Research on the water hammer protection of the air vessel caused by underground pipe burst in long distance water supply system

Xingtao Wang¹, Jian Zhang^{1,a}, Xiaodong Yu¹ and Lin Shi¹

¹ College of Water Conservancy and Hydropower Engineering, Hohai University, 210098 Nanjing, Jiangsu, China

Abstract. The conventional air vessel installation is usually installed behind the check valve at the upstream end of the pipeline to effectively control the water hammer pressure due to pump trip. However, the water hammer pressure caused by underground pipe burst has been neglected. The water hammer protection of air vessel due to pipe burst in long distance water supply system was discussed in this paper. According to analysis of the process of the pipe burst, the mathematical model of underground pipe burst and air vessel were established. A new air vessel installation that was installed in the middle of the pipeline was proposed. The new air vessel installation was simulated by method of characteristics. Then it was compared with the conventional air vessel when the pump trip and the pipe burst occur respectively. The results show that both the conventional air vessel and the new air vessel can effectively protect the water hammer due to the pump trip. Moreover, when pipe burst occurs, the conventional air vessel cannot achieve the safe operation of the long distance water supply system. However, under the same air vessel type parameters, the new air vessel installation can effectively protect the water hammer pressure.

1 Introduction

Worldwide demand for water has been increasing rapidly [1]. Accordingly, pipelines are of growing importance as a means of water transportation. Long distance pipeline water supply can be especially good solutions because they can connect water source and consumption site directly and their pressurized water transmission is efficient and inexpensive [2]. Although there are such advantages, long distance pipeline water supply system also risk pipe burst. This pipe burst have catastrophic effects on production losses, health, safety and the environment. Therefore, studying for more accurate model for the prediction of the burst pressure of steel pipelines is a primordial task.

It is generally accepted that underground pipe burst is a serious accident in the operation of the long distance water supply system. When underground pipe burst occurs, which will directly affects the normal operation of system, including economic and safety. In previous studies, the underground pipe burst related problems have been intensively investigated. On the one hand, many studies did a lot of research on the cause of underground pipe burst [3]. The reference pointed out that underground pipe burst normally provided by multiple factors caused, including the own reasons, external reasons and operational reasons [4, 5]. The own reasons are the material, diameter, age and arrangement of the pipe. The external reasons are climatic conditions, geological conditions, and installation conditions. The operational reasons are water hammer pressure, hydraulic vibration and sediment abrasion. On the other hand, there are a large

number of published papers about the prediction and protection of the underground pipe burst [6-8]. For instance, Jung et al. proposed a method for quantifying mechanical reliability based on the simulation of a single-meter failure for water distribution system pipe burst detection [9]. Qi et al. investigated the underlying capacity of existing PSSs for pipe burst detection using a set of quantitative metrics [10]. However, there is little study about transition process of underground pipe burst. Moreover, when designing water hammer protection scheme, the conventional air vessel is usually placed behind the check valve at the upstream end of the pipeline to effectively control the water hammer pressure due to pump trip, and the water hammer pressure caused by underground pipe burst has been neglected. Thence, it is unknown whether the conventional air vessel protection measure can effectively protect the water hammer pressure when underground pipe burst occurs. Therefore, motivated by the above discussions, this paper focuses on studying the transition process when underground pipe burst occurs, and the water hammer protection of air vessel due to pipe burst in long distance water supply system.

The rest of the paper is organized as follows: (1) A mathematical model of underground pipe burst and air vessel were established and analysed. (2) A new air vessel installation scheme that was the air vessel installed in the middle of the pipeline was proposed. (3) According to the air vessel installation scheme proposed in this paper, the numerical simulation is carried out through the method of characteristics, and compared with the conventional air

^a Corresponding author: jzhang@hhu.edu.cn

vessel installation scheme. (4) Conclusions are at the end of the paper.

