EXPERIMENT AND ANALYSIS ON PRESSURE PULSE PROPAGATION IN A PLASTICALLY DEFORMING PIPE

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This paper presents the experimental and analytical study on the behavior of pressure pulse propagation travelling through a piping system. The simple, well-defined experiments have been performed to provide the fundamental data to verify a dynamic response computation code. Experimental facility consists of a test pipe and a pulse gun filled with water at room temperature. The pressure pulse has been generated by low velocity SK explosive, high velocity pentolite and low energy detonator. The SK explosive was composed mainly of potassium perchlorate and aluminum in flake and grain form. Experiments have been performed by using 3 m - long, 16 cm - outer diameter, 0.287 cm - thick stainless steel pipes both with and without 90 degree elbow section. The experimental results show that the pulse entering a test pipe attenuates rapidly to the yield pressure (about 14 MPa) of the pipe on about 40 cm of inlet section. The plastic deformation extends over wider range in low velocity explosive experiments than in high velocity pentolite ones. The peak pressure attenuates while passing thick-walled elbow particularly in high velocity pentolite experiment rather than in low velocity explosive one.

The experimental results have been analyzed by a two-dimensional dynamic fluid-structure response code. The prediction of pressure pulses in test pipes are in fairly good agreement with the experimental results. The predictions of residual strains of the pipes are 30 - 100% larger than the results. Further investigation will be required to improve the predictions of residual strains.

1. Introduction

The main objective of the present study is to obtain basic information on the behavior of pressure pulse attenuation by pipe deformation /1/. Experimental facility consists of a pulse gun installed with a low velocity SK explosive or a high velocity pentolite and a thin-walled stainless steel 316 pipe with gradient of 15 degree filled with water at room temperature. Experiments are designed to be as simple as possible enough for computer simulation.

In order to verify a two-dimensional hydrodynamic and structural response code PISCES-2DELK /2/ predicting behavior of pressure pulse propagation in piping and the effects of pressure pulse propagation on deformation of pipe wall, the predictions have been compared with the experimental results. The code uses a coupled Eulerian-Lagrangian explicit finite differential scheme and has capability of predicting interaction between pressure pulse and elastic-plastic structural response. In other words, the following subject are calculated by the code.

- 1) Pressure pulse propagation in the test pipe, and
- 2) Transient deformation of pipe wall.

2. Experimental Facility

The experimental facility consists of test pipe and pulse gun as shown in Fig. 1. Straight pipe experiments have been carried out on 3 m - long, 16 cm - outer diameter, 0.287 cm - thick stainless steel 316 pipe. Elbow pipe experiments have been performed using the same pipe model except for 90 degree elbow and entrance pipe. The test pipe is joined rigidly to 1 m - long 0.045 m - thick-walled pulse gun, in which pressure pulse is generated by detonation of explosive. The inner diameter of the pulse gun is the same as that of test pipe in order to avoid flow disturbance due to change of cross section at the junction between the pulse gun and the test pipe.

3. Experimental Results

Straight and elbow pipe experiments have been carried out by using 10g, 20g and 30g SK explosives, 3.5g pentolite and detonator. Pressure pulse entering into the test pipe causes large deformation in the inlet section of the test pipe. The plastic deformation raised on the inlet section by approximately 40 cm absorbs energy of pressure pulse in which attenuates

to the yield pressure of the test pipe (14 MPa). The attenuated pressure pulse travels downwards through test pipe further with slight attenuation of peak pressure and gives small plastic deformation of the test pipe.

3.1 Pressure Pulse Behavior

Typical behavior of pressure pulse propagation in a test pipe is presented in Fig. 2. Pressure pulse generated in the bottom of the pulse gun maintains its shape in the thick-walled pulse gun and attenuates rapidly in the inlet section of the test pipe due to interaction with pipe deformation. As peak pressure is suppressed to yield pressure of the test pipe, the pulse shape has wide plateau over 40 cm. The pulse oscillation with 1 ms time intervals seems to be caused by pressure pulse reflection at the inlet flange of the test pipe.

