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Water Hammer Analysis in Long Pipelines

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ABSTRACT
Ca Hydraulic transient is a factor to be considered during structural design of water conveyance system. The most common hazardous situation is the uncontrolled pump trip due to power failure. Therefore, surge analysis is important for a water delivery project having long pipeline. Customized software WH 2.7 is used to solve the problem of surge in pipeline. Method of characteristics is widely used mathematical scheme for solving the phenomenon because of higher accuracy. The partial differential equations may be transformed by the method of characteristics into total differential equations. The later equations may then be integrated to yield finite differential equations which are conveniently handled numerically. This paper describes the problem of water hammer in long pipeline of lift irrigation scheme. The pumping station of lift irrigation scheme is located on riverbank and is to lift the water to the reservoir located at distance of 5.5 km through 1300mm diameter and 11/8 mm thickness mild steel pipeline. Three vertical turbine pumps each having capacity of delivering 0.937 m3/s (total discharge capacity 2.8 m3/s) and 43.24 m total head to irrigate the command area of 3300 ha. Continuous number of trials led to select combination of one air vessel of capacity 50 m3 and 10 Air Valves. Studies carried out helped to foresee advent conditions like column separation well in advance before implementation. This way it helps to finalize piping system incorporating anti surge devices like air vessel and air valves to keep the pipeline safe from water hammer due to power failure to the pumps and hence reliable operation for long run.

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***KEYWORDS**: Water hammer, Vertical turbine pumps, Method of characteristics, Air vessel and Air valves*

INTRODUCTION
Long pumping water supply lines are subjected to water hammer whenever there is a sudden pump stoppage, pump startup or valve closure. Whenever system changes from one steady state condition to another there is a transient change in flow and pressures as the system settles to the final steady state condition. The magnitude of surge pressures or water hammer and the time duration of this condition depends on the flow rate, velocity, pipeline material and the system boundary condition's such as reservoirs, pumps, air valves, control valves and changes in pipeline diameter. The phenomenon of water hammer is generally ignored in the area of water supply schemes. This is due to the difficulty in carrying out a comprehensive analysis which considers all the system components and their interaction. It is common practice for designers to simply add a nominal pressure increase to allow for water hammer. This approach can be too conservative and unnecessarily costly and, in some cases, there have been system failures due to inadequate water hammer protection being provided. The undertaking of a water hammer analysis and selection of anti-surge devices should be an integral part during the design phase. There are water hammer programs available which can assist designers in identifying potential water hammer problems and helps in the selection of anti-surge. This paper deals with surge analysis in long pipelines used for lift irrigation schemes with emphasis on use of different safety devices to mitigate water hammer pressures. Author use the customized software WH 2.7 to solve the problem of water hammer in long pipeline.

