CHAPTER - 1

INTRODUCTION

Introduction

1.1 Structure of the water supply system

The structure of the water supply system comprises many components like intake reservoir or source, pumping station, water treatment system, pumping main, elevated reservoir, gravity main, distribution reservoir and valves etc. The overall work of these components is to supply the water from the intake source to the customers. The main objectives of good water supply system are to provide safe water up to the customers, fulfill the fire demand at required pressure and also fulfill the demands of public institutions and industries. Transmission and Distribution system are the two main parts in which the whole water supply system can be divided.

1.1.1 Transmission system

Transmission system is provided the facility of transport the water from the intake source to treatment plant or treatment plant to distribution reservoir. The transmission pipeline may be laid either on above the ground surface or underground which is depending on the topography of the area. Generally in the transmission system, pipe diameter is used more than 250 mm. its length is vary in high range and may be extends up to many kilometers. In the transmission system, pumps are used to transmit the water from intake source to distribution reservoir or elevated reservoir at required pressure. The major components of transmission main are inlet valve, air valve, scour valve or main-hole etc. The supply of water up to the individual customer is not permitted from the transmission main directly but in some cases distribution main can be connected at intermediate points along the length of transmission main.

1.1.2 Distribution system

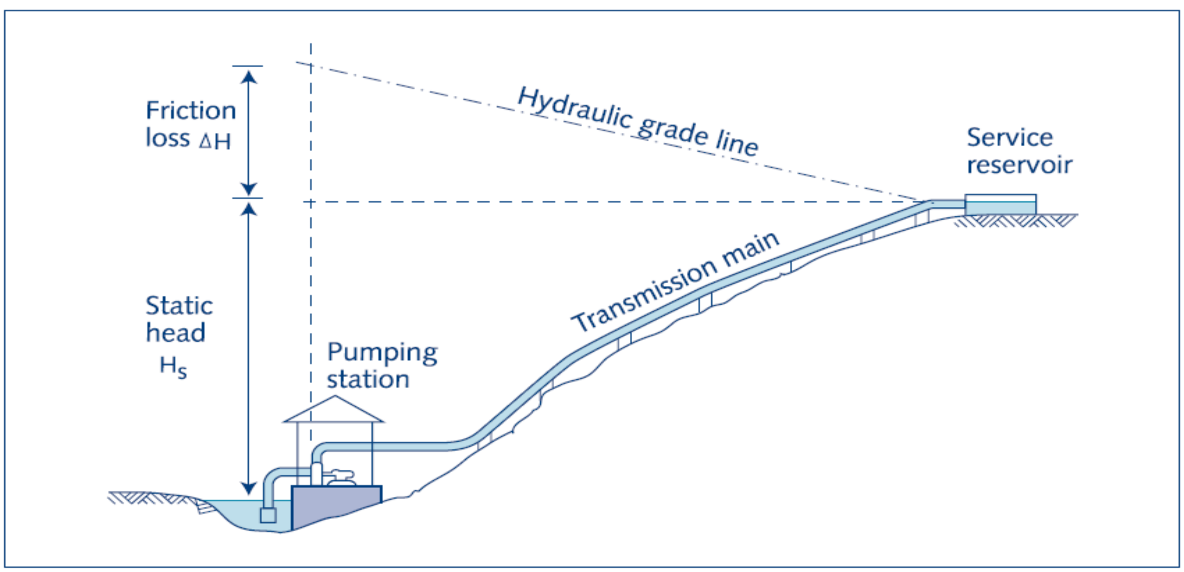
Distribution system is a major part of the water supply system which is transport the water from the distribution reservoir or service reservoir to the particular households or customers. In distribution system, two types of pipes are used which are distribution main and service connections. Usually the diameter of distribution main is smaller than the transmission main. The alignment of distribution system follows the street path generally because it is helpful in construction and maintenance purposes. Different pipelines of distribution mains meet at different junctions and forming a network of loop. At the end of every single branch of network, stop valves are installed. Some other valves are also installed in the distribution main like installation valves, scour valve, pressure release valve etc. The basic purpose of installation of different valves are to proper functioning of distribution main and prevent from losses due to huge pressure and negative pressure.

1.2 Types of water conduits

- Aqueducts and tunnels
- Canals
- Free-flow pipelines
- Pressurized pipelines

1.3 Water Transmission by Pumping

Transmission through the pumping is used for the transmission of water along the large distances or in hilly terrains. For the transmission through pumping, a definite head is needed which is sum of the static head and the frictional head loss for the design flow rate.



(Source www.google.co.in)

Fig.1.1 Pumped supply

And head losses through friction for design flow rate can be calculated by the various formulas for different-different diameters. It should be needed a pump which is capable to provide the required head (figure-1.1).

1.4 Pipe Materials

The most common materials used for manufacturing of pipes are asbestos cement AC), cast iron (CI), ductile iron (DI), polyethylene (PE), polyvinyl chloride (PVC) and steel.

1.5 Pipe failure

Pipe failure founds due to reduction in pipe strength which is caused by corrosion, excessive forces like surge, ageing of pipeline with time and human error etc.

1.5.1 Causes of failure

Kleiner et al. (2001) has divided the weakening of pipes into two parts, first is structural deterioration, structural resiliency and its capability to resist the various kind of forces imposed upon it and second is the weakening of inner surface of the pipe which results the reduction in hydraulic capacity of pipe. Pipe breakage occurs due to external interference and operational stresses which are results of corrosion, degradation and manufacturing defects etc.

1.5.1.1 Corrosion

Maker et al. (2001) & Rajani and Kleiner (2001) gave the reason of weakening of exterior of cast and ductile iron pipes i.e. electro- chemical corrosion with the damage founding in the form of corrosion pits. Corrosion pits are grown with the time and made the reason of breaking of pipeline. Deterioration of pipeline can be effected by the physical environment of pipeline also. The deterioration of Asbestos cement and concrete pipes are occurs due to several chemical processes.

1.5.1.2 Failure of pipeline due to surge (transient forces)

Chambers et al. (2000) (3) has discussed the effects of surge on a pipe line and have discussed the negative and positive issues in the pipeline system. Water hammer, or a pressure surge, is caused in pipelines as a result of changes in fluid flow velocities. Changes in the flow velocity essentially cause of the kinetic energy associated with velocity to be converted to pressure. This situation in a pipeline is known as the hydraulic transients. The surge magnitude depends on the rate of change in flow velocity.

Surges are caused by one or more events that change the velocity of the water in the pipeline. Common causes of surge events include the following conditions.

- Pump failure
- Pump startup or shutdown
- Rapid valve closure or opening
- Column separation
- Malfunctioning check valve
- Sudden releases of entrapped air.

1.5.1.3 Ageing of pipelines with time:

Transmission pipelines are mainly pumping mains. The pipelines are subjected to continuous stresses in the form of hoop tensile stress, dynamic stresses due variation in pumping characteristics, external stresses due to superimposed load, dynamic traffic loads as well as electrochemical effects from the surrounding soil. This leads to gradual deterioration of pipelines with time.

1.6 Project Area:- A Transmission Main Pipeline for Water Supply in UNA district, Himachal Pradesh.:-

A water supply scheme has been implemented by Himachal Pradesh Irrigation and Public Health Department, Una district, Himachal Pradesh to supply water from Swan River to town of Una district.

The Intake station has been built at the bank of Swan River. A nearby hillock, whose elevation is 179 m from the ground level, situated approximately 5.3 kms from the intake station has been utilized to create a sufficient head for gravity flow.

The elevation of hill top has been utilized to ensure continuous water supply through gravity to the villages. The river is a huge source to meet the water demand.

Source – www.mapsofindia.com

Figure 1.2 showing the location of UNA, HIMACHAL PRADESH.

The clear water pressure main which was laid from the intake station to the hill-top junction was chosen to be DI K9 pipe of diameter 250 mm and the gravity main which was laid from the hill-top junction to the villages of town was also chosen to be DI K9 pipe of diameter 250 mm.

1.7 Problem Statement –

The problem occurred when the pipeline was being commissioned. It had seen that leakage occurred at various locations of the transmission main pipeline, when it had subjected to pumping. This leads to wastage of large amount of water and delay in project completion.

1.8 Objective of the study –

i) To analyze the reasons for failure of water supply transmission main of the project area.

ii) An attempt has also been made to suggest a suitable and simple approach for analyzing the problems of water transmission main.

