II − 6 Study on waterhammer and velocity in pipe network

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1. INTRODUCTION

The velocity variation of simple pipe line is calculated by Bernoulli equation and the friction factor is given by Moody diagram. However, this value given by calculation is too high.

The steady state condition of velocity in pipe network is analyzed by the Hardy Cross method. The instantaneous velocities at each pipe in pipe network are measured by the ultrasonic Doppler flow meters.

The continuity equation and momentam equation of waterhammer are dealt with one dimensional unsteady flow and they are analyzed by the method of characteristics. The Joukowsky equation is also used to discuss the superposition of waterhammer waves.

2. STEADY STATE VELOCITY IN PIPE NETWORK

2.1 *Velocity analysis in simple pipe*

In order to find the friction factor, f, from Moody diagram the Reynolds number is calculated by using parameters of steel pipe materials. In case of velocity 1.0 m/s at the end of pipeline Reynold's number becomes 5192. The diameter of the pipe, 0.0525 m and coefficient of roughness, e/D=0.049 and coefficient of kinetic viscosity 0.1011 cm^2/s are used. The friction factor becomes 0.071. This value is too high to calculate the single pipeline velocity. We use 0.02 for the value of friction factor to calculate the headloss and velocity variation in pipeline. As the result, the velocity at L_5=34.7 m becomes v_5=1.57 m/s in straight line, the velocity at L_7=45.1 m becomes v_5=1.71 m/s in short round line and the velocity at L_5=57.1 m becomes v_5=1.84 m/s in long round line.

2.2 *Theoretical approach to pipeline network by Hardy Cross method*

The analysis is keep calculating until the convergence of the error of flow rate, the equation (2.4).

$$\sum_{i=1}^{N} K_i Q_i^{\,n} = 0\,,\ \sum_{i=1}^{N} K_i (Q_i + \Delta Q_i)^n = 0 \qquad (2.1)$$

$$h_f = \frac{aL}{C_{HW}^{\,1.852} D^{4.87}} Q^{1.852} \qquad (2.2)$$

$$K = \frac{fLv^2}{2gD(Av)^{1.874}} \qquad (2.3)$$

$$\Delta Q = \frac{\sum_{i=1}^{N} K_i Q_i^{\,n}}{-n\sum_{i=1}^{N} K_i Q_i^{\,n-1}} \qquad (2.4)$$

2.3 *Steady state velocity experiment*

Figure 2.1 shows the ultrasonic flow meter which measures the velocity of each pipe in pipe network. Principal of the ultrasonic flow meter is that the ultrasonic wave is generated and emitted from outside of the pipe and received the ultrasonic by detector. The velocity in pipe is given by Doppler effect of the ultrasonic wave. The ultrasonic wave emitter and detector are attached to the location of pipe to measure the velocity by two belts at both sides. The ultrasonic emitter and detector are connected to the transfer unit. As soon as power is on the most effective distance between the emitter and detector is shown on a display. The distance is fixed again according to the number shown. The velocity in transfer unit is set to zero when the pipe is filled with water. It is decided that the upstream is positive. It is ready to measure the velocity. The velocity is measured at 17 locations in the pipe net work. The velocity at each pipe in seven patterns is taken by ultra-sonic flow meter during steady state velocity experiment as shown in Table 2.1. It has been impossible to measure the velocity by the ultrasonic flow meter until all pipeline is replaced by steel pipes because the PVC lining pipes made the ultrasonic wave not to penetrate into the center of pipes.

Table 2.1 Flow pattern

1. Single pipe(straight)	Pattern S-1
2. Single pipe(short round)	Pattern S-2
3. Single pipe(long round)	Pattern S-3
4. Double pipe (short round)	Pattern D-1
5. Double pipe(long round)	Pattern D-2
6. Triple pipe(three lines)	Pattern T-1
7. All pipe(full pipe line)	Pattern A-1

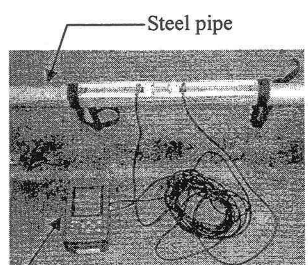

Figure 2.1 Ultrasonic flow meter

3. WATERHAMMER IN PIPENETWORK

3.1 *Governing equation of waterhammer*

The equation of motion and the equation of continuity for waterhammer analysis are (3.1) and (3.2). They are solved by the method of characteristics.

$$\frac{\partial V}{\partial x}V + \frac{\partial V}{\partial t} + g\frac{\partial H}{\partial x} + f\frac{V|V|}{2D} = 0 \qquad (3.1)$$

$$\left(\frac{a^2}{g}\right)\frac{\partial V}{\partial x}+\frac{\partial H}{\partial x}V+\frac{\partial H}{\partial t}-\frac{\partial Z}{\partial x}V=0 \qquad (3.2)$$

Two boundary conditions are as follows,

1) The upstream boundary condition is water level of the upper tank.

