STUDY ON WATER TRANSMISSION PIPELINE FAILURES IN INDIA AND ITS SOLUTION

A PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE

OF

MASTER OF TECHNOLOGY
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ENVIRONMENTAL ENGINEERING

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CERTIFICATE

It is certified that the work presented in this project entitled **"Study on Water transmission pipe line failure in India and its solution"** by Roop Mukherjee, Roll No. 09/ENE/2010 in partial fulfillment of the requirement of the Master of Technology (M.Tech) in Environmental Engineering, Delhi Technological University (Formerly Delhi College of Engineering), Delhi, is an authentic record. The work is being carried out by him under our guidance and supervision in the academic year 2013.

The work embodied in this major project has not been submitted for the award of any other degree to the best of our knowledge.

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Last but not the least I convey my deepest love and thanks to my family for their support.

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DECLARATION

I, hereby declare that the work being presented in the Project Report entitled **"STUDY ON WATER TRANSMISSION PIPELINE FAILURE IN INDIA AND ITS SOLUTION"** is an original piece of work and an authentic report of our own work carried out during the period of 6th Semester as a part of my major project.

The data presented in this report was generated & collected from various sources during the above said period and is being utilized by the undersigned for the submission of our Major Project Report to complete the requirements of Master's Degree of Examination in Environmental Engineering, as per Delhi Technological University curriculum.

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CONTENT

LIST OF ABBREVIATIONS

AC	-	Asbestos Cement
BWSC	-	Bar Wrapped Steel Cylinder Pipe
BPS	-	Booster Pumping Station
CI	-	Cast Iron
Class K9	-	Pressure Class of Ductile Iron pipe
Cumec	-	Cubic meter per second
CWR	-	Clear Water Reservoir
DI	-	Ductile Iron
ESR	-	Elevated Service Reservoir
GLSR	-	Ground Level Service Reservoir
GRP	-	Glass Fibre Reinforced Plastic
HDPE	-	High Density Polyethylene
IRR	-	Internal Rate of Return
Kpa	-	Kilopascal
LCC	-	Life Cycle Cost
LICAN	-	Life Cycle Cost Analysis Model
PE	-	Polyethylene
PN	-	Nominal Pressure
RL	-	Reduced Level
RM	-	Rising Main
RPM	-	Revolutions per minute
RW	-	Raw Water
SBR	-	Styrene Butadeine Rubber
SCE	-	Scuffled Complex Evolution

SM	-	Service Main
SN	-	Nominal Stiffness
SUGR	-	Semi Underground Reservoir
TM	-	Transmission Main
UGR	-	Under Ground Reservoir
uPVC	-	unplasticised Polyvinyl Chloride
WSS	-	Water Supply Scheme
WTP	-	Water Treatment Plant

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Water transmission main plays an important role in a water supply system. They are the lifelines for human developments. As a matter of fact, with the depletion of water source in the vicinity of urban dwellings and industrial developments, long distance water transmission mains have become inevitable to transport water from sources located at far off distances. Failures of water transmission mains not only lead to wastage of precious water, but also the disruption of service has huge financial and social implications. Therefore it is imperative to design and choose appropriate piping system so as to ensure uninterrupted and sustainable water supply system to the consumers.

In this study a problem on water transmission main in Gadwal region of Mehboobnagar district of Andhra Pradesh has been analysed to provide a technical solution to the problem. Methodologies on pipe selection criteria have been evaluated to arrive at a proper approach for a holistic solution.

Case studies on similar type of problem in transmission mains in other parts of India has also been analysed to have a better understanding of the reasons for failure and the factors affecting the sustenance of the system. The cases of failure have been analysed using high end software like Hytran, SAP and customized MS Excel sheets. The model created in the software has been calibrated by incorporating field data, so as to ensure simulation of the system as to actual ground conditions. The analysis of the model has been done by simulating the probable modes of failure, like steady state analysis and transient analysis. The results generated was also analysed on the basis of material of pipeline used, type of jointing system adopted, protection devices being installed, number and type of pumping system, etc and many other factors comprising a water transmission system.

Further to analyzing the technical issues affecting the performance of a transmission main, it is imperative to understand the techno-commercial, economic, social and cultural factors which contribute to decision making towards implementation of a water supply system. Therefore the study attempts to formulate designs and systems on the basis of Life Cycle Cost Analysis, Ranking of pipelines on different parameters, Economic diameter selection etc. The systems developed will help engineers and planners in decision making towards selection of right piping system for transmission mains.

The study opens up scope for further research on performance of different pipe materials on different site and hydraulic conditions, condition assessment of the existing assets and performance evaluation of the assets already under use. Future research on the said topics will help in effective planning for future developments in water supply system, capital investment programme and preventive maintenance plan.

CHAPTER 1
INTRODUCTION

A water supply system primarily consists of a raw water intake station, from where raw water is pumped into the system. Thereafter physical, chemical and biological purification of raw water is done in a Water Treatment Plant. The treated water is then pumped to a primary storage reservoir, which is generally located near the area to be served. Further the treated water from the primary storage reservoir is either pumped to a secondary reservoir or a booster pumping station located at strategic location within the service area. From the secondary reservoir, the water is then pumped to elevated reservoirs, from where the water flows through gravity to the distribution network or pumped from a booster pumping station directly to the service mains feeding to the distribution network. The individual households are served through house service connections, tapped from the distribution network.

1.1 Components of water supply system.

A water supply system comprises of four primary processes. The processes are utilized to clarify the raw water from its physical, chemical and biological impurities and make fit for potable purpose.

1.1.1 Raw Water Intake Station:

The Raw Water intake station are structures constructed to intake raw water from Surface Source like, Rivers, tanks, lakes, lagoons etc. or from ground water source like aquifers, infiltration galleries etc. Water from the Intake station is pumped to Water Treatment plant through raw water Rising mains.

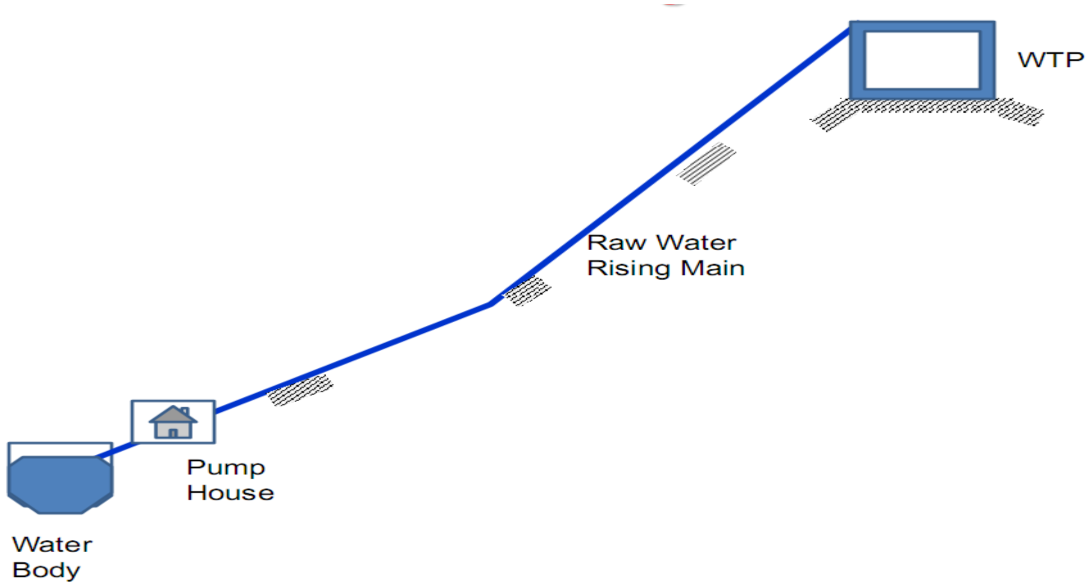


Figure 1.1 –Schematic diagram of Raw Water Rising Main.

1.1.2 Water Treatment Plant (WTP):

A conventional WTP consists of the following processes:

i. Screening Chamber – The screening chamber removes the floating and suspended organic matters from the raw water.

ii. Coagulation Chamber – In this chamber the raw water is mixed with Chemicals like alum to remove the suspended and colloidal impurities.

iii. Flocculation chamber – In this chamber the colloidal particles mixes with alum to form flocs. The floc settles in the bottom of the chamber in the form of sludge, which is then removed from the system.

iv. Filtration Units – In this chamber the finer particles like suspended fine particles, colloidal particles, biological impurities etc are removed either by Slow Sand Filtration method or Rapid Gravity Filtration method or Pressure filtration method.

v. Disinfection unit – The filtered water is disinfected from pathogens by Chlorine dosing or Ozone dosing.

vi. Potable Water Reservoir – The treated water finally is stored in a Clear Water Reservoir from where it is pumped to the distribution system.

