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Investigating the Effect of Water Hammer on Gravity Water Transmission Lines using Fiberglass Pipes

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Abstract

This study investigates water hammer control strategies in gravity-fed water transmission systems, using the drinking water pipeline from wells west of Mashhad as a case study. Key sections of the system include the transfer routes from the Islamabad reservoir to the Coward reservoir and from the Coward reservoir to the Area F reservoir, where abrupt flow stoppages have been shown to induce considerable pressure variations. The analysis reveals that sudden closures generate maximum positive pressures of 161 and 181 meters of water column, while negative pressures can drop to -10 meters, posing significant risks of structural damage to the pipeline. The research demonstrates that extending the valve closing time to at least 10 minutes substantially reduces the occurrence of extreme pressure fluctuations. Additionally, installing a pressure control valve upstream of the final valve effectively moderates peak pressures in emergency scenarios, such as sudden valve closures. These adjustments significantly enhance the system's resilience without requiring extensive or expensive shock control equipment. The findings underscore the importance of operational modifications over mechanical interventions. Implementing controlled valve operations with a closing time of 15–20 minutes and strategically integrating pressure control valves make it possible to mitigate water hammer effects effectively. This approach not only minimizes potential damage but also reduces maintenance costs and enhances the system's longevity. The results of this study have broad implications for the design and operation of gravity-fed water transmission systems. By adopting such strategies, operators can optimize system performance, ensure the safety of infrastructure, and avoid unnecessary expenditures on specialized equipment. These outcomes highlight the feasibility of combining practical operational changes with targeted engineering solutions to address common challenges in water supply systems.

1. Introduction

Water hammer, also known as the Hammer effect, occurs in pressurized pipelines due to sudden changes in pressure, flow rate, or velocity. This phenomenon is common in hydraulic systems such as water pipelines, oil networks, turbines, pumping systems, and gravity flow systems. It causes rapid pressure waves that can be destructive, especially when

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pipelines, valves, and pumps fail. A water hammer is triggered by a sudden change in flow rate, like when a pump shuts down, creating a negative pressure wave that travels through the pipeline and reflects back as a positive wave. This cycle repeats, weakening with each iteration due to friction and other factors. In gravity transmission lines, if a valve closes suddenly, the fluid's momentum creates a pressure surge that moves like an oscillating wave through the pipe, causing potential damage to valves and other components. The pressure increase from water hammer can cause significant damage in a short period or due to fatigue. To mitigate these effects, controlling the valve opening and closing is essential to limit the hammer pressure. The analysis of water hammer is particularly important in two scenarios: sudden valve closure and controlled valve closure. Previous studies, such as those by Namdari and Taleb Beydokhti (2008), Karimi Donna et al. (2013), and Agham Majidi et al. (2020), have explored the water hammer effect using various methods, including the Hammer application and finite element analysis. These studies highlighted factors like pipe elasticity and thickness, which influence the severity of water hammer. This paper presents a case study of the west Mashhad drinking water transmission line, analyzing the water hammer effect in gravity water lines using Water Hammer software. Fiberglass pipes provide several advantages for water transmission systems, making them an ideal choice for efficient and durable infrastructure. They offer high resistance to pressure, enabling them to withstand fluctuations and water hammer effects that can otherwise cause damage. Additionally, their lightweight structure simplifies transport and installation, which is particularly beneficial for long-distance projects. Fiberglass pipes are highly resistant to corrosion, which enhances their lifespan and reduces maintenance needs. Furthermore, their smooth internal surface improves hydraulic performance by minimizing friction and pressure loss, allowing for a more efficient water flow. Together, these benefits make fiberglass pipes especially suitable for gravity-fed water transmission lines and effective at reducing the adverse effects of water hammer.

2. Materials and Methods

2.1 Water Hammer in Pipelines with a Focus on GRP Pipes

A water hammer is a hydraulic phenomenon that occurs when a sudden change in flow velocity creates pressure waves within a pipeline system. It typically results from valve closures, pump startups or shutdowns, and changes in flow rates. These pressure surges can cause significant structural damage to pipelines and associated equipment if not properly managed.

Water Hammer Formula

The general formula to estimate the pressure rise (ΔP\Delta PΔP) due to water hammer is:

$$\Delta P = \rho . c . \Delta \upsilon \tag{1}$$

Where:

- ΔP\Delta PΔP: Pressure rise (Pa or N/m²)
- ρ\rhoρ: Fluid density (kg/m³)
- ccc: Wave speed (m/s), dependent on the material and fluid
- Δv\Delta vΔv: Change in velocity (m/s)

The wave speed (ccc) for a pipeline can be calculated as:

$$C = \sqrt{\frac{K}{\rho(1 + \frac{K_d}{E} \cdot \frac{t}{D})}} \tag{2}$$

Where:

- K: Bulk modulus of the fluid (Pa)
- Kd: Pipe material's modulus of elasticity (Pa)
- E: Young's modulus of the pipe material (Pa)
- t: Wall thickness of the pipe (m)

- D: Diameter of the pipe (m)

GRP Pipes and Water Hammer

Glass Reinforced Plastic (GRP) pipes are increasingly used in water transmission systems due to their superior properties, including lightweight design, corrosion resistance, and high elasticity. These characteristics play a critical role in mitigating water hammer effects.

1. **Elasticity Advantage**

   GRP pipes exhibit higher elasticity compared to steel, allowing them to absorb pressure waves more effectively. Studies show GRP pipes can reduce water hammer pressures by approximately 15 meters compared to steel pipes under similar conditions.

2. **Wall Thickness and Pressure Impact** Increasing the wall thickness of GRP pipes enhances their ability to withstand dynamic loads. For instance, a 1 mm increase in wall thickness raises the system's pressure resistance by about 3 meters.

3. **Diameter and Pressure Relationship** Increasing the pipe diameter significantly reduces maximum pressure from water hammer. A larger diameter provides more room for pressure dissipation, reducing stress on the pipeline walls.

4. **Integration with Flywheels**

   The inclusion of flywheels in pumping systems with GRP pipelines has demonstrated a significant reduction in water hammer effects. Doubling the system's moment of inertia reduces maximum pressure by up to 115 meters.

2.2 Advantages of GRP Pipes in Mitigating Water Hammer Effects in Pipelines

The use of Glass-Reinforced Plastic (GRP) pipes in water transmission systems offers significant advantages in managing water hammer effects. GRP pipes exhibit superior elasticity compared to traditional materials such as steel, which enables them to absorb and dissipate pressure surges more effectively. This inherent flexibility reduces the magnitude of both positive and negative pressure waves during sudden changes in flow conditions, such as valve closures or pump failures. Studies have shown that GRP pipes can lower water hammer pressures by approximately 10–15% compared to steel pipes, thereby minimizing the risk of structural damage and leakage. Additionally, the lightweight nature and corrosion resistance of GRP pipes make them ideal for long-term applications in challenging environments. By combining these properties with proper valve operation strategies, GRP pipes enhance the safety, reliability, and economic efficiency of pipeline systems prone to water hammer.

2.3. General Specifications of West Mashhad Water Transmission Line

Considering the special status of drinking water supply required by the resident and mobile population of Mashhad and the necessity of predicting the crisis of water shortage due to the reduction of groundwater level, the possible reduction of surface water resources and considering the appropriate quality of wells of West Mashhad plain in terms of drinking, the creation of new water capacities to provide sustainable drinking water of Mashhad as the religious metropolis of the country by the respected Khorasan Regional Water Company Joy has been studied and examined.

The transmission line starts from Islamabad reservoir in the west of Golbahar city and passes through Golbahar into the access road of Islamabad, Suran, and Nazeriye wells along this dirt road by passing from the south of the village of Gauterna to the Kavardeh reservoir, then it continues along the highway and from the west side of Mashhad it enters Elahieh boulevard and after passing through the boulevard exhibition and cutting off Vakilabad Boulevard leads to the area behind the IRGC land on Brunsi Boulevard. From there, after turning the IRGC land, the reservoir of area F (water treatment) ends. The approximate length of this line is about 47 km. In Figure 1, the approximate path of the transmission line is shown.

Figure 1. The approximate path of the water transmission line west of Mashhad.

In Table 1, the hydraulic specifications of the transmission line are presented considering the internal diameter, and in Table 2, the specifications of pipes used in the transmission line are displayed. Also visible in Figure 2 of the hydraulic path profile.