CHAPTER - 2

LITERATURE REVIEW

Literature Review

2.1 General

Though the number of papers on water distribution network and water transmission main is available, but the exact analysis on surge and its effect on water transmission main is not yet found. Few of the literature available are presented and discuss on the water transmission as given below:

2.2 Review of Papers

A.Bergant et al. (2006) described that the closure of a valve or shutdown of a pump may cause pressures so low that the liquid will cavitate. The collapse of vapor cavities and rejoinder of water columns can generate nearly instantaneous extremely large pressure that may cause significant damage or ultimately failure of the pipe system. According to him for the analysis of water hammer, most significant models that have been developed in past are the DVCM, the DGCM and the GIVCM (Generalized Interface Vapor Cavity Model). He said that the DVCM is the most popular model used in currently available commercial computer codes for water hammer analysis. He gave conclusion that despite its simplicity, the DVCM reproduces the essential features of transient cavitation. The versatility of the model has been demonstrated by the varity of pipe systems used in the tests. The major deficiency of the model is the appearance of nonphysical oscillation in the results. The DGCM gives reliable results but they still are quite complicated for general use. [1]

A.Hoskins and I. Stoianov (2014) explain a method for analysis of dynamic hydraulic conditions in WSS. They said that InfraSense data logging and Management Technology are capable to characterize the transient state flow. They gave conclusion that from the detection of leakage, we reduce the chances of bursts and improve the quality of service. They also said that hydraulic instabilities and transient forces affect the failure of pipe assets so this technology is helpful in continuous monitoring and analysis of the transient state. [2]

Anton Bergant et al (2011) has studied the dynamic behavior of air valves is large scale pipeline apparatus. In this study they have proposed an experimental program an the dynamic behavior of the air values since the quasi steady flow tests did not used to realistic result, The authors have considered dynamic flow testes at large scale . Float type air valves of 50 and 100 mm were tested is geometrically similar 200 and 500 mm test sections , to allow for the assessment of dynamic scale effects and the development of dimensionless parameter group and dynamic square laws. This approach of determination of dynamic performance of air valves is to measure its response to flow acceleration/deacceleration. The air valve behavior following events like system start-up , pump trip and pipe rupture is simulated result of the dynamic flow tests including air release tests and column separation tests are discussed by the author. [4]

B. Brunone et al. (2013) analyzed the water distribution system of Novara in the North-West part of Milan, Italy for using wavelet transform (WT) method and a Lagrangian Model (LM). Wavelet transform gives the information about automatic detection of singularities in pressure signals. And Lagrangian model find out the reason of discontinuities. He found after analysis that these approaches are not sufficient to calculate the effect of transient forces in the WDS. [6]

Bong Seog Jung et al, (2009). has shown the need of a pressure sensitive demand representation to assess the effect of pressure changes, they compared the pressure insensitive demand assumption with pressure sensitive demand for surge analysis. They concluded that time were a few deficiencies in pressure insensitive demand assumption. Firstly it ignores the implicit relationship between demand and pressure inherent in actual pipeline systems. Secondly, the transient result of the two demand models were quite different even in first cycle of a surge wave normally use to estimate the maximum and minimum system pressure. Moreover the pressure insensitive demand had fixed demand characteristic and finally, the pressure sensitive demand model can assess the effect of transient induced contaminant intrusions more accurately. [7]

Bong Seog et al (2007) discussed a number of guidelines and suggestion found in various AWWA publication of water hammer analysis. they provided a set of warnings about the misunderstanding and dangers which can arise from the simplification which have been widely applied to simplify the analysis . These simplification restricts the number and the difficulties of the transient case which needs to be evaluated. [8]

Dalius Misiunas (2008) focus the failure management and pipe condition assessment in water supply systems. He discussed on failure development mechanism, management cycle and associated cost and gives a brief review of existing method and research results. The main aim of his study was to explore the feasibility of using available low cost measurements and information to improve the operation, reliability, safety and availability of the urban water supply system. He developed algorithm for failure detection and location in both single pipelines and pipe networks and tested in the field, using real water supply system. [9]

Dalius Misiunas et al. (2005) represent an algorithm for the detection of sudden bursts and its location in water distribution network. This network works on the basis of both continuous monitoring of pressure and hydraulic transient computation. This approach is mainly useful for medium and large bursts which are responsible for sudden rupture of pipe wall or other elements of water supply network. To find the location of a burst, burst-induced transient wave arrival times and magnitudes measured at two or more points are used. In this approach, wave4 arrival times and magnitudes are to find out using the modified cumulative sum (CUSUM) change detection test. Results of validation of this approach on a real network show the potential of the proposed burst detection and location technique to be used in water distribution system. According to them, by the implementation of proposed technique could increase the efficiency and reliability of the water supply. [10]

D. Sala and P. kotakowski (2014) try to give an approach for implementation a system which is able to find out of leaks and control of flow in water distribution system. They basically analyze the system in steady-state flow condition and using Hazen-Williams constitutive law for calculating frictional losses in water supply network. [12]

H. F. Duan (2013) analyzed the wave-blockage interaction under transient flow in the pressurized pipelines by transfer matrix method. He shows that frequency response in the pipe systems with extended blockage can change resonant frequencies and amplitudes. But discrete blockage can only affect the resonant amplitudes. He analyzed the system with assumption of frictionless and simple pipe configuration. [14]

H. Fares & T. Zayed (2008) design a framework to evaluate the risk of water transmission pipeline failure by the use of Hierarchal Fuzzy Expert System. This model considers many risk factors which can be divided broadly into deterioration factors that lead to the failure event and consequences factors that are incorporated in the model (11 deterioration factors and 5 consequence factors). Hierarchal Fuzzy Expert System considers the uncertainty in the water main attribute. They said from the developed model, it can be deduced that pipe age has the highest effect on risk of water main failure among the other factors then come pipe materials and breakage rate. They were used a set of water network real data as a case study to apply and examine the developed model. [15]

Hugh Jackman et al (2012) manager of aqua environmental developed an internal link detection and pipeline condition assessment technology for pipes of longer diameter . Earlier the leak detection in large diameter transmission pipelines was a difficult task for the operators. However leakage detection in smaller diameter pipeline have worked but larger diameter have worked but larger diameter transmission main are the backbone to most utility systems. Technology that detect acoustic activities with leaks offer an inspection techniques for transmission main assessments to occur during full operation of the pipeline. The defects found is the pipeline are a source of non-revenue i and harmful environment impact. The technique presented by the author allows for a unique un-teltered inspection of many kilometers in a single deployment. The technique discussed here has been successfully deployed over 2000 km of water pipeline .This technology has been adopted to also complete pipe wall condition assessment by emitting a low frequency resonance into the pipeline . The author has discussed challenges and solution in order to successfully deploy and analyze data for an untethered device is pipeline for several utilities. [16]

I. Abuizian et al (2013) studied the use of desurging tank with automatic air control “DTAAC” which is a water hammer protection device. It can operate an open tank or a closed surge tank according to the water level inside the surge tank with the volume of air trapped. It has many advantage like easy maintenance and no need of an external energy source. They have developed a computer program on the basis of the characteristic method to simulate flow transient phenomenon is pressurized water pipeline system. They influence of using protection device to control the adverse effect can be analyzed by this model .They have obtained the results which shows that this model is an effective tool for water hammer analysis. They have also shown the advantage of using DTAAC. [18]

I. Abuizian et al (2013) discussed a solution for the hydraulic transient phenomenon. These transients many cause pump and valve failures and many other problems. He discussed about the requirement of flow control and transient control. In the presented method the fourth order Runga-kutta method has been used to solve the dynamic and continuity equation in the rigid column method, while the characteristics method is used to solve equation in the full elastic method .The problem of modeling and simulating of transient phenomenon is conveying pipeline system based on the rigid column and full elastic method is presented by the authors. The influence of using the protection device to protect the pipeline systems from damaging due to the gain pressure is also explained. Thus an efficient tool for flow transient analysis is obtained. [19]

I. Abuizian et al (2013) formulated an effective numerical model which can be used to analyze the potential transient events and to identify and evaluate alternative solution for controlling hydraulic transient. They presented the influence of using the protection device to control adverse effect of the transients. [20]

I Abuiziat et al, (2014). present the problem of modeling stimulation of transient phenomenon in conveying pipeline systems based on the rigid column and full elastic method, they use two method for analysis of transient flow, first one was fourth-order Runga-kutta method which has been use to solve dynamic and continuity equation in the rigid column method and second one was the characteristics method which has been used to solve these equations in the full elastic method. According to them, results obtained from the model on efficient tool for flow transient analysis and provide approximately identical results by using these two methods. [21]

J. Zhang (2014) analyzed the risk of water hammer in the pipeline of water supply system by fuzzy comprehensive evolution method for risk assessment. By this method, he calculated the water hammer at various conditions and identifies the sections which are more sensitive from its effect. The conclusion of his study was very high risk of failure of long distance water transmission pipeline due to surge and according to him, chance of pipe burst found near the throttle control valve and he suggest the strengthening of near the throttle control valve is needed. [25]

L. Berardi et al. (2008) described an application of a new data mining technique for failure prediction in water distribution system which is known as Evolutionary Polynomial Regression (EPR). It produces symbolic expressions that are essentially explicit mathematical models for pipe burst predictions originating in data driven analysis. This approach has tested and verified by him on a real-life U.K. water distribution system. Finally he gave conclusion that an individual pipe structural deterioration model has been derived from the EPR aggregate model and the methodology on how to use such a model to support asset management decision making presented. [27]

Paul F. Bouloset al, (2005). Discussed the effect of transients into a water distribution system, the effect like large pressure forces and rapid fluid acceleration can lead to pump and device failures, system fatigues and pipe raptures and also the intrusion of dirty water. They can lead to catastrophic pipe line failures. They have presented practical guidelines for their suppression and control, the formulation and computational performance of widely used hydraulic systems has been compared to enhance the ability of water utilities and to evaluate cost effective and reliability water supply protection and management strategies. [35]

R. Puust et al. (2010) provides a comprehensive review of the leakage assessment methods, leakage detection methods and leakage control models with the objective to identify the current state-of-the-art in the field and to then make recommendations for future work. He gave conclusion that there is still a lot of scope and need for future work, despite all the advancement made in the past especially in area of real time models for pipe networks which should enable fusion of leakage detection, assessment and control methods. With regard to the use of various transient based methods for leakage detection it should be noted that these methods had limited success so far, typically in simpler pipe systems only. It is envisaged that transient simulation models need to be developed further before they can be utilized for leakage detection and assessment in more complex pipe systems. [36]