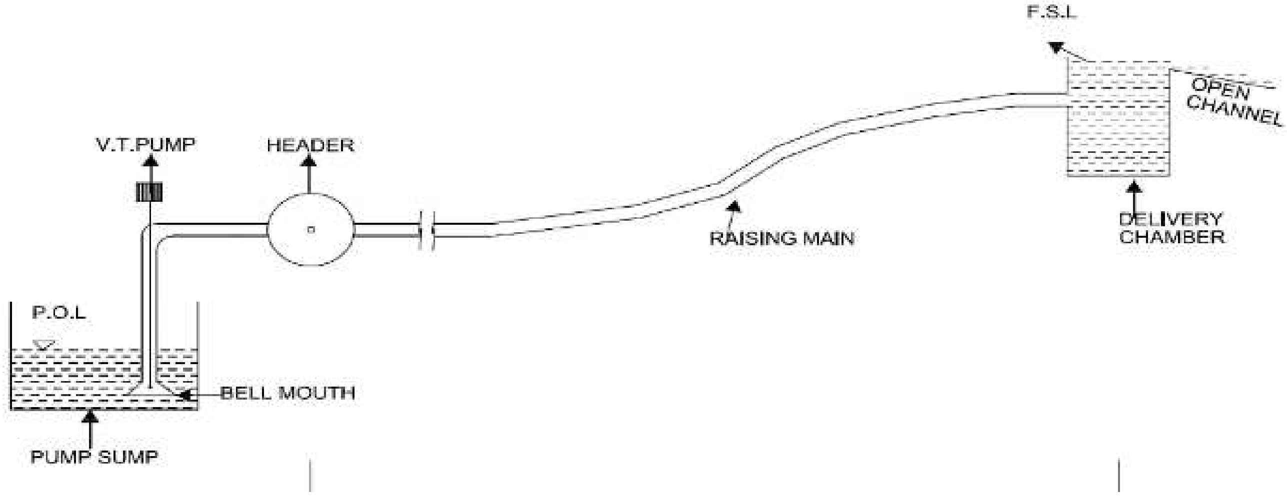

Figure 1- Schematic Layout of Lift Irrigation Scheme.

PRIMARY CAUSE OF WATER HAMMER

Primary surge occurs whenever the fluid velocity in pipe systems suddenly changes, such as at pump stop and start up or valve opening and closure. It is important to design pumping systems to prevent water hammer in order to avoid potentially devastating consequences such as damage to components and equipment's and risk to personnel. A hydraulic surge which is a flow condition where the velocity and pressure changes rapidly with time, can collapse a water distribution system if that system is not equipped with adequate protection devices. The occurrence of transients can introduce large pressure forces and rapid fluid accelerations into a water distribution system and if the system is not well protected, it can fail. A hydraulic transient normally occurs when a flow component changes status and this change flows through a system as a pressure wave. Example, a valve can be closed in two ways; linear or stepwise or pump stop could be due to planned stop, power failure or mechanical problem with the pump. A pump with high inertia can also reduce transients significantly. The water velocity and the friction coefficient were seen to be important factors which affect the hydraulic transient even though both relate to each other. A high frictional coefficient reduces the velocity and as a result reduces the transients and vice versa. Also, low frictional coefficients lead to increase in water velocities and a result increase in hydraulic transients and vice versa.

WATER HAMMER PHENOMENAL PROCEDURE AND ITS HARMFUL EFFECTS

Water Hammer could be potentially dangerous if the pumping system is not properly designed with necessary safety devices. In a pumping system the water hammer caused by mains power failure to the pump motors is generally most severe. Due to the failure of power supply to the motor the rotative speed of the pump starts dropping down. The head (H) developed by the pump and the flow rate (Q) delivered are dependent on the rotative speed (N) by the relationship given below:

$H \alpha N^2$

$Q \alpha N$

Where H = Head developed by the pump

Q = Flow rate

N = Rotative speed

Owing to reduction in rotative speed, both head and discharge of pump start dropping down. This causes down surge pressure wave to travel along the pumping main to the delivery reservoir at the velocity of sound close to 1000m/s. On reaching the delivery reservoir this wave is reflected to the pump. When the pump speed drops so low that it hardly develops any head then reversal of flow from delivery reservoir to pump might takes place. Owing to the moment of inertia the pump and motor rotor would continue to rotate in the same direction for some more time, The liquid column in the pipeline owing to its momentum would also continue to flow in the forward direction. Both these motions contribute to keep the NRV disc open. Eventually, the speed of the pump would start dropping down and the forward moving liquid column would momentarily come to rest. Therefore, the liquid column would have tendency to flow in the reverse direction. After each pump a non-return valve (NRV) usually provided. NRV remains open during forward flow and depending on its design it may close upon flow reversal. Depending on the design of the valve the disc of NRV may close at this point of time or near about time which is also affected by factors like inherent characteristics of the valve, damper, springs, or other devices to control the rate of closure etc.