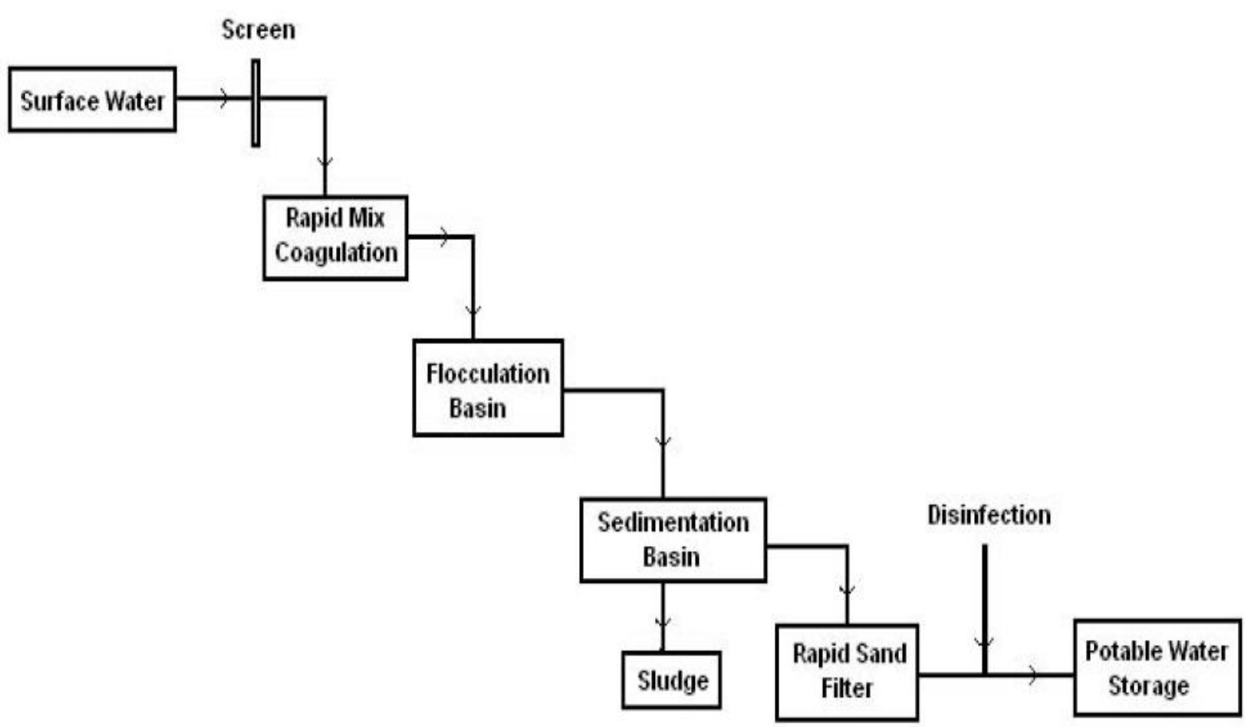


Figure 1.2 Flow diagram of conventional Water Treatment process.

1.1.3 Water Transmission System:

After the water is treated in a Water Treatment plant the Clear water is pumped either to a Elevated Service Reservoir (ESR) or stored in Semi Underground Reservoir (SUGR). ESR's are used for supply to smaller command area, where as for supply to larger command areas like in cities, Booster pumping Stations (BPS) are located besides the SUGR from where water is pumped to the distribution network.

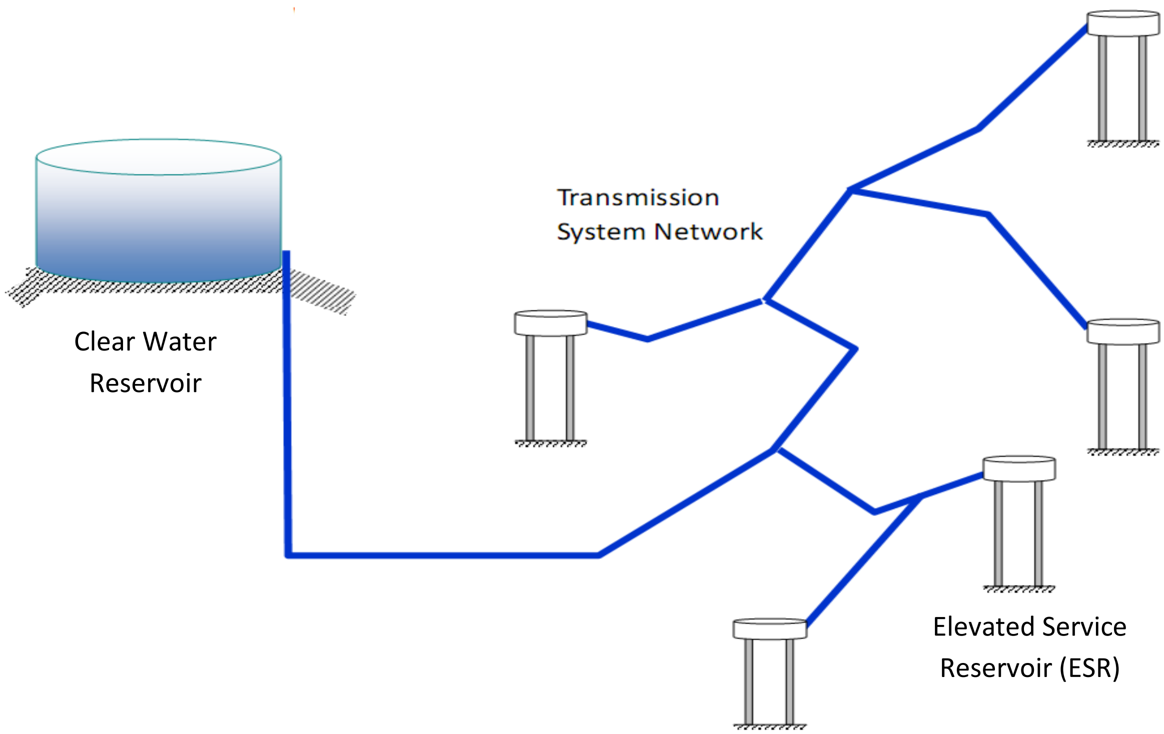


Figure1.2 Schematic layout of Water Transmission Systems

1.1.4 Water Distribution System:

From the ESR the water flows through gravity to the distribution system. In case of BPS, the water is either pumped to a Secondary transmission system to service far off areas or directly pumped to a distribution system situated near the booster pumping station.
The distribution pipe network is laid in the form of Grid system, Ring system or Branch system, depending upon the layout of the households. The individual households are connected to the service pipes through house service connections comprising of ferrule, stopcock, water meters, and service taps.

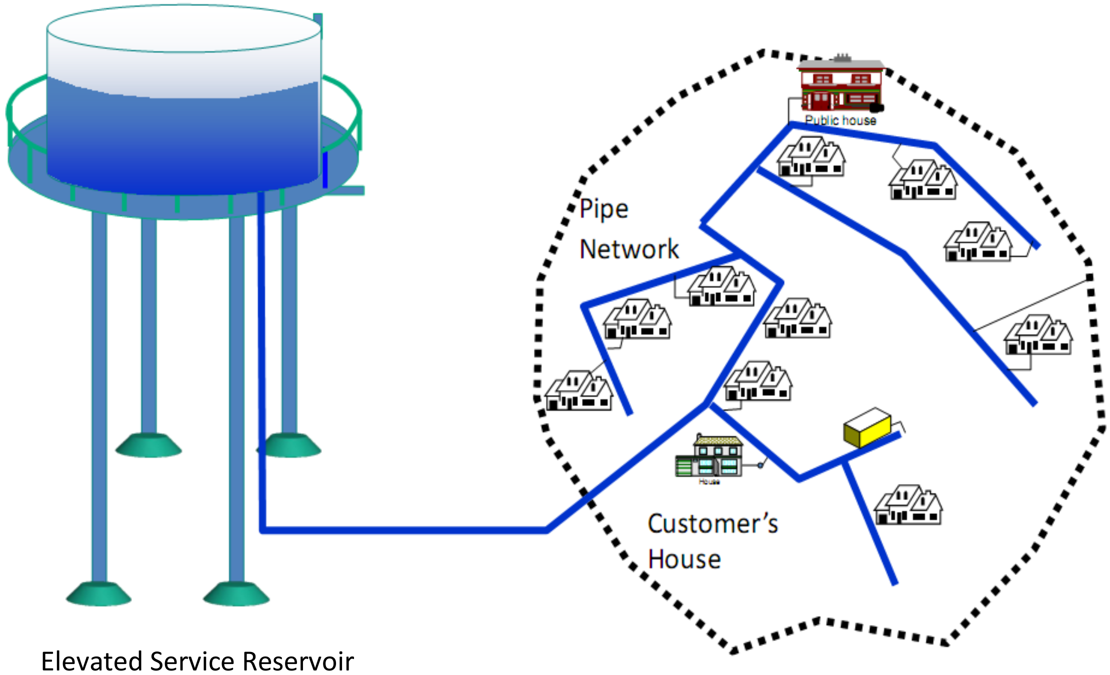


Figure1.3 Water Distribution Network

1.2 Role of pipeline in Water Supply System.

Pipelines are the conduit for transmitting water (Clear & Raw) from the Source to the Consumer. The pipelines comprise of 70% of the cost of the Water Supply system and hence are lifelines for any human settlements.