2 Mathematical model

In the following paragraphs of this section, the mathematical model of air vessel is built in detail. Then, according to analysis of the process of the pipe burst, the mathematical model of underground pipe burst is established and analysed.

2.1 Mathematical model of air vessel

In long distance water supply system protected by air vessel, it is assumed that the gas in the vessel is ideal and its variation process follows the ideal gas state equation. Concurrently, the elasticity of the water is neglected. Sectional area of the air vessel is a circular, and its area is an invariant constant. The mathematical model of the air vessel is shown in Figure 1.

The characteristic equations [11]

$$\begin{aligned} C^+: H_P &= C_P - B_P Q_1 \\ C^-: H_P &= C_M + B_M Q_2 \end{aligned} \quad (1)$$

where H_P is the pressure at the connection point between the air vessel and the pipeline (m). Q_1 is the flow in front of the node (m^3/s), and Q_2 is the flow behind the node of the air vessel (m^3/s). C_P, B_P, C_M, B_M are all known quantity at time $t-\Delta t$, and Δt is the time step. The values of C_P and B_P are calculated by the pressure and flow in front of the node of the air vessel at time $t-\Delta t$. The values of C_M and B_M are calculated by the pressure and flow behind the node of the air vessel at time $t-\Delta t$.

Figure 1. Mathematical model of air vessel.

It can be assumed that the air enclosed at the top of the air vessel follows the poly-tropic relation for a perfect gas, then[12]

$$PV_{\text{air}}^m = C \quad (2)$$

where P is the absolute pressure of gas in the air vessel (N/m^2). V_{air} is gas volume in the air vessel (m^3). m is the exponent in the poly-tropic gas equation, and C is a constant. The values of m is 1.0 for an isothermal and 1.4 for adiabatic expansion or contraction of the air. In this calculation, it can be taken $m=1.2$, because the transients are usually rapid at the beginning, but are slow near the end. The value of C is depend on the initial state of the gas in the air vessel.

The relationship between water level and flow rate of air vessel.

$$A_{\text{st}} \frac{dZ_{\text{st}}}{dt} = Q_{\text{st}} \quad (3)$$

where A_{st} is the cross-sectional area of the water surface in the air vessel (m^2). Q_{st} is the flow flowing into or flowing out of the air vessel, and when water flows into the vessel, it is positive, otherwise it is negative (m^3/s). Z_{st} is the water level in the air vessel (m).

Energy equation

$$H_P = Z_{\text{st}} + \frac{P - P_a}{\gamma} + kQ_{\text{st}}|Q_{\text{st}}| \quad (4)$$

where P_a is the local atmospheric pressure (N/m^2). k is the hydraulic loss coefficient at the connection point between the air vessel and the pipeline. γ is water density (N/m^3).

Continuity equation

$$Q_1 = Q_{\text{st}} + Q_2 \quad (5)$$

Considering that the size of the time step is small in the method of characteristics, it can integrate Equations (3) and (4), and take a second-order approximation, then

$$\Delta Z = Z_{\text{st}} - Z_{\text{st}0} = \frac{\Delta t(Q_{\text{st}} + Q_{\text{st}0})}{2A_{\text{st}}} \quad (6)$$

$$H_P = Z_{\text{st}} + \frac{P - P_a}{\gamma} + kQ_{\text{st}0}|Q_{\text{st}0}| \quad (7)$$

Using Taylor series expansion, Equation (2) can be written as

$$\begin{aligned} P(Z_0 - Z_{\text{st}})^m &= P(Z_0 - Z_{\text{st}0})^m \left[1 - \frac{m(Z_{\text{st}} - Z_{\text{st}0})}{Z_0 - Z_{\text{st}0}} \right] \\ &= C_1 \end{aligned} \quad (8)$$

$$P = C_2 + C_3(Z_{\text{st}} - Z_{\text{st}0}) \quad (9)$$

where $C_1 = \frac{C}{A_{\text{st}}^m}$, $C_2 = \frac{C_1}{(Z_0 - Z_{\text{st}0})^m}$, $C_3 = \frac{mC_2}{Z_0 - Z_{\text{st}0}}$. Subscript 0 parameters are all known quantity at time $t-\Delta t$.