Depending upon the rate of change of velocity, the magnitude of pressure rise would vary. During the down surge the negative pressure formed may drop down to vapour pressure of water. This would cause water to vaporise and form a cavity at some intermediate point in the pipe which could increase in size. The continuum of water inside the pipe is separated by the cavity, a phenomenon known as "column separation. Upon reversal in pressure during wave propagation, the positive pressures cause cavity to collapse within a very short interval of time. Thus, the two separated water columns would collide with each other lead to uncontrollable bursting pressures. The positive pressure rise could also be dangerous if the hoop stress caused by it is large enough to damage the pipe.

$$\sigma = \frac{Pi\ d}{2t}$$

Where σ = hoop stress in kg/cm2
Pi = instantaneous pressure in kg/cm2
d = pipe diameter in cm
t = pipe wall thickness in cm

FACTORS AFFECTING TRANSIENT FORMATION

Transients can be described by basic state equations which results from the physical characteristics of water and the fundamental principles of physics. In essence, mathematical efforts attempt to model a system where the energy from the changing velocity is simultaneously trying to compress the water and stretch the conduit circumferentially. Water has a couple of properties that accentuate its ability to create these pressure waves. First, water has a high density, for pipelines that are typically long relative to diameter, the water column is significant. Due to water density, this means that the mass, momentum, and kinetic energy can be quite large. Second water is for all intents and purposes incompressible. This makes water a very effective energy transfer medium. Therefore, whenever a pressure wave is formed, there is negligible dampening due to water compression.

Given these characteristics, when a moving column of water is abruptly stopped or started, a pressure wave is formed. The magnitude and of the pressure wave are mathematically defined by two differential equations that satisfy the Conservation of Mass and of Conservation of Momentum criteria. While computer simulations are required for actual design, some simplified equations can provide an indication of the magnitude for noncomplex systems.

The magnitude of a pressure change under a transient condition is expressed by Joukow sky's law for instantaneous valve closure:

$$\Delta h\ (max) = - \frac{a * \Delta V}{g}$$

Where Δh (max) = Change in pressure in metre head
a = Speed of the surge wave through the liquid in the pipeline in m/s
ΔV = Change in velocity m/s
g = Acceleration due to gravity as 9.8 m/s^2

Use of water hammer program becomes handy for determining likely pressure surges even in simple piping system. There are many factors that influence transient pressure surges they include:

- Pipeline profile (especially peak points)
- Pipeline anchorage.
- Type of pipeline material.
- Presence of linings.
- Location of Storage.
- Type of Check Valves.
- Pump performance curves and operating speeds.
- Rotational moment of inertia for pump motor assemblies.
- Pump station configurations.
- Location and type of air valves.
- Protection devices installed.
- Configuration of piping network.
- Valve types, size and their opening and closing speed.

ESSENTIAL SAFETY AND PROTECTION DEVICES

Even water supply systems are unique in relation to water hammer effects. The most effective solution to a potential water hammer problem may be a single or combination of protection devices. The relative merits of various devices should be compared and the best solution evaluation during the design phase of a new project. Several commonly used protection devices are described in the foregoing discussion.

1. **Non-Return Valve (NRV)** – The primary aim of providing NRV after each pump is to prevent the reversal of flow of water from the delivery chamber to the sump in the event of failure of power supply to pumps. During normal functioning the pumps are delivering water into the rising main. The disc of the NRV is hinged at one end and the momentum of the forward flow keeps it open In a situation where several pumps are operating in parallel and if one of the pumps fails, then it is possible that high head flow delivered by other working pumps would rush to the suction side through the failed pump. It would

cause reverse rotation at a high speed and consequent damage to the failed pump. However, the provision of NRV after each individual pump would prevent such a happening.