Hence, it is important to design a water supply system which fulfills the following criteria:

i) Hydraulically efficient–The system should transmit water at minimum operating cost.
ii) Durable - Water supply networks are designed for a service period of at least 30 years.
iii) Leak proof jointing system – The efficacy of the piping system depends on the effectiveness of the joints. Pipe joints are Rigid, flexible and semi Rigid. In whatever conditions the pipe lines are subjected to, there should be perfectly leak proof joints throughout the service life of the pipe. Leakage through joints contributes to maximum water loss in a Water supply system.
iv) Ease in Laying – Pipes should be flexible enough to be laid easily underground.
v) Having high structural strength- The pipelines should be able to withstand high dynamic stresses as well as external traffic loads and over burden pressure.
vi) Resistant to tampering and theft.
vii) Cost economics– The pipe line chosen should be cost economic in terms of basic cost of pipeline, laying cost, repair & maintenance cost as well as transmission cost of water.

1.3 The Project Area: CPWS Scheme for Gadwal town, Mehboobnagar distt, Andhra Pradesh.

A water supply scheme has been implemented by Public Health Engineering Department, Mehboobnagar district, Andhra Pradesh to supply water from the impounding reservoir of Jurala Dam to 122 villages in Gadwal area.

The Intake station has been built at the impounding reservoir of Jurala Dam. A Water Treatment Plant of capacity 15 MLD has been built near the Intake station. The CWR is located adjacent to the WTP. The distance of the WTP to the service area comprising of cluster of 122 villages is approximately 35 kms.

A nearby hillock, whose elevation is 90 m from the ground level, situated approximately 5 kms from the Intake station has been utilized for building a primary storage reservoir of capacity 30 Million Litres. The scheme of the water supply system is given in Fig 3.1 below;

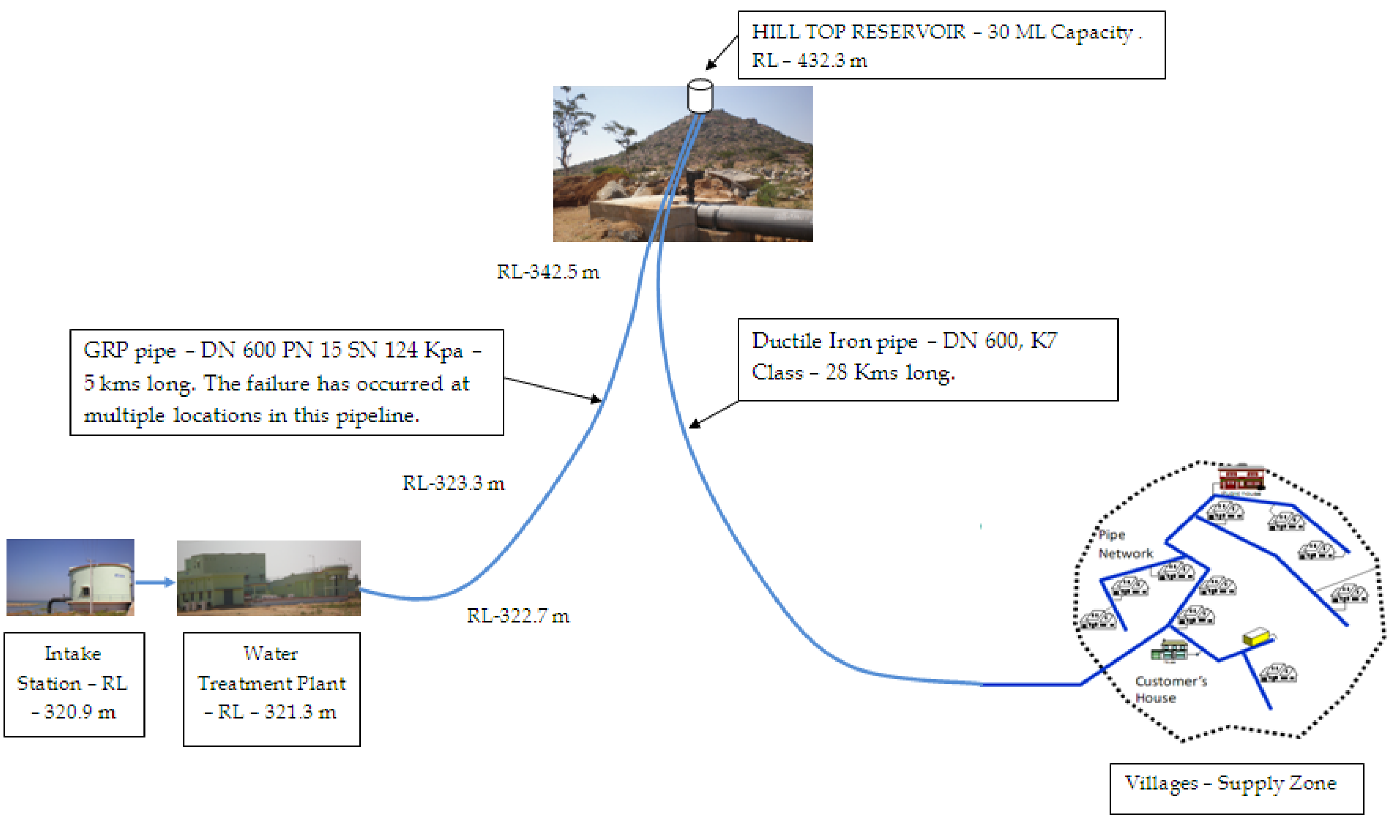


Fig 3.1 Schematic diagram of CPWS scheme, Gadwal town, Mehboobnagar District, AP

From the above figure it can be observed that the elevation of hill top reservoir has been utilized to ensure continuous water supply through gravity to the villages. The impounding reservoir is a huge source to meet the water demand. The WTP which has been newly built is a conventional type and is the right choice to treat good quality raw water available at the Jurala dam reservoir.

Table 1.1 Salient Features of Transmission system

Srl No	Features of the pipeline	Values
A	RISING MAIN DATA	
1.	No of rows of Rising main	1 no.
2.	Length of the pipeline	4735 meter
3.	Nominal Diameter of the pipeline	600mm
4.	Discharge through Rising main	0.282 cumec
5.	Pipe material used	Glass Reinforced fiber plastic (GRP)
6.	Pressure class of pipeline	PN 15 (15 bar)
7.	Stiffness Class of pipeline	SN 124 Kpa
8.	R.L at the pump end	321.3 meter
9.	R.L at the discharge end.	432.3 meter
B	PUMP AND SUMP DATA	
1.	RL of Low water level at Clear Water sump.	307.5 meter
2.	Number of pumps.	3 (2 working + 1 Standby)
3.	Rated discharge of each pump.	0.145 cumec
4.	Rated head of each pump.	138 meter
5.	Rated speed of pump.	1460 RPM
6.	NRV on each pump delivery.	500 mm diameter
7.	Discharge valve on each pump delivery.	500 mm diameter
8.	Pump torque at duty point.	168 kg.m
9.	Pump + Motor GD^2	23 $kg.m^2$

The clear water transmission main which was laid from the WTP to the Hill top reservoir was chosen to be GRP pipe of diameter 600 mm. The primary reason for choosing the pipe was low basic cost of the pipes compared to other available alternatives. The pressure class and stiffness of the pipeline was chosen after carrying out detailed design analysis.

The problem occurred when the pipe was being commissioned. It was observed that leakage occurred at various locations of the pipe, when it was subjected to pumping.
This lead to huge wastage of precious water resource. Moreover, the department was unable to commission the water network which was laid at a cost of not less than Rs 200 Crores for the benefit of villagers of Gadwal Area, Mehboobnagar district.