Rustabh R. Sabadra et al, (2014). Compare and suggest the best option to mitigate the water hammer, various control devices and detailed methods used for transient carried out globally, this study is helpful to minimize the effect of transient condition in pipe line system, they are suggested some guideline at primary level for water pipeline system. [41]

Srinivasa Lingireddy et al,(2004). Demonstrated the positive impact of smaller outflow sizes of air through two example application, they found that the improper sizing of an air valve could lead to rapid expulsion of water at high elevations, this could result in excessive pressure surge at the air valve. They deduced a simplified equation to estimate the magnitude of the pressure surge based on different characteristics in the valve before the final release of the wall. [42]

Tan Weachoon et al,(2012) study the condition where the water hammer effect occure in pipeline and also study on the prevention of water hammer effect. They suggest as a prevention method in installation of the bypass pipe with non-written valve, they had done experiment by capture the vibration singnal by using data acquisition device and accelerometer. The pressure signal was capture after a sudden shutoff for the valve andand then signal was analyze and convert to wave speed, they also differentiating and compare the water hammer phenomenon with different pipe material,pipe length, inlet diameter of pipe and pressure in pipeline, on the basis of experimental result, they shown that the lower strength material pipe, small inlet diameter pipe abd longer pipe will deal with larger water hammer effect. finally they give conclusion of their study that the prevention method by installing by pass pipe non- retain valve of water hammer effect is reduce by 33.33% of pressure. [44]

2.3 Concluding Remark

The above literature review indicates that studies available on the analysis of failure of water transmission main are sufficient but approaches are not simple and not easy understandable by new user. For the analyze the effect of surge on the water transmission main, a simple and systematic approach is try to given in this project.

CHAPTER – 3

METHODOLOGY AND APPROACH

Methodology and Approach

Transmission main is very important part of the water supply scheme. So the failure of water transmission main is very serious issue which can be analyzed by proper investigation of site conditions and by using some software and procedures through systematic approach.

4.1 Evaluation of problem

Water transmission failure problem can be mitigate by the systematic procedure. First of all by the site visit, collect the field data of water supply scheme from the site office, department of irrigation and public health, UNA District Himachal Pradesh and by the physical visualization. Plan a systematic approach to analyze the failure problem according to site condition and availability of data. Then select two software from the market for analyze the system, one for steady state flow and another for transient state flow are EPANET and SAP respectively which are used in this project.

For analyze of water supply transmission main in EPANET software, a systematic model of transmission main is needed to prepare. After the preparation of model, analyze the transmission main in steady state flow by the help of EPANET software and obtain the result of stresses. Then compare these results with the maximum allowable working pressure of used ductile iron pipe in the water supply scheme. For the analysis in EPANET software, many data needs to evaluate the stresses like diameter of pipeline, R.L. of intake reservoir, R.L. of pump, R.L. of elevated reservoir, flow-head characteristics etc.

After analyze of transmission main in steady state flow, analyze the system in transient flow state with the help of SAP software. For the analysis in SAP software, a lot of data are needed like design discharge in the transmission main (cum/sec), internal diameter of the transmission main (mm), length of the transmission main (m), start chainage of transmission main (m), pump head (m), pressure wave velocity (m/sec), water level in the sump (RL , m), number of working pump, water discharge of the pump (cum/sec) and rated pump head (m) etc. These data has been collected from the site office. In the SAP, firstly analyze the transmission main without the surge protection device i.e. air valve and then with the air valve. After the analysis, obtain the stresses in transient state and compare it with the maximum allowable working pressure of ductile iron pipe.

The maximum allowable working pressure is calculated from the given procedure in the BS ISO 2531 -2009 (E) and finally check the stresses generated in steady state and transient state are less than maximum allowable pressure of used ductile iron pipeline or not. After Compare these results, reached up to a final result and conclusion of the analysis. Try to suggest the some solutions and precaution for the prevention of transmission main failure.

4.2 Approach to Mitigate the Problem

The approach used to mitigate the problem technically by using the two different software, one for the analysis of steady state and another for the transient state flow condition. First of all by using EPANET software, steady state of flow was analyzed and then by using SAP software, transient state of flow was also analyzed. Then generated results were obtained. A further maximum allowable working stress of pipe material was calculated with the systematic procedure by using BS ISO 2531:2009(E). Generated stress results by software are compared with the maximum allowable working stress of the pipe material to simulate the effect of generated stresses in transmission main. Finally obtain a result of analysis and conclusion to make for the problem. After that conclusion, try to suggest some precaution and solution for the protection of transmission main.

CHAPTER-4

RESULTS AND DISCUSSION

Results and Discussion

During the initial stage of site visit the details of the transmission system was studied. The data available at site on pipe profile, pumping details, type of leakages occurred during commissioning of the pipeline etc. was collected.

Table – 4.1 Salient features of Transmission System

S.No.	Features of the pipeline	Values
A	***Pressure main details***	
1.	No. of pipelines	1
2.	Length of pipeline	5300
3.	Nominal diameter of the pipeline	250 mm
4.	R.L. at the pump end	530.68 m
5	R.L. at the pressure main end	709.69 m
B	***Pumping Details***	
1.	Discharge through pipeline (pumping main)	45.44 lit/sec
2.	Rated power	2 x 100 HP
3.	No. of pump	3(2 working + 1 standby)
C	***Gravity main details***	
1.	No. of pipeline	1
2.	Length of the pipeline	7500 m
3.	Nominal diameter of the pipeline	250 mm
4.	R.L at the pressure main end	709.69 m
5.	R.L. at the discharge end	683.40 m

Source- Himachal Pradesh Irrigation and Public Health Department, Una district

4.1 Results

4.1.1 Analysis of transmission main in steady state

A system is said to be in steady state when the different properties (p) of the system like velocity, discharge, pressure, viscosity etc. may differ from point to point but do not change with time. This means that for those properties of the system, the partial derivative with respect to time is zero.

$$\frac{\partial p}{\partial t} = 0$$

In many systems, steady state is not achieved until sometime after the system is started or initiated. The initial situation is often identified as a transient state, start-up or warm-up period.

The analysis of transmission main in steady state has done by the help of EPANET software. To analyze the flow conditions of the pipeline, a model of the system is essential to create in the software. A model had been drawn according to survey data which had collected at site. The pipeline used for the transmission main is Ductile Iron pressure class K9 pipe of size DN250. Impounding reservoir is situated at the R.L. of 531.50 m and hill top junction of pipe is situated at the R.L. of 709.69 m. A summary of the results is given below –

From below figure-4.1 it can be observed that the pipeline is subjected to a steady state pressure of maximum 200.0 m of water column at outlet of the pump which reduces gradually up to 3.74 m of water column at elevated reservoir along the 5.3 km length of pressure main. Thereafter the pressure in the pipeline reduces gradually to the residual pressure of 3.74 m of water column. It can be observed from analysis that maximum pressure generated in steady state flow condition was less than the maximum allowable operating pressure of Ductile Iron pipeline i.e. 693 m of column.

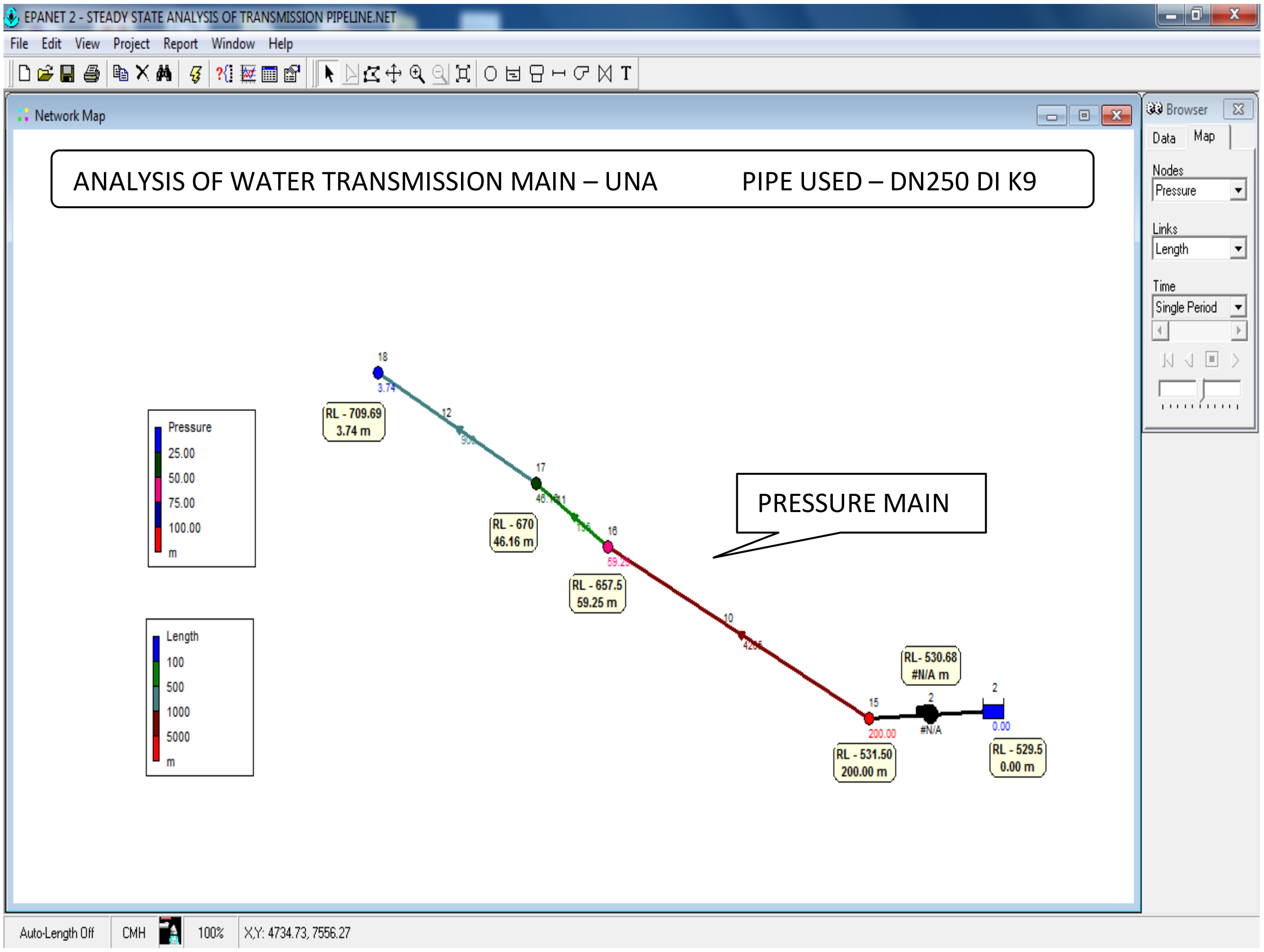


Figure-4.1 – Showing steady state pressure after analysis in EPANET Software

Table 4.2- Results obtained from steady state analysis in EPANET software.