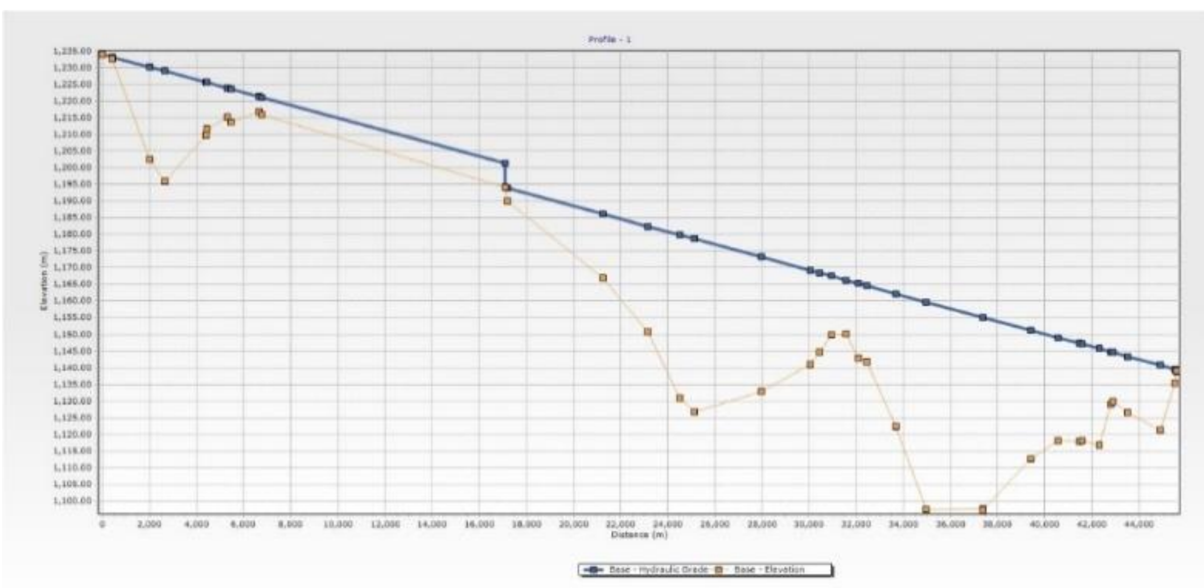

Figure 2. The hydraulic profile of the selected option

The graph represents the profile of a water transmission pipeline, showing the relationship between distance along the pipeline and both the elevation (in brown) and the base hydraulic grade (in blue). The hydraulic grade indicates the energy level, combining both pressure and elevation, at various points along the pipeline. Initially, the elevation is higher, and the hydraulic grade decreases as the distance increases, suggesting potential energy losses or changes in flow conditions. The graph reveals areas with significant drops in both elevation and hydraulic grade, which could highlight sections prone to pressure fluctuations or water hammer effects. These trends are crucial for assessing system stability, identifying trouble spots, and planning necessary pressure control or system modifications.

Table 1. Hydraulic specifications of the selected option from the Islamabad reservoir to the zone F reservoir, including the internal diameter

Description	Path length	Nominal diameter	Inner diameter	Pipe material	Transfer flow	Speed	loss of track	Maximum nominal pipe pressure
	(km)	(mm)	(mm)		(LS)	(ms)	(m.km)	(bar)
Transmission line from Islamabad to Korde	17.7	1200	1182	fiberglass	2000	1.82	1.94	10
The transmission line from Korda to the tank of area F	28.5	1400	1378	fiberglass	3000	2.1	1.92	16

Table 2. Specifications of selected option pipes

km	Nominal pipe diameter	Inner diameter of the pipe	Nominal pressure
Direction	(mm)	(mm)	(bar)
From km 0 to 7.17	1200	1182	10
From km 7.17 to 35	1400	1378	10
From km 35 to 39	1400	1378	16
From km 39 to 46.2	1400	1378	10

2.2. Specifications of water hammer Modeling Software

The V8i WATER HAMMER is a computer program that draws and solves algorithms and equations of unstable flows in various fluids. The capabilities of this model can be summarized as follows:

- The software is under the Windows operating system that uses all the features covered by this operating system.
- Ability to download files from other software such as Epanet, Water CAD and Water Gems.
- The design of transmission lines in a stable state is limited to a more limited extent than Water Gems.
- Reduces frictional pressures using three formulas of Hazen Williams, Darcy Weisbach and Shazzy Manning.
- It can model the electromotors with constant and variable speed.
- It models different types of valves available in the transmission line, such as cut-off valves, unidirectional valves,

pressure regulating1 valves including pressure release valves (PRVs), pressure holding valves (PSV), pressure relief valves (2PBV) and flow control3 valves (4FCV).

- Ability to analyze and calculate vapor pressure along the transmission line.
- Fully turbulent and steady.
- It is possible to analyze unstable currents in fluids with different densities.

2.3. Numerical Methods and Software Input Parameters

In order to solve the flow numerically and analyze the Water Hammer effect in transmission lines, it is necessary to apply the governing equations such as the continuity equation, momentum, and other auxiliary equations such as the Darcy Weisbach equation and. Dissolve in stable and unstable conditions. In addition, it is necessary to start the analysis of the initial conditions and boundary conditions in the software. For this purpose, the calculation menu with two stable and unstable solvers is considered in the software.

In the transient analysis of the Water Hammer effect in transmission lines, Hammer software requires initial inputs including speed in pipes and pressure in nodes. For this purpose, the software initially uses stable state solution or EPS (Extended Period Solver) and calculates the initial inputs for transient analysis, although the initial inputs can be calculated using the EPS method, but experience shows using the steady method will yield more accurate results for transient solution.

Hammer software to analyze pressure drop in pipes uses Darcy Weisbach's formula, but this feature is created in the software that can be calculated by entering the C coefficient (Hazen Williams relation).

For this purpose, the designer enters this coefficient and software after converting it to f in the Darcy Weisbach relationship, it starts the pressure drop analysis according to the water velocity inside the pipe and the Reynolds number.

The method of calculating the friction coefficient f for transient solver analysis should be specified in the software, which is done by the four methods mentioned below.

In a steady state, the friction coefficient f is assumed to be constant and the results of software calculations in this state will form transient state inputs, obviously, in the transient state at any time interval, the friction coefficient is recalculated according to the flow velocity and the relevant Reynolds number, which will increase the accuracy of calculation for the analysis of the transient state of Hammer effect.

In the Hammer software in the Transient Solver menu, how to calculate the friction coefficient for the transient state. Four states Steady, Quasi-Steady, Unsteady, and Unsteady-Vitkovsky can be considered to calculate the friction coefficient during transient state analysis.

2.4. Steady Transient Friction Method

In this case, the coefficient of friction in terms of initial analysis values (Steady State) the calculation. If the initial analysis of the flow rate inside the pipe is zero, the coefficient of friction specified according to the material of the pipe is considered as the base value in the calculations.

If the flow rate inside the pipe is not zero in the initial analysis, the software calculates the amount of friction coefficient according to the length and diameter of the pipe as well as the flow velocity inside it, and is considered constant until the end of the Hammer effect transient analysis. Hubby (Sciamarella and Artana, 2009; Tijsseling, 2007; Wang et al., 2014).

[1] Pressure Relief Valve
[2] Pressure Sustaining Valve
[3] Pressure Breaking Valve
[4] Flow Control Valve

2.5. Quasi-Steady Transient Friction Method

In this method, the friction coefficient at each time step is recalculated and used according to the values of speed and Reynolds number obtained for each pipe in the previous time step as well as the roughness of the pipe. Therefore, at each time step, the value of the friction coefficient is not constant, and after calculation in the pressure loss equation and finally, momentum is used (Don et al., 2005; Ghidaoui and Kolyshkin, 2001; Sang-Gyun et al., 2014).

2.6. Unsteady/Vitkovsky Transient Friction Method

It is obvious in the real case is that by increasing turbulence caused by turbulence, shear stress of pipe walls on the fluid increases, which reduces the water Hammer effect created in the pipe due to energy loss caused by wall friction.

In Hammer software, it can be demonstrated by analyzing the unsteady state that, in this case the software uses a series of coefficients. The number of changes in the coefficient of friction calculated in the quasi-stable state determines Quasi-Steady and considers the obtained coefficient in the equations.

The coefficient of friction calculated in this state is greater than or equal to the coefficient calculated in the quasi-steady state, which is why the pressure wave created in the pipe is degraded faster than the quasi-steady state due to the increased losses caused by the pipe wall shear stress. Although the unsteady state of the Hammer effect analysis is closer to reality, what is certain is that the analysis of steady and quasi-steady semi-stable results in the choice of safer equipment with a higher reliability factor. The quasi-steady mode, in particular, by changing the friction coefficient at different steps provides more appropriate, results and its results are very efficient in selecting safe and reliable equipment. In Figure 3 the sample of analysis is in all three ways is shown.