Thus the objectives of the study are:

i) To study the reasons for failures of water supply transmission main of the scheme as well as similar failures in other parts of India.

ii) An attempt has also been made to suggest an appropriate approach for designing and selection of proper pipeline for water transmission main.

CHAPTER 2
LITERATURE REVIEW

The focus of the literature review is to understand the design principles employed in designing of water pipeline system. Attention was given to understand the stresses developed in a piping network, with emphasis on transmission main. The reason for occurrence of transient stresses in a pipeline, its magnitude and effect was the primary focus of the study. To understand such stresses on different pipelines, it was imperative to study the characteristics of different pipe material, considering its material of construction, Finally, the economic aspect of the pipe selection procedure was of prime importance, and therefore it was necessary to study the techno commercial aspects involved in final decision making process towards selection of a pipeline.

2.1 Causes of failure in transmission main.

Not much data is available in the Indian scenario about the reasons for failure of transmission mains. However, the causes of failures in transmissions mains occurring globally can also be attributed to Indian condition also.

The primary reasons for failure of transmissions mains are given below;

2.1.1 Corrosion:

Corrosion is one of the main reasons for failure of pipelines. Various studies on corrosion and corrosion protection of pipeline suggest that deterioration of pipeline, especially for metallic pipelines, occurs due to corrosive effect of the soil surrounding it. Dr. Anees U Malik (1989) (1) has studied the corrosion on steel transmission main at Aziziah plant at Saudi Arabia. It has been found in the study that inspite of cathodic protection method was adopted to protect the cement mortar coated pipeline, the same was not enough to arrest the corrosion of the base metal of the pipeline because of high resistivity of the soil, development of micro cracks in the cement mortar coating and seepage of water through the cracks.

2.1.2 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.

Pipes do not deteriorate at a constant rate. During the initial period following installation, the deterioration rate is relatively slow. As pipes near the end of their life cycle, they begin to deteriorate more rapidly, dramatically increasing the repair and upkeep expenses.

In addition, the rate of deterioration of a distribution system is not solely a function of age, but rather a combination of factors including the characteristics of the water, soil conditions and climate.

In a paper by Zheng Liu, Yehuda Kleiner, and Balvant Rajani on Condition Assessment Technologies for Water Transmission and Distribution Systems (March 2012) (2) for United States Environment Protection Agency, they have categorized deterioration of pipes into two types i) Structural deterioration and ii) deterioration of internal pipe surface. They have also identified distress indicators for different type of pipes. They have elaborated the methods for discerning the distress indicators for condition monitoring of the pipelines.

2.1.3 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. According to them surge effect in a pipeline is caused due to various reasons. According to them the two major causes of water hammer or surge are:

a) The closing or opening, fully or particularly, of a valve in a pipeline system.
b) The starting up or shutting down of a pump flow.

Both of the above occurrences cause changes in the velocity and consequently in the quantity of water flowing in the pipeline, leading to water hammer.

Empirical relationship given by Chamber et al.(2000)(3) to assess the time of closure 't' for such pumps/ valves etc. is

$$t = \frac{2L}{a}$$

where, L = 'Characteristic' length of the network, m
a = Wave speed, m/sce. They have also guided that the value of 'a' depends on the pipe material and other factors. 'a' equals 300 – 500 m/s for a plastic pipe, 1000 – 1300 m/s for an steel pipe and 900-1200 m/s for asbestos cement pipe.

2.1.3.1 Types of Surge

Surges are of two types, viz., Positive surge and Negative surge.

Positive Surge: Positive surges are waves of pressure higher than the normal pressure level.

Negative Surge: Negative surges are pressure waves below the normal pressure level. Negative surges usually do not cause problem except when they cause water column separation. If it happens, extremely high positive surges result when the cavity closes and this may cause serious problem. Surge is normally most severe in high head pumping main.

2.1.3.2 Magnitude of Surge

Much of the literature has been contributed by the members of engineering profession on this subject. For calculating the magnitude of surge many theories and formulas have been proposed. Some of which are good within limits but most of which should be used with caution.

A list of formulae proposed by different persons for maximum pressure is given in table below;

Table 2.1: Different design formulae for maximum surge pressure

Name of the Formula	**Formula**
VENSANO	$h = \frac{2LV}{gT}$
WARREN	$h = \frac{LV}{g\left(T - \frac{L}{C}\right)}$
JOHNSON	$h = \frac{LV}{2g^2HT^2}\left[LV + \sqrt{4g^2H^2T^2 + L^2V^2}\right]$
FANNING	$h = \frac{LV}{gT}$
DE SPARRE	$h = \frac{2LV}{gT} \frac{1}{2\left[1 - \frac{LV}{2gTH}\right]}$

Where,
L = Length, V = Flow velocity, T = Closing time, H = Head, C = Max. wave velocity, h = surge pressure.

However, the elastic wave theory of N.Joukovsky (4) and L. Allievi (5) is the best proven and accepted one. According to Joukovsky, the pressure rise for instantaneous closure (h) is directly proportional to the fluid velocity (v) and to the magnitude of the surge wave velocity (c) and is independent of the length of the conduit.

CPHEEO manual on Water Supply and Treatment (6) has recommended the following expression for maximum surge pressure head above normal pressure as

$$H_{max} = \frac{CV}{g}$$

Where,

C = Velocity of travel of pressure wave $= \frac{1425}{\sqrt{1+\frac{kd}{ECt}}}$ m/sec

H_{max} = maximum pressure rise in the closed conduit above the normal pressure in m,

V = normal velocity in the pipeline, before sudden closure in m/s.

k = Bulk Modulus of water (2.07×10^8 kg/m^2)

E = Modulus of Elasticity of pipe material in kg/m2 (Ref. Table 2.2)

d = Pipe diameter in m.

Ct = Wall thickness of pipe in m.

g = Acceleration due to gravity in m/s^2 (9.8 m/s^2)

Table 2.2 below gives a list of Modulus of Elasticity for different pipe material as recommended in CPHEEO manual (6).

Table 2.2: Modulus of Elasticity of different pipe material (6)

Material	**E (kg/m2)**
Polyethylene – LDPE	1.2×10^7
Polyethylene – HDPE	9×10^7
PVC	3×10^8
Concrete	2.8×10^9
Asbestos Cement	3×10^9
Reinforced Cement Concrete	3.1×10^9
Pre-stressed Concrete	3.5×10^9
Cast Iron	7.5×10^9
Ductile Iron	1.7×10^{10}
Steel with flexible coating (otherwise same as concrete)	2.1×10^{10}

However Joukovsky equation acts only as an indicator and not considered very accurate since it does not consider the effect of length, type of terrain, no of bends etc. The ideal approach is, every individual pipeline where surge is anticipated should be examined critically as an individual case and accordingly remedial measures are to be taken. A number of software are available to estimate the most likely point and maximum intensity of water hammer will occur in a given pipeline once the L section, pump details, head etc. are known.

2.1.3.3 Consequences of water hammer.

Of the causes responsible for surge, sudden stoppage of pump is most critical. When power failure occurs pump comes to a stop in a time depending upon its rotating mass (WR^2); the quantity of water pumped into the main decreases rapidly. However, the water column in the rising main continues to move forward due to its own momentum, thus creating a pressure reduction in the main. A physical separation of water column may also take place depending on the alignment of the pipeline and magnitude of pressure reduction. The water column come to a rest slowly and then reverses itself. The velocity of column goes on increasing in the reverse direction. If this returning water column velocity is to suddenly reach to zero due to presence of a reflux valve, then the entire momentum of water column would be suddenly destroyed giving rise to very high surge pressure.

Surge pressure caused by re-uniting of water columns after separation is on many occasions responsible for bursts of pipes. The energy is divided between compressing the water itself and stretching the pipe walls suddenly increasing the internal hoop stress and if it goes beyond a certain limit the pipe may rupture. Successive positive and negative pressure waves are generated till the energy of the column is dissipated.

