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EVALUATION OF THE FLOW CONTROL SYSTEM OF MEYBOD-ARDAKAN WATER CONVEYANCE PIPELINE USING A TRANSIENT MODEL (A CASE STUDY)

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In this paper the efficiency of a flow control logic proposed for improving the flow control system of Meybod-Ardakan water conveyance pipeline is numerically investigated. Lack of truly-selected valves both at the end of the line and two intermediate reservoirs cause that at the moment flow can not be controlled from the downstream end and the system is operated under two phase flow condition. To prevent air entrainment, a control logic in which flow is completely controlled from the downstream end, is proposed. To make the implementation of this logic possible, the existing automatic–pressure-sustaining valves at the end of system and automatic–flow-control valves at the intermediate reservoirs are replaced by some needle valves equipped by manual-electrical actuators and floater-cable mechanisms respectively. In the proposed logic water hammer induced during operation depends not only on opening and closing rates of the downstream valves but also on the volume of intermediate reservoirs which in turn control the opening and closing rates of their valves. So to find the optimum values for opening and closing rates of the downstream valves, the system is analyzed as a whole. In order to trace the transient behavior of the system a full elastic computer model was developed. The model employs the method of characteristics and enables to simulate all required boundary conditions. To evaluate the efficiency of control system, different operation scenarios tried on the model and optimum parameters of the control system was determined. The results show that the proposed control logic provides a safe and stable hydraulic condition and protects the system against severs transient pressures.

INTRODUCTION

Meybod-Ardakan water conveyance pipeline system was designed to supply drinking water for both cities of Meybod and Ardakan in Iran.

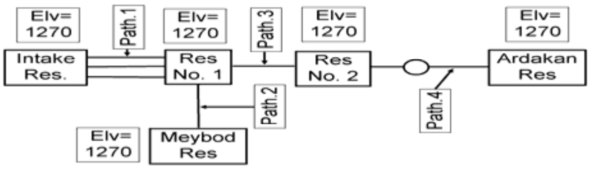

Figure 1. Layout of Meybod-Ardakan water conveyance system

As shown in Figure 1, the system absorbs treated water from a reservoir which in turn is part of Esfahan-Yazd water conveyance system. Water then is conveyed through three parallel pipes to a 400 cum reservoir hereinafter called reservoir No. 1. From this reservoir two pipelines are issued. The former supplies Meybod service reservoir and the later conveys water to a 200 cum reservoir hereinafter called reservoir No. 2. From this reservoir a pipeline provides water for Ardakan service reservoir. The characteristics of the pipelines including type and diameter for different parts of the system are summarized in table 1.

Table 1. The characteristics of pipelines

Path No	From Km (00+000)	To Km (00+000)	Pipe Dia. (mm)	Type
Path 1	0+000	2+675	3*300	AC
	2+675	3+235	3*400	DI
	3+235	3+635	700	DI
Path 2	3+635	6+435	500	AC
	6+435	11+820	400	DI
Path3	3+635	10+915	450	AC
	10+915	11+860	400	AC
Path4	11+860	14+860	600	AC
	14+860	16+560	500	AC
	16+560	20+185	600	AC
	20+185	24+560	500	AC
	24+560	25+623	400	DI
AC=asbest cement, DI=ductile Iron				

The maximum discharge required by the cities of Meybod and Ardakan in destination year was predicted to be the same and each one equal to 0.3 cms. So, maximum discharge in paths 1, 2, 3 and 4 are 0.6, 0.3, 0.3 and 0.3 cms respectively.

In order to make flow control possible, a number of valves (regardless of whether they were truly selected) were predicted in the system. In reservoir No.1 three parallel automatic-pressure-sustaining valves each one has an internal diameter of 200 mm were installed. Two parallel valves similar to those installed in reservoir No.1 were also predicted in reservoir No.2. In both Meybod and Ardakan service reservoirs, two parallel automatic-pressure-reducing valves each one has an internal diameter of 200 mm were employed. In addition, two inline automatic-pressure-reducing valves each one has an internal diameter of 200 mm were installed just 3000 m downstream of reservoir No. 2 to reduce the pressure to two bars.

