Water Hammer Analysis in the main pipe-line for the proposed Taq-Taq Dam irrigation project in Iraq

I R Karim¹, S A Sahib², H H Abdullah³ and R R Aziz⁴

¹PhD, Asst. Professor of Water Resources Eng., Civil Eng. Dep., University of Technology, Baghdad, Iraq
²BSc, Water and Hydraulic Structures Eng., Civil Eng. Dep., University of Technology, Baghdad, Iraq
³MSc, Civil Engineer, Center for Engineering Studies and Design, Ministry of Water Resources, Baghdad, Iraq
⁴MSc, Asst. Lecture of Hydraulic Structures Eng., Civil Eng. Dep., University of Technology, Baghdad, Iraq

Email: 40049@uotechnology.edu.iq

Abstract. A water hammer is a common problem occurring in water distribution systems, such as water transport pipelines. Transient hydraulic occurs in the distribution system, which may cause system failure due to pipe collapse or bursting. In this paper, an irrigation pipeline system of the proposed Taq-Taq dam (north-eastern part of Iraq) is used to represent the common situation of lifting water from the dam reservoir to another higher reservoir (irrigation project reservoir) through a pipeline. The transmission line is subject to a potential water hammer where the water level in two main reservoirs is controlled at both ends. The hydraulic simulation model used in the design and analysis of hydraulic and transverse behaviour (water hammer) was adopted by a software named Bentley HAMMER through two scenarios (with and without control device). An operational control measure was proposed to be adopted by a surge tank for minimizing the probability of the occurrence of the water hammer, also to protect the dam from this problem. The results showed that using of surge tank protects the pipe network effectively from the effect of water hammer. Distribution profiles of velocities and pressures on the pipeline indicate that the water hammer on the pipeline was clearly reflected.

1. Introduction

Water conveyances through a huge pipeline arrangement normally faces various issues, for example, water hammer or pressure driven transient. Water hammer usually occur when the flow is caused to suddenly stop or change direction, leading to a surge of propagating waves. Several actions during pipe network operation can generate water hammer phenomena such as a sudden valve closure or during a water pump startup/shutdown. This can cause serious issues, for example, commotion/vibration, or pipe break/breakdown. Furthermore, the water transient stream amid a water hammer occasion will have huge effect on the water quality and, subsequently, wellbeing suggestions. Water hammer has become one of the major research areas in hydraulic studies due to its major impact on the process of water delivery.

Water hammer shows itself as weight changes in funneling frameworks, as rotational speed varies (over speed, turn around pivot) in pressure driven hardware or as water level motions in flood tanks. The speed profiles in quick homeless people are fundamentally unique in relation to the "unfaltering" profiles in gradually fluctuating drifters. Homeless people in pipelines may make a drop-in weight sufficiently substantial refute the suspicion of liquid homogeneity and progression. Gas air pockets might be entrained in a fluid because of gas discharge amid low-weight homeless people, cavitation
and additionally section partition. The mechanical properties of pipe divider material and the inflexibility of pipe supports may essentially impact the power of weight motions. Unwanted water hammer impacts may aggravate the task of the pressure driven framework (hydroelectric power plant, siphoning framework) and harm the framework segments; for instance, pipe removal or crack may happen. Water hammer problem can be kept away as far as possible by satisfactory control of operational routines, establishment of flood control gadgets or overhaul of the first pipeline design [1].

This study deals with water hammer effect inside pipelines and the effect of a surge tank at the pipelines. The study continues with analysis of the connection between water hammer and surge tank as well as the effect of surge tank in decreasing the pressure height inside the pipelines. Many numerical techniques have been applied for pipeline transient analysis. They include Method Of Characteristics (MOC), Wave Characteristic Method (WCM), Finite Difference Method (FDM) and Finite Volume Method (FVM).