2.2 Optimisation of Investment

Various work done in the past on water network has produced outcome which is worth to be considered in designing a transmission main for a water distribution network. In this regard Giustolisi & Mastrorilli (1989)(7) has emphasised on the appropriateness of the large investment made for the implementation of the water network system. In their opinion it is supposed to be in the improvement and innovation of the procedures in order to gain in efficiency of the network system. A population based optimisation approach is taken in the system. The decision support system developed to solve a multi objective function is based on the following functions.

$$f_1\left(\sum_{i=l}^{pipes} C(d_{ij}, L_{ij} \right)$$

$$f_2 (h_i - h_{geodetics} - X)$$

where, d_{ij} = pipe diameter

L_{ij} = pipe lengths

C = Cost Constraints

X = Level of service constraints

h_i = head

$h_{geodetics}$ = elevation

Liong and Atiquzzaman(2004) (8) has studied development of a system that suggests the optimal pipe diameter of a network under EPANET environment. A Shuffled Complex Evolution (SCE) technique study, SCE is applied for the design of a cost effective water distribution network. The findings of the study show that in SCE the computation is much faster when compared with other widely used algorithms presently used is optimisation of distributions network. The optimal network design is quite complicated due to non-linear relationship between flow and head loss and the pressure of discrete variables such as market pipe sizes (Kessler and Shamir,1989)(9). In a paper on Analysis of water distribution system of Kolkata city (2006), Sovanbrata Chattopadyay (10) have studied the water network model in EPANET software by modifying the default algorithm to accommodate higher numbers of decision variables and the decision variables (Pipe Sizes) are converted to commercially available diameters in determining the cost of the network. The model selects the optimal pipe sizes in the final network satisfying implicit constraints (e.g. conservation of mass and energy) and explicit constraints (e.g. pressure head and design constraints). The hydraulic constraint, for example, deals with hydraulic head at certain nodes to meet a specific minimum value. If the hydraulic head constraint is violated, the penalty cost is added to the network cost. The hydraulic information obtained from the network solver is then passed to the SCE for computation of fitness of the design. The fitness of a trial solution representing a pipe network design is based on the hydraulic performance of the network. It consists of two parts 1) network cost and 2) penalty cost.

The network cost is calculated as the sum of the pipe costs where pipe costs are expressed in terms of cost per unit length. Total network cost is computed as follows:

$$C = \sum_{k=1}^{N} C_k (D_k) L_k$$

Where, $C_k(D_k)$ = cost per unit length of the k^{th} pipe with diameter D_k .

L_k = length of the $k^{th.}$ pipe and,

N = Total number of pipes in the system

The penalty cost is based on the degree of pressure head isolations. The penalty functions may be defined, for example as,

$$C_1 = P*C_{max} * Max\,(H_{min} - H_i)$$

If the pressure is less than minimum limit and greater than zero or,

$$C_1 = 2* P*C_{max} - 2* C$$

If the pressure is less than or equal to zero.

Where, P = penalty cost coefficient

C_{max} = maximum possible cost that is calculated based on largest commercial pipe available

$(H_{min} - H_i)$ = maximum pressure deficit, which is the difference between the required head (H_{min}) at each node and the head found after simulations (H_i). If the pressure head is greater than the minimum required limit, no extra cost is charged to the network cost. Thus the minimised cost of the distributions network is calculated by the summarisation of Network Cost and Penalty Cost

C = actual network cost.

Thus the minimised cost of the distribution network is calculated by the summation of network cost and penalty cost.

The above mentioned model and equations are applicable for designing of water distribution network, however the study guides us in formulating an approach towards designing a optimized model of transmission mains having several branches emanating from it.

2.3 Life Cycle Cost Analysis Approach - Choosing the best suitable pipeline amongst available alternatives.

With so many years of experience, water authorities have experienced with direct and indirect cost implication that are necessary to be considered while design of water supply systems. It is very essential that **life cycle cost** of the water supply system while arriving suitable pipe diameters and proper pipe material selection. Michael Ambrose et al on their paper on Life Cycle Analysis of Water Networks (11) have given details on the parameters to be considered for selection of pipes.

In their paper they have described about **Life cycle cost prediction of pipelines** in their Life Cycle Cost Analysis Model (LICAN).

The LICAN model calculates potential future costs for the collection of pipe assets over a defined forecast period (typically one hundred years). The model predicts failures and interruptions on a year by year basis, replaces any selected pipe assets, and then moves on to the next year in the forecast period and repeats the process on the updated asset set.

The cost calculations include:

- Installation cost – During the first few years of the planning period assets are added to the network as the system grows. The cost per foot associated with the new material and diameter is multiplied by the length to give the installation cost for the asset.
- Repair cost – The specified cost of a repair event plus any length replaced. The event cost is multiplied by the fractional number of repair events expected in the given year to generate the total repair cost for the asset for the given year.
- Leakage cost - The model calculates background leakage from joints. The volume of water lost by the asset is then multiplied by the unit leakage cost (per 1000 gallons) to determine the leakage cost.
- Replacement cost – An asset is replaced when the prediction of the total discounted repair costs for the asset is greater than the cost of replacing the asset and experiencing a (presumed) lower rate of failures (and repairs) into the future. The period for which these calculations are done is entered in the program as the "discounting time span". If in a given year the asset is not replaced, then the replacement cost will be zero.

Other costs like pumping cost, corrosion cost, customer rebates etc are not included in the calculations.

American Concrete Pipe Association (12) in their Design data 25, Kyle Haas (13) in her paper on Lifecycle Cost and Performance of Plastic Pipelines in Modern Water Infrastructure have elaborated on the following approach.

1. Revenue loss due to leakages,
2. Maintenances and repairs cost and
3. Pipe replacement costs for short lived pipe material over project life (30 Years) with consideration of inflation which is inevitable. Formulation of calculation of present worth with inflation is as follows. The rate of interest and rate of inflation to be calculated as per current market rates.

From the literature survey it is evident that research work on the failures of transmission main has mostly been done outside India. Hence, the Indian factor towards failures of such pipes could not be ascertained. Moreover, the approaches on selection of piping system as mentioned in the literatures are guidelines and recommendations.

CHAPTER – 3
METHODOLOGY AND APPROACH

The reasons for water transmission failure in India have been derived through a systematic evaluation of the site condition and the systems used in the project.

3.1 Water Transmission System Evaluation Procedure

The evaluation of a water transmission system consists of an in-depth analysis of the following basic elements:

- The performance of the pumping station.
- Data collection of flow and pressure at the pumping station as well as strategic location of the rising main.
- Operational aspect of the system.
- Detailed investigation of the material and type of pipeline used.
- Evaluation of the pipe laying methodology being practiced for the project.
- Evaluation of the efficacy of the protective devices being used, like Air valves, Non return valves, surge protection devices etc.

Information and data for each element are gathered and analyzed in four interrelated phases, namely

i) Preparation of site visit
   Preparation for site visit includes compilation and review of information which provides a description of the water supply system's physical settings, previous records etc.

ii) On-site Inspection
   On-site Inspection includes interaction with Operating Personnel, Chief Engineer, Site Manager, Consultants and review of records & data.

iii) Problem Identification
   The first step in problem identification and evaluation is to determine if the pumping system and the transmission main is meeting the design parameters, by comparing the flow and pressure data at which the system is designed to that actually occurring at site. The help of softwares to simulate and analyse the problem has been taken.There are several softwares available in the market for analysis of transient stresses developed in a pipe line, like

   a. KY pipe developed by Dr. John Wood and Dr. Srini Lingireddy.

b. Hytran V 3.7.2 developed by Dr. Norman Lawgun.

c. Bentley Hammer V8i developed by Bentley Systems.

d. SAP – Developed by IISC, Bangalore, India.

Apart from the above software, customized solutions can be achieved by developing algorithms with the help of established formulae.

It is to be noted that the results provided by the software should only be interpreted only as guidance. It is the experience and understanding of the piping system of the designer, which shall be effective to provide a comprehensive solution to the problem.

For the problem in this project, the help of Hytran Solutions, SAP software has been taken to find out an optimal solution. A brief description of the software used is given in Annexure –I.

3.2 Approach to mitigate the problem.

A dual approach methodology has been deployed to mitigate the problem.

Firstly, a technical solution to the problem is arrived to rehabilitate the transmission main with appropriate pipe material and type. To come to a solution it is necessary to evaluate the stresses (both internal and external) acting on the pipeline, which is causing failure. A model has been prepared in Hytran software with inputs from the field data. The model is then run to simulate the Steady and Transient flow conditions.
To ascertain whether the model is simulating the right conditions, it is calibrated with field data (in this case the pressure gauge readings in strategic locations of the pipe line). Further, it is mentioned that an independent analysis of the pipe failure was done by a consultant using SAP software. The result of the report was studied in details and results evaluated. Finally, the results generated by the Hytran model was compared and corroborated with the field results and consultants report.