By Combining Equations (1) (5) to Equation (9), it can be gotten

$$H_P = \frac{C_4 + C_5(\frac{C_P}{B_P} + \frac{C_M}{B_M})}{1 + C_5(\frac{1}{B_P} + \frac{1}{B_M})} \quad (10)$$

where $C_4 = Z_{\text{st}0} + \frac{C_2}{\gamma} - \frac{P_2}{\gamma} + (1 + \frac{C_3}{\gamma}) \frac{\Delta t Q_{\text{st}0}}{2A_{\text{st}}}$, $C_5 = (1 + \frac{C_3}{\gamma}) \frac{\Delta t}{2A_{\text{st}}} + k|Q_{\text{st}0}|$.

H_P can be calculated from Equation (10), then the value of $Z_{\text{st}}, Q_1, Q_2, Q_{\text{st}}, P$ are determined.

2.2 Process analysis of underground pipe burst

For underground pipelines in long distance water supply system, the process of pipe burst can be divided into three stages. ① the stage of pipeline burst, ② the stage of water

impact covering layer, ③ the stage of water jetting out of the ground. They are shown in Figure 2.

When the underground pipe bursts, the pressure at the burst point drops sharply for the first time. At the same time, the water flows into and forms an impact on the cover layer. Then, it continuously penetrates the cover layer. With the rise of the water level, the thickness of the cover layer is continuously decreasing, and the pipeline pressure drops rapidly. Because of the change in pressure, the flow before the burst point increases, but the flow of pipe after the burst point decreases. As the thickness of the cover layer decreases and the inertia of the water increases, the speed of the water impact covering layer is accelerated, and finally jets out of the ground. When the water is jetting out of the ground, the pressure at the burst point drops a second time and eventually stabilizes at a constant. It can be seen that when the pipe burst occurs, the pressure of the pipeline at the burst point does not decrease uniformly. The change in pressure is also affected by various factors such as the uniformity and the density of the cover layer. Therefore, the pressure change at the burst point is very complicated when the pipe burst occurs.

Figure 2. Schematic diagram of transient flow analysis for pipe burst.

According to Figure 2 and related theoretical analysis, it can be found that the transient flow process of the underground pipe burst has a remarkable feature, that is, the pressure at the pipe burst point gradually approaches a constant value after the pipe burst ends. Therefore, the pressure equation of the burst point can be written as

$$H_{PB} = Z_p + \Delta h_1 + \Delta h_2 + \Delta z \quad (11)$$

$$\Delta h_1 = \alpha_1 Q_s^2 \quad (12)$$

$$\Delta h_2 = \Delta h_{21} + \Delta h_{22} = (\alpha_{21} + \alpha_{22}) Q_s^2 \quad (13)$$

$$\alpha_1 = \frac{1}{2gA_s^2\varphi^2} \quad (14)$$

$$\begin{cases} \alpha_{21} = \frac{1}{2gA_F^2} \varepsilon_1 \\ \alpha_{22} = \frac{1}{2gA_F^2} \varepsilon_2 \end{cases} \quad (15)$$

where H_{PB} is the pressure at the burst point (m). Z_p is the difference between the ground elevation and the pipe centerline elevation (m). A_F is equivalent area of water flow channel of cover layer (m²). Δh_1 is the loss of local water head at the orifice of the pipe burst (m). It is directly related to the size of the orifice. Normally, the diameter of the orifice will generally not exceed the diameter of the pipe. For safety considerations, the diameter of the burst orifice can be considered in accordance with the diameter

of the pipe. Δh_2 is frictional water head (m). Δz is the jetted water head (m). Q_s is the flow at the point of pipe burst (m³/s). A_s is equivalent area of the burst orifice (m²). φ is resistance coefficient of the orifice, its value ranges from 0.6 to 0.8. ε_1 and ε_2 denote the coefficient of frictional water head and local head loss of cover layer, respectively. ε_1 and ε_2 are related to the thickness of the cover layer. For a homogeneous cover layer, this value decreases with the thickness of the cover layer decreases.