Node ID	**Elevation(m)**	**Head(m)**	**Pressure(m)**
Reservoir 2	531.50	531.50	0.00
Junction 15	530.68	729.50	200.00
Junction 16	657.50	716.75	59.25
Junction 17	670.00	716.60	46.16
Junction 18	709.69	713.43	3.74

Table 4.2 represents the steady state pressure is maximum of 200.00 m of water column at near the pump and then gradually reduces to outfall pressure of 3.74 m of water column at the hill-top.

4.1.2 Transient flow analysis of transmission main-

Once the pipeline is analyzed for a steady state solution, it is imperative to analyze the pipeline for a transient state analysis. A transient flow is defined as such a flow where the velocity and pressure changes over time. Transient flows usually occur during the starting or stopping of a pump, the opening or closing of a tank, or simple changes in tank levels. A transient flow occurs when there is a variance in flow and pressure in a pipeline due to fluctuation of input power in the pumping system, sudden stoppage of the pump due to power failure or sudden closure of a valve in the system. Transient flow results in surge pressure or water hammer, which is very detrimental to the piping system. Precautions in the form of surge arrestors, air valves, non return valves, bypass valves etc are taken to prevent bursting of pipes during surge.

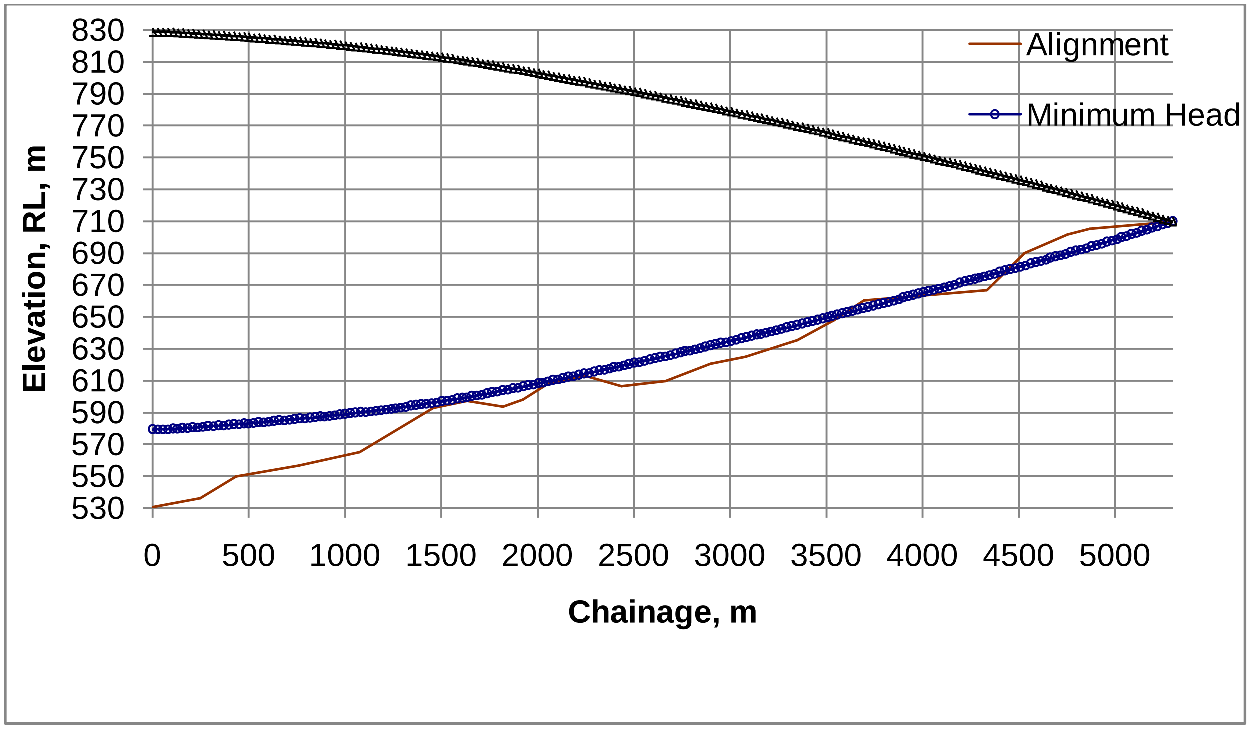


Fig 4.2 Minimum and Maximum Piezometric Heads without Surge Protection Device

In the figure-4.2, it can be observed that hydraulic transient stresses have been generated in the pipeline immediately after starting of the pump. From the graph it can be inferred that the maximum dynamic stresses developed in the pipeline is predominated at the pumping end and decreases gradually along the length of the pipeline upto a distance of 5.3 kms from the pumping end and minimum dynamic stresses developed in the pipeline is also predominated at the pumping end and increases gradually along the length of the pipeline upto a distance of 5.3 kms from the pumping end. By the analysis in SAP software, maximum head found at the pump end i.e. 830 m of water column and minimum head found at the pump end i.e. 580 m of water column. And also it can be observed that from the graph, both maximum and minimum head has become approximately equal to each other at the entry of elevated reservoir.

Above result is shown occurrence of surge at many locations of the transmission main. For the prevention of surge, surge prevention device Air Valve has been fitted at the 3 locations in the transmission main pipeline according to data of site. Three locations where air valves had been fitted are following –

Table -4.3 Showing the location of Air Valves in the transmission pipeline

S.No.	Chainage (in meter)	Invert Level (R.L.,in meter)
Location 1	1635	597.20
Location 2	3350	635.30
Location 3	4530	690.00

Analysis of transmission main with air valve by the SAP software gave more reliableresultswhich are shown by the following graphs-

Below Figure-4.3 showing the minimum and maximum piezometric heads after applying air valve for the prevention of surge at the three locations. It can be observed by the graph that the occurrence of surge has been less in comparison of analysis without surge protection device.

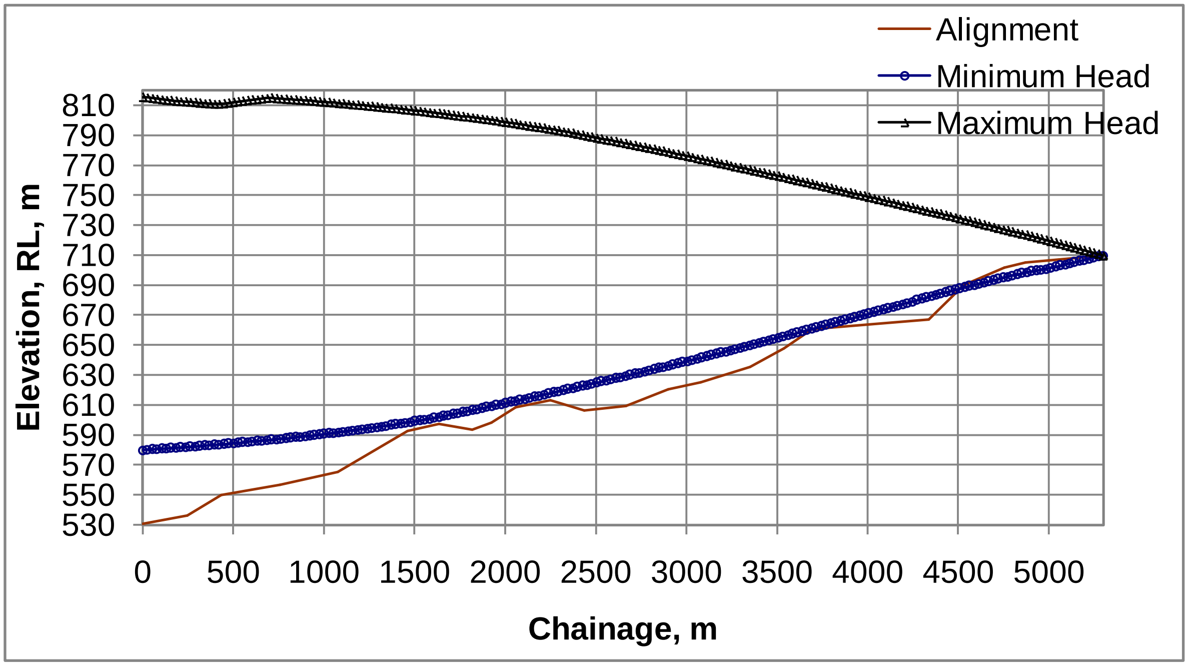


Fig-4.3 Minimum and Maximum Piezometric Heads with Surge Protection Device

It can be clearly observed from the above results that maximum pressure generated in the transient state was more than the maximum allowable operating pressure of Ductile Iron pipe i.e. 693 m of water column.