2. **Air Valve (AV)** – The air valve is another dynamic and important element fitted to the rising mains. Primary function of the air valve is to:
   - To expel air during filling of pipe with water and after having filled the pipe with water, it should prevent further loss of water through the openings meant for expelling air.
   - To admit atmospheric air into the pipe when pressure drops to sub atmospheric level inside the pipe and controls the negative pressure.
   - Air valves are also useful to reduce the generation of high pressures when separated liquid columns during down surge rejoin.
3. **Air Vessel (AVs)** – I t is a pressure vessel containing air and water. It is a very effective device for controlling both positive and negative pressure surges and is often used a last resort because of high capital costs.
4. **One Way Surge Tower** – I t is an open ended device which is connected to the pipeline by a check valve. It allows water to enter the pipeline when the pipeline is subjected to vacuum pressures. This is generally used for simple and shorter pipeline systems.
5. **Control Valves** – They are often fitted on pump discharges. They are opened and closed slowly to minimise water during pump stoppage and startup. They are not effective during a sudden pump stoppage.
6. **Surge Anticipator Valves** – They are fitted to a pump delivery. They are hydraulically activated control valves which open when a pump stops and starts to close as the pressure starts to build up when down surge reaches the pump. The slow closure of the valve minimises water hammer pressures.

A CASE STUDY

A case study consists of pumping station of lift irrigation scheme is located on riverbank and is to lift the water to the reservoir located at distance of 5.5 km at an altitude of 32 metres above river level through 1300mm diameter and 11/8 mm thickness mild steel pipeline. Three vertical turbine pumps each having capacity of delivering 0.937 m^3/s (total discharge capacity 2.8 m^3/s) and 43.24 m total head to irrigate the command area of 3300 ha. Each of the above pumps is driven by 988 rpm 630 H.P. electric motor and moment of inertia of rotating parts of each pump as 45 Kg-m^2. The diameter of the delivery pipe taking off from each the above 3 pumps is 700mm and NRV provided for each pump is 700 mm in diameter. On coming out from the pump house each of the above 700 mm pipeline is connected to 1300mm diameter MS rising main pipeline. The MS rising main pipeline is epoxy painted from inside. Water hammer caused by sudden stopping of all pumps owing to electrical power failure can lead to unacceptable positive and negative pressures. A properly designed air vessel or selection of anti surge device provides safety to the pipeline by controlling both the pressures.

Based on the information above the following iterative procedure was adopted.

1. Undertake computation of maximum and minimum pressures without any protective device and examine necessity of providing it.
2. Carryout water hammer analyses of the system with number of air valves in position at a particular chainage, air valves distributed along the rising main and examine the likely extent of pressure fluctuations.
3. Carryout water hammer analyses of the system with ZVV (it is a type of a Non-Return Valve i.e., dampened Non-Return Valve) with built (initial) in closure time in position at a particular node, air valves distributed along the rising main and examine the likely extent of pressure fluctuations.
4. Carryout water hammer analyses of the system with air vessel in position at a particular node, air valves distributed along the rising main and examine the likely extent of pressure fluctuations.
5. If the protection is found to be inadequate, another location and/or higher size of air-vessel are tried. The vertical location of air vessel at a particular chainage, is also varied to assess the effect on water hammer pressures.
6. If the protection is found to be adequate, the volume of air-vessel is slightly reduced, the position along the length is kept the same and iteration is taken to examine the pressures.
7. Minor adjustments are also carried out in elevation of air vessel, initial position of water level in air vessel and initial pressure of air (as related to the static pressure at the specified point), and each time the pressures are reassessed.
8. The entire procedure is repeated till the least volume of air-vessel leading to acceptable positive and negative pressures is obtained.

Based on the above data the program compute maximum and minimum pressures along the length of rising main as a function of time. Numerous runs of the program were made on the WH 2.7 to arrive at feasible solution. Only some of the important cases are discussed here to highlight the solution.

Case 1 - First, water hammer analysis for the scheme has been carried out without any safety devices. The surge pressure was varying from 364.08 m to 103.89 m Hydraulic Grade Level (HGL) above and below the conduit centre line respectively. Results are depicted in the figure 1, hence safety devices are necessary to control the negative surge pressures.

