces resulting from two methods.

2. Methods and Results

2.1. Force-Balanced Method

The hydrodynamic forces in a piping system can be computed by applying Newton's Second Law of Motion. A force within a pipe segment can be calculated from the fluid acceleration term. Forces calculated at each sub-volume should be summed together to be a resultant force in the pipe segment. In this reason it is called a force-balanced method. Considering the pipe segment which contains the end of a piping system, the force at the terminal surface should be contained in addition to the acceleration forces. The general equation of hydrodynamic forces for one-dimensional two-phase flow can be expressed as:

$$F_A = -\frac{d}{dt}[\rho_f V_f (1-\alpha) + \rho_g V_g \alpha] Al \quad (1)$$

Where :

F_A is an acceleration force
ρ_f is a fluid density
V_f is a fluid velocity
α is a void fraction of gas
ρ_g is a gas density
V_g is a gas velocity
A is a volume surface area
l is a volume length

$$F_T = -[P + \rho_{fJ} V_{fJ}{}^2 (1-\alpha_J) + \rho_{gJ} V_{gJ}{}^2 \alpha_J] A_J \quad (2)$$

Where :

F_T is a terminal surface force
P is a fluid pressure
ρ_{fJ} is a junction fluid density
V_{fJ} is a junction fluid velocity
α_J is a junction void fraction of gas
ρ_{gJ} is a junction gas density
V_{gJ} is a junction gas velocity
A_J is a junction surface area

2.2. Momentum-Balanced Method

The hydrodynamic forces can be computed by another method. Forces at the control volume can be computed by considering the effects of normal stress and shear stress. Normal stress is approximated by the quasi steady change in momentum. The net force is summed together over a control volume, so this method is called momentum-balanced method. The general equation of hydrodynamic forces for one-dimensional two-phase flow can be expressed as:

$$\begin{aligned} F_M = &-(P_{I1} + \alpha_f \rho_f V_f{}^2 + \alpha_g \rho_g V_g{}^2) A_{I1} \\ &+(P_{I2} + \alpha_f \rho_f V_f{}^2 + \alpha_g \rho_g V_g{}^2) A_{I2} \quad (3) \\ &+P_{E1} A_{E1} - P_{E2} A_{E2} \end{aligned}$$

Where :

F_M is a momentum force
P_{I1} is an internal fluid pressure at the inlet
α_f is a void fraction of fluid
ρ_f is a fluid density
V_f is a fluid velocity
α_g is a void fraction of gas
ρ_g is a gas density
V_g is a gas velocity
A_{I1} is an internal area at the inlet
P_{I2} is an internal fluid pressure at the outlet
A_{I2} is an internal area at the outlet
P_{E1} is an external fluid pressure at the inlet
A_{E1} is an external area at the inlet
P_{E2} is an external fluid pressure at the outlet
A_{E2} is an external area at the outlet

$$F_S = (W_f V_f + W_g V_g) Al \quad (4)$$

Where :

F_S is a shear force
W_f is a fluid wall friction drag coefficient
V_f is a fluid velocity
W_g is a gas wall friction drag coefficient
V_g is a gas velocity

A is a volume surface area
l is a volume length

2.3. Description of the Sample Problem

A sample problem is designed by changing some parameters of the sample in the informal report of R5FORCE in order to compare the result from different force calculation methods. The valve(V101) separating the supply vessel and the accumulator is initially opened. A pressure of the accumulator is increased linearly from 16.55MPa to 17.58MPa in 0.2s. The relief valve(V102) is opened at setpoint 17.24MPa which is occurred at 0.134s. The supply pressure is maintained until V101 is closed at 0.4s. V102 is closed at 16.38MPa which is occurred at 0.446s.. Figure 1 shows the piping system of the sample problem.

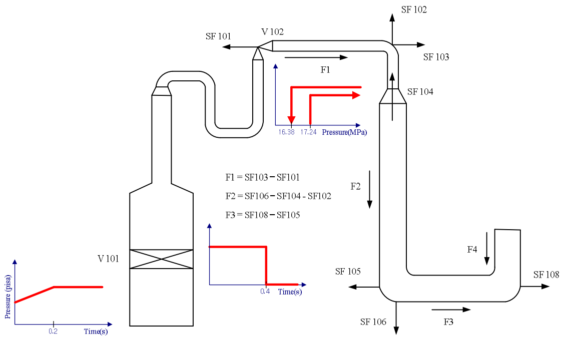

Fig. 1. Piping system of the sample problem

2.4. Results

The hydraulic data was derived from the RELAP5/MOD3.1. The hydrodynamic forces were plotted by two different methods for 1 second.

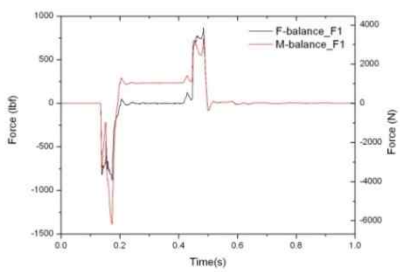

Fig. 2. Wave forces on F1

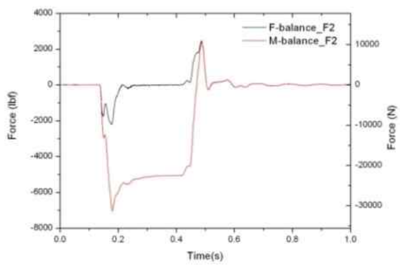

Fig. 3. Wave forces on F2

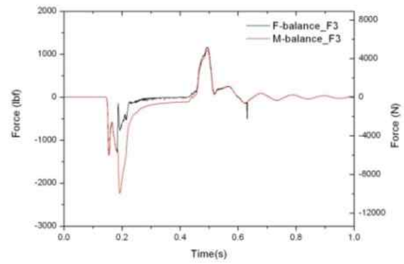

Fig. 4. Wave forces on F3

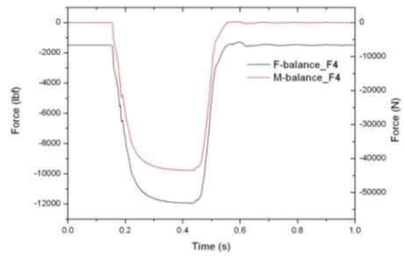

Fig. 5. Blowdown forces on F4

Figures 2 to 5 show the results of hydrodynamic force calculation by two different methods. Overall trend at each event is similar. Table I shows the difference between two methods.

Table I: Summary of the result

	F-balanced	M-balanced
Wave	Reasonable	offset
Blowdown	offset	Reasonable

3. Conclusions

The hydrodynamic forces were computed by two different methods using the RELAP5/MOD3.1 hydraulic output. The resultant trend is well reflecting the sample problem, but each method has a wrong offset at a different point. From the findings, governing equations need to be peer-reviewed.

ACKNOWLEDGEMENT

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