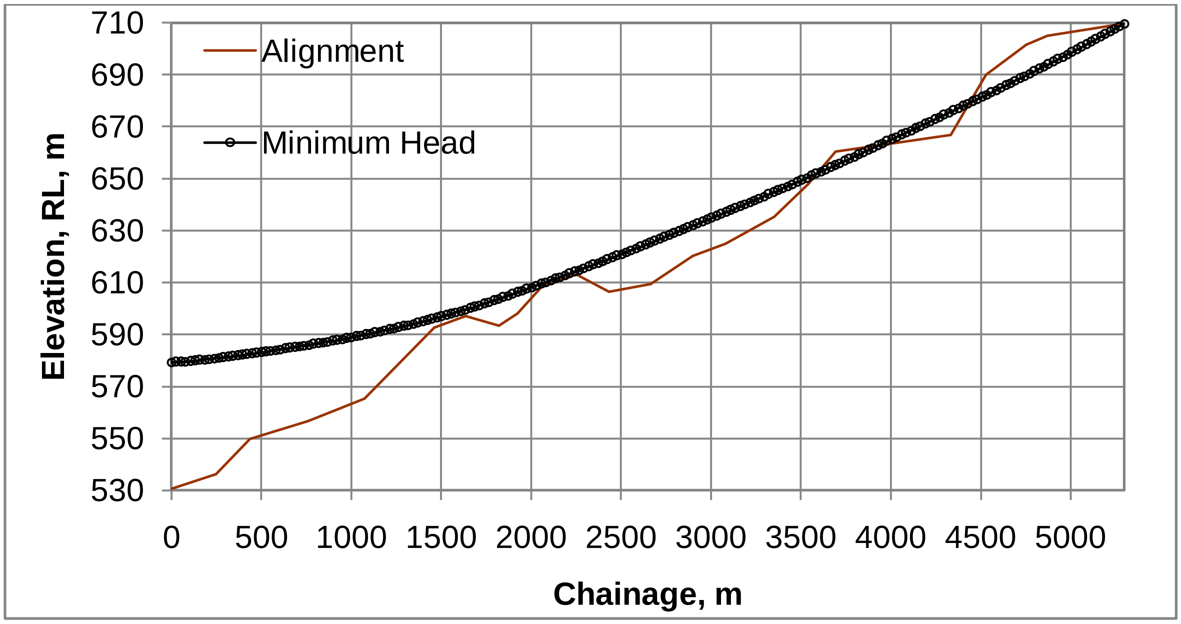


Fig -4.4 Minimum Piezometric Heads without Surge Protection Device

In the figure-4.4, it can be observed that minimum piezometric heads along the transmission pipeline have shown by the graph which is found by transient analysis in SAP software. In the graph, minimum piezometric head has gone below the alignment of pipeline at some points which is shown that negative pressure occurs at those points. These negative pressures have responsible for surge.

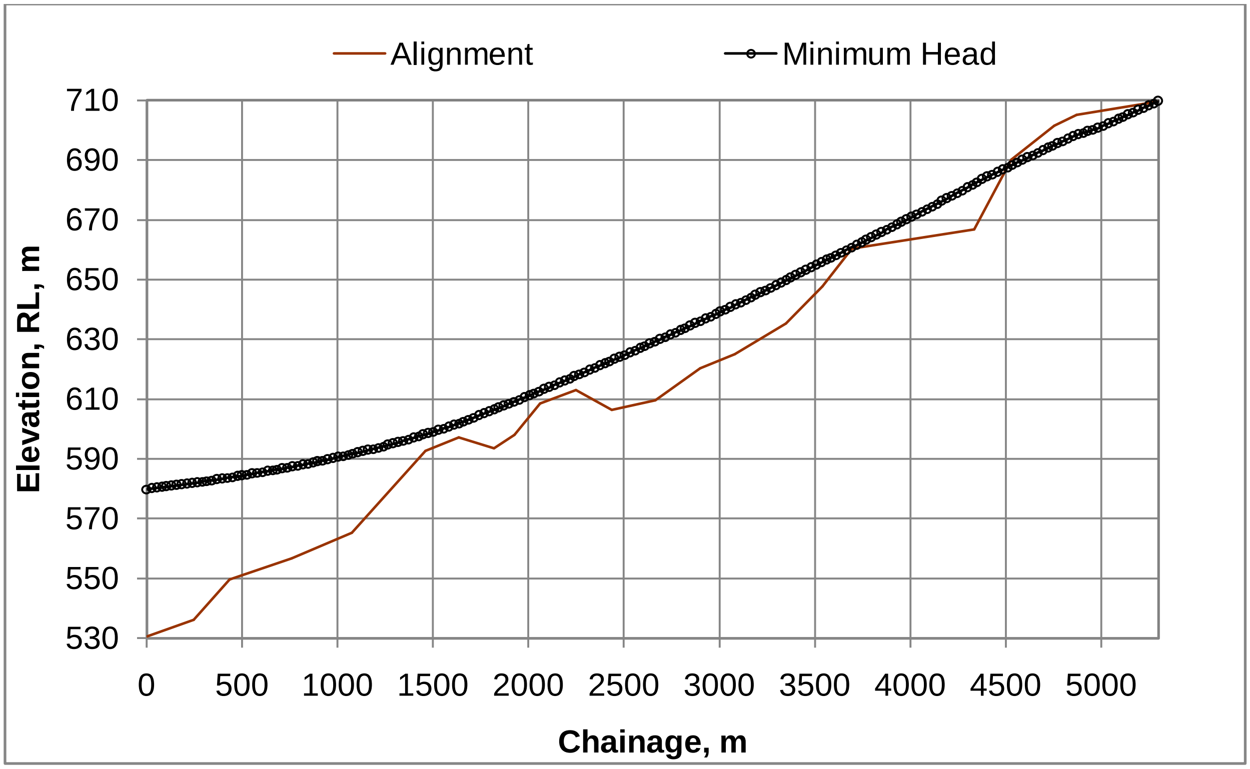


Fig-4.5: Minimum Piezometric Heads with Surge Protection Device

In the above figure-4.5, showing the minimum pizometric heads in the transmission main after the application of surge protection device at specified locations. From the graph, it can be observed that minimum pizometric head has been gone below the elevation of transmission main at once only and also difference between minimum piezometric head and elevation has been reduced which shows the reduction in surge due to air valve.

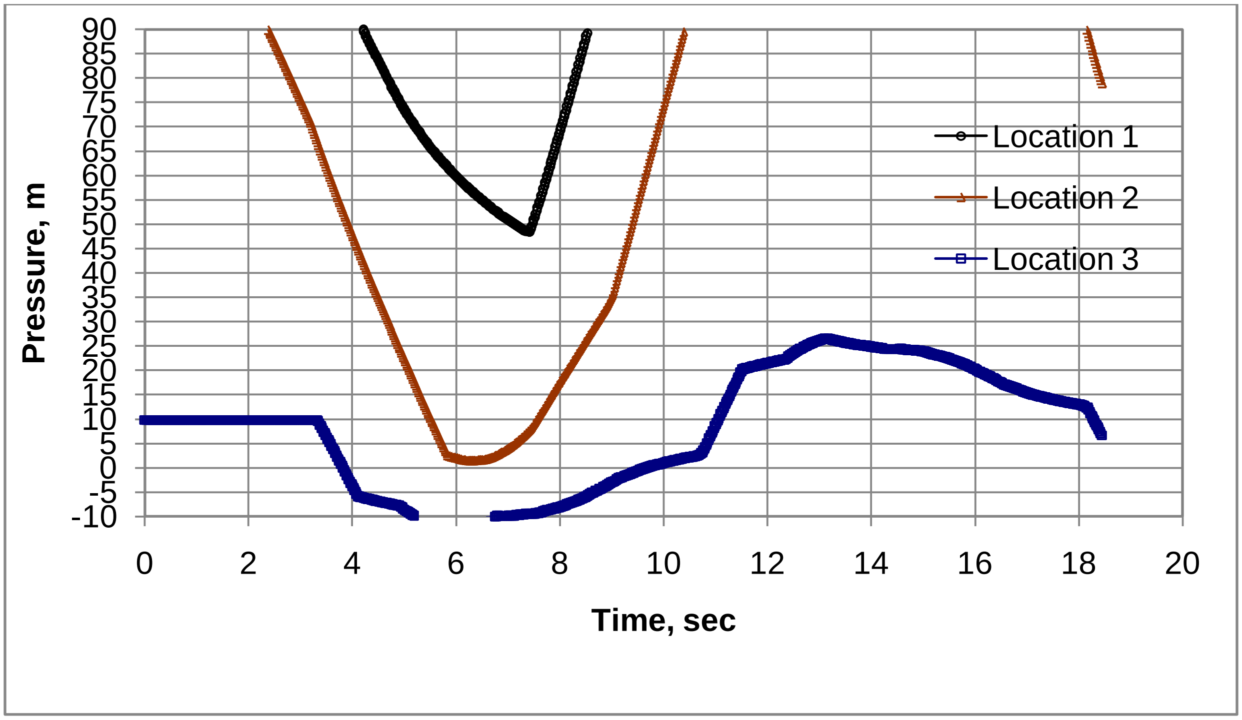


Fig-4.6: Rate of Pressure Drop at Specified Locations without Surge Protection Device

In the figure-4.6, rate of pressure drop with respect to time at three specified locations have been shown in the above graph. The specified locations where rate of pressure drop with respect to time have been plotted by the SAP software are-

Table – 4.4 showing the points at which pressure drop calculated

S.No.	Chainage (in meter)	Elevation (R.L.,in meter)
Location 1	0	530.68
Location 2	2250	613.00
Location 3	4755	701.50

At 1st and 2nd location, graph shows drop in pressure maximum upto the zero pressure but at 3rd location, graph shows drop in pressure below the zero pressure which shows that negative pressure at location 3rd. It means surge occurs at 3rd location.