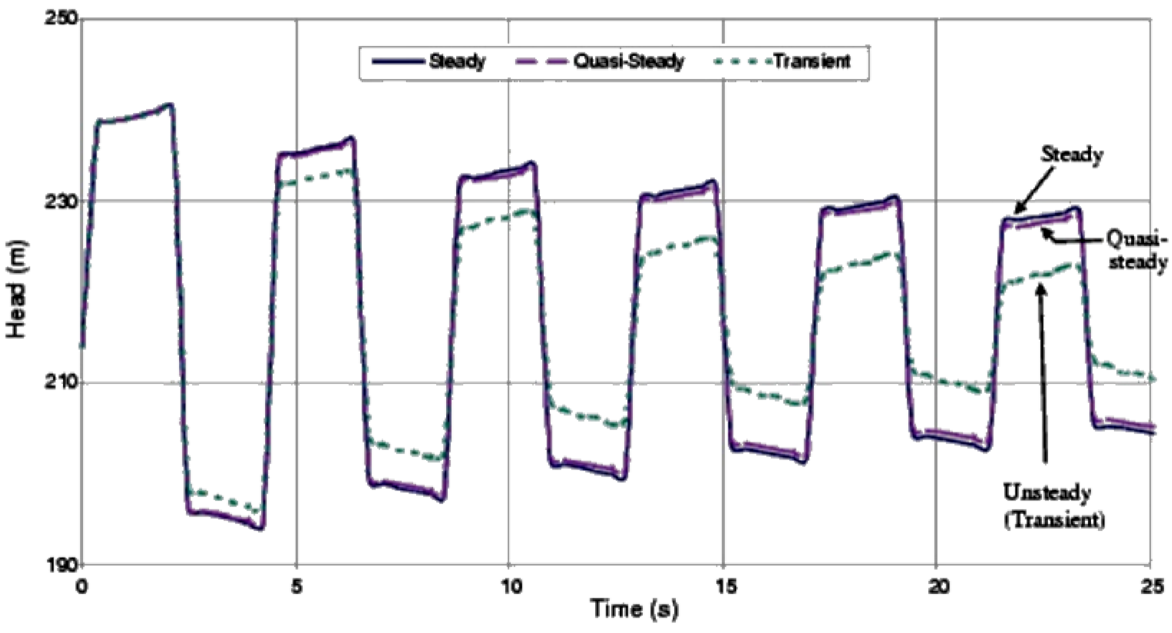

Figure 3. Analysis of water hammer in three modes: Steady, Quasi-steady, and Unsteady.

The graph illustrates the variation of head (in meters) over time (in seconds) in a hydraulic system, depicting the transition from steady to unsteady conditions. The steady state, represented by the blue line, indicates that the head remains constant over time, suggesting a stable flow without significant disturbances. This state reflects normal operating conditions in the system, where the hydraulic conditions are balanced. In contrast, the purple dashed line shows a quasi-steady state, where the head experiences minor fluctuations but remains relatively stable. These fluctuations could be caused by small variations in flow or system adjustments that don't significantly impact the overall stability.

On the other hand, the green dotted line represents an unsteady or transient state, characterized by significant fluctuations in head. These variations likely result from transient phenomena such as water hammer or sudden changes in flow conditions, which the system has not yet stabilized from. The graph also shows the dynamic transitions between these states, with sharp rises and drops in head reflecting instability. This kind of analysis is crucial for understanding how the system responds to disturbances and can help in designing control mechanisms to mitigate issues like water hammer, ensuring the system remains stable and operational under varying conditions.

In the analysis of the West Mashhad water transmission line, considering that the results of the analysis by the Quasi-Steady method led to the selection and design of Hammer effect equipment with higher safety and reliability, this method is used.

In the transient state analysis of Water Hammer effect, other parameters are also used, some of which are mentioned below.

A) Initial Flow Consistency

For faster convergence of Hammer effect analysis, this value is determined so that the pipe in which the incremental flow change is greater than the specified value compared to its previous timeframe, is considered as the start of the Water Hammer effect. This value is considered by default in software of 0.57 liters per second.

B) Initial Head Consistency

For faster convergence of the Water Hammer effect analysis, this value is determined so that the node in which the incremental head change (pressure) is greater than the specified value compared to its previous time period, is considered as the starting point of the Water Hammer effect.

This value is considered by default in the application of 0.03 meters of water.

C)Friction coefficient criterion

Pipes with a friction coefficient greater than this in the calculation are indicated at the output with an asterisk.

In terms of how the software specifies the timeframe to achieve the desired result, or in other words, how the software can calculate the timescales for a better numerical solution of the Water Hammer, two conditions can be defined for it:

-Based on the length of the pipe (Length)
-Based on the wave speed in the pipe.

The length of time a wave moves from a point to a point in its vicinity can be calculated from a relation, in which the duration of wave displacement$t_i = {L_i}/{a_i}\, t_i$, $\boldsymbol{L_i}$is the desired length between two points, and $\boldsymbol{a_i}$ is the speed of the wave between two points.

It is obvious that in the design of the transmission line profile, there are pipes of different lengths between the nodes, so in the opening ΔT (The time step) that the software calculates may be based on the length of the pipe or the speed of the wave, (whichever is the matching criterion), the Hammer effect wave passes through the initial or end node of a pipe, and therefore the software cannot calculate the speed in the pipe or the pressure in the next node. For this purpose, in the software, the adaptability of the length of the pipe with the wave speed and ΔT It must be specified or, if the wave speed method is used. Measure its versatility.

Finally, the software according to the amount Max Adjustment and quantity. ΔT Considering the length or speed of the wave in each pipe in such a way that the most versatility between the wave speed, the length of the pipes and the ΔT It will arise. When the design and design are less accurate, it can be used more efficiently. Wave Speed He used it ،but to get the exact answers ،he had to do it. Length Adjustment be used.

2.7. Basics of Hammer Effect Calculations

In all the calculations, the basics of calculations for all different conditions of the mentioned water transmission line are as follows:

- Time Setup is based on length in all calculations.
- The analysis time of each part of the transmission line is 40L/a.
- Hydraulic analysis of transmission line is considered based on stable state.
- The water temperature is assumed to be 20 °C in all analysis.
- Due to the fact that the water vapor pressure changes slightly with the elevation, the water vapor pressure values in each section are slightly different.
- Friction calculation method for Hammer effect is done by quasi-steady method.
- The loss of valves and connections in the transmission line is considered to be 5% of the length of the path. This amount of pressure loss is calculated and is considered in the friction loss factor of all pipes.
- The analysis of the Hammer effect on the gravity line is done in the worst case i.e., the sudden closure of the valve at the end of the path.
- The material of the fiberglass transmission line pipes is considered.
- The Haysen-Williams coefficient is assumed to be 140 in fiberglass pipes.

3. Results and Discussions

3.1. Water Hammer effect analysis from Islamabad reservoir to Kavardeh reservoir

The transmission line from the Islamabad reservoir to the Kavardeh reservoir is gravitational. The length of the transmission line in this section is about 17.7 km and the difference in the height of the points of the beginning and end of the transmission line is about 40 meters. In this gravity part of the transmission line, the Water Hammer effect caused by sudden outflow will create a maximum positive pressure equal to 161 meters of water column and minimum negative pressure equal to 10 meters of water column.

Therefore, in order to prevent damage, resulting from this situation and inhibition of negative and positive pressure waves along the transmission line need to increase the closing time of the flow control valve at the end of the route. Figure 4 shows the hydraulic profile of the transmission line from Islamabad to Kavardeh reservoir in a stable state. In Figure 5 (8) changes in pressure wave, pressure profiles, and hydraulic gradient at the end of the path of this section of transmission line in case of sudden closing of the valve, the end of the path is provided.

In Figures No. (9) to (12), changes in pressure waves, pressure profiles, and hydraulic gradients at the end of the path of this section of the transmission line are provided in case of controlled closure of the valve at the end of the track. The minimum suitable time to close the valves at the end of the path to minimize the effects of the Water Hammer effect is 10 minutes.

It should be noted that in the diagrams, red lines indicate the maximum pressure or maximum hydraulic gradient, blue lines indicate the minimum or minimum hydraulic gradient and green lines in pressure charts, the pressure in stable state, and in hydraulic gradient diagrams specifies the ground profile.

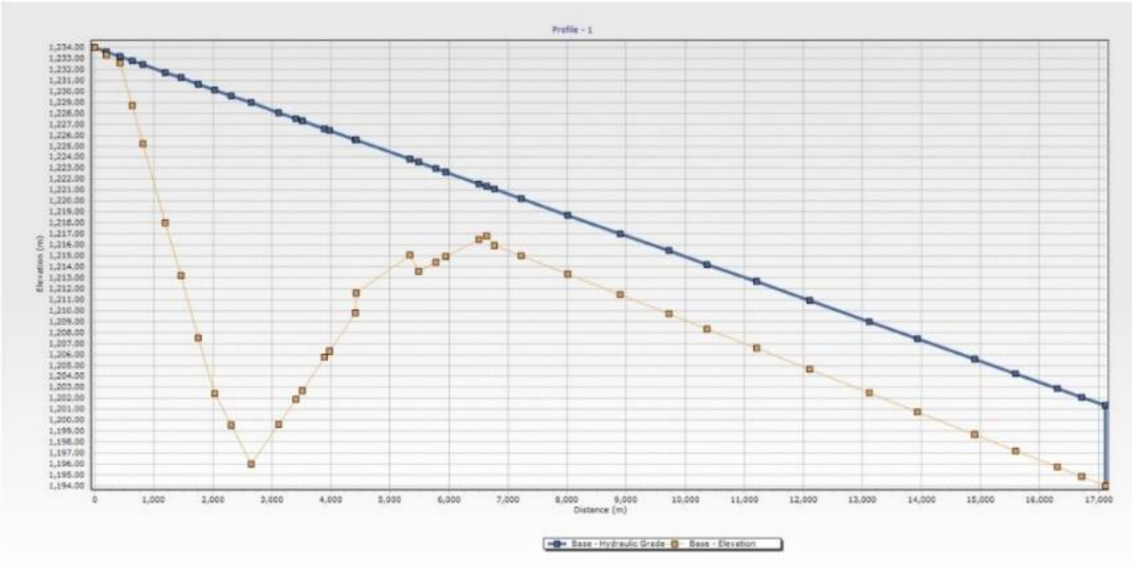

Figure 4. Hydraulic profile of transmission line in steady state (from Islamabad reservoir to Kavardeh reservoir)