Al-Bahrani, (2009) arranged a scientific model for al – Kut water supply venture contingent on the numerical techniques, for example, Newton - Raphson strategy and Gaussian end strategy to unravel non – straight synchronous conditions with realized limit condition and by utilizing the trademark strategy, the halfway differential conditions were changed to standard differential conditions. In his scientific model, the estimations of the created weights were determined when utilizing control gadgets or without, additionally, to discover the impact of this gadget on the weight esteems was found. Notwithstanding, he found that the appropriate number of control gadgets required for every pipeline to keep the weight esteems inside a middle as far as possible.

Gseea, and Dekam, (2010) concentrated the qualities of the system part, for example, valve type, valve shutting rate, pipe material, rubbing model and flood security gadget, which were observed to be profoundly influencing the measure of weight flood in the system. There results were affirmed that the utilizing of shaky erosion factor prompts less swayed weight contrasted with unfa ltering contact factor, and the establishment of an air chamber at a short separation from the siphon release would decrease the wavering of weight as that delivered because of utilizing variable speed siphon when the static leader of the siphon was moderately low because of higher siphon height.

Khudair, and AbdulRazzak, (2013) contemplated and clarified the Iraqi customer various examples about the phenomenon of water hammer, which happens in the water pipeline working with weight. They were concern a common sense investigation of the attributes of this wonder and financially unsafe to the shopper a similar time, various pipe fittings were utilized expected to lessen this marvel and its work as options in contrast to the fabricated arresters that used to stay away from water hammer in the sterile establishments, while the customer did not have any information with regards to the non-exchanged for some, reasons, including the water weight diminishes in the systems and the utilization of purchaser siphons to draw water straightforwardly from the system. Their examination arrived at various conclusions and suggestions of the most significant pipe fittings, which have been useful in controlling this phenomenon.

Emad, A., (2013) discovered the correct answers for water hammer phenomenon in low lift siphon station situated on Tigris Stream. He considered the water driven information that was taken from the siphon station situated on Tigris Waterway. When he input this information to the Bentley Programming, he found that the putting of flood tanks in the spot of most astounding purpose of weight make the weight diminished from 22bar to 7bar around.

2. Water Hammer Governing Equations
The administering conditions for the flimsy/transient stream (amid the water hammer occurrence) are gotten from the essential laws of material science: The Law of Preservation of Mass, condition (1) and
the Law of Protection of Vitality, condition (2). The two conditions are disentangled to the instance of one-dimensional incompressible liquid stream.

The continuity equation (1) for unsteady fluid flow is as follows:

\[
\frac{\partial H}{\partial t} + \frac{a^2}{gA} \frac{\partial Q}{\partial x} = 0 \tag{1}
\]

\[
\frac{\partial Q}{\partial t} + gA \frac{\partial H}{\partial x} + RQ |Q| = 0 \tag{2}
\]

where \(a\), pressure wave speed; \(x\), distance along the pipe; \(t\), time; \(g\), gravitational constant; \(Q\), discharge; \(A\), cross sectional area of pipe; \(H\), pressure head; \(f\), friction coefficient; \(D\), pipe diameter. Equations (1) and (2) are a set of quasilinear, hyperbolic, partial differential equations with no possible closed-form solution. Therefore, numerical techniques have been used to solve these equations.

The most widely used method to solve these equations for the transient flow is Method Of Characteristics (MOC) by transforming the two partial differential equations to a pair of equations to solve for \(H\) and \(V\) for every point and time step. The MOC is expressed mathematically as follows [2]:

\[
\begin{align*}
\frac{dV}{dt} + \frac{gDH}{a dt} + \frac{f V|V|}{2D} &= 0 \tag{3} \\
\frac{dH}{dt} + \frac{gVA}{a dt} + \frac{f V|V|}{2D} &= 0 \tag{4} \\
\frac{dV}{dt} + \frac{gDH}{a dt} + \frac{f V|V|}{2D} &= 0 \tag{5} \\
\frac{dH}{dt} + \frac{gVA}{a dt} + \frac{f V|V|}{2D} &= 0 \tag{6}
\end{align*}
\]

The MOC can't be comprehended systematically yet can be communicated graphically as appeared Figure (1).