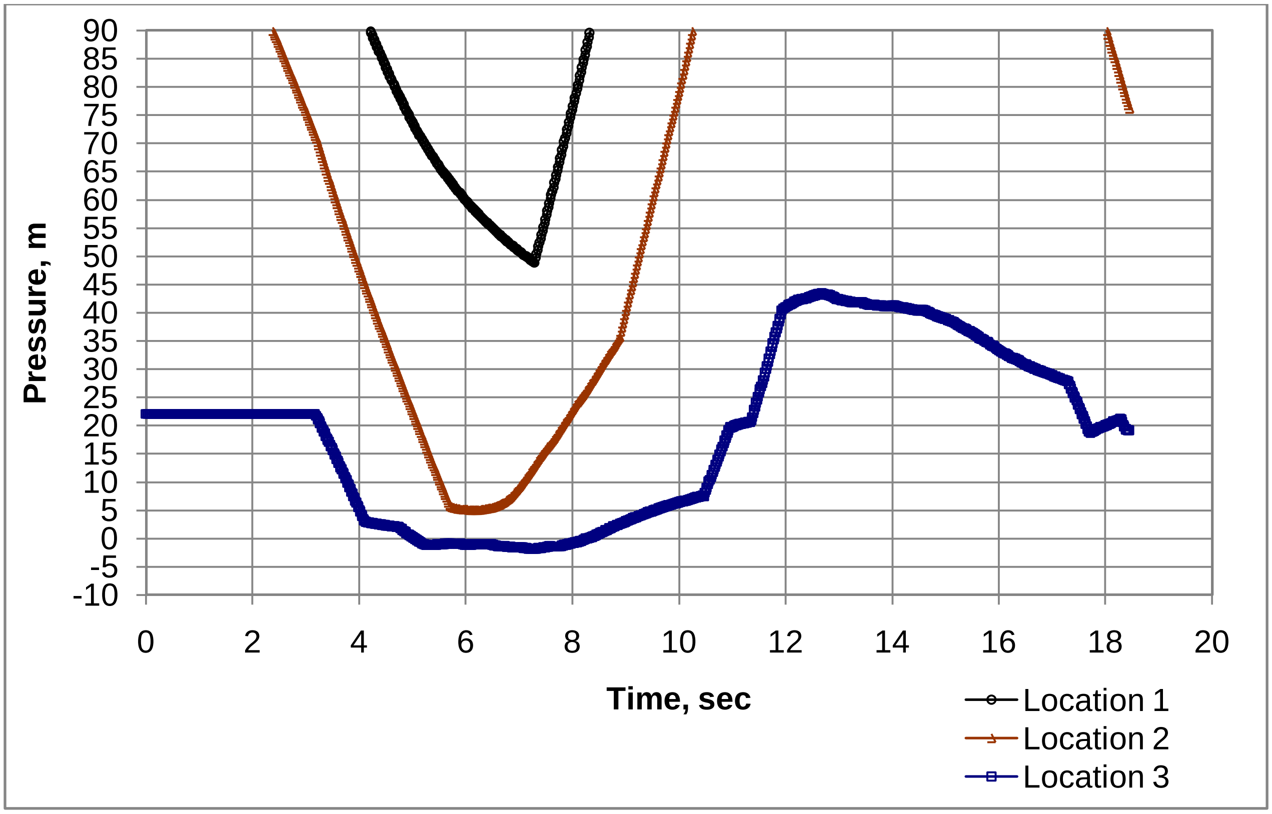


Fig 4.7: Rate of Pressure Drop at Specified Locations with Surge Protection Device

Figure-4.7 showing the rate of pressure drop with respect to time at specified locations which are already given in table-1. It can be observed from the graph that negative pressure at specified location 3 has been reduced due to application of surge protection device and hence chance of failure due to surge became less. After the application of air valve, maximum negative pressure occurred upto -2.5 m of water column.

4.1.3 Maximum Allowable Operating Pressure of Ductile Iron Pipe

Each pipe is having some specific tolerance pressure according to own thickness against generated stresses in the pipe. That's why we calculate the maximum allowable operating pressure of ductile iron pipe which is helpful to visualize the generated stresses in pipeline bearable or not. Hence for calculating maximum allowable operating pressure, first of all we calculate the thickness of pipe by using ISO 2531:2009 (E) then use this thickness, calculate the maximum allowable operating pressure.

According to ISO 2531:2009 (E); minimum thickness of DI pipeline should be–

$$e_{min} = k\,(0.5 + 0.001 \times DN)$$

$$= 9\,(0.5 + 0.001 \times 250)$$

$$= 6.75 \text{ mm}$$

Where,

e_{min} = the minimum pipe wall thickness, in millimeters (should not be less than 3 mm in any case)

k = Pressure class of DI pipe;

DN = Nominal pipe internal diameter in millimeters.

Now we find the allowable operating pressure (PFA) (in bars) by the help of minimum wall thickness formula for pipes which is given by ISO 2531:2009(E).

$$e_{min} = \frac{(PFA \times SF \times DE)}{20R_m + (PFA \times SF)}$$

$$6.75 = \frac{(PFA \times 3 \times 274)}{20 \times 420 + (PFA \times 3)}$$

PFA = 70.72 bar

= 693 m of water column

Where, e_{min} is the minimum pipe wall thickness, in millimeters;

PFA is the allowable operating pressure, in bar;

SF is the safety factor for PFA (=3);

DE is the nominal pipe external diameter, in millimeters;

R_m is the minimum tensile strength of ductile iron, in MPa (R_m = 420MPa)

4.2 Discussion

On the basis of result obtain from analysis it is observed that the pressure generated in the pipeline were very high and not within the allowable working pressure of Ductile Iron pipe i.e. 693 m of water column.

So it is clearly observed that the main reason of failure of pipeline is the pressure generated due to transient forces.

The photographs of the DI pipe at site as shown below which are clearly indicate that the improper laying is also a reason of failure.

Photographs of the DI Pipeline at site-

Fig 4.8 Photograph showing leakage of Ductile Iron pipe at the joint

From the above figure 4.8, it can be observed that the gasket of the ductile iron had been damaged due to excessive deflection of the joint.

From the below figure 4.9 it can be observed that the leakage from the pipe is occurring at the joints, while the pipe was laid over pedestals to cross a river stream. It can also be observed that the positioning of the support for the pipeline has not been done on the correct position.

Fig 4.9: Photograph showing leakage of Ductile Iron pipe from the joint.

CHAPTER – 5

CONCLUSION AND RECOMMENDATION

Conclusion and Recommendation

5.1 Conclusion

From the analysis of transmission main in steady state condition in the EPANET Software, it is evident that no fluctuating pressures generate in the pipeline at steady state condition and maximum pressure generates in steady state i.e. 200.00 m of water column at near the pump is under allowable limit of pressure of ductile iron pipeline which is 693 m of water column according to BS ISO: 2531-2009(E).

But during start up and shut down of the pumps, transient flow comes into the play in pipeline for some time either before the steady state flow condition or after achieved, which generates fluctuating pressures in the pipeline. From the results obtained by the analysis in SAP software, it is observed that the pipeline has subjected to maximum pressure of 830 m of water column which is more than the allowable operating pressure of Ductile Iron pipeline i.e. 693 m of water column and negative pressure of -11. 5 m of water column has also found. From the figure – 4.4 & 4.5, it can also be observed that negative pressure zones had formed at few locations along the pipeline.

Hence by the result of analysis of transmission main in steady state, it is clear that the transmission pipeline had been capable to transmit the required water flow and generated pressure. But by the result of analysis of transmission main in transient state, it is also observed that the surge had generated during the transient flow which was above the allowable operating pressure limit of ductile iron pipeline.

So as a conclusion it can be inferred that the reason for failure of transmission main pipeline can be for the following on the basis of analysis and site investigation -

i. Failure of pipeline occurs due to generation of large magnitude of transient forces i.e. surge.
ii. Inadequate arrangement of surge protection devices.
iii. Failure of joints due to decay of the Gasket of joints.

iv. Improper laying of pipeline with respect to hilly terrain.

5.2 Recommendations-

1) Proper installation of devices to prevent the excessive transient stresses like-
    a) Air Valve
    b) Surge Protection Devices like surge tank, discharge tank, pump bypass reflux valves, air vessels etc.
2) Proper fitting of pipelines and installation of joint kits.
3) Proper designing and laying of pipeline in hilly terrain.
4) Condition Assessment of Pipeline will be take in practice for proper functioning of pipeline upto long period and for prevention of the future failure.

5.3 Future Scope of the Study

1) It can be helpful in determining the stresses in the pipeline at the time of pipeline design and avoid to such type of failure problem in future.
2) It is also helpful in trouble free commissioning of water supply system in those areas where the risk of transient forces is more specially in hilly terrain.

