Chapter 10
Water Hammer Analysis for Pipe Line Network Using HAMMER V8i

Ajmal Hussain, Muhammad Mustafa, S. M. Ahbar Warsi, and Sumit Kumar

Abstract Hydraulic transients occur as a direct result of rapid variations of flow field in pressurized (closed-conduit) systems. The change in velocity from valve closures or pump operations causes pressure surges that are propagated away from thesource throughout the pipeline. If the maximum pressures exceed the bar ratings(mechanical strength) of the piping material, different types of failure such as pipe bursts canoccur. Similarly, if the minimum pressure drops below the vapour pressure of the fluid, cavitationcan occur and can be detrimental to the pipeline system. The purpose of present study is to asses and simulate the hydraulic transients in a pipe line network of treated effluent rising main of Mpophomeni sanitation scheme using Bentley HAMMER V8i. A total of five scenarios were simulated using different combinations. The simulation results shows that the transient pressures in the pipeline exceeded the bar rating of the pipe where the burstsor cavitation may occur for the simulated scenarios. This study shows that the transient pressures in pipe line system were reduced to safe limit after providing water hammer protection devices.

Keywords Hydraulic transient · Water hammer · Cavitations · Bentley HAMMER V8i

10.1 Introduction

Water hammer commonly occurs when a valve closes suddenly at an end of a pipeline system, and a pressure wave propagates in the pipe (Chaudhry 1979). Under steady state conditions in a pipeline system, flow variables like discharge remainconstant. However, if a sudden change occurs in the system through a change in control operations such asthe closure of an outlet valve or the sudden shutdown of a pump due

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R. Jha et al. (eds.), *Water Resources Management and Reservoir Operation*,
Water Science and Technology Library 107,
https://doi.org/10.1007/978-3-030-79400-2_10

to power failure, a transientstate is initiated, and it takes a finite amount of time before another (new) steady-state conditionis established in the pipeline system. The flow phenomenon associated with such rapid changesis called a hydraulic (or fluid) transient. The main concern during a hydraulic transient in asystem is the rapid fluctuations in the pressure since dramatic changes in the pressure can resultin catastrophic damage to pipelines and hydraulic machinery.

By closing the valve rapidly,the valve converts the kinetic energy carried by the fluid particles into strain energy in the pipewalls. This results in a "pulse wave" of abnormal pressure to travel from the disturbance into thepipe system. Energy losses due to mainly friction cause the transient pressure waves todecay until a new steady state is established. Hydraulic transient events in water distribution system can cause significant damage, disruption,and expense (Huo et al. 2007). In general, transient events are usually most severe at control valves, pump stations, in high-elevation areas, and in remote locations that are far from overhead storage tanks. However, all systems have to start up, switch off, undergo flow changes, and so on. In addition, water systems are not immune from human errors, malfunction and break downof mechanical devices, and other risky events. Emadi and Solemani (2011) investigated the effect of parameters such as pipe diameter, thickness and type, moment of inertia and temperature on maximum water hammer in the context of Kuhrang Pumping Station. Fluid pipeline failures due to water hammer effects are described in detail by Schmitt et al. (2006).

During a hydraulic transient state, a pipeline may be subjected to objectionable high and lowpressure cycles. The high pressures can damage the pipeline system components, such as valves,pumps, and other pipeline components, as discussed earlier. The change in the fluid velocity (more correctly discharge) in the pipeline systems is the first step that leads to a hydraulictransient. The resulting change in pressure is directly proportional to the change in velocity. Hence, as much as possible, sudden changes in the velocity should be avoided to minimize theoccurrence of pressure transients in the system. Bergant et al. (2012) presented a comprehensive water hammer analysis of pumping system for control of water in underground mines. Deshmukh (2014) presented the hydraulic transient analysis of Kolar water pipeline using using Bentley HAMMER V8i.