![Figure (1): Wave characteristics in x-t plan to express the MOC after Larock, (2000)](image)

At each inside game plan point, signals get in contact from the two adjacent concentrations in the meantime. A straight mix of \(V\) and \(H\) is invariant along every trademark if grinding incidents are disregarded; thus, \(V\) and \(H\) can be obtained decisively in course of action centers. With head mishaps collected at game plan centers and the assumption that grinding is nearly nothing, WPM (Wave Plan Technique) can used identical with MOC to push the course of action in time.
3. Bentley Hammer Application

Bentley HAMMER V8i Edition is an advanced numerical simulator of hydraulic transient phenomena (water hammer) in water, wastewater, industrial and mining systems. Built with busy engineers in mind, it simplifies data entry and allows you to focus on visualizing, improving, and delivering your results quickly and professionally. With Bentley HAMMER V8i Edition, you can analyze drinking water systems, sewage force mains, fire protection systems, well pumps, and raw-water transmission lines. You can change the specific gravity of the fluid to model oil or slurries, for example. Bentley HAMMER V8i Edition assumes that changes in other fluid properties, such as temperature, are negligible. It does not currently model fluids with significant thermal variations, such as can occur in cogeneration or industrial systems [3].

Water hammer modeling essentially consists of solving its equations, for every solution point and time step, for a wide variety of boundary conditions and system topologies.

Bentley HAMMER V8i software has been used in this study. The proposed irrigation pipeline system of the Taq-Taq dam is composed of a pump station that draws water from a reservoir (Res 1), with normal water level of (380.00) m and transports 468 L/s along a transmission pipeline to another reservoir (Res 2), with normal water level of (540.00) m for a total static lift of 58 m, as illustrated in figures (2) and (3). The level of a constant-speed pump is (383.00) m and its speed is 1760rpm. Irrigation pipeline includes several pipes in series with different lengths, in addition to the suction and discharge pipes connected to the pump. All pipes are made of Glass Reinforced Polyester (GRP) and have a diameter of 600 mm [4]. Data for pipes’ lengths and nodes’ elevations is shown in Tables (1).

4. Analysis Scenarios

Two scenarios are conducted to analyse (simulated) the water hammer phenomena and it controlling through transient analysis without and with control.

![Figure (2): Longitudinal section of the main pipe connecting the dam reservoir and the reservoir of the irrigation project (R-2)](image)

| Table 1. Pipes lengths and nodes elevations |
|--------------------------------------------|
| Pipe | Length (user defined) | Node | Elevation(m) |
|------|-----------------------|------|--------------|
|      |                       |      |              |

4
|     |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|
| Ps1 | 3   | Pj1 | 383 |
| Pmp1s | 5 | Pj-2 | 417.7 |
| Pmp1D | 50 | j-1 | 421.7 |
| P-1 | 195 | J-2 | 417.7 |
| P-2 | 151 | J-3 | 425.7 |
| P-3 | 203 | J-4 | 425.7 |
| P-4 | 65 | J-5 | 417.7 |
| P-5 | 91 | J-6 | 417.7 |
| P-6 | 86 | J-7 | 413.7 |
| P-7 | 51 | J-8 | 421.7 |
| P-8 | 125 | J-9 | 447.7 |
| P-9 | 117 | J-10 | 450.1 |
| P-10 | 92 | J-11 | 450.1 |
| P-11 | 38 | J-12 | 437.7 |
| P-12 | 112 | J-13 | 437.5 |
| P-13 | 52 | J-14 | 460.3 |
| P-14 | 138 | J-15 | 490.1 |
| P-15 | 39 | J-16 | 500.5 |
| P-16 | 217 | J-17 | 520.3 |
| P-17 | 59 |     |     |
| P-18 | 145 |     |     |

**Figure 3.** Irrigation pipe-line system

4.1 First Scenario Transient Analysis without Protection
In this scenario, the system described in paragraph (3) and table (1) above has been activated and the transient hydraulic analysis (without protection) is performed using the model software. That is to determine its vulnerability to transient events.