CHAPTER – 6

ANNEXURE

Annexure

Annexure A –

EPANET Software

EPANET is software which is used for the simulation of hydraulic and water quality parameter analysis within the pressurized network. It was developed by U.S. Environmental Protection Agency. It is design for improving our understanding about the water supply system. Network comprises nodes, junction, reservoir, pump, tanks etc. It is efficient to determine the hydraulic parameter at different nodes or junction in a different branch of pipelines.

EPANET has involved many steps to analyze a model of water supply system-

- Draw a network of water supply system.
- Edit the different properties of the system and put the valves of new system properties.
- Describe the system operation procedure.
- Choose a set of analysis.
- Run a hydraulic or water quality analysis.
- Finally obtain the results in different forms like tabular, graphical, statistical etc.

The function of EPANET can be divided into two categories –

I. The Input Data File
II. The EPANET Computer Program

The Input Data File is described the related properties of the water supply system like nodes, junctions, pumps and valves.

The EPANET Computer Program plays the role in solving the nonlinear energy equations and the linear mass equations for pressure values at nodes and flow rates in pipes.

EPANET (Input data file) - The EPANET have the ability to automatically create the data file through MIKE NET, that have the explanation and descriptions that related to the physical characters of pipes and nodes, and the connectivity of the pipes in a water distribution network system.

The most attractive advantage of EPANET is that it helps to easily layout the water distribution network graphically, and it is easy to enter pipe network parameters through an easy to use dialog boxes. Mike NET then starts to generate the EPANET input data file in the format required to run the analysis. The pipe Parameters includes the length, minor loss coefficient, roughness coefficient, and pipe inside diameter.

EPANET (Computer Program) - In addition, to the ability to compute the flow rates and the HGL at the nodes, EPANET can offer accurate results in water quality flowing through the pipes.

Furthermore, the calculation of flow rates engages different iteration as the mass and energy equations are non- linear. The number of iterations depends on the system of network equations, and the accuracy of the user.

Annexure B –

Surge Analysis Program (SAP) Software

The Surge Analysis Program (SAP) is a software which has developed by the Indian Institute of Science, Bangalore. This software is older than 20 years and several design option and system complexities are gradually incorporated in it after its evolution. As a result the software can analyze any complex situation with regard to surges in pumping mains. It is used for the design of pipeline which is safe from the surge.

Features of SAP software

- SAP software works on the basis of iteration process and proposed a particular protection against the power failure condition or pump failure condition etc.
- It is find the evaluated surge pressure for a particular condition of failure and on the basis of these results, system can be modified.

- This software is older than 20 years and several design option and system complexities are gradually incorporated in it after its evolution. As a result the software can analyze any complex situation with regard to surges in pumping mains.
- Very easy data input procedure.
- The software scope is sufficiently large to cater to most of the common applications, involving pumping stations with cross country pipelines, requiring significant surge protection measures.
- The software can be used for a comprehensive solution with different types of surge protection devices.
- The graphical outputs are more effective to give a proper understanding of the system pressure.
- The scope of the program should be sufficiently wide so as to cater to nearly 90% of common applications, involving pumping stations with cross country pipelines, requiring significant surge protection measures.

Annexure C –

Condition Assessment of Pipeline

1. Objective, Scope and Background

EPA (2007) defines pipe condition assessment as "the collection of data and information through direct and/or indirect methods, followed by analysis of the data and information, to make a determination of the current and/or future structural, water quality, and hydraulic status of the pipeline." This task focuses on the structural aspect of condition assessment. Pipe condition assessment may be undertaken with specific objectives, which include following points

- Monitoring and detecting critical indicators to prevent or mitigate catastrophic failures Implementing appropriate and timely repair/rehabilitation measures
- Early detection of accelerated deterioration for timely implementation of preventive measures (e.g., retrofit cathodic protection [CP]) and for anticipation (and, where

possible, mitigation) of spikes in failure rate during extreme conditions (e.g., abnormally cold winters or drought)

- Setting inspection schedules and frequencies
- Screening and prioritizing assets to focus detailed, expensive inspections on critical sections
- Estimating remaining service life for pipe cohorts for mid- or long-term financial planning and rate setting
- Detecting and reducing leakage to reduce water losses and water main breaks
- Determining whether structural vs. non-structural rehabilitation is suitable
- Providing insight into new pipe selection decisions – this could come from break histories, forensic evaluations, screening inspections, or detailed inspections.

The aging of water mains, coupled with the continuous stress placed on these systems by operational and environmental conditions, has led to their deterioration, which has structural, hydraulic and water quality manifestation.

The structural deterioration of water mains and their subsequent failure are complex processes, which are affected by many factors, both static (e.g., pipe material, size, age, soil type) and dynamic (e.g., climate, CP, pressure zone changes).

The assessment of the structural condition of water mains and decision making on pipe renewal include several elements:

(1) Physical modeling of the pipe in the soil.

(2) Understanding of pipe failure modes and their associated frequencies, including observable or measurable signs (or distress indicators) that point to these modes, as well as inferential indicators that point to potential existence of deterioration mechanisms.

(3) Inspection of the pipe to discern distress indicators.

(4) Interpretation of distress indicators to determine pipe condition.

(5) Empirical/statistical modeling of historical failures (mainly in small diameter distribution mains).

(6) Modeling deterioration to forecast future failure rates and pipe residual life.

(7) Assessment of failure consequences (direct, indirect and social costs).

(8) Scheduling pipe renewal so as to minimize life-cycle costs while meeting or exceeding functional objectives of water distribution (quantity, quality, reliability, etc.)

2 Pipe Deterioration, Distress Indicators and Failure Modes

2.1 Overview of Distress Indicators and Failure Modes

Pipe condition is the cumulative effect of many factors acting on the pipe. Al-Barqawi and Zayed (2006) classified these factors into three categories: physical, environmental, and operational. The factors in the first two classes can be further divided into static and dynamic (or time-dependent). Static factors include pipe material, pipe geometry, and soil type, while dynamic factors include pipe age, climate, and seismic activity. Operational factors are inherently dynamic.

2.2 Distress Indicators for Major Pipe Types

Rajani et al. (2006) defined distress indicators as the observable/measurable physical manifestations of the aging and deterioration process. Each distress indicator provides partial evidence for the condition of specific pipe components.

It is noted that leakage could also be considered as a universal distress indicator regardless of pipe type (although the presence of a leak often indicates that failure has already occurred). Leakage out of pressurized water mains is not an acceptable public health risk and short-term pressure surges may pull contaminants into the pipe.

2.3 Inferential Indicators for Major Pipe Materials

Inferential indicators point to the potential existence of a pipe deterioration mechanism without actual knowledge if this potential has actually been realized. Many of the environmental indicators are inferential in nature, such as soil type, groundwater fluctuations, etc. It is important to note that inferential indicators do not provide direct evidence about pipe deterioration, but rather indicate the potential thereof.

3.0 Technologies for Condition Assessment of Water Mains

3.1 Nondestructive Testing and Evaluation

There are two types of observations to be made in the course of pipe condition assessment, namely observation of distress indicators and observation of inferential indicators.the observation of inferential indicators is always nondestructive and nonintrusive, the observation of distress indicators can be destructive or nondestructive as well as intrusive or nonintrusive. Destructive testing entails the removal of a sample from pipe wall to analyze remaining thickness, defects, damages, and residual strength.

Nondestructive testing (NDT) techniques (also commonly referred to as NDE) include the direct visual observation of defects such as cracks, corrosion pits or holes, as well as techniques that provide signals or signatures that are interpreted into distress indicators.

3.2 Pit Depth Measurement

Pit depth can be measured with a pointed micrometer or needle-point depth gauge. Other methods include a grid with ultrasonic spot measurement, automated ultrasonic scanner, and laser range measurement. The pit depth measurement can be carried out in the field on exposed sections of the pipe (for external corrosion) or in a laboratory on pipe samples (for external and internal corrosion).

3.3 Visual Inspection

The condition of the internal surfaces of the pipe can be assessed by a visual inspection. It may be done without specialized equipment or a variety of vision aids (e.g., closed-circuit television, videoscope, or laser-based surface profiler) may be employed to augment human vision.

3.4 Electromagnetic Inspection

3.4.1 Magnetic Flux Leakage

The magnetic flux leakage (MFL) method uses large magnets to induce a saturated magnetic field around the pipe wall. If the pipe is in good condition, a homogeneous distribution of magnetic flux is obtained. Anomalies such as metal loss will alter the distribution of the magnetic flux. Flux leakage is recorded by a detector coil. The pipe surface needs to be cleaned for direct contact with the MFL detection device.

3.4.2 Remote Field Eddy Current

A remote field eddy current (RFEC) system consists of an exciter coil and one or more detectors.The exciter coil is driven by a low-frequency alternating current signal.

3.5 Hydraulic Transient-Based Methods

Hydraulic transient-based techniques are also available to detect and locate existing leaks. The information regarding the presence of a leak is extracted from a measured transient trace.

3.5.1 Leak reflection method

The method is based on the principle of time domain reflectometry. A transient wave is reflected at the leak and can be identified in a measured pressure trace. The location of the leak can be calculated.

3.5.2 Inverse transient analysis

Least square regression is applied to the modeled and measured transient pressure traces. The minimization of the deviation between the measured and calculated pressures gives the leak location and size.

3.5.3 Impulse response analysis

The impulse responses of the same pipeline with and without a leak are compared. The presence of a leak will introduce the change of the impulse response.