As the complexity of the cover layer, and the water penetrates path in the cover layer is also uncertain. Therefore, the frictional water head generated by the cover layer is difficult to calculate quantitatively. Considering that the process of pipe burst lasts for a short time, and when the pipe burst occurs, the thickness of the cover layer decreases due to the water penetrates the cover layer. Therefore, the local resistance is also getting smaller and smaller, and the frictional loss is gradually increasing. At the same time, the total head loss in the process of water flowing through the cover layer is getting smaller and smaller. According to the above analysis, firstly, it can be assumed that the resistance generated by the cover layer at the start time of pipe burst is the pressure of the pipe at that moment. Lastly, when the water jets out of the ground, the local resistance of the cover layer is reduced to zero. Therefore, it can be considered that the loss of local water head follows a linear variation throughout the pipe burst.

The equation (11) can be written as

$$H_{PB} = Z_p + \Delta h_1 + \Delta h_{21} + [H_{PB0} - \frac{H_{PB0}}{T_{B2} - T_{B1}} (T - T_{B1})] + \Delta z \quad (16)$$

where T is calculating time (s). $T_{B1} \ll T \ll T_{B2}$, T_{B1} is the start time of pipe burst. T_{B2} is the moment when the water jetting out of the ground. H_{PB0} is the pressure at the time of T_{B1} (m).

2.3 Mathematical model of underground pipe burst

In long distance water supply system, overflow tower which connected to the main pipeline acts as a flat pressure. The overflow tower is shown in Figure 3. In order to enable to simulate the transient process of underground pipe burst, the initial operating state of the overflow tower is set as follows in this paper. When the pipeline is in normal operation, the valve at the bottom of the overflow tower is completely closed, the resistance coefficient of the valve is infinite, and the flow rate of the valve is zero. The overflow tower is separated from the pipeline by the closed valve. It can be used to characterize the normal operation of the pipeline when it does not burst. When the underground pipe burst occurs, the valve at the bottom of the overflow tower opens quickly. The time that the pipe burst occurs is simulated by controlling the speed of the valve opening. As shown in Figure 3, Z_p is the height of the overflow tower (m), which characterizes the distance from the centreline of the pipe to the ground. A_s is the area of the connecting pipe (m²), which characterizes the area of the pipe burst. According to the

soil mechanics, the water permeability coefficients of different geological conditions are different [4, 5]. In order to realistically simulate the process of water impact covering layer when pipe burst occurs, the corresponding permeability coefficient is selected by the geological conditions of the buried soil of the pipeline in this paper. The greater the permeability coefficient, the shorter the time it takes for the water to jet out of the ground. Therefore, the permeability coefficient of the soil can be characterized by selecting the appropriate cross-sectional area of the overflow tower. According to the operation of the valve at the bottom of the overflow tower, it can completely simulate the transient process from normal operation to burst of the pipeline.

Figure 3. Schematic diagram of the underground pipe burst model based on the overflow tower.

Continuity equation of the overflow tower

$$Q_S = Q_1 - Q_2 \quad (17)$$

$$Q_S = Q_T + Q_Y \quad (18)$$

where Q_1 and Q_2 are the flow of inflow and outflow of point P, respectively (m^3/s). Q_S is the flow which flow into the overflow tower (m^3/s). Q_T is the flow in the overflow tower (m^3/s). Q_Y is the overflow flow of overflow tower (m^3/s).