During the first commissioning, the Yazd Regional Water Company hereinafter called the client found that there was no control on the system and flow could not be regulated at all. Unfortunately the problem was not solved even after making several modifications on the control system. So the client had to employ a temporary solution in which flow is controlled from the upstream end of the system through the operation of the service valves existed just after the intake reservoir. This temporary solution, however, has not been successful and until now several accidents in which the pipeline was collapsed due to transient pressures resulted from air-flow in the pipeline have been reported. So the client asked the LAR Consulting Engineers to study the flow control system if there is an optimum solution. In fact this work is outcome of that project managed by the first author of this paper.

FLOW CONTROL SYSTEM, PROBLEMS AND SOLUTION

Existing valves, problems

The collected information show that the type of valves installed in the Meybod and Ardakan services reservoirs as well as in reservoirs No.1 and No.2 were not selected truly (at least the authors of this paper couldn’t realize why they were used) . In both Meybod and Ardakan service reservoirs where the demands should be ordered a numbers of automatic-pressure-sustaining glob valves were employed. This type of valve sustains a predefined-set pressure on its upstream face automatically. The pilot system changes the opening value of glob valve until the predefined-set pressure would be reached. Although it is possible to control outflow rate by changing the set point of the valve but at least for such a system whose discharge might be even changed daily it is not practical and off course safe. The sever water hammer pressure tapes may be set up when the pilot trays to adjust low-inertia-quick-response glob valve. Moreover the valve would be damaged by the cavitations when the flow rate is low and the pressure at the upstream face of valve is high. In the reservoir No.1 and No.2 a number of automatic-flow-control glob valves were also used. In this type of valve, the pilot system changes the opening value of glob valve until the predefined-constant flow measured by an orifice installed in downstream face of the valve would be reached. So the valve already works with a predefined-constant discharge and unable to control flow in an appropriate range.

Existing flow control, problems

As mentioned before, at present time a temporary solution is employed by the client. In this solution flow is regulated through the operation of service valves existed in upstream end of the system whereas the other valves are kept fully open. Although this type of operation has made a temporary-imperfect flow control possible, the new problems have been created due to air-water flow in the system.

The air entrainment is occurred when the upstream service valves try to restrict intake reservoir’s outflow and the pipe system having more conveyance capacity is stealing water from the pipeline. If enough air is admitted to the pipeline, flow in part of pipeline would be changed to free flow. In this condition free flow zone grows until the equilibrium condition would be reached in the pipeline. A hydraulic jump whose location is affected by many factors such as flow discharge, pipeline profile, and maximum capacity of pipe system then fills the pipeline completely. Air bobbles whose content is proportional to flow discharge and the Froude number of the flow just before the jump (Falvey. [1]), are pushed through the pressurized zone by the hydraulic jump. Depending on if the air bobbles move downstream or upstream pipeline may experience some dangerous phenomena such as blowback and pulsating flow which in turn results sever pressures in the pipe system (Falvey. [1]).

Proposed flow control system

In the proposed method it is assumed that the pipe system remains completely full during the operation and no air entrainment occurs. Therefore flow is predicted to be controlled from the downstream end i.e. in the Meybod and Ardakan service reservoirs.

In order to make this possible, the existing valves in these two reservoirs would be replaced by two new flow control valves which allow the operators to order their requests through the manual-electrical actuators. Any changes in the valve's opening value results in changing the pressure and discharge in the upstream face of the valve. The information (changing in discharge and pressure) is then propagated through the pipeline with a velocity which is equal to the wave velocity of the pipeline. The communication is no longer possible when the message reaches to the intermediate reservoirs. To transmit the message to the upstream side of the reservoirs, a floater-cable mechanism is predicted in the intermediate reservoirs. When the message reaches to the intermediate reservoirs, it affects the outflows and causes changing in the water surface of the reservoirs. The floaters then sense the changing and convey it to the new flow control valves through the cables. The cables then, change the opening of the valves and reproduce the messages in the upstream sides of the valves. In this way, the massages are transmitted to the upstream end of pipe system where the fixed-level intake reservoir is continuously replying the requests.