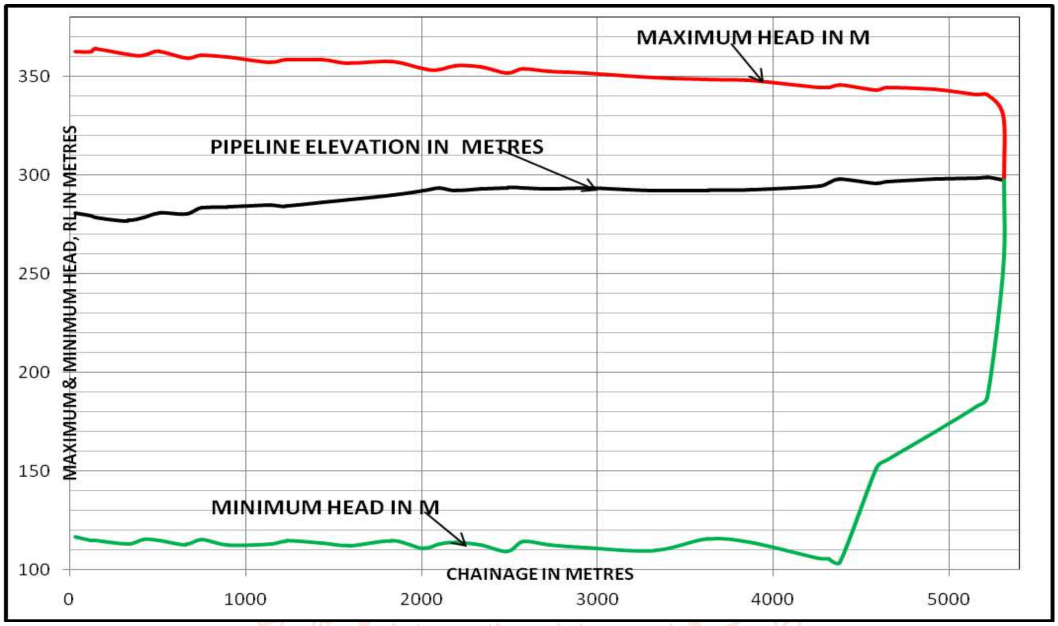

Figure 2- Maximum and minimum Pressure without any safety device

Case 2 - On the above background, water hammer analysis was again undertaken with introduction of ten Air Valves (AVs) at the suitable locations. The surge pressure was varying from 364.08 m to 292.18 m. which has given an improvement in pressure summary. Results are depicted in the figure 2, after this, an attempt is made for improving the pressure fluctuations.