Figure 3 summarizes the distribution of peak pressure measurement in straight pipe experiments. The results show that pressure pulse attenuates to the yield pressure of the test pipe in all of the experiments except in detonator one where the generated pulse is under the yield pressure. The behavior of pulse attenuation in elbow pipe is approximately the same as in straight pipe for all of the experiments. In a pentolite experiment, however, a larger attenuation of pulse through the elbow section is observed.

3.2 Residual Strains

The radial strains in the pipe inlet section over 30 cm are measured precisely as shown in Fig. 4. The residual strains caused by high velocity pentolite are localized in the inlet section with rapid attenuation pulse. The radial strains are restricted in the vicinity of the inlet flange of the pipe and thick-walled elbow.

3.3 Pressure pulse attenuation in small residual strain region

The pressure pulse attenuates further slightly even after the peak pressure attenuates below yield one of the test pipe and causes small residual strains of 0.2%.

In high velocity pentolite experiment, the attenuation through the elbow section is observed to be larger than that through the straight pipe. In low velocity SK explosive experiments, the attenuation through the elbow section is approximately the same as that through the straight pipe.

Pressure pulse attenuation through the elbow section seems to depend on the characteristic of explosive.

4. Predictions and Comparison with the Experimental Results

4.1 Computation code and calculation model

To verify the predictions by two-dimensional code the experimental results have been analyzed by using PISCES-2DELK code /2/. The calculation model is made to simulate physical system and boundary conditions in the experiments. The observed pressure pulse in the middle of pulse gun is used as boundary condition of pressure. A 20g SK experiment of straight pipe is a typical case and selected for comparison with prediction.

4.2 Pressure pulse

The predictions of pressure pulse profile in the inlet section of the test pipe is compared with the experimental results in Fig. 5. The comparison shows fairly good agreement between predictions and the results.

4.3 Plastic deformation

The predictions of plastic deformation profile of the pipe are compared with experimental results. The prediction of maximum residual strain is about 50% larger than the result. The deviation may be attributable to the difference in physical and mathematical model of the stress strain curve under large strain rate condition and the boundary condition of pressure.

5. Conclusion

5.1 Experiments

Pressure pulse propagation experiments have been performed on thin-walled stainless steel 316 pipe filled with water at room temperature. Straight and elbow pipe experiments have been carried out by using 10g, 20g and 30g SK explosives, 3.5g pentolite and detonator.

(a) Pressure pulse with higher pressure than yield one entering the test pipe attenuates to yield pressure of the pipe and causes a large plastic deformation in the inlet section over the longitudinal distance by 40 cm.

(b) Pressure pulse with lower pressure than yield one attenuates gradually while travelling downwards the pipe.

(c) The attenuation in the elbow section is observed to be larger than that in straight pipe for sharp pulse generated by pentolite. The attenuation depends on pulse width. For broad pulse generated by SK explosive,

a smaller attenuation through the elbow section is observed.

5.2 Predictions

An accuracy of prediction by the two-dimensional code PISCES-2DELK has been evaluated by experimental results of the pulse propagation.

(a) Pressure pulses in the test pipe are fairly well predicted by the code.

(b) Predictions of residual strain are relatively larger than experimental results. Further investigation both of stress strain curve under large strain rate condition will be required to improve predictions of residual strain.

Reference

- /1/ ROMANDER, C.M., CAGLIOSTRO, D.J., FLORENCE, A.L., GRAN, J.K.,
"The Response of Water-Filled Pipes to Pressure Pulses", Trans. Fourth International Conference on Structural Mechanics in Reactor Technology, San Francisco (1977), paper E 4/7.
- /2/ S.L. Hancock, "Application of a Coupled Euler-Lagrange Computer Program to the Structural Response of LMFBR", Nucl. Eng. Des., 42, 69 (1977).

Fig. 1 Schematic of Test Facility

Fig. 2 Behavior of Pressure Pulse in Test Pipe

Fig. 3 Peak Pressure Distribution in Straight Pipe

Fig. 5 Pressure Pulse Profile at Point C

Fig. 4 Radial Plastic Deformation Distribution in Inlet Section