Overflow equation

$$Q_Y = k_y(Z_T - Z_0) + Q_{Y0} \quad (19)$$

where Z_T is the water level of the overflow tower (m). Z_0 is the overflow level of the overflow tower (m). Q_{Y0} is the initial overflow flow of the overflow tower (m^3/s). k_y is the overflow coefficient.

It can be assumed that the top section of the overflow tower is approximately a circle. According to the experimental results of the reference [13], the calculation formula for the overflow coefficient can be obtained as follows

$$k_y = \lambda^{15} \left[-77.85 \left(\frac{h_r}{\lambda} \right)^4 + 28.64 \left(\frac{h_r}{\lambda} \right)^3 - 7.89 \left(\frac{h_r}{\lambda} \right)^2 + 2.36 \frac{h_r}{\lambda} - 0.051 \right] \quad (20)$$

where $\lambda = \frac{D}{4}$, D is the diameter of the overflow tower (m). $h_r = Z_T - Z_0$ is the water head of a circular weir (m).

The control condition for overflow of the overflow tower is: $Z_T > Z_0$ and $\frac{h_r}{\lambda} > 0.05$.

The relationship between the water level and flow.

$$A_T \frac{dZ_T}{dt} = Q_T \quad (21)$$

where A_T is area of overflow tower (m^2).

Energy equation

$$H_{PB} = Z_T + (\alpha_1 + \alpha_{21})Q_S^2 + [H_{PB0} - \frac{H_{PB0}}{T_{B2} - T_{B1}}(T - T_{B1})] \quad (22)$$

The time step is small. Therefore, it can be obtained for equations (21) and (22).

Considering that the size of the time step is small in the method of characteristics, it can be obtained by using the second order approximation for equations (21) and (22).

$$A_T \frac{Z_T - Z_{T0}}{\Delta t} = \frac{Q_T + Q_{T0}}{2} \quad (23)$$

$$H_{PB} = Z_T + \alpha |Q_{S0}| Q_S \quad (24)$$

H_{PB} can be calculated by combining Equations (1), (17) ~ (19), (23) and (24). Then, other transient parameters can be obtained

3 Feasibility analysis

The use of air vessel is a conventional and effective measure to control water hammer in long distance water supply system. The air vessel is installed behind the check valve at the upstream end of the pipeline to make full use of the air vessel's water-hammer protection performance. The general design principle of air vessel is to effectively protect the water hammer pressure caused by pump trip or incorrect valve operation. However, the water hammer caused by underground pipe burst is neglected when air vessel are applied in long distance water supply system. In the long distance water supply system, the pipelines have hundreds or thousands of kilometers, and they often needs to cross rivers, highways, railways and residential areas. Thereby the geology and topography along the pipeline are complex. In addition, the operating conditions of the water supply system are changeable. The pipeline may be damaged by fatigue or external construction and other reasons, which greatly increase the probability of pipe burst accidents. Therefore, the water hammer caused by underground pipe burst should be taken into account when air vessel is used as a protective measure.

The main consequences of underground pipe burst are as follows: First, when the pipe burst occurs, the pressure of the burst point decreases rapidly, leading to a sharp increase in the upstream discharge and a large amount of water gushing out of the ground, which in turn cause serious damage to the surrounding environment. Second, the only measure for water hammer protection is the air vessel, and the air vessel is installed behind the check valve at the upstream end of the pipeline. Because of the pipe sudden burst, the negative pressure wave generated by the pipe burst propagates downstream, and the points where the initial pressures are relatively low along the

pipeline may be reduced to the vaporization pressure, thereby causing the new burst points.

Table 1. Size parameters of the air vessel.

Installation position of air vessel	Water Height (m)	Gas Height (m)	Cross-Sectional (m ²)	Connection diameter (m)	Total Volume (m ³)
placed behind the check valve at the upstream end of the pipeline	4.2	4	60	1.0	425

From the above analysis, if the water can be supplied to the downstream pipeline in time when underground pipe burst occurs, the negative pressure wave propagating downstream will be cut off. Therefore, the new pipe burst accident can be avoided, and then ensure the safety of downstream pipelines.