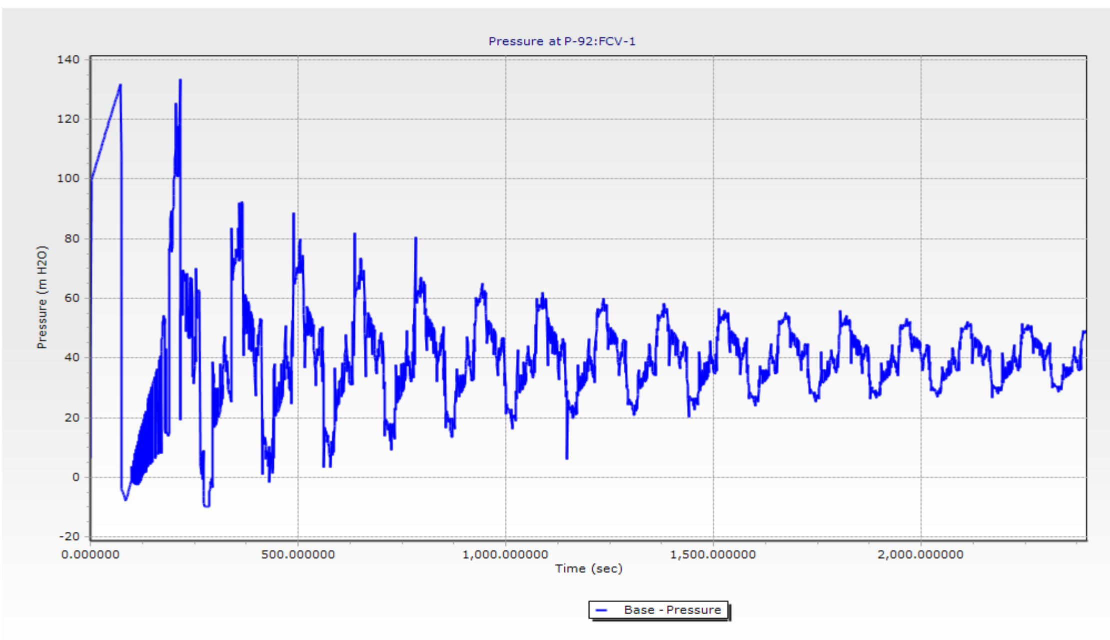

Figure 5. Pressure wave changes at the end of the path in case of sudden closing of the valve at the end of the path (from Islamabad tank to Kavardeh tank)

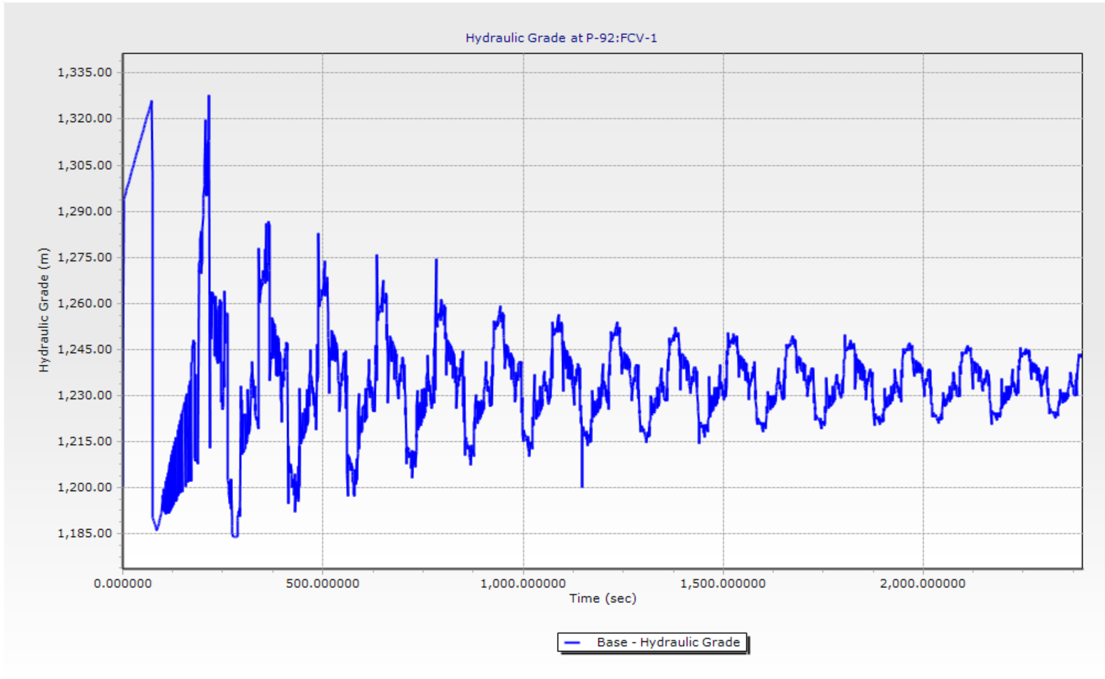

Figure 6. Hydraulic gradient changes at the end of the path in case of sudden closing of the valve at the end of the path (from Islamabad tank to Kavardeh tank).

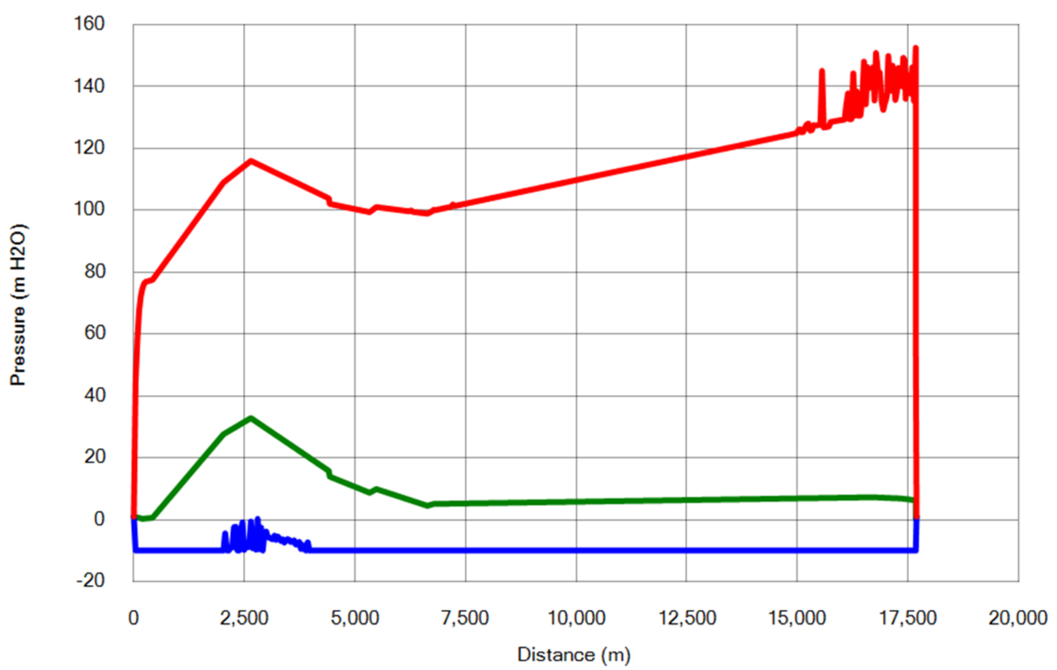

Figure 7. The profile of the minimum and maximum pressure, in case of sudden closing of the valve at the end of the path (from Islamabad tank to Kavardeh tank)

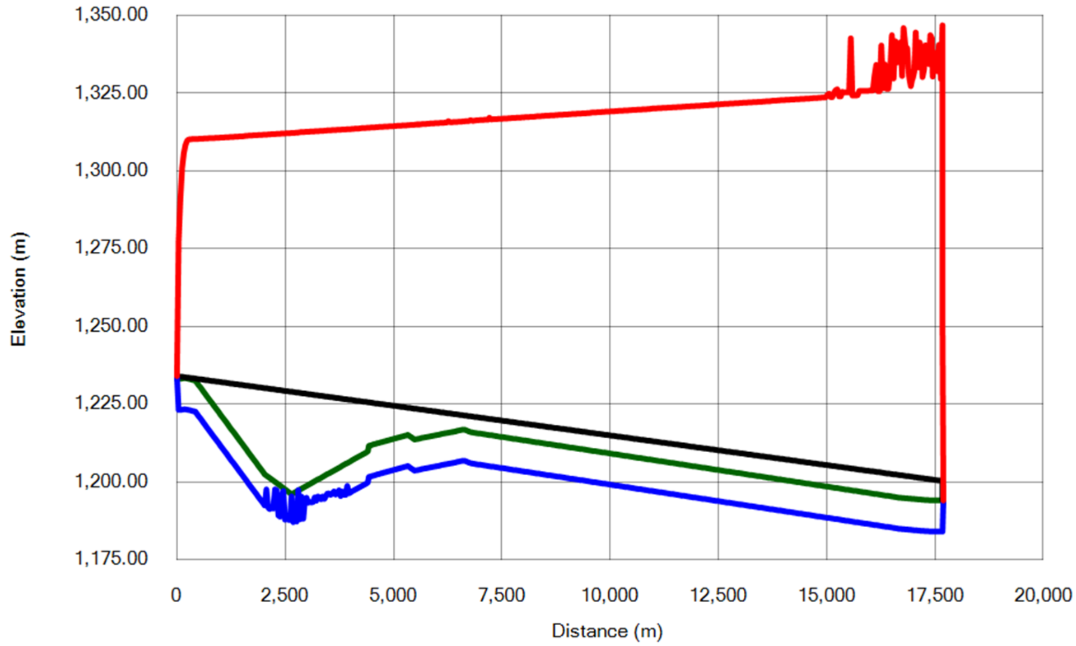

Figure 8. Profile of minimum and maximum hydraulic gradient, in case of sudden closing of the valve at the end of the path (from Islamabad tank to Kavardeh tank)