The present study was conducted using the popular surge software Bentley HAMMER V8*i*. Bentley HAMMER V8*i* is a versatile program capable of modeling any type of surge protection device and its powerful graphical results presentation and interpretation capability has helped thousands of engineers worldwide design large complex transmission mains, small branching networks as well as large distribution networks for over 30 years. Bentley HAMMER V8*i* is based on technology originally created by Environmental Hydraulics Group (HAMMERTM 2005). Water hammer equations for elastic pipes produce a 1-D partial equation and may be solved by Methods of Characteristics (MOC). Hammer Software uses the Method of Characteristicto solve non-linear differential equations which have the following form, Evangelisti (1969), Fox (1977), Streeter (1967, 1972):

$$\frac{dV}{dt} + \frac{1}{\rho c} \cdot \frac{dP}{dt} + \frac{f|V|V}{2D} = 0 \tag{10.1}$$

$$a^2 \frac{\partial V}{\partial s} + \frac{1}{\rho} \frac{\partial \rho}{\partial t} = 0 \tag{10.2}$$

Solution of the above equations using MOC will be

C+:

$$\frac{a}{gA}(Q_p - Q_{i-1}) + (H_p - H_{i-1}) + \frac{f\Delta x}{2gDA^2} Q_p|Q_{i-1}| = 0 \tag{10.3}$$

C-:

$$\frac{a}{gA}(Q_p - Q_{i+1}) - (H_p - H_{i+1}) + \frac{f\Delta x}{2gDA^2} Q_p|Q_{i+1}| = 0 \tag{10.4}$$

For the solution there are many boundary conditions are considered requiring like reservoirs, pumps, pipeline branches, dead ends etc. This method not only saves times but also reduces likelihood of mistakes which may occur while copying date to the software.

10.2 Problem Statement and Procedure of Analysis

The present study is carried for a pipe line network of treated effluent rising main of Mpophmeni sanitation scheme, South Africa which consists of following major units:

a. Pump: Pump working with the capacity of supplying a flow rate of 250 m^3/h up to a head of 76 m. Pump has a rated power of 90 kW at 1450 rpm.
b. Rising Main Network: Rising main consists of PVC class 12 pipe of diameter 400 mm for first 3000 m and then the pipe diameter reduces to 315 mm upto 5423 m,then pipe diameter increases to 400 mm till 5503 m,then again reduces to 315 mm and continues till the tail end discharging into the receiving chamber. The whole network configuaration is shown in Fig. 10.1.

Profile for the elevation with chainage of the rising main network is shown in Fig. 10.2. The pump station is located at zero chainage of the profile and the rising main culminates in free fall at a receiving chamber at the tail end. As evident from Fig. 10.2; three major peaks and low points are observed along the network path and in the last leg of the network i.e. after chainage of around 5500 m, network will be acting under gravity. The undulating topography of the rising main path exposes the network to the risk of surge occurrences in events of power failure, sudden closure of valves etc. The main objective of the study is to identify transient issues for this system and recommend surge protection alternatives.