Considering the maximum discharges and pressures in the pipelines entering the reservoirs, a 450 mm anti cavitations needle valve equipped by a manual-electrical actuator is proposed in both Meybod and Ardakan service reservoirs. Two anti cavitations needle valves with the internal diameters of 500 mm and 350 mm are also proposed for the reservoir No. 1 and No. 2 respectively. These two valves are equipped by the cable-floater mechanisms.

In the proposed method, the operator should just push the opening or the closing push buttons of the downstream end valves and wait until the flow meters, already existed in the places, show the requested discharges. Although a simple digital board enables to do the job easier and also to control the overshooting of the pipe system better, the client asked us to keep the control system as simple as (or may be cheap as well) possible and to design a manual one.

The water hammer pressures induced through the operation depend not only on the opening rates of the valves proposed in the Meybod and Ardakan reservoirs but also on the volumes of the intermediate reservoirs which in turn control the opening rates of their corresponding valves. So to find optimum opening rates of the downstream valves and also to check if the intermediate reservoirs have enough volume, the system is analyzed as a whole.

THEORITICAL BACKGROUND AND NUMERICAL SOLUTION

Governing equations

Transient flow in closed conduits is governed by the following two partial differential relationships known as momentum and continuity equations respectively (Chaudhry. [2], Watters. [3], Wylie *et al*. [4])

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x} + g\frac{\partial H}{\partial x} + f\frac{v|v|}{2D} = 0 \quad (1)$$

$$\frac{\partial H}{\partial x} + v\frac{\partial H}{\partial x} + \frac{a^2}{g}\frac{\partial v}{\partial x} + v\sin\theta = 0 \quad (2)$$

Where H=piezometric head, v=flow velocity, a=wave velocity, f=Darcy-Weisbach friction factor, D=conduit internal diameter, θ =conduit center line angle with horizon, x and t=distance and time independent variables respectively and g=gravitational acceleration.

Numerical solution

Except in very simple cases, Eq. (1) and Eq. (2) have no analytical solution and numerical methods should be employed to solve them. Although a number of numerical methods are available, the method of characteristic is the most general and compatible one (Watters. [3], Chaudhry. [2]) and employed in this paper.
Considering paper size restriction, description of the method of characteristic as well as common boundary conditions is completely neglected. Only the valve-floater-reservoir boundary condition which has not discussed in detail anywhere yet is presented herein.

Valve-floater-reservoir boundary condition

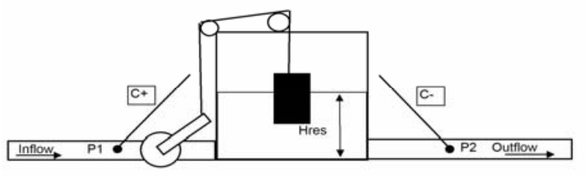

Figure 2. Schematic of the valve-floater-reservoir

Considering Figure 2 showing the valve-floater-reservoir boundary condition schematically and also neglecting velocity head as well as minor losses, we can write five equations which are negative and positive characteristics, continuity, upstream and downstream energy equations respectively as follows.