The graph illustrates the elevation profile of a pipeline or flow path over distance, where the x-axis represents the distance (in meters), and the y-axis represents elevation (in meters). The different colored lines represent various hydraulic or topographical conditions along the pipeline route. The red line, which sharply increases and then experiences irregular fluctuations towards the end, likely indicates a sudden elevation change or a problem such as a hydraulic surge or water hammer in the system. This drastic change in elevation suggests a pressure buildup or an issue at this point, which could lead to potential damage or instability in the pipeline.

In contrast, the blue, green, and black lines show relatively more stable and gradual elevation changes. These lines suggest more consistent and controlled flow conditions in the pipeline, without abrupt fluctuations. The sharp rise and fluctuations in the red line indicate a significant disruption in the flow or system, potentially caused by valve closures, water hammer, or other transient phenomena. From the graph, it is evident that managing and controlling sudden changes in the flow, particularly in the section where the red line is observed, is crucial. These fluctuations can cause severe damage to the pipeline infrastructure, and appropriate measures, such as pressure relief systems or controlled valve operations, must be implemented to avoid such issues. The findings highlight the importance of maintaining a stable hydraulic profile across the entire pipeline to ensure long-term operational reliability.

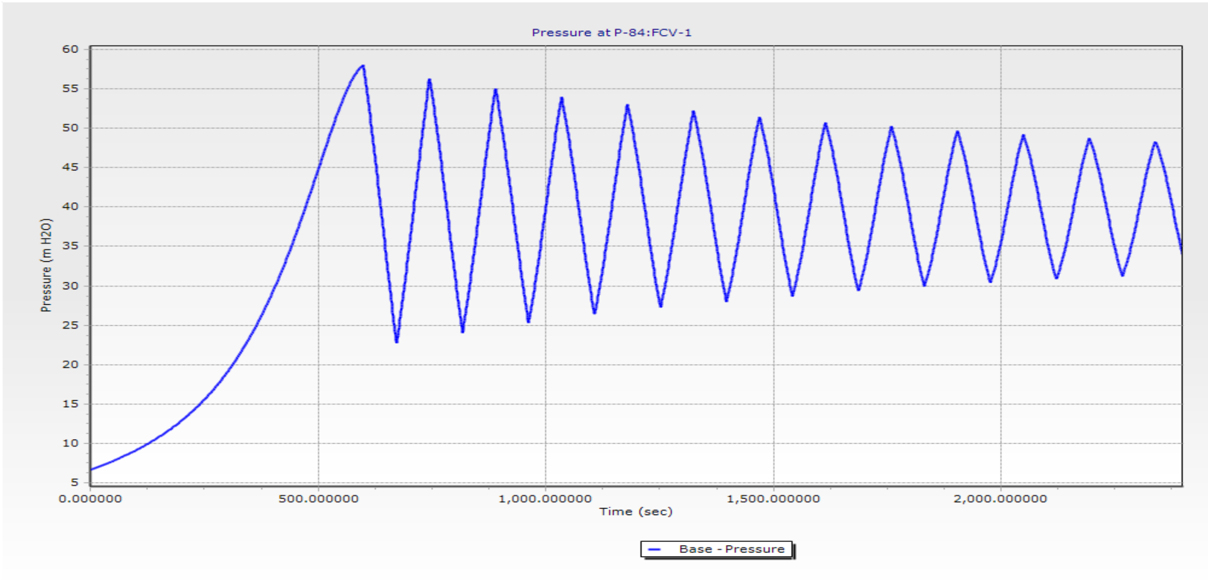

Figure 9. Pressure wave changes at the end of the path in case of controlled closing of the valve at the end of the path (from Islamabad tank to Kavardeh tank)

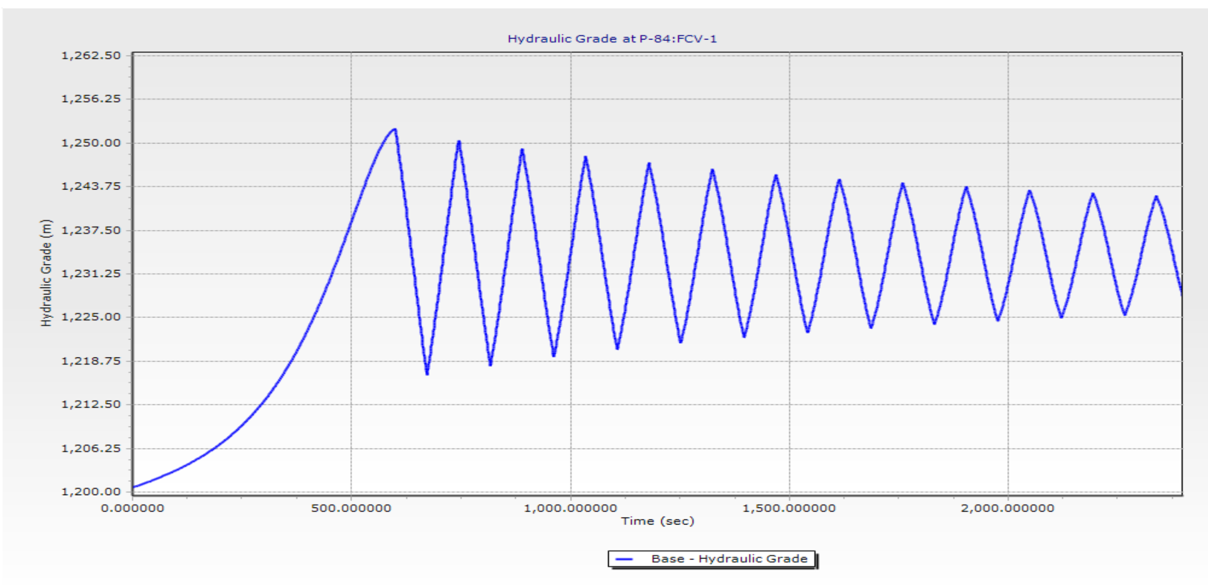

Figure 10. Hydraulic gradient changes at the end of the path in case of controlled closing of the valve at the end of the path (from Islamabad tank to Kavardeh tank)

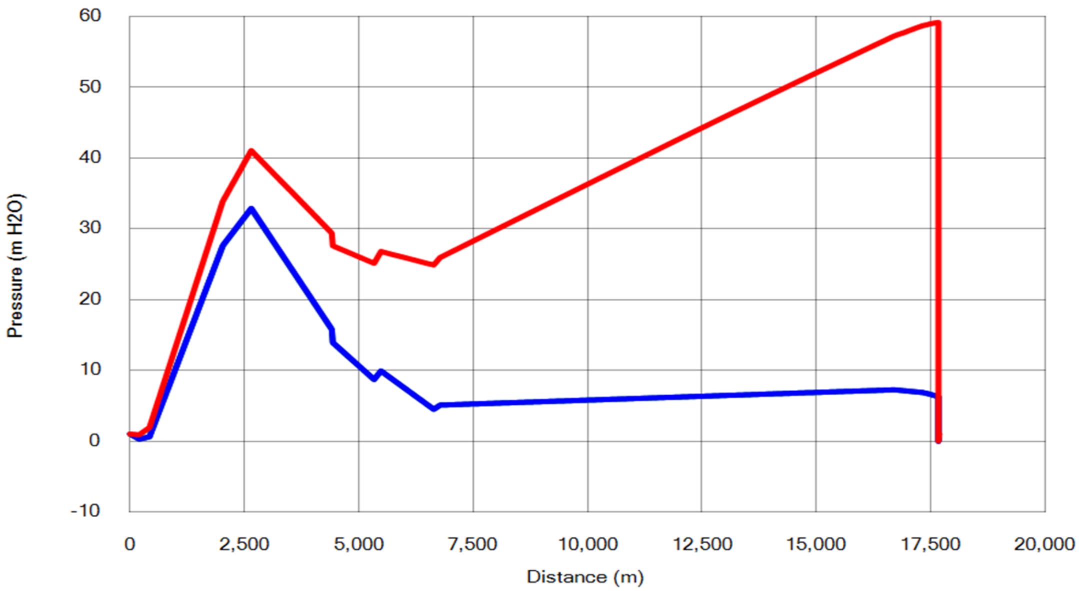

Figure 11. Profile of minimum and maximum pressure, at the end of the path in case of controlled closing of the valve at the end of the path (from Islamabad tank to Kavardeh tank)