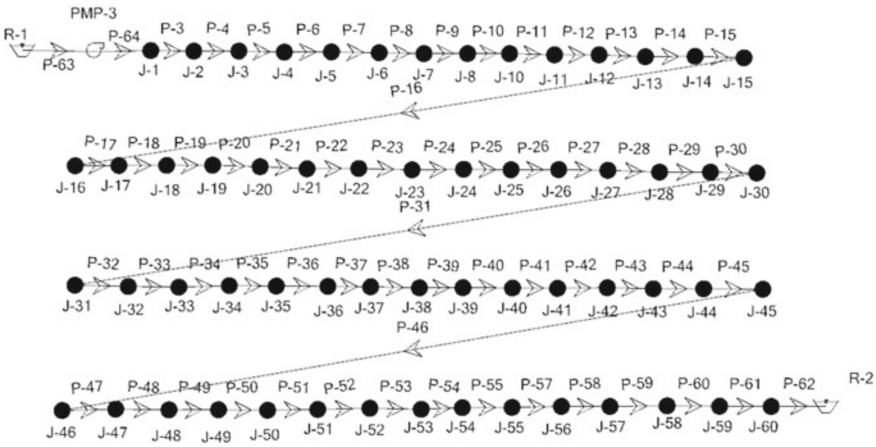

Fig. 10.1 Steady state model for problem 2

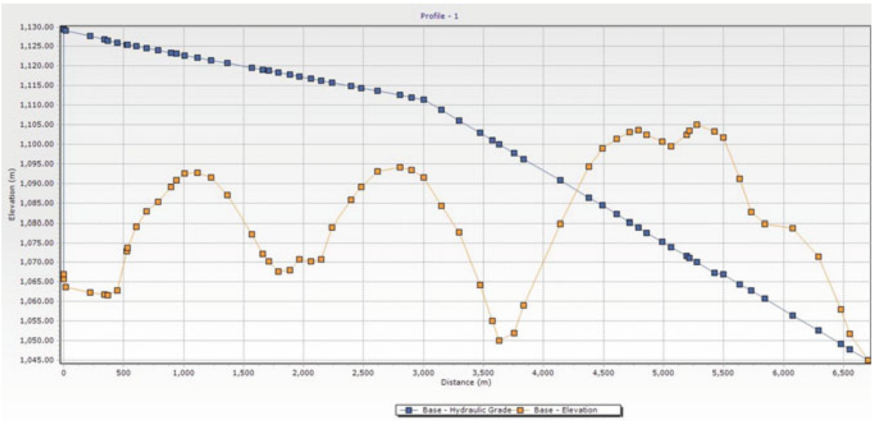

Fig. 10.2 Profile of hydraulic grade line and elevation with chainage of the rising main network

10.3 Results and Analysis

10.3.1 Baseline Scenario: Steady State Conditions

A baseline run of the network is conducted to identify the baseline scenario that is network running under steady state without any transient event. This is conducted to identify the steady state conditions for the network. Baseline scenario model is shown in Fig. 10.2.

Figure 10.2 indicates thatHGL is significantly below the ground elevation after around 4300 m chainage. So, to counter negative pressure heads in this region, a

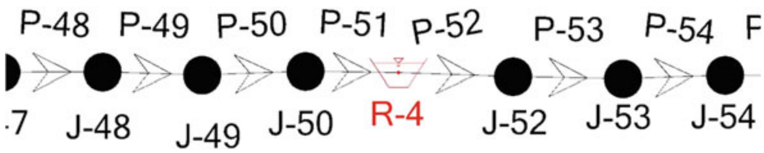

Fig. 10.3 Reservoir location between J-50 and J-52

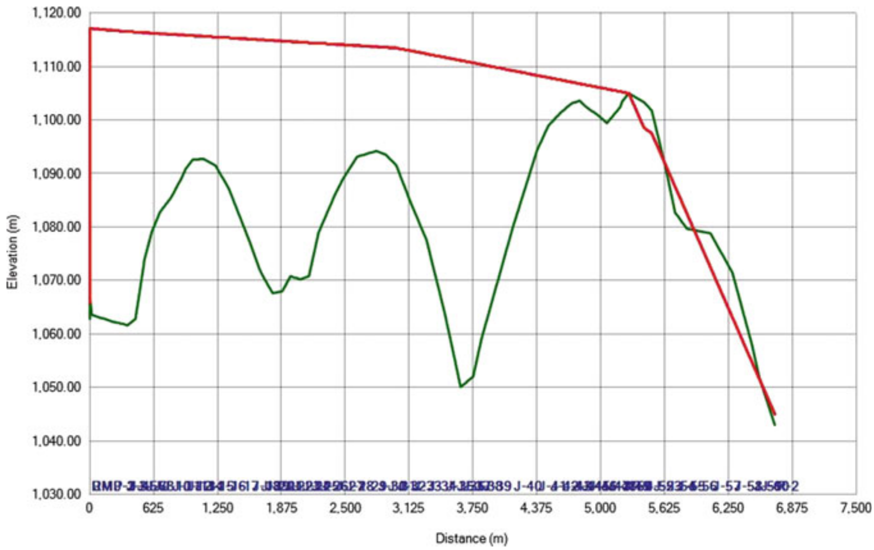

Fig. 10.4 Hydraulic Grade Line after providing the reservoir for the network

reservoir at the highest elevation point(1105 m) at J51 is provided which is shown in Fig. 10.3.