4 Water Main Deterioration Models

Deterioration models of water mains can be classified into two main categories, physical (or mechanistic) models and statistical/empirical models.

4.1 Physical/Mechanistic Models

The physical mechanisms that lead to pipe breakage are often very complex and are not completely understood, but recent efforts look promising. These physical mechanisms involve several aspects including pipe-intrinsic properties (e.g., material type, pipe geometry, type of joints, quality of installation); loads (including internal loads due to operational pressure and external loads due to soil overburden, traffic, frost and third party interference); and finally material deterioration (due to external and internal chemical, bio-chemical and electro-chemical environment).

4.2 Statistical/Empirical Models

Statistical/empirical models quantify the structural deterioration of water mains by analyzing historical performance data. In small distribution water mains, this historical performance is manifested in observed breakage frequency. Historical performance of large transmission mains is usually measured on an ordinal condition rating scale.

5 Conclusion

As water mains age, they are increasingly exposed to continuous stress from operational and environmental conditions. These mains deteriorate structurally and hydraulically, adversely impacting water quality, leakage, and reliability. Effective management of these assets requires condition assessment, which includes the collection of information about their condition, analysis of this information, and ultimately transformation of this information into knowledge, leading to effective decision about renewal.

CHAPTER - 7

REFERENCES

References

1. A.Bergant et al. (2006): *Water Hammer With Column Separation: A Historical Review*, Journal of Fluids and Structures Vol. 22 Page No. 135-171.

2. A.Hoskins and I.Stoianov (2005) : *Infrasense – A Distribution System For The Continuous Analysis Of Hydraulic Transients*, Procedia Engineering Vol. 70 Page No. 823-832.

3. Abuiziah et al. (2013) "*Simulating Flow Transients in Conveying PipelineSystems by Rigid Column and Full Elastic Methods:Pump Combined with Air Chamber"* International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering Vol:7 No:12

4. Anton Bergant "*Dynamic Behavior of Air Valves in a Large-Scale Pipeline Apparatus"* Journal of Mechanical Engineering 58(2012)4, 225-237.

5. BS ISO 2531-2009 (E) for Ductile Iron Pipe.

6. B.Brunone et al. (2013): *The Characterization Of Milan Water Distribution System By Pumping Switching Off: Field Test Assessment* , Procedia Engineering Vol. 70 Page No. 201-208

7. Bong Seog Jung et al. (2007) "The Need for Comprehensive Transient Analysis of Distribution Systems" Journal American water works association.

8. Bong Seog Jung et al. (2009) *"Effect of Pressure-Sensitive Demand on Surge Analysis"* Journal American Water Work Association.

9. Dalius Misiunas (2008): *Failure Monitoring and Asset Condition Assessment in Water Supply Systems*, 7th International Conference of Environment Engineering.

10. Dalius Misiunas et al. (2005): *Burst Detection and Location in Water Distribution Networks*, water supply Vol. 5 Page No. 71-80.

11. Dr. Anees U Malik - *Water Transmission Line failure at Aziziyah plant*.July 1989. Research & Development Center. Saline Water Conversion Corporation, Saudi Arabia.

12. D.Sala and P.Kotakowski (2003): *Detection Of Leaks In A Small Scale Water Distribution Network Based On Pressure Data- Experiment Verification*, Procedia Engineering Vol. 70 Page No.-1460-1469.

13. H.E. Emara-Shabaik, Y.A. Khulief, and I. Hussaini (2002). "*A non-linear multiple-model state estimation scheme for pipeline leak detection and isolation*." Proceedings of the Institution of Mechanical Engineers Part I: Journal of Systems and Control Engineering, 216(6), 497-512.

14. H. F. Duan et al. (2013) : *Transient wave blockage interaction in pressurized water pipelines*, Procedia Engineering.

15. H. Fares & T. Zayed (2008): *Evaluating Water Main Failure Risk Using A Hierarchial Fuzzy Expert System*, Department of building, civil and environment engineering, Concordia University, Montreal, Quebec, Canada.

16. Hugh Chapman(2012) "*Development of a Successful Internal Leak Detection and Pipeline Condition Assessment Technology for Large Diameter Pipes*" Tamworth Regional Entertainment & Conference Centre, 27 to 29 March, 2012

17. IS 8329**:**2000 Centrifugally Cast Ductile Iron Pressure Pipes for Water, Gas and Sewage-Specification.

18. I. Abuiziah (2013) "*Controlling Transient Flow in Pipeline Systems by Desurging Tank with Automatic Air Control*" International Journal of Mathematical, Computational, Physical and Quantum Engineering Vol:7 No:12

19. I. Abuiziah et al. (2013) "*Sizing the Protection Devices to Control Water Hammer Damage*" International Journal of Civil, Architectural, Structural and Construction Engineering Vol:7 No:11

20. I. Abuiziah et al. (2013) "*Simulating Flow Transients in Conveying Pipeline Systems by Rigid Column and Full Elastic Methods: Pump Combined with Air Chamber*" International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering Vol:7 No:12

21. I. Abuiziah et al. (2014) "Comparative Study on Status and Development of Transient Flow Analysis including Simple Surge Tank" International Journal of Civil, Architectural, Structural and Construction Engineering Vol. 8 No:2.

22. J.A. Liggett, L.C. Chen 1994. I*nverse Transient Analysis in Pipe Networks*, Journal of Hydraulic Engineering 120: 934-55

23. J.P. Vítkovský et al. (2003). "*Leak and Blockage Detection in Pipelines via an Impulse Response Method.*" Pumps, Electromechanical Devices and Systems Applied to Urban Water Management, Valencia, Spain, 22-25 April, 423-430.

24. J. Zhang 2001. *Statistical pipeline leak detection for all operating conditions* Pipeline & Gas Journal: 42-5

25. J. Zhang et al. (2014) : *A Case Study On Risk Assessment Of Long Distance Water Supply System*, Procedia Engineering Vol 70 Page No. 1762 -1771.

26. K. Chambers, J. Creasey, L. Forbes, (2003) *Design and Operation of Distribution Networks.*

27. L. Berardi et al (2008) *"Devolopment Of Pipe Deterioration Models For Water Distribution System Using EPR"* journal of Hydroinformatics Vol. 10.2

28. L. Jönson and M. Larson (1992). "*Leak detection through hydraulic transient analysis.*" In: Pipeline Systems, B. Coulbeck and E. Evans (eds.), Kluwer Academic Publishers, 273-286.

29. Makar et al. (2001). Failure modes and mechanisms in gray cast iron pipe, *Underground Infrastructure Research; Municipal, Industrial and Environmental Applications,* Kitchener, Ontario,Canada, June 10-13, 2001, page 1–10.

30. *Manual on Water Supply and Treatment* – Central Public Health and Environmental Engineering Organization. Fourth Edition 1999.Ministry of Urban Development, Government of India Publication.

31. M. Basseville, and I.V. Nikiforov (1993). *Detection of Abrupt Changes: Theory and Applications*. Englewood Cliffs, NJ, Prentice-Hall.

32. M.G. Kirkwood, M. Karam, "*A Scheme for Setting Pipeline Inspection, Maintenance and Repair Priorities*", Pipeline Pigging and Integrity Monitoring Conference 11-14 April, Amsterdam.

33. N. Joukovsk (1898): *The Hydraulic Hammer On Water Supply Pipes,* English translate by O. Simmon (1904).

34. O. Giustolist, M. Mastrorilli (1989). *Optimal – Robust Design of Water Distribution Networks under Uncertain Scenario.*

35. Paul F. Boulos et al.(2005) "*Hydraulic Transient Guidelines for Protecting Water Distribution Systems*" Journal American water works association.

36. R. Puust et al. (2010): *A Review Of Methods For Leakage Management In Pipe Networks*, Urban Water Journal Vol. 7 No. 1 Page 25-45.

37. Reference from website : www.google.co.in

38. Reference from website : www.wikipedia.com

39. Roop Mukherjee, *Study On Water Transmission Pipeline Failures In India And Its Solution*, Department of Environment Engineering, Delhi Technological University, Delhi, July 2013.

40. R.S. Pudar, J.A. Liggett 1992. *Leaks in Pipe Networks*, Journal of Hydraulic Engineering, ASCE 118: 1031-46.

41. Rustabh R. Sabadra et al, (2014) "Surge Control : A Review" International Journal of Advanced Technology in Engineering and Science, Vol. 2 No.7

42. Srinivasa Lingireddy et al. (2004) "*Pressure Surges in Pipeline Systems Resulting from Air Releases*" Journal American water works association.

43. S.Y. Liong & Md. Atiquzzaman (2004) *Design of Water Distribution Network, using Shuffled Complex Evolution.*, Journal of the. IEI, Singapore Vol 44, Issue I Page 93 – 107.

44. Tan Wee Choon et al. (2012) "Investigation of Water Hammer Effect Through Pipeline System" International Journal on Advance Science Engineering Information Technology Vol. 2 No. 3

45. Water and Waste Water Engineering by Prof. S.K.Garg.

46. W. Mpesha, S.L. Gassman, M.H. Chaudhry 2001. *Leak Detection in Pipes by Frequency Response Method*,.Journal of Hydraulic Engineering, ASCE 127: 134-147.

47. Y. Kleiner and B. Rajani (2001). *Comprehensive Review Of Structural Deterioration Of Water Mains: Statistical Models*, Urban Water **3**(3): 131–150.

48. Zheng Liu et al. (2012) *Condition Assessment Technologies for Water Transmission and Distribution Systems*, National Risk Management Research Laboratory Office of Research and Development, U.S. Environmental Protection Agency, USA.