The effect of a power failure for a few minutes is reproduced and broken down. It is accepted that control is hindered abruptly and all of a sudden. The reason for this sort of transient examination is to guarantee that the water system pipeline framework and its parts can withstand the subsequent transient weights and decide to what extent it must be trusted that the transient vitality will disperse.

Figure (4) shows the transient state hydraulic grade line (HGL) and elevations along the irrigation pipeline system employing the model software. Figure (5) illustrates pressures (max, min) along the irrigation pipeline system. Velocities (max, min and initial) after (60, 90 and 120 sec) from power failure along the irrigation pipeline system are shown in figures (6), (7) and (8), respectively.

![Figure 4](image1.png)

**Figure 4.** Hydraulic grade line versus elevations along the irrigation pipe-line system

![Figure 5](image2.png)

**Figure 5.** Pressures (max, min) along the irrigation pipe-line system
Figure 6. Velocities (max, min and initial) along the irrigation pipe-line system after (60sec) from the power failure

Figure 7. Velocities (max, min and initial) along the irrigation pipe-line system after (90sec) from the power failure
Figure 8. Velocities (max, min and initial) along the irrigation pipe-line system after (120sec) from the power failure

4.2 Second Scenario Transient Analysis with Protection

The change in the velocity of the fluid (discharge) in the irrigation pipe system is the first step leading to transient hydraulic. During a transient hydraulic condition, a pipeline may be exposed to high- and low-pressure cycles. High pressures can damage pipeline system components such as valves, pumps, and other pipeline components. Thus, sudden changes in speed should be avoided to reduce the incidence of transit pressure in the system. Based on the interpretation and analysis of the results of the first scenario and for the purpose of reducing the impact of the water hammer phenomenon on the irrigation pipeline system, a surge tank is suggested downstream the pump station at node (j-1) as shown in figure (9). The transient state analysis was performed using the model program.

Figure 9. Irrigation pipe-line system with surge tank

Figure 10. Hydraulic grade line versus elevations along the irrigation pipe-line system

Figure (10) shows the transient state hydraulic grade line (HGL) and elevations along the irrigation pipeline system employing the model software. Figure (11) illustrates pressures (max, min) along the irrigation pipeline system. Also, velocities (max, min and initial) after (60, 90 and 120 sec) from power failure along the irrigation pipeline system are shown in figures (12), (13) and (14), respectively.
Figure 11. Pressures (max, min) along the irrigation pipe-line system

Figure 12. Velocities (max, min and initial) along the irrigation pipe-line system after (60sec) from the power failure

Figure 13. Velocities (max, min and initial) along the irrigation pipe-line system after (90sec) from the power failure
5. Results Analysis
The impact of adding a surge tank as a protection to the pipeline can be stated as:

1) The Base pressure:
   i) The Maximum pressure along the pipeline decreased approximately as an average (64.6%) as shown in figures (5) and (11).
   ii) The Minimum pressure along the pipeline decreased approximately as an average (30.7%) as shown in figures (5) and (11).

2) The change in velocity:
   a) For the first scenario (without any protection): the velocity changed rapidly with the time from (60sec) through (90 sec) to (120 sec) as shown in figures (6), (7) and (8), respectively.
   b) For the second scenario (with adding surge tank as a protection devise): the velocity changed slightly with the time from (60sec) through (90 sec) to (120 sec) as shown in figures (12), (13) and (14), respectively.

6. Conclusions
The study of water hammer in irrigation network is very important in order to consider its risk on the pipeline and to understand how to control its effect.

   From the study, the following points can be concluded:
   1. EPANET software can be used as a simple and effective way to analyze the pipeline network and to design the irrigation network.
   2. Bentley Hammer V8i software is very efficient and user defined for the study of water hammer analysis because it has many outputs helping the designer specify the problems in the network.
   3. Placing a surge tank upstream the pump is very useful where the surge tank is a reservoir which water can rise and fall in to reduce pressure swing. By doing this, it helps reduce the negative effects of water hammer. To protect the pump from damage, the pressure will decrease and the change in velocity will approach to zero.

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