After providing the reservoir; Hydraulic Grade Line (HGL) for the network is shown in Fig. 10.4. As a result the negative pressure heads are well within the limits ie −10 m H_2O (or −98.1 kPa) and the positive pressure heads are also within the safe limits as shown in Fig. 10.5.

10.3.2 Surge Analysis on Baseline Network Without Surge Protection

In the next stage the impact of a power failure is simulated without any surge protection device. Hydraulic Grade Line for baseline network without surge protection device is shown in Fig. 10.6. For the analysis it is assumed that the check valves installed at the pump closes after 5 s of power failure, which is below the critical

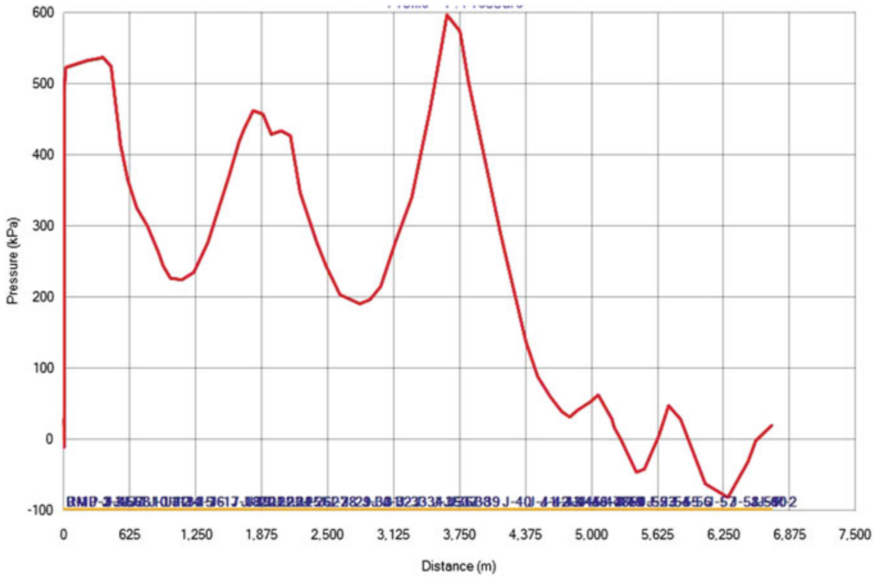

Fig. 10.5 Pressure diagram for steady state analysis after providing reservoir

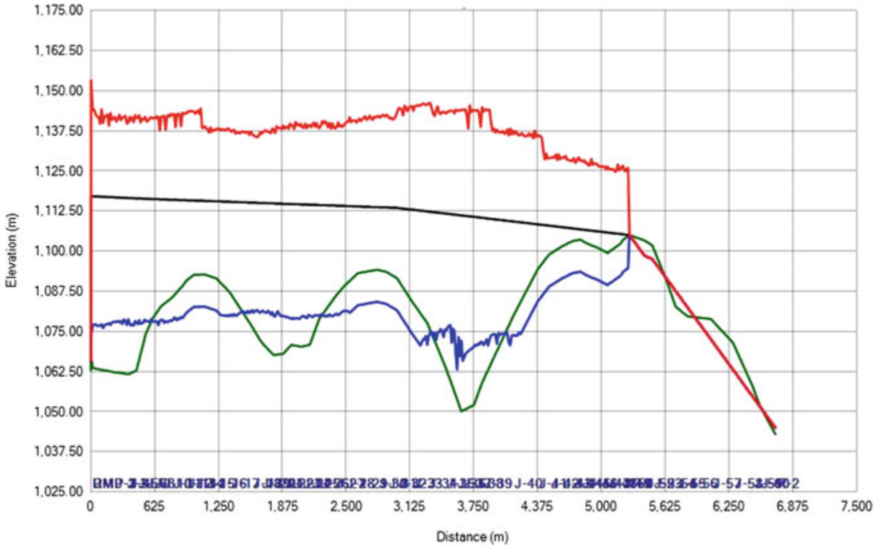

Fig. 10.6 Hydraulic grade line for baseline network without surge protection device

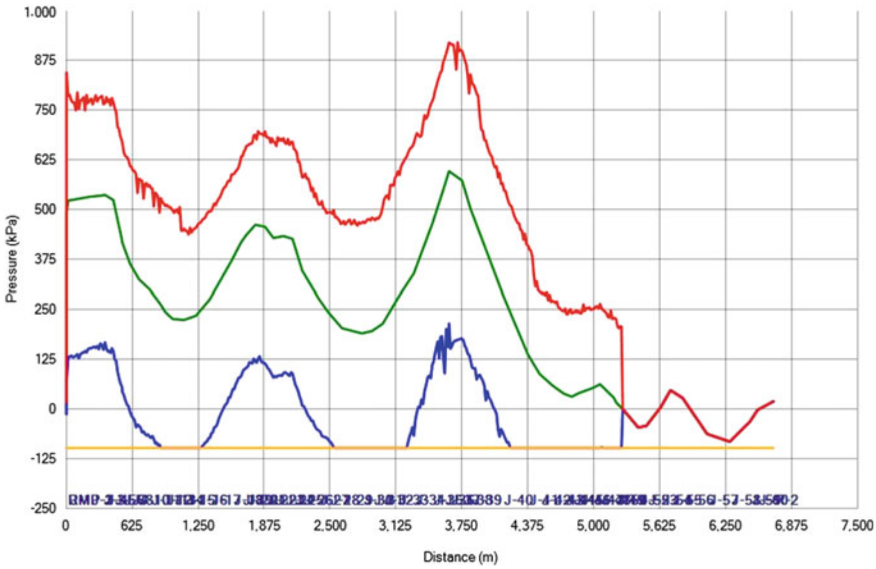

Fig. 10.7 Pressure diagram for transient analysis for the network without surge protection device