$$V_{p2} = C_1 + C_2 H_{p2} \tag{3}$$

$$V_{p1} = C_3 - C_4 H_{p1} \tag{4}$$

$$\left(V_{p1} \times A_{p1} - V_{p2} \times A_{p2}\right) \times \Delta t = \left(\left(H_{res}\right)_{t_{i+1}} - \left(H_{res}\right)_{t_i}\right) \times A_{res} \tag{5}$$

$$H_{p1} - K\frac{V_{p1}^2}{2g} = \left(H_{res}\right)_{t_{i+1}} + Z_p \tag{6}$$

$$H_{p2} = \left(H_{res}\right)_{t_{i+1}} + Z_p \tag{7}$$

Where V_{p1}, V_{p2} = inlet and outlet velocities respectively, H_{p1}, H_{p2} = upstream and downstream piezometric head respectively, Z_p = reservoir bottom elevation, A_{p1}, A_{p2} = inlet and outlet pipe cross section areas respectively, A_{res} = reservoir area, $\left(H_{res}\right)_{t_{i+1}}, \left(H_{res}\right)_{t_i}$ = the height of water in the reservoir at times t_{i+1} and t_i respectively and K = valve head loss coefficient.

Heads and velocities in the upstream and downstream pipelines as well as the height of water in the reservoir can be easily calculated by simultaneous solution of Eq. (3) through Eq. (7). It should be noted that K values depend on valve opening which in turn depend on the height of water in the reservoir.

NUMERICAL RESULTS

To find optimum opening and closing rates of the needle valves proposed in the Meybod and Ardakan service reservoirs, two major scenarios are selected and tried on the model.
In the first scenario it is assumed that there is an emergency and flow must be completely cut off when the system is working in its maximum capacity and in the second scenario flow must be reached to its maximum value when the system is under no flow condition. In fact all other operational scenarios are embedded in these two scenarios.

The first scenario

While the system is working in maximum discharge, steady state analysis shows that the opening value for the needle valves proposed in the Ardakan and Meybod are %60.68 and %100 respectively. In the reservoirs No. 1 and No. 2 both having a height of 4m, the floaters are set in such a way that needle valves are completely closed when the water height in the reservoirs are equal to 3m and fully open when the reservoirs are completely empty. In this condition the equilibrium heights in reservoir No. 1 and No. 2 are 1.46 m and 1.31 m respectively which completely protect their downstream pipelines against air entrainment. Also the equilibrium valves opening in these reservoirs are %51.33 and %56.33 respectively.
To find optimum closing rates of Ardakan and Meybod valves, the model was run several times. The results show that the optimum closing rates for Ardakan and Meybod needle

valves are 0.1 and 0.17 percent/sec respectively. Figures 3 and 4 shows maximum and minimum head generated in this condition.
It can be seen that the maximum pressures are slightly more than static pressure (less than %10) and nowhere in the system suffer undesirable overpressures.

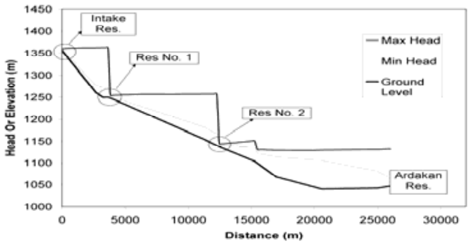

Figure 3. Max and min head in Ardakan pipelines

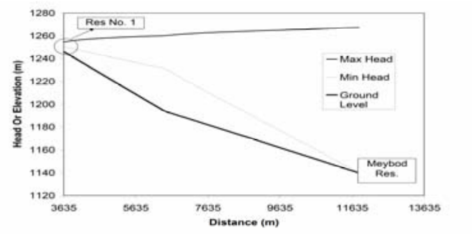

Figure 4. Max and min head in Meybod branch

Figure 5 shows the water level variation in both reservoirs No. 1 and No. 2. It can be seen that the water level in these reservoirs are gradually reached to their maximum height in about 1400 sec and provide a gradual and safe changing for their needle valves as well.