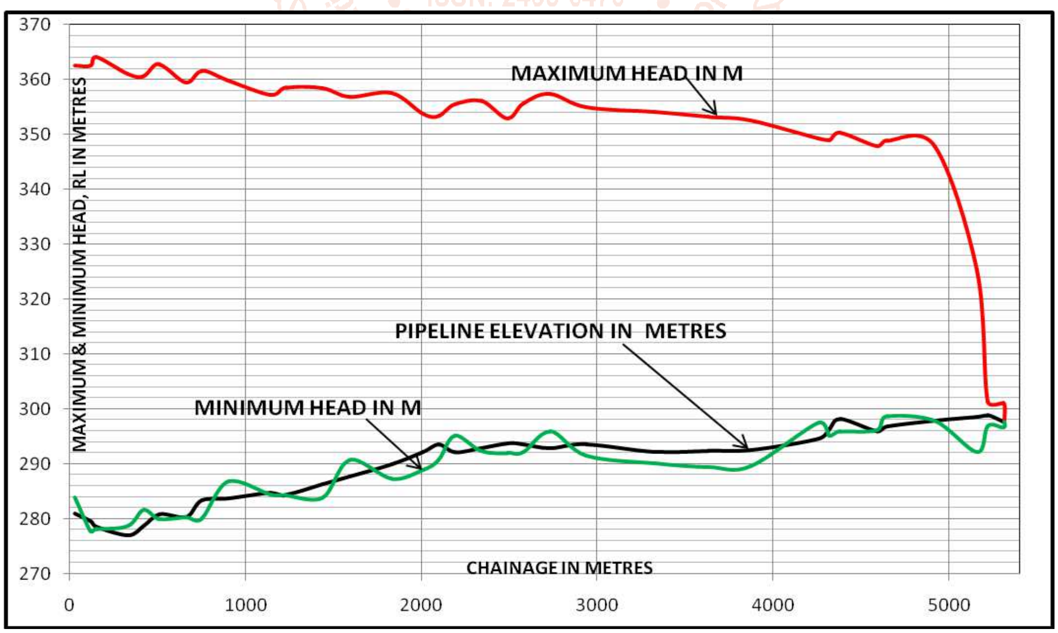

Figure 3- Maximum and minimum Pressure with 10 air valves

Case 3 - From these results, it was felt necessary to further minimize these surge pressures for safety of the pipeline. Accordingly, several computer runs were undertaken to achieve value of minimum positive and negative pressure surges by incorporating ZVV. Results are depicted in the figure 3, Though with this step, the value of surge pressures is not improved.

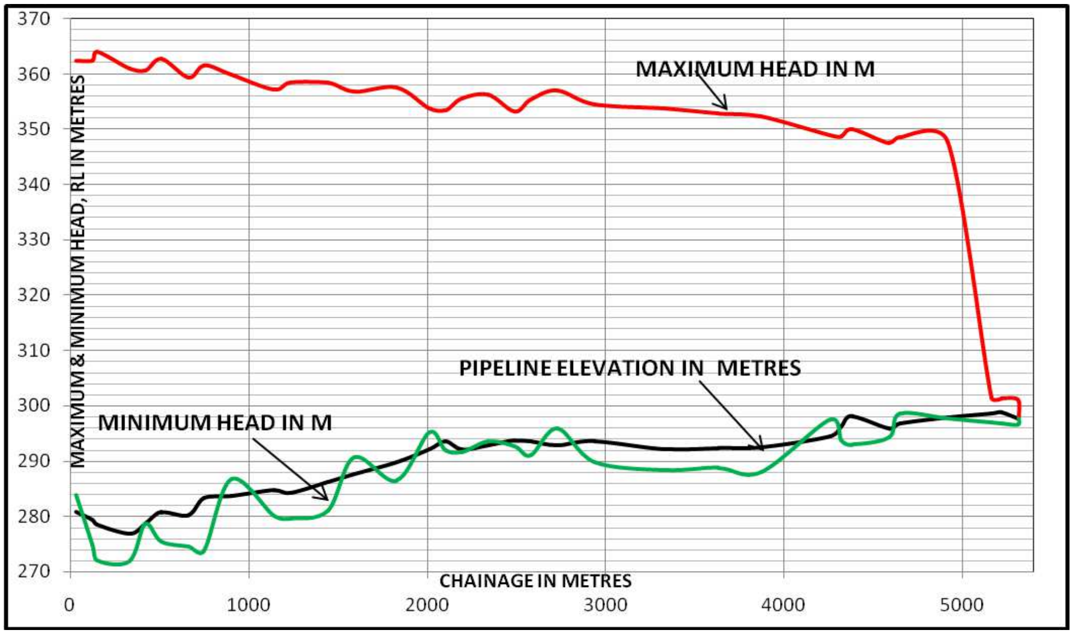

Figure 4- Maximum and minimum Pressure with 10 air valves + ZVV

Case 4 – Further remedial measures of deploying air vessel from size 100 m^3 was tried and then reducing the capacity of air vessel to 50 m^3 was considered with 10 Air Valves. Results in figure 4 show improvements in the negative pressures as well as bringing down the pressure fluctuations in the pipeline when this combination of arrangements of safety devices is adopted.