time period. After running transient simulation, it's found that the transient effect is only in the portion before the reservoir at high point as shown in Figs. 10.6 and 10.7. Also negative pressures are below −98 kPa in many parts of the pipeline. So, surge protection devices are required for protection from water hammer in this region only.

10.3.3 Analysis with Surge Protection Device

10.3.3.1 With Application of Four Air Valves

To minimize negative pressure heads, double acting Air Valves, with inflow orifice dia. 80 mm and out flow orifice dia. 2.0 mm, are adopted, at different locations shown in Table 10.1 and Fig. 10.8.

The results obtained after adding valves in the pipe line network are shown in Fig. 10.9. The locations at which valves were added, negative pressures are reduced

Table 10.1 Location of air valve at different chainage along the pipe line

Air valve no	Chainage
AV-1	1080
AV-2	2728
AV-3	4785
AV-4	5260

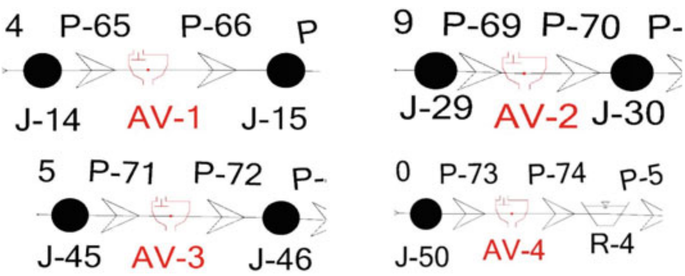

Fig. 10.8 Air valve location (AV-1, AV-2, AV-3 & AV-4) at different locations of the network