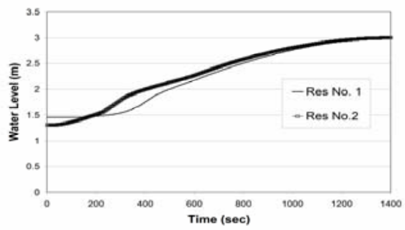

Figure 5. Water level variation in reservoirs No.1 and No.2

The second scenario

In this scenario it is assumed that the system is under no flow condition. So the needle valves proposed in Ardakan and Meybod are completely closed and maximum water level in the reservoirs No. 1 and No. 2 keep their needle valves fully closed.
In this condition the Ardakan and Meybod valves must be so operated that nowhere in the system experiences negative pressures. The model results show that the closing rates obtained in the first scenario can be effectively used for opening as well. So the opening

and closing rates for both Ardakan and Meybod needle valves are selected 0.1 and 0.17 percent/sec respectively.

Figures 6 and 7 show the maximum and minimum head generated during the operation throughout the system. It can be seen that no where in the system suffer negative pressures.

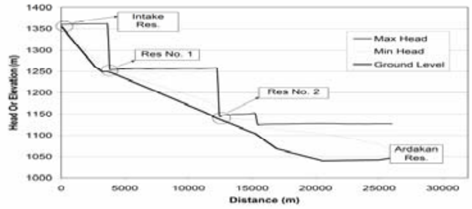

Figure 6. Max and min head in Ardakan pipelines

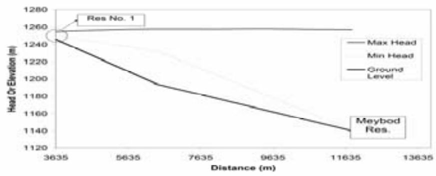

Figure 7. Max and min head in Meybod branch

Since the system is operated manually, as soon as the flow meter shows the requested discharge the operator would turn the actuator off. Unfortunately at this time the water column is not reached to the steady state condition and contains a little acceleration. The head absorbed by the acceleration would be changed to the driving force as the water column reaches to the steady state condition. Therefore discharge converges to a value grater than those shown by the flow meter when the operator turned the actuator off. Since no correction is assumed to be done by operators, the control system should have an acceptable discharge offset error. Figure 8 shows the discharge offset error for controlling the discharges of 0.5, 0.1, 0.15, 0.2, 0.25 and 0.3 cms in Ardakan reservoir. It can be seen that offset errors are limited between %0.4 and %3.6 and are very much reasonable for such a manual control system.

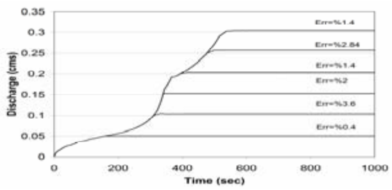

Figure 8. Discharge offset errors in Ardakan reservoir

Nearly similar results were obtained for Meybod reservoir, so the results are not presented herein.

CONCLUSION

A transient model was developed to evaluate the efficiency of the proposed control logic and also to find the optimum setting of control system parameters. According to the results obtained from the model it can be concluded that:

The proposed logic is able to efficiently control flow in the system in a wide range between 0 and maximum discharge.

The system will not suffer undesirable overpressures and negative pressures if the opening and closing rates of the valves in both Ardakan and Meybod reservoirs are equal to 0.1 and 0.17 percent/sec respectively.

The intermediate reservoirs have a sufficient volume for the proposed control logic. The interaction of these reservoirs with both floaters and needle valves also provide an excellent device for the reproducing the information they receive from their downstream pipes.

Discharge offset errors are limited between %0.4 and %3.6 and is very reasonable for such a manual control logic.

The method of study presented herein is highly recommended for choosing the best control logic as well as compatible instruments at design stage.

REFRENCES

[1] Falvey, Henry.T, “*Air-water flow in hydraulic structures (engineering monograph No. 41*.”, United state bureau of reclamation,(1980).

[2] Chaudhry, M.H, “*Applied hydraulic transients*”, Van nostrand rainhold book Co., New York. (1987).

[3] Watters, Grayz, “*Analysis and control of unsteady flow in pipelines*”, Butterworth Co., (1984).

[4] Wylie, E.B, Streeter, V.L,” *Fluid transients in systems*”, Prentice Hall, New Jersey, (1993).