2) The instantaneous velocity changes linearly with closing the high speed valve. This is downstream boundary condition.

The superposition of Waterhammer pressure in the different pipes is considered by using Joukowsky equation as the equation (3.3).

$$\Delta H=\frac{a}{g}\Delta v \qquad (3.3)$$

3.2 *Experimental apparatus of waterhammer in pipe network*

Numerical models for the same system as the experimental apparatus have been developed which has height of upper tank, 12.14 meter, diameter of pipe, 0.05 meter and length of pipeline, 60.21 meter. Water flow down from the upper tank through the pipeline and it is connected to pipe net work at flat area. The velocity of flow is controlled by the valve which is connected at the end of line just before the lower tank. The velocity is adjusted to 1.0 m/s by this velocity control valve. The high speed closing valve is connected 2.5 meter before the velocity control valve.

Figure 3.1 shows the bird's eye of pipe net work which is located at flat area of pipeline and it is showing locations of pressure transducers numbered from CH-1 to CH-30 and closing valves from 1 to 30 just before the transducer pick-ups(Figure 3.2). The closing valves are set to both sides of each pipe to control the direction of flow as single straight line to close valves at 9 and 30 and long round single line to close 4, 11, 15, 23, 28, and 3 and so on. Water hammer is occurred by closing the high speed closing valve located at the downstream of the pipeline. Pressure are picked up by pressure transducers at each location and amplified and stored in a computer in every 1/10000 second in 30 channels at the same time.

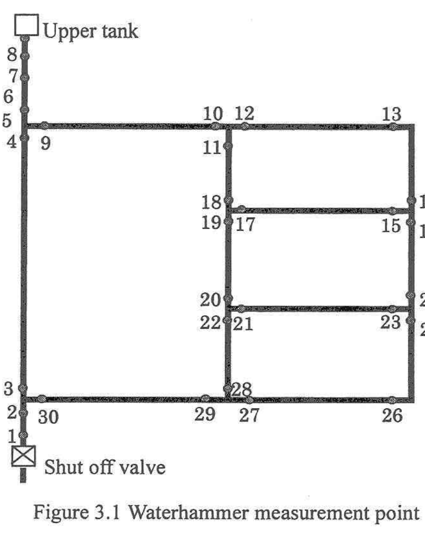

Figure 3.1 Waterhammer measurement point

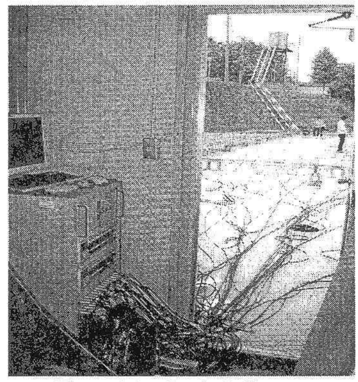

Figure 3.2 Strain indicator

3.3 *Result of waterhammer experiment in pipe net work*

Figure 3.3 shows that the comparison between the result of experiment at the end of line (CH1) and the result of analysis by Joukowsky equation. The result of analysis is given by considering superposition of waterhammer between the result of single straight line and single short round line.

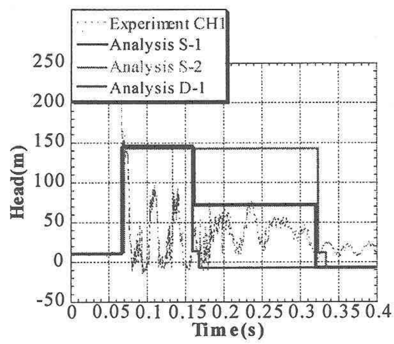

Figure 3.3 Waterhammer at the end of line (D-1)

4. CONCLUSIONS

It is found that the friction factor in this line is very small as 0.0002 because of high static pressure.

It has the tendency that water flows down the straight line. The velocity of connection line is one or two order smaller than other line.

The value of waterhammer in experiment shows similarity to the results of analysis in straight line. However it has the reflections and several peaks when the line has corners in round lines.

In parallel line it is found that the highest peak is given by larger waterhammer. The superposition of surge pressure does not occur in this line. The duration time is controlled by longer line and the superposition of waves occurs as negative wave subtracts from high peak of longer line.

REFERENCES

Y. Kono, T. Moriya, Y. Sugai, M. Watanebe, M. Shimada : *Study on propagation of pressure surge in steel pipe network*,. 4th International Symposium on Environmental Hydraulics and 14th Congress of Asia and Pacific Division,ASCE, Hong-Kong, 2004.