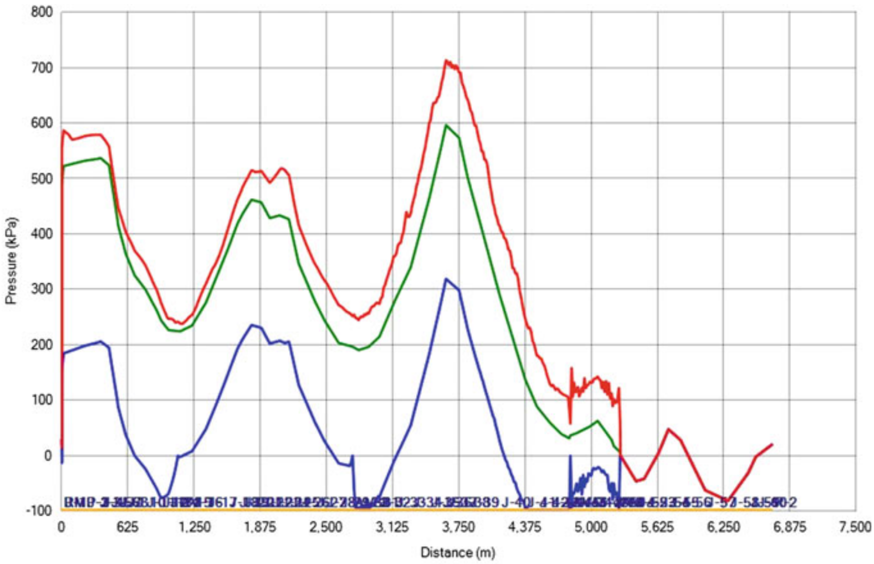

Fig. 10.9 Pressure diagramafter addingfour air valves to the network

but they are more than the permissible limits at many locations. So, some other combination of surge protection devices is to be used.

10.3.3.2 With Application of 4 Air Valves and 1 Hydropneumatic Tank

To further reduce the negative pressures, a hydropneumatic tank to the network at J1 is provided as shown in Fig. 10.10. The properties of the hydropneumatic tank are: Volume = 2000 L, Liquid Volume(Initial) = 1600 L, Tank Calculation Model = Gas Law Model, Dia. (Tank inlet Orifice) = 175 mm and HGL (initial) = 1140 m.

The results obtained after adding four valves and a hydropneumatic tank in the pipe line system is shown in Figs. 10.11 and 10.12. After adding hydropneumatic