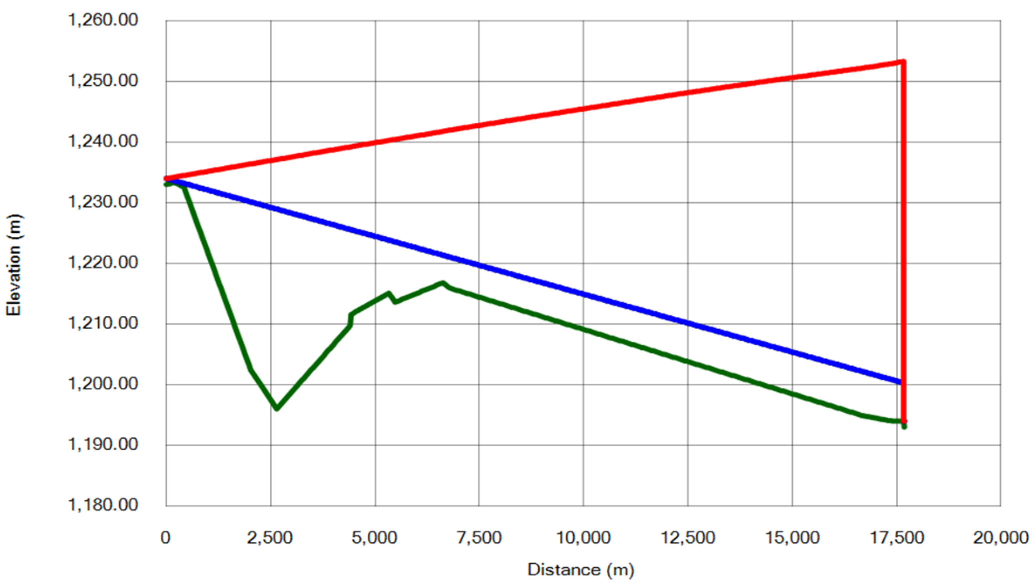

Figure 12. Profile of the minimum and maximum hydraulic gradient, at the end of the path in case of controlled closing of the valve at the end of the path (from Islamabad tank to Kavardeh tank)

The summary of the results of the water Hammer effect analysis of the transmission line from Islamabad reservoir to the Kavardeh reservoir is presented in tables (3) and (4).

Table 3. Results of transmission line Water Hammer analysis, in case of sudden closing of the valve at the end of the path

Steady state				**Water hammer state**			
Minimum pressure		Maximum pressure		Minimum pressure		Maximum pressure	
Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter
The beginning and end of the path	0	2.5	33	17.7 km of path	-10	17	161

Table 4. The results of the Water Hammer analysis of the transmission line, in case of controlled closing of the valve at the end of the path

Steady state				Water hammer state			
Minimum pressure		Maximum pressure		Minimum pressure		Maximum pressure	
Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter
The beginning and end of the path	0	2.5	33	The beginning and end of the path	0	17.7	56

3.2. Water Hammer effect analysis from Kavardeh reservoir to F zone tank

The transmission line is gravity from the Kavardeh reservoir to the F zone tank. The length of the transmission line in this section is about 28.5 km and the difference in height of the points of the beginning and end of the transmission line is about 56 meters. In this gravity part of the transmission line, the Water Hammer effect caused by the sudden outflow will create a maximum positive pressure equal to 181 meters of water column and the minimum negative pressure equal to -10 meters of water column. Therefore, in order to prevent damage, resulting from this situation and inhibition of negative and positive pressure waves along the transmission line need to increase the closing time of the flow control valve at the end of the path. Figure 13 shows the hydraulic profile of the transmission line from the Kavardeh reservoir to the reservoir of the F zone, in a stable state. In Figures (14) to (17) pressure wave changes, pressure profiles and hydraulic gradients at the end of the path of this section of the transmission line is provided in case of sudden closure of the valve at the end of the path.

In Figure (18) to (21) pressure wave changes, pressure profiles and hydraulic gradients at the end of the path of this section of transmission line in case of controlled closure of the end of the valve is presented. The minimum time suitable for closing the valves at the end of the path to minimize the effects of the Water Hammer effect is 10 minutes.

In the diagrams, red lines indicate the maximum pressure or maximum hydraulic gradient, blue lines indicate the minimum or minimum hydraulic gradient and green lines in pressure charts, the pressure in stable state, and in hydraulic gradient diagrams specifies the ground profile.

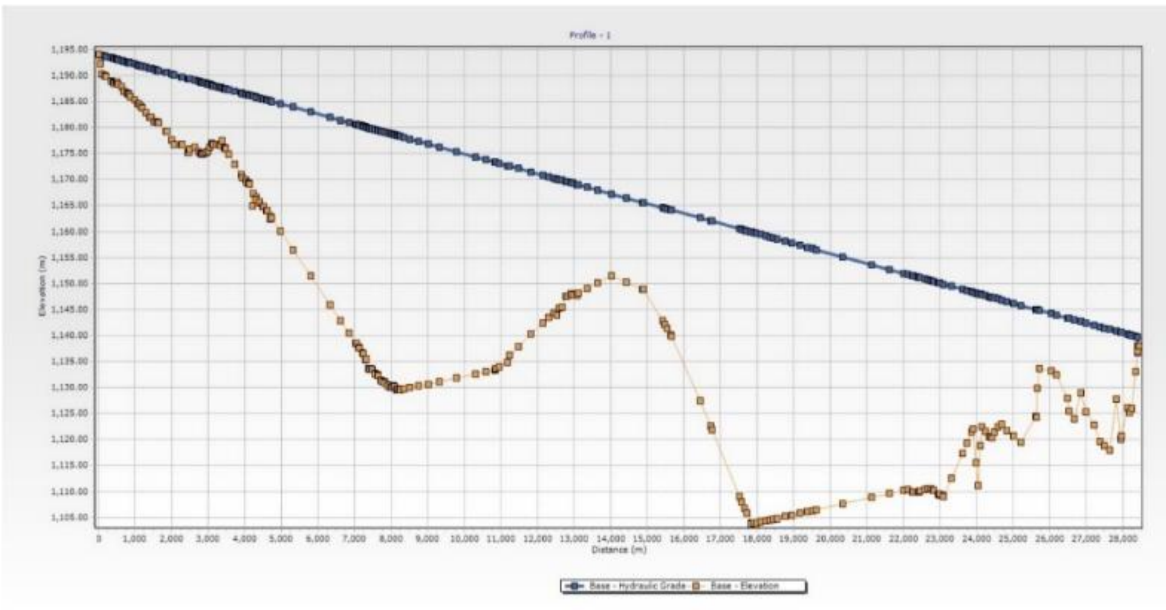

Figure 13. The hydraulic profile of the transmission line in a stable state (from the Kavardeh tank to the F zone tank)

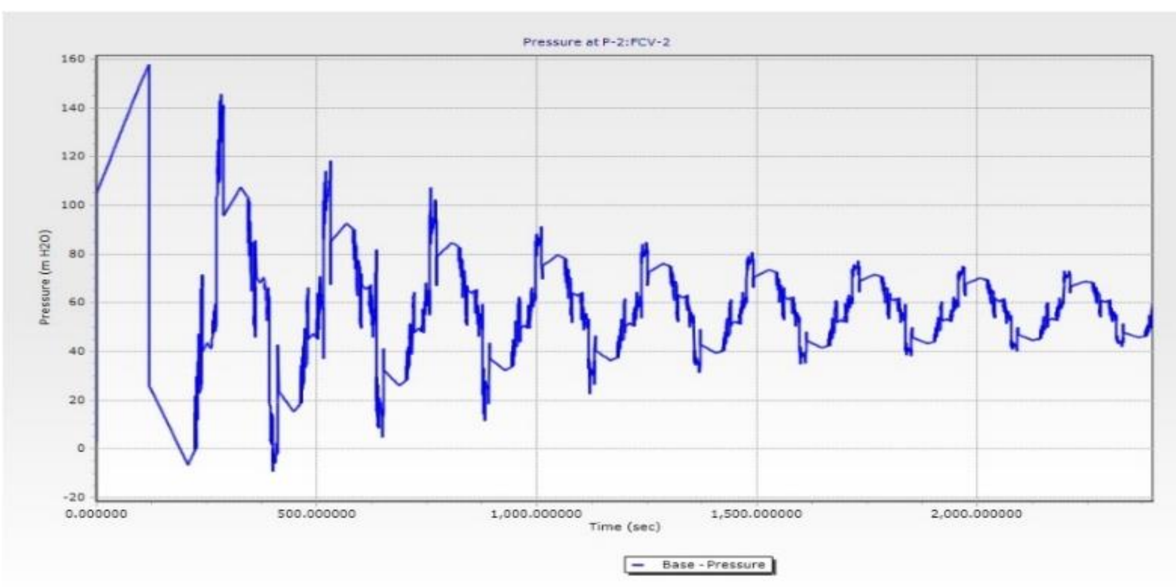

Figure 14. Pressure wave changes at the end of the path in case of sudden closing of the valve at the end of the path(from Kavardeh tank to F zone tank)