Secondly, to find a holistic solution to the problem, it is imperative to look beyond the technical failure of the pipeline. It is imperative to understand as to what the factors which govern the decision making process during selection of a pipeline.
The factors can be classified as:
a) Technical factors: These are factors which determine the technical suitability of the pipeline in terms of;

i) Mechanical strength like tensile strength, yield strength, bursting strength, stiffness, bending strength, hoop strength etc.

ii) Hydraulic efficiency like smoothness of the internal surface of the pipe (C value, friction factor, etc.)

b) Durability factors: These are factors which contribute to the Useful Service Life of the pipeline like;

i) Corrosion and its protective measures.

ii) Resilience to fatigue stress.

c) Ease in laying the pipes: These factors are predominant while choosing a pipeline as several hindrances have to be taken into account during laying work in different site conditions. They are;

i) Flexibility of the pipe material.

ii) Type and flexibility of the jointing system.

iii) Ease in handling – The weight of the pipe plays an important role.

d) Availability factors: The proximity of the manufacturing unit and the availability of the requisite size and quantity from the same is also an important factor because it has bearing on the transportation cost of the pipeline. Apart from the pipes, the availability of fittings and appurtenances are also play an important role towards choosing a pipeline.

e) Maintenance factors: Decision makers look for a pipeline which are hassle free, fit and forget type. To ensure such maintenance free installations, the availability of quick repair fittings and the ease in repair works is considered. Now a days, even resistance to tampering by miscreants are taken into priority.

f) Cost factor: Last but not the least, the cost economy aspect of an installation is one of the prime guiding factors towards decision making.

Based on the above factors, CPHEEO Manual on Water supply and Treatment (6) has identified twenty one (21) parameters for ranking of pipelines on a 10 point scale. A programme of MS Excel has been prepared on the guidelines of CPHEEO to measure the performance of different pipe materials on a 10 point scale. For example, the Hydraulic smoothness of different pipes are evaluated on a 10 point scale on the basis of Hazen Williams C Value (friction factor) ascertained to the pipe internal surface by an authentic source (Hazen Williams C value for HDPE pipe is considered 145 and that of Cement mortar lined Ductile Iron pipe is considered as 140). Similarly the structural strength (internal) parameter is evaluated on a 10 point scale, for different pipes on the basis of tensile strength of the pipe material (Tensile Strength of Ductile Iron pipe is 4200 kg/cm2 and that of HDPE pipe is 280 kg/cm2).

b) Condition Assessment of Water Supply system Assets: It is recommended in Manual for Water Supply & Treatment, CPHEEO, that pumping system should be designed for 15 years whereas the pipeline system should be designed for 30 years. However, it is a fact that for a developing country like India, the pipe line serves for more than 50 years.

Condition assessment of the buried assets is important to ascertain the useful life of the pipeline. In India not much data is available on the condition of assets which has been serving the system for more than 30. Therefore, it is difficult to ascertain the performance of different types of pipe material and their condition in Indian scenario. The condition of the pipeline was assessed by using physical inspection of the exposed pipeline and analyzing the failed pipe portion kept aside for testing.

Ambrose et al on their paper on Life Cycle Analysis of Water Networks (11) has suggested on selection of piping system by comparing the capitalised cost incurred during the useful service life of a pipeline, accordingly a programme on MS Excel has been prepared to compare the life cycle cost of different pipe materials with different diameters.

The basic inputs in the programme are as follows:

i) Basic price of the pipelines to be compared.
ii) Laying price of the pipelines, including the bedding requirements is taken into account.
iii) The Design Useful Service life of pipeline.
iv) The frequency of leaks and the estimated cost of leakage.
v) The repair and maintenance cost of a pipeline.

The results thus obtained in a tabular form as well as in a graphical representation, enable a designer to make a right choice towards selection of piping material for the project.

CHAPTER - 4
RESULTS AND DISCUSSIONS

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.

4.1 Results:

To simulate the flow conditions of the pipeline, it is essential to create a model of the system in the software. The longitudinal profile had accordingly been drawn from the survey data available at site.

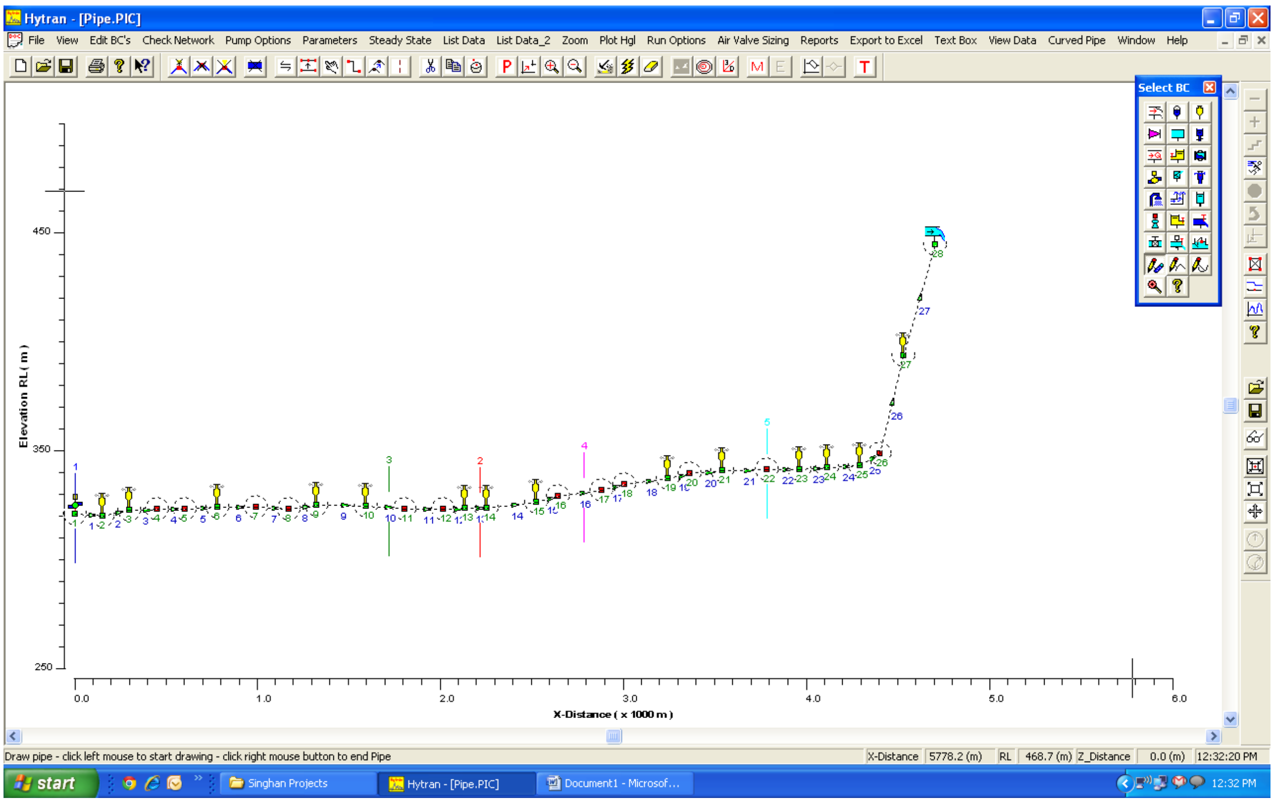


Fig 4.1 – Profile of transmission main from pump house to the elevated reservoir.

Fig 4.1 reveals that the pipeline follows a fairly gentle gradient upto a length of 4.0 kms from the pump house, thereafter it takes a steep slope to rise up to the hill top reservoir. The level difference at the final stretches of the pipeline is 90 meters.

As mentioned earlier, the pipeline used for the transmission main is Glass Fibre Reinforce Plastic pipe of size DN 600 with mechanical parameters like, Pressure class PN 15, Stiffness 248 kilopascals. The details of GRP pipe is mentioned in Annexure II attached.

The analysis of the transmission has been done in Hytran software, where the following type of analysis is done.

A system is said to be in steady state, when many of its properties does not change with time. In case of flow through pipes, in a steady state, the quantity of flow (discharge), velocity of flow, pressure at a given point, viscosity, etc do not change with time. A steady state flow is not achieved until sometime after the system is stared or initiated. A summary of the results is given below:

Table 4.1 Results obtained from Steady State analysis in Hytran software.

Chainage (in m)	Pressure in 'bar'	Pressure in head of water (m)
0	12.84	125.96
600	12.51	122.7
1200	12.44	122.01
1800	12.44	122.08
2300	12.48	122.47
2800	11.93	117.05
3300	11.11	108.98
3900	10.68	104.73
4400	10.48	102.77
4670	0.20	2.00

Table 4.1 represents the steady state pressure is maximum at 12.84 bar near the pump end and then gradually reduces to outfall pressure of 0.2 bar at the hill top reservoir inlet.