According to the above analysis, the water hammer pressure caused by underground pipe burst can be avoided when the water can be supplied to the downstream pipeline in time. The conventional air vessel installation is usually installed behind the check valve at the upstream end of the pipeline to effectively control the water hammer pressure due to pump trip or incorrect valve operation. Therefore, when underground pipe burst occurs, the conventional air vessel cannot provide water hammer protection for the section between the point of the burst and the downstream. In order to enable the air vessel to effectively protect for the section between the point of the burst and the downstream, air vessel should be installed in the middle of the pipeline. It is verified in the next section.

4 Case analysis and discussion

Taking a long distance water supply system as the research object, and the schematic diagram of the long distance water supply system is shown in Figure 4. Two identical pumps are operated in parallel in the system. The rated flow discharge of each pump is 3.25 m³/s, and the pump head is 186.0 m. The length and diameter of pipe are 11.4 km and 2.4 m, respectively, and the roughness coefficient is 0.012. The wave speed is 1000 m/s. A butterfly valve is installed at the upstream end. Upstream and downstream water level are 532.0 m and 708.0 m, respectively. Moment of inertia and rated speed of pump is 12000 kg m² and 750 r/min, respectively. In order to ensure the stable and safe operation in this long distance water supply system, it is required that all negative pressures should be eliminated and the maximum pressure should be below 260 m along the pipeline. According to the above the requirement of water hammer protection, the condition, when pump trip occurs, is simulated by the method of characteristics, and air vessel protection measures which were placed behind the check valve at the upstream end of the pipeline were applied to the system. When pump trip occurs, the air vessel parameters which can achieve the water hammer protection are listed in Table 1, and the maximum and minimum pressure curves along the pipeline are shown in Figure 5.

Figure 4. Schematic diagram of the long distance water supply system.

Figure 5. The maximum and minimum pressure curves along the pipeline when pump trip occurs.

4.1 Air vessel protection without considering underground pipe burst

In theory, there is a possibility of underground pipe burst anywhere in long distance water supply system. Therefore, the calculation and analysis of the transition process when underground pipe burst occurs should focus on the points of the most harmful to the system. According to the previous studies about the long distance water supply system [4, 5], the most dangerous point of the underground pipe burst is generally in the hump, turn, joint, etc. of the pipe. From the elevation of the pipe centerline shown in Figure 4, it can be known that the elevation of the pipe centerline fluctuates greatly between the pump and the stake 6+500 m, and the center line elevation is the local minimum point at the stake 6+500 m. According to the above analysis of the danger point of the pipe burst, it can be known that the stake 6+500 m is the most dangerous pipe burst point in this system. When

pipe burst occurs at the stake 6+500 m with an air vessel whose size parameters as shown in Table 1. The condition of pipe burst is simulated by the mathematical model of underground pipe burst of the section 2.3. The maximum and minimum pressure curves along the pipeline are shown in Figure 6.

Figure 6. The maximum and minimum pressure curves along the pipeline when pipe burst occurs.

It can be seen from Figure 6. When underground pipe burst occurs at the stake 6+500 m, the air vessel placed behind the check valve at the upstream end of the pipeline cannot effectively prevent the water hammer. It is obvious that the maximum pressures of the pipeline are within the control standard of 260 m. However, most of the minimum pressures along the pipeline are below vaporization pressure after pipe burst. The minimum value of the minimum pressure occurring in the back section of the pipeline is -52.3 m. It will cause serious damage to the pipeline system, resulting in secondary bursting of the pipeline. According to the characteristics of the water flow after pipe burst, when underground pipe burst occurs at the stake 6+500 m, the whole pipeline is divided into two sections by the burst point, and the only water hammer protection measure for the system is installed behind the check valve at the upstream end of the pipeline. As a result, the air vessel cannot provide water hammer protection for the section between the point of the burst and the downstream. Therefore, it is necessary to take protection measures to achieve the safe operation of the water supply system. In order to enable the air vessel to effectively protect for the section between the point of the burst and the downstream, a scheme that is the air vessel installed in the middle of the pipeline is proposed in this paper.