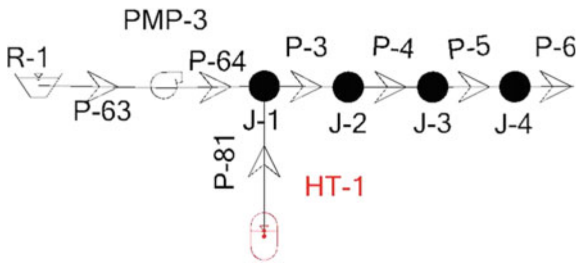

Fig. 10.10 Hydropneumatic tank at J1

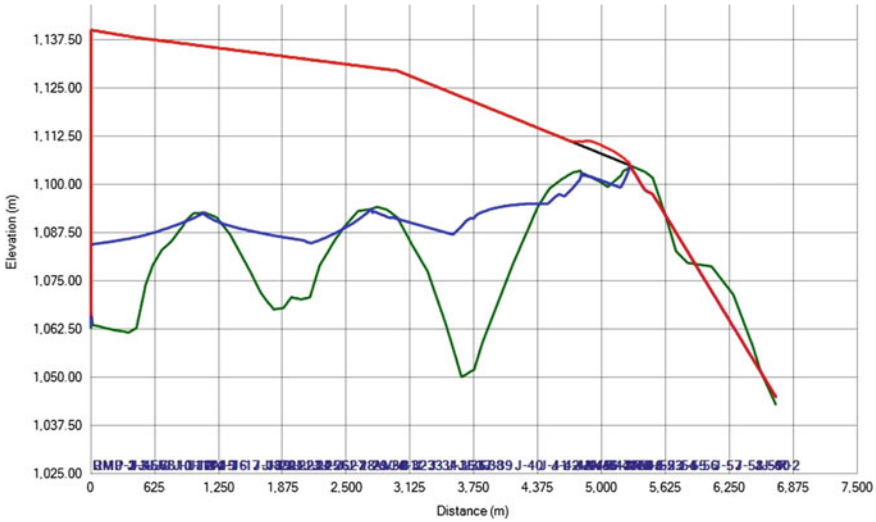

Fig. 10.11 Hydraulic grade line with elevation and chainage for the network with hydropneumatic tank and four air valves

tank, the negative pressure values have been reduced significantly and are within safe limits as shown in Fig. 10.12. Positive pressures also do not exceed the safe limits. Therefore, it can be said that the pipe line network of treated effluent rising main of Mpophmeni sanitation scheme is safe with the present mitigation measures.

10.4 Conclusion

Based on the findings, application of four air valves and one hydropneumatic tank is recommended for the safe operation of treated effluent rising main of Mpophmeni sanitation scheme. Without surge protection device, the negative pressure was greater

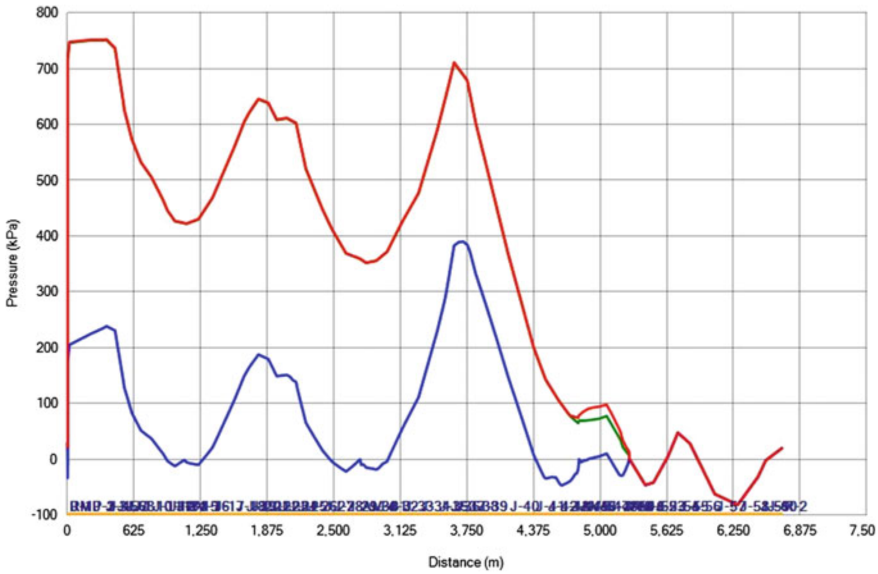

Fig. 10.12 Pressure diagram for transient analysis with hydropneumatic tank and four air valves

than −98 kPa on several points, but after providing surge protection, negative pressures are well below the safe limit. The hydropneumatic tank may be provided at the immediate downstream of the pump. A minimum of above four air valves shall be provided to contain the effect of downsurge in the network, however any additional air valves provided in the network will further improve the network performance. It can be concluded that the present developed model for the pipeline system reduces the risk of damages associated with water hammer and consequently increase the safety and as well as reduce the failure rate for the present pipe line system. It also reduces wearing and tearing effects of water hammer in pumping and pipeline systems, and increase lifetime of the infrastructure.

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