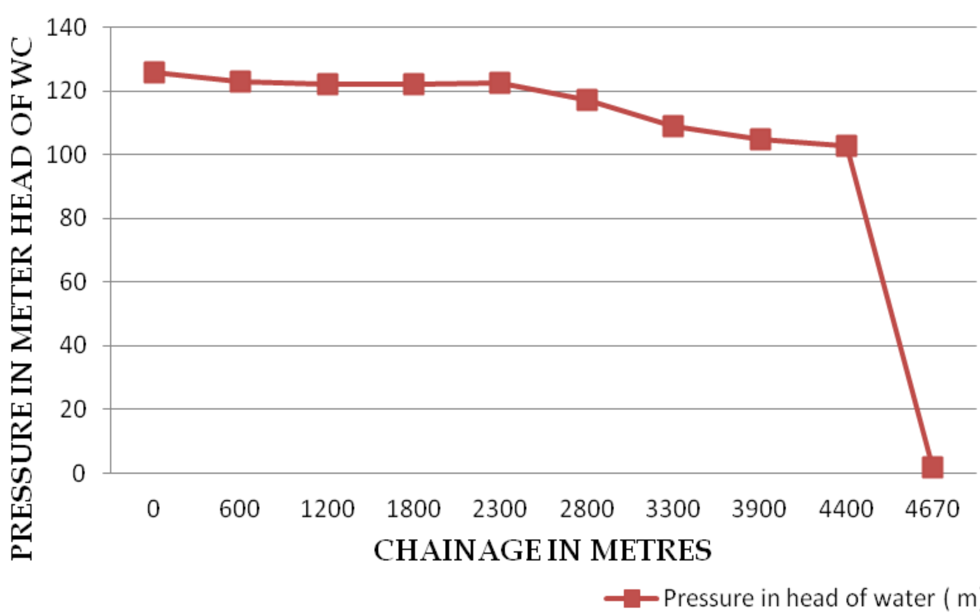


Fig 4.2 Graph showing steady state pressure after analysis in Hytran software.

From Fig 4.2 it can be observed that the that the pipe line is subjected to a steady state pressure of maximum 12.84 bar (or 125.96 metres of water column) which reduces gradually to around 10 bar upto 4.4 km length thereafter the pressure in the pipeline reduces rapidly to the residual pressure of 0.2 bar (or 2.0 metres of water column).

Once the pipeline is analysed for a steady state solution, it is imperative to analyse 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.

Transient flow analysis had been done by incorporating all parameters on surge protection device being adopted at site. The figure below shows a graphical representation of the analysis being done.

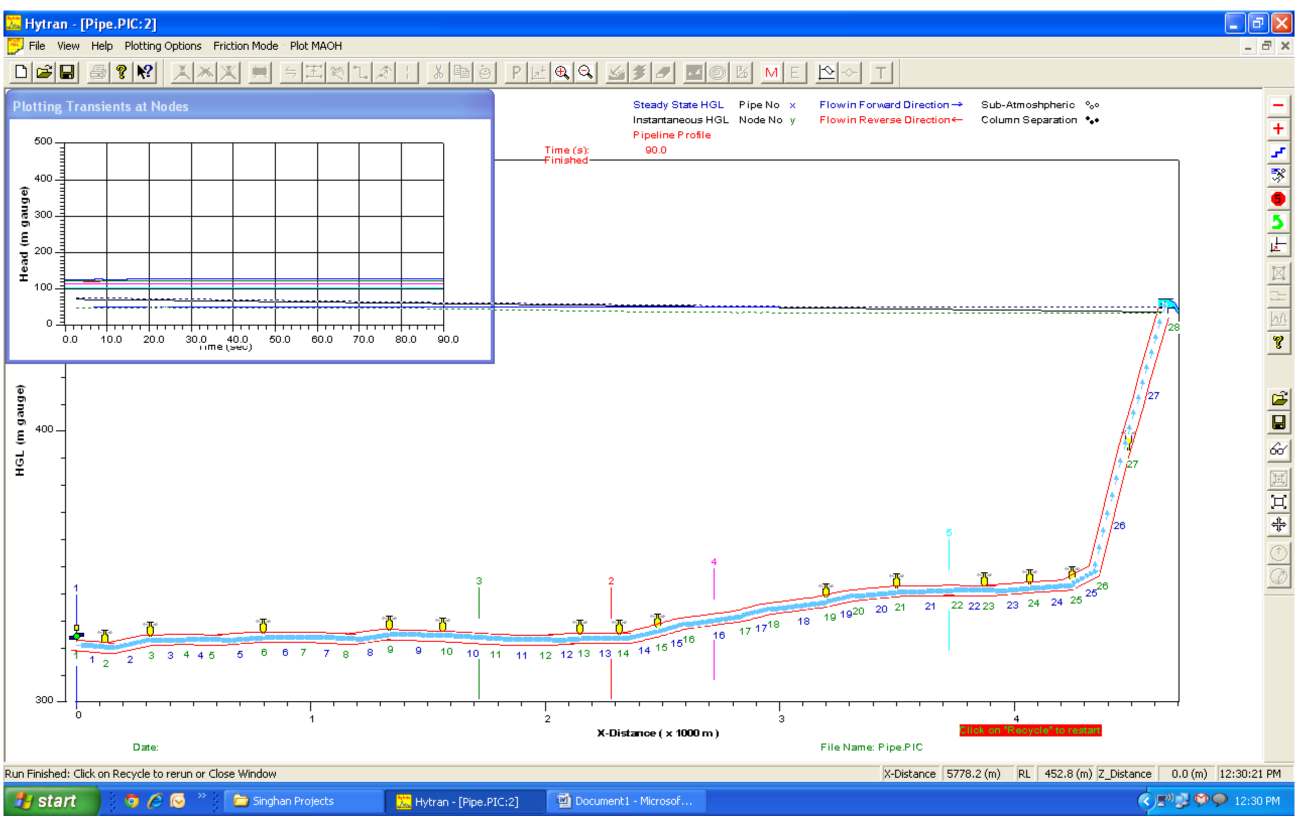


Fig 4.3 – Graphical representation of transient forces on the pipe analysed in Hytran.

From the above figure it is evident that the pipeline is not subjected to any negative pressures due to surge nor there is any abrupt fluctuation in pressure at strategic locations marked as 1,2,3,4,5 in the figure above. The graph at the top corner shows the pressure developed in the strategic locations of the pipe. The straight line in the graph there is a smooth transition of pressure in the pipeline. The blue colour on the pipe profile shows that the pipe line is subjected to minimal variance in pressure and there is no occurrence of water hammer being created during the operation of the pipeline.

The Hytran software provides node wise report of the analysis which is given in tabular form below.

Table 4.2 Results obtained from transient state analysis in Hytran software.

Chainage (in m)	Pressure in 'bar'	Maximum transient Head (in m)	Pressure in 'bar'	Minimum transient Head (in m)
0	13.09	128.4	12.69	124.5
600	12.80	125.6	12.49	122.5
1200	12.66	124.2	12.41	121.7
1800	12.59	123.5	12.35	121.2
2300	12.59	123.5	12.33	121
2800	11.99	117.6	11.72	115
3300	11.11	109	10.89	106.8
3900	10.67	104.7	10.45	102.5
4400	10.48	102.8	10.24	100.5
4670	0.20	2	0.00	0

Table 4.2 represents the maximum and minimum pressure generated at nodes. From the graph it can be observed that the variance between maximum and minimum transient heads is below 3 %. Hence it can be safely inferred that the pipeline almost attains steady flow condition.

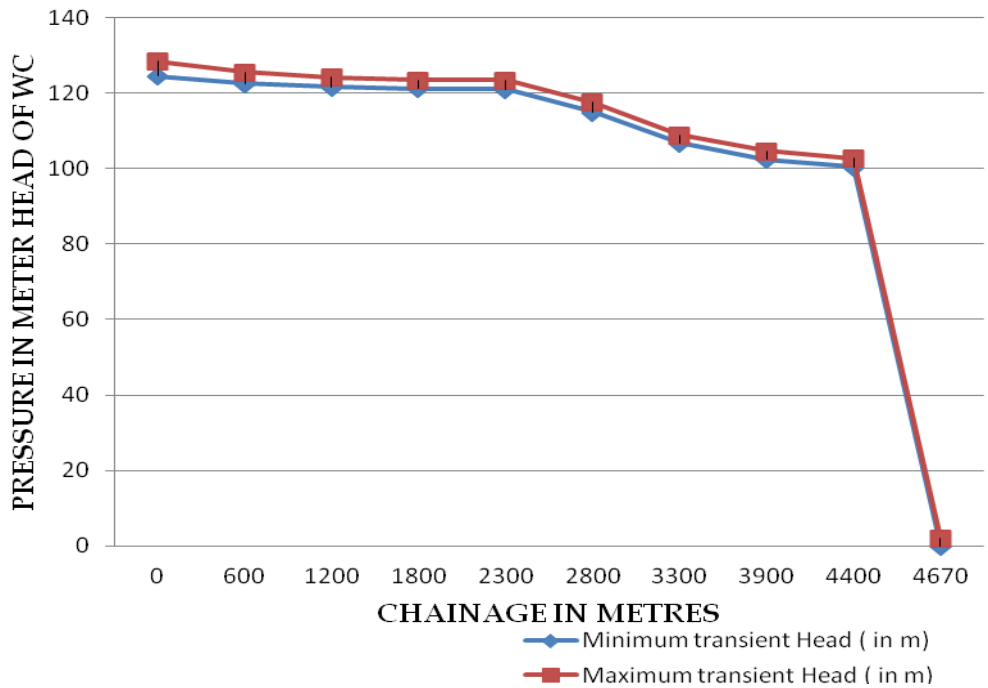


Fig 4.4: Maximum and minimum transient pressure after analysis in Hytran software.