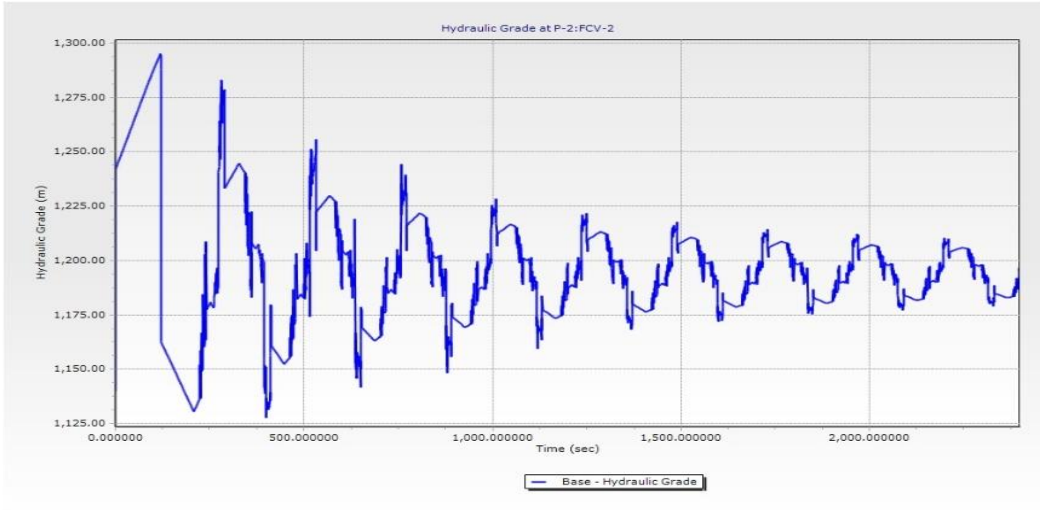

Figure 15. Hydraulic gradient changes at the end of the path in case of sudden closing of the valve at the end of the path(from Kavardeh tank to F zone tank)

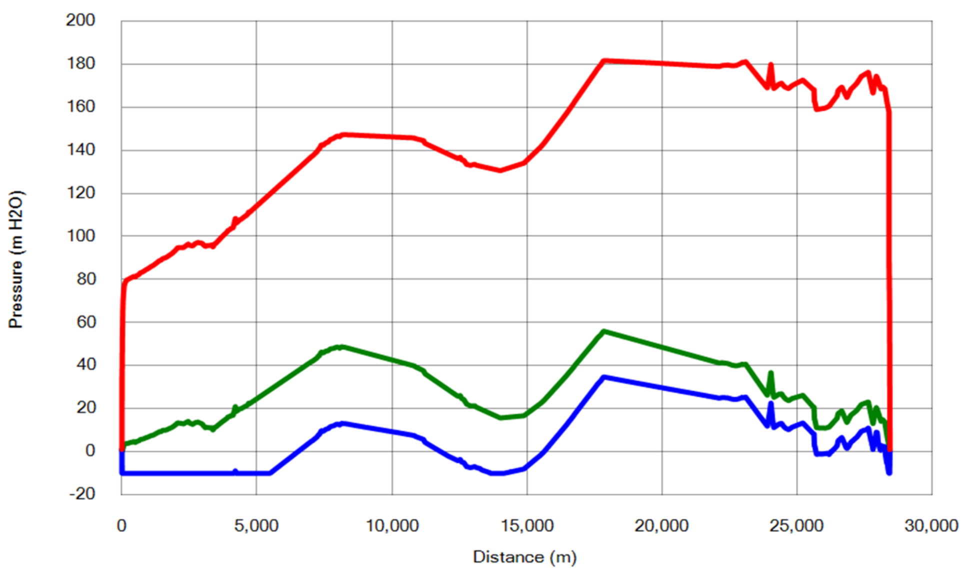

Figure 16. Profile of minimum and maximum pressure, in case of sudden closing of the valve at the end of the path (from Kavardeh tank to F zone tank)

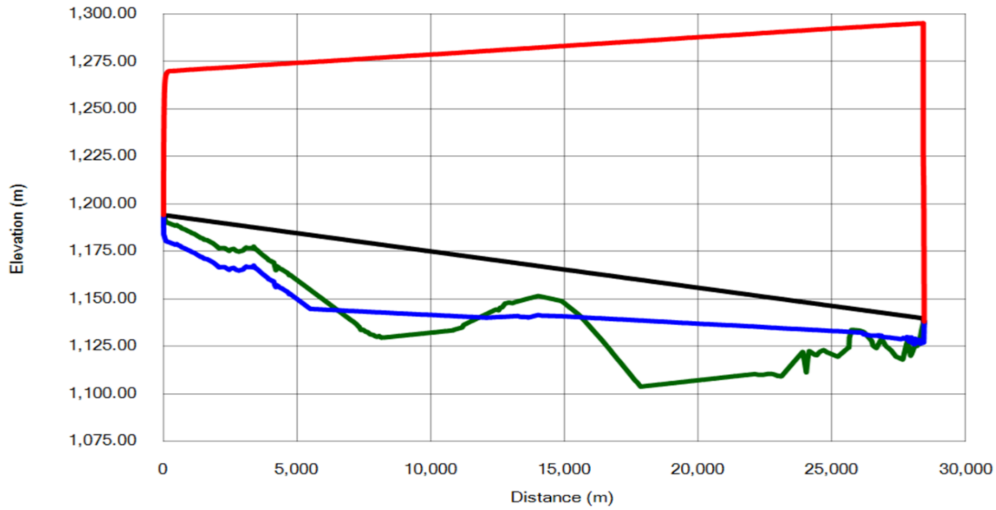

Figure 17. Profile of the minimum and maximum hydraulic gradient, in case of sudden closing of the valve at the end of the path(from Kavardeh tank to F zone tank)

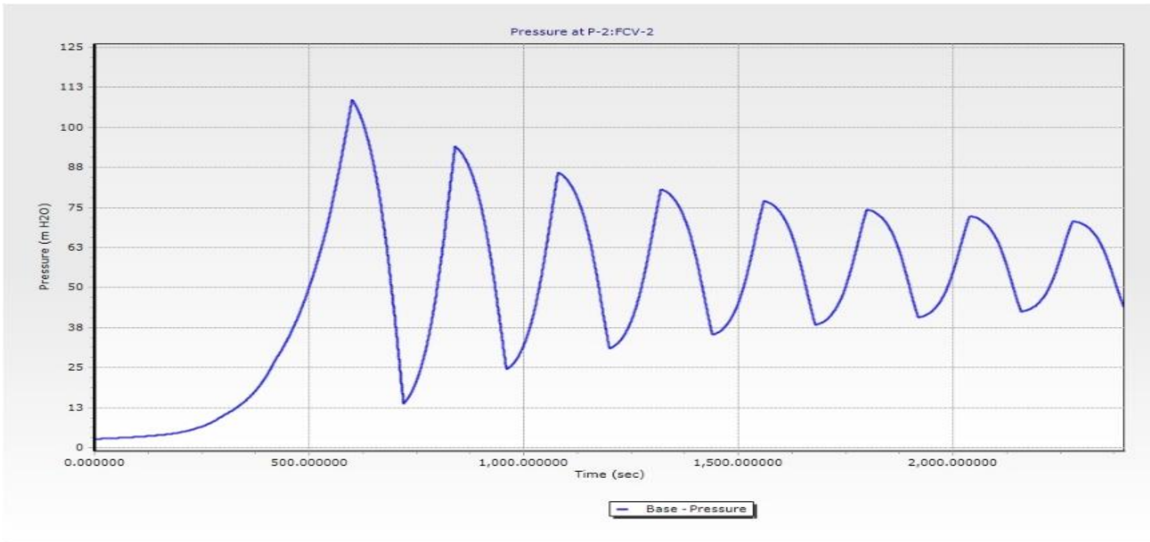

Figure 18. Pressure wave changes at the end of the path in case of controlled closing of the valve at the end of the path(from Kavardeh tank to F zone tank)

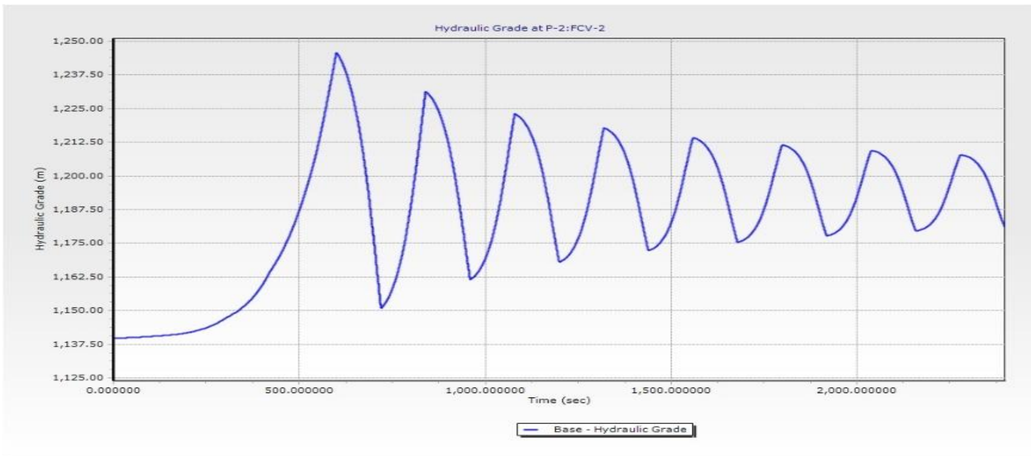

Figure 19. Hydraulic gradient changes, at the end of the route, in case of controlled closing of the valve at the end of the path (from Kavardeh tank to zone F tank).