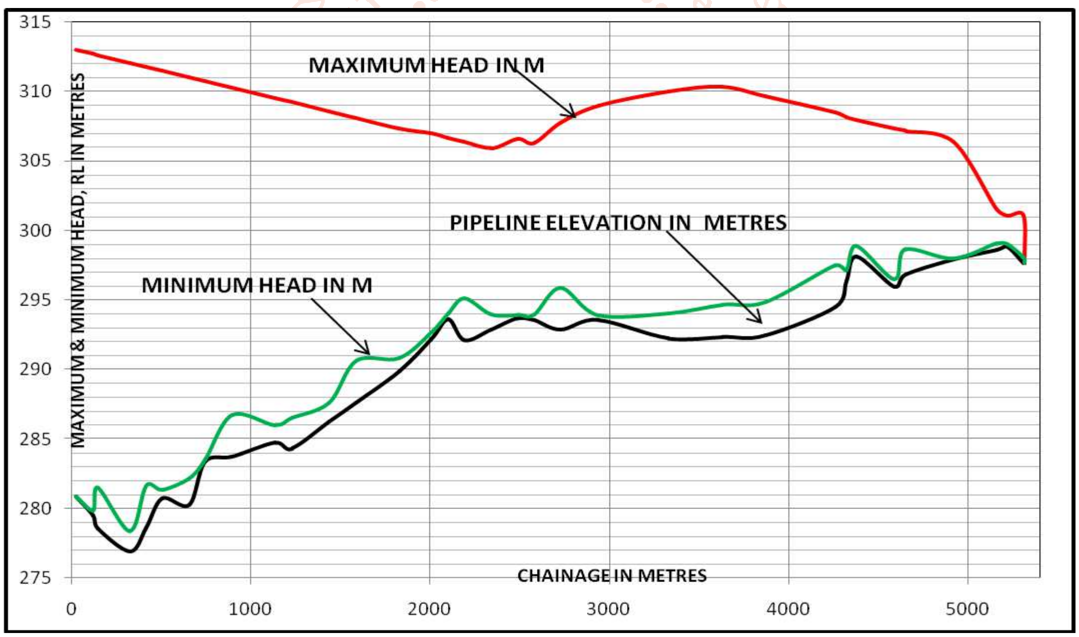

Figure 5- Maximum and minimum Pressure with 10 air valves and air vessel of 50 m3

Conclusions

After analyzing the water hammer pressures in the rising mains, capacity of air vessel has been optimized at 50 m^3 along with the 10 air valves. The air vessel internal diameter is to be kept as 3.5 m and its straight length be kept as 5.2 m. The vessel is to be located at chainage of 15m and the centreline of air vessel may be kept at 3 m above the centre line of the rising main. While the Air Valves is to be located at chainages of 150 m, 420 m, 900 m, 1.59 km, 2.19 km, 2.73 km, 4.26 km, 4.65 km, 4.92 km and 5.16 km respectively.

References

[1] Hydraulic Transients Analysis in Pipe Networks by the Method of Characteristics (MOC) by Roman Wichowski

[2] Fluid Transients by Wylie and Streeter.

[3] Fluid transients in Pipeline systems by A.R.D. Thorley

[4] Transients In Pumping Systems by M. Hanif Chaudhary

[5] Optimal volume selection of air vessels in long-distance water supply systems by Lin Shi et.al.

[6] Water Hammer protection with air vessels A comparative study by R. Verhoeven et.al.

[7] Water Hammer protection with air vessels A comparative study by R. Verhoeven et.al.

[8] Performance Analysis for Lift Irrigation Schemes- A Case Study by Anirudha S. Jadhav et.al.

[9] Takari Lift Irrigation Scheme Case Study by Abhijit M. Zende et. al.

[10] Case Study of Mhaisal Lift Irrigation Scheme by Vidya Purandare et.al.