4.2 Air vessel protection with considering underground pipe burst

According to the analysis in Section 4.1, the air vessel, which is installed behind the check valve at the upstream end of the pipeline, cannot provide water hammer protection for the section between the point of the burst and the downstream when underground pipe burst occurs. On the premise of ensuring that the water hammer pressure caused by pump trip can be effectively protected, the air vessel installed in the middle of the pipeline is applied to control the water hammer pressure due to pipe burst in this paper. Based on the elevation of the pipe

centerline shown in Figure 4, the stake 6+500 m is the most dangerous pipe burst point in this long distance water supply system. In order to enable the air vessel to provide effective protection for the section between the point of the burst and the downstream, the air vessel is installed at the stake 7+300 m, and size parameters of air vessel are shown in Table 1. When the air vessel is installed separately behind the check valve at the upstream end of the pipeline and at the stake 7+300 m, the comparison of the maximum and minimum pressure curves along the pipeline when pump trip occurs is shown in Figure 7, and the comparison of the maximum and minimum pressure curves along the pipeline when underground pipe burst occurs is shown in Figure 8.

Figure 7. Comparison of the maximum and minimum pressure curves along the pipeline when pump trip occurs.

Figure 8. Comparison of the maximum and minimum pressure curves along the pipeline when underground pipe burst occurs.

Based on the comparison of the maximum and minimum pressure curves along the pipeline as shown in Figure 7, when pump trip occurs, air vessel can effectively control the water hammer pressure regardless of whether it is installed behind the check valve at the upstream end of the pipeline or at the stake 7+300 m. The results show that the maximum pressures of the pipeline are below the control standard of 260 m, as well as the minimum pressures of the pipeline are above the control standard of 0 m. However, when underground pipe burst occurs at the stake 6+500 m, from the comparison of Figure 6 and Figure 8, the air vessel installed behind the check valve at the upstream end of the pipeline cannot achieve the safe operation of the long distance water supply system. On the contrary, under the same air vessel type parameters,

the air vessel installed at the stake 7+300 m can effectively protect the water hammer pressure. According to the above analysis, when air vessel is installed at stake 7+300 m, air vessel can effectively control the water hammer pressure regardless of whether pump trip occurs or underground pipe burst occurs at the stake at 6+500 m.

5 Conclusions

To effectively protect the water hammer pressure caused by underground pipe burst in long distance water supply system, air vessel was used as a water hammer protection measure. Firstly, according to analysis of the process of the underground pipe burst, the mathematical model of underground pipe burst was established and analyzed. Secondly, the conventional air vessel installation is usually placed behind the check valve at the upstream end of the pipeline. Therefore, the installation cannot provide water hammer protection for the section between the point of the burst and the downstream when underground pipe burst occurs. A new air vessel installation that was the air vessel installed in the middle of the pipeline was proposed in this paper. Additionally, compared with the conventional air vessel installation under the same air vessel type parameters, the following conclusions can be drawn. On the one hand, when pump trip occurs, air vessel can effectively control the water hammer pressure regardless of whether it is installed behind the check valve at the upstream end of the pipeline or at the stake 7+300 m. On the other hand, when underground pipe burst occurs at the stake 6+500 m, the conventional air vessel installation cannot achieve the safe operation of the long distance water supply system. On the contrary, under the same air vessel type parameters, the air vessel installed at the stake 7+300 m can effectively protect the water hammer pressure.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (NSFC) (grant No. 51839008) and the National Key R&D Program of China (2016YFC0401810).

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