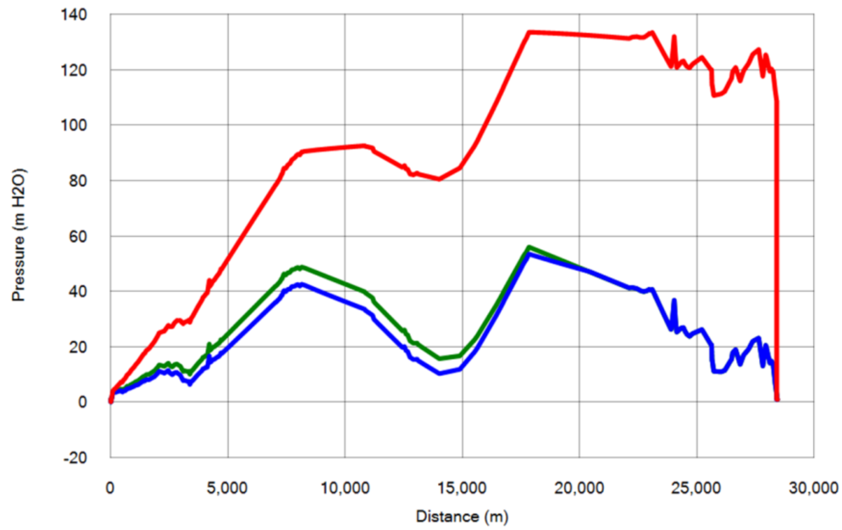

Figure 20. Profile of minimum and maximum pressure, in case of controlled closing of the valve at the end of the path (from Kavardeh tank to F zone tank)

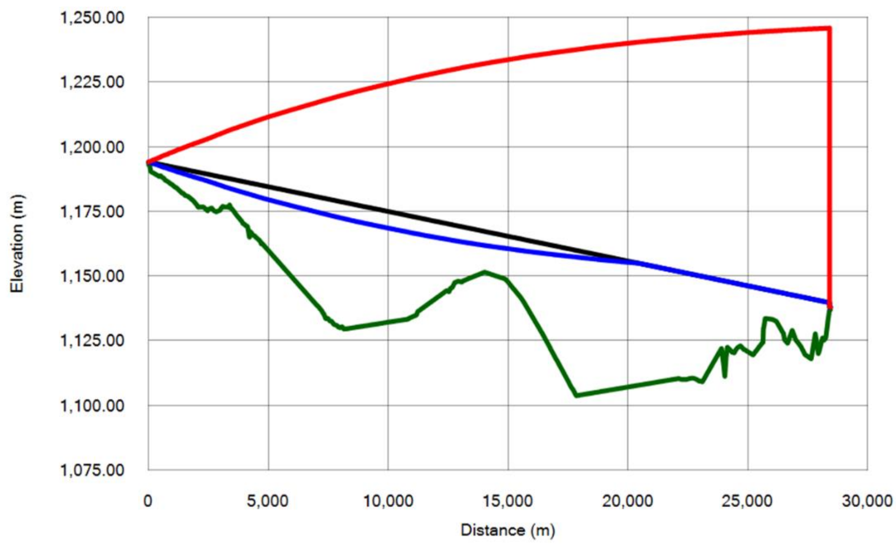

Figure 21. The profile of the minimum and maximum hydraulic gradient, in case of controlled closing of the valve at the end of the path (from Kavardeh tank to F zone tank)

A summary of the results of the Water Hammer effect analysis of transmission line from Kavardeh reservoir to reservoir of F zone in tables (5) and (6) are presented.

Table 5. The results of the Water Hammer analysis of the transmission line in case of sudden closing of the valve at the end of the path

Steady state				**Water hammer state**			
Minimum pressure		Maximum pressure		Minimum pressure		Maximum pressure	
Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter	Distance from origin (km)	the amount of water) column (meter
The beginning and end of the path	0	35.7	56	10 km of path	-10	35.7	181

Table 6. The results of the Water Hammer analysis of the transmission line in case of controlled closing of the valve at the end of the path

steady state				Water hammer state			
Minimum pressure		Maximum pressure		Minimum pressure		Maximum pressure	
Distance from origin (km)	the of amount water) column (meter	Distance from origin (km)	the of amount water) column (meter	Distance from origin (km)	the of amount water) column (meter	Distance from origin (km)	the of amount water) column (meter
he beginning and end of the path	0	35.7	56	beginning The and end of the path	0	35.7	133

3.3. Necessary measures to minimize the effects of water Hammer effect in gravity sections

In order to protect the gravity transmission line, the closing time of the flow control valve at the end of the path can be controlled. In addition, pressure control valves can be used in case of higher pressures than the pipe and valves when the Hammer effect occurs. It should be explained that the minimum time suitable for closing the valves at the end of the path to minimize the effects of the Water Hammer effect is equal to 10 minutes.

Figure 22 shows the pattern of closing the flow control valve in a time interval of 600 seconds (10 minutes), it is observed that this pattern is described in Table 7. Anyway suggests that a pressure control valve be installed before the end of the path flow control valve to reduce the pressure control valve in case of sudden closure of the flow control valve for any reason, regardless of the time pattern of operation, the pressure control valve and reduce the pressure of the transmission line.

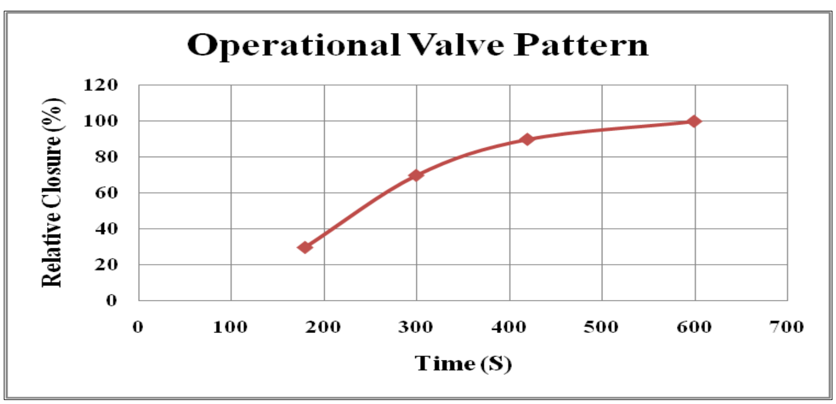

Figure 22. Flow control valve function pattern

Table 7. Flow control valve closing function pattern

Closing time from the start moment (seconds)	Percentage Closing
180	30
300	70
420	90
600	100

4. Conclusion

This study explored the impact of the water hammer phenomenon on gravity-driven water transmission lines, specifically examining fiberglass pipelines in the drinking water supply system in western Mashhad. Water hammer, triggered by sudden changes in water flow and pressure, can produce severe pressure surges, potentially causing substantial damage to pipes, valves, and related infrastructure. The results indicated that controlling the rate at which valves open and close is a critical strategy in managing water hammer effects, especially in gravity-fed systems where high momentum can lead to significant pressure fluctuations.

The use of fiberglass pipes in this system has proven advantageous due to their high pressure resistance, corrosion resistance, and smooth internal surface, which reduces friction and pressure loss. These characteristics not only help in maintaining system integrity but also minimize the need for additional surge protection equipment. By increasing the closing time of control valves to at least 10 minutes, the destructive effects of water hammer can be considerably reduced. In cases where valve closure times exceed 15-20 minutes, the system operates with such stability that further protective measures, such as shock absorber tanks, may not be necessary.

Overall, this study underscores the importance of strategic valve management and material selection in minimizing the adverse effects of water hammer. Future work may focus on optimizing valve control systems and exploring alternative materials that further enhance the durability and efficiency of water transmission lines in similar applications. The innovations of this paper, compared to previous research, focus on several key aspects. Firstly, it explores the application of fiberglass pipes in gravity-fed water transmission lines, addressing the specific impact of water hammer in these systems. This material choice is innovative, given the unique properties of fiberglass pipes, such as corrosion and pressure resistance and reduced internal friction. Secondly, the paper emphasizes the use of timing control for valve opening and closing as a cost-effective method to mitigate water hammer effects, in contrast to traditional water hammer control equipment like surge tanks. This approach can reduce water hammer impacts without additional equipment. Thirdly, the study analyzes water hammer in gravity-fed lines using data from a real system, the Mashhad Western Water Transmission Line. Unlike many prior studies focused on theoretical models or smaller systems, this research provides practical and realistic insights for large urban systems. Finally, the findings and recommendations, such as optimized valve timing and pressure control valve installation, can be applied to large systems similar to Mashhad's, supporting the optimization of urban water supply systems. These innovations make this study a practical and unique contribution to improving gravity-fed water transmission systems and managing water hammer in these networks.

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Conflicts of Interest

The author declares no conflict of interest.

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