In the Fig 4.4 it can be observed that hydraulic transient stresses has been generated in the pipeline immediately after starting of the pump. From the graph it can be inferred that the dynamic stresses developed in the pipeline is predominant at the pumping end and decreases gradually along the length of the pipeline upto a distance of 4.4 kms from the pumping end. Thereafter there is a sharp drop in the pressure of the pipeline as the pipeline traverses the steep gradient upto the hillock, where the Over ground reservoir is located.In the analysis of the pipeline in Hytran software it has been observed that the maximum pressure developed in the pump end is 13.09 bar (128.04 metres of water column) and the corresponding minimum pressure is 12.69 bar (124.5 metres of water column).

The results generated from the Hytran software was validated by readings taken from the site. In this case Pressure guage readings at selected locations of the pipe were taken. **It is mentioned that the results obtained during field test is instantaneously recorded, because once after the pipeline was subjected to the pressures given below, immediate rupture of a portion of pipeline occurred, leading to sudden drop in the pressure.**

The pressure recorded in the table below is corresponding to transient flow conditions in the pipeline as the failure of pipeline happened within 5 minutes of start of the pump.
We therefore can assume that the pipeline was subjected to maximum transient pressure during the short duration of commissioning of pipe.

Table 4.3 Pressure guage readings in field prior failure of the pipeline.

Srl No	Location in the field (Chainage in metres from Intake point)	Pressure Guage readings in 'kg/cm²' (bar)	Pressure guage reading in head of water (metres)
1.	0.00	12.5	125
2	1200	12.0	120
3	1800	12.0	120
4	2800	11.5	115
5	4000	10.5	105

Table 4.3 represents the onsite recording of instantaneous pressure in the pipeline recorded from pressure gauges installed at the given chainages. Bourdon type pressure gauges were installed to take the readings. The readings were recorded by visual observation by field staff positioned at the respective chainage point. From the pressure readings we can observe that the pipe was subjected to stresses which were within the permissible range of the design strength of the GRP pipeline.

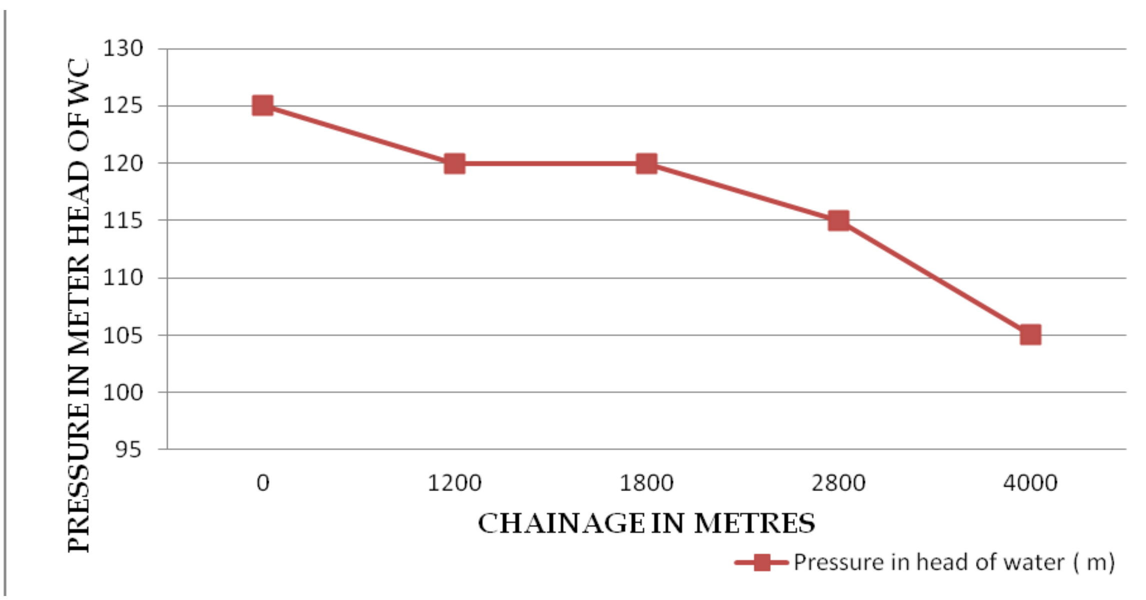


Fig 4.5: Graph showing field pressure as recorded prior to failure of pipeline.

From the pressure readings at site, it is observed that the readings almost coincide with the results as obtained from model analysis. The slight variation in the field readings from that of the model is negligible and can be attributed to variance due to human error or instrumental error.

4.2 Discussions

From the results available after analysis it is observed that the pressure generated in the pipe line were well within the permissible Working pressure of the GRP pipe (PN 16 – Permissible Working pressure – 24 N/mm2).

It is imperative to understand the reason for the failure of pipes.
As a field investigation process, we have excavated the GRP pipes laid for the project and physically examined the condition of the pipe being used.

It is also mentioned that the laying of pipe was done almost 24 months before the pipe was commissioned. The pipe remained unused and empty for such period of time. The time factor towards deterioration of pipe, should also be considered in these type of cases.

The photographs of the GRP pipe at site as shown below, clearly indicates that the basic structure of the pipe material and its composition has deteriorated as a result the pipe is unable to withstand the design pressure on the basis of which it is manufactured.

Fig 4.6: Photograph showing leakage in repaired GRP pipeline.

Fig 4.7: Photograph showing cracks in pipe wall due to presence of sharp object in the surrounding.

Fig 4.8: Photograph showing disintegration of GRP fibers subjected to high internal pressure.

From the detailed analysis of the pipe failure, it can be inferred that the failure of the GRP pipeline in the above project can be for the following reasons;

- The pipe material has disintegrated with time, leading to reduction in pressure rating from 15 bars to below 10 bars. The pipes have leaked at 12 bar pressure during hydro test at site.
- No special embedment of the pipeline had been provided as GRP pipe requires compacted embedment after laying with special backfill.
- Deflection of the pipe at the joints might have occured due to overburden pressure leading to leakage.
- The GRP pipeline was unable to bear the transient pressures developed in a pumping main.
- Repair works were not done with skilled manpower or with proper repair materials.

To understand the failure in transmission main in other parts of India, detailed case studies on different projects in India had been done.

4.3 Case Study No 1 – Failure of Transmission Main for Markapur Water Supply Scheme in Andhra Pradesh.

In this project the twin transmission pipe had to pass through a fairly undulating terrain where the where the ground level varied from a maximum RL of 154.5m to minimum RL of 126.8m.

The Salient features of the transmission pipe line are given in the table below:

Table 4.4: Salient features of transmission main (Markapur WSS)

Srl No	Features of the pipeline	Values
A	TRANSMISSION MAIN DETAILS	
1	No of pipe lines	2 (two)
2	Length of the pipeline	28200 meter
3	Nominal Diameter of the pipeline	450 mm
4	Type of pipeline proposed	GRP
5	Class of pipeline	PN 12.5 kg/cm2
6	RL at the Pump end	127.15m
7	RL at the discharge end	154.52m
B	PUMPING DETAILS	
1	Discharge through twin pipeline (Pumping main)	188 cum /hr
2	Rated Head of pump	59 MWC
3	Rated pump speed	1475 rpm
4	Efficiency of pump	75%
5	No of pumps	2 Working + 1 Standby.

The Table 4.4 shows that twin pipelines have been used to pump the required discharge. The level difference between the pumping end and the discharge end is 27.37m in a length of 28.2 kilometers, which is quite gentle and common in case of transmission main. However, it was been observed that failure at sixteen locations on the pipeline has occurred after commissioning of the pipeline. To understand the failures, it was imperative to create a model of the pipeline in Hytran software so that steady state and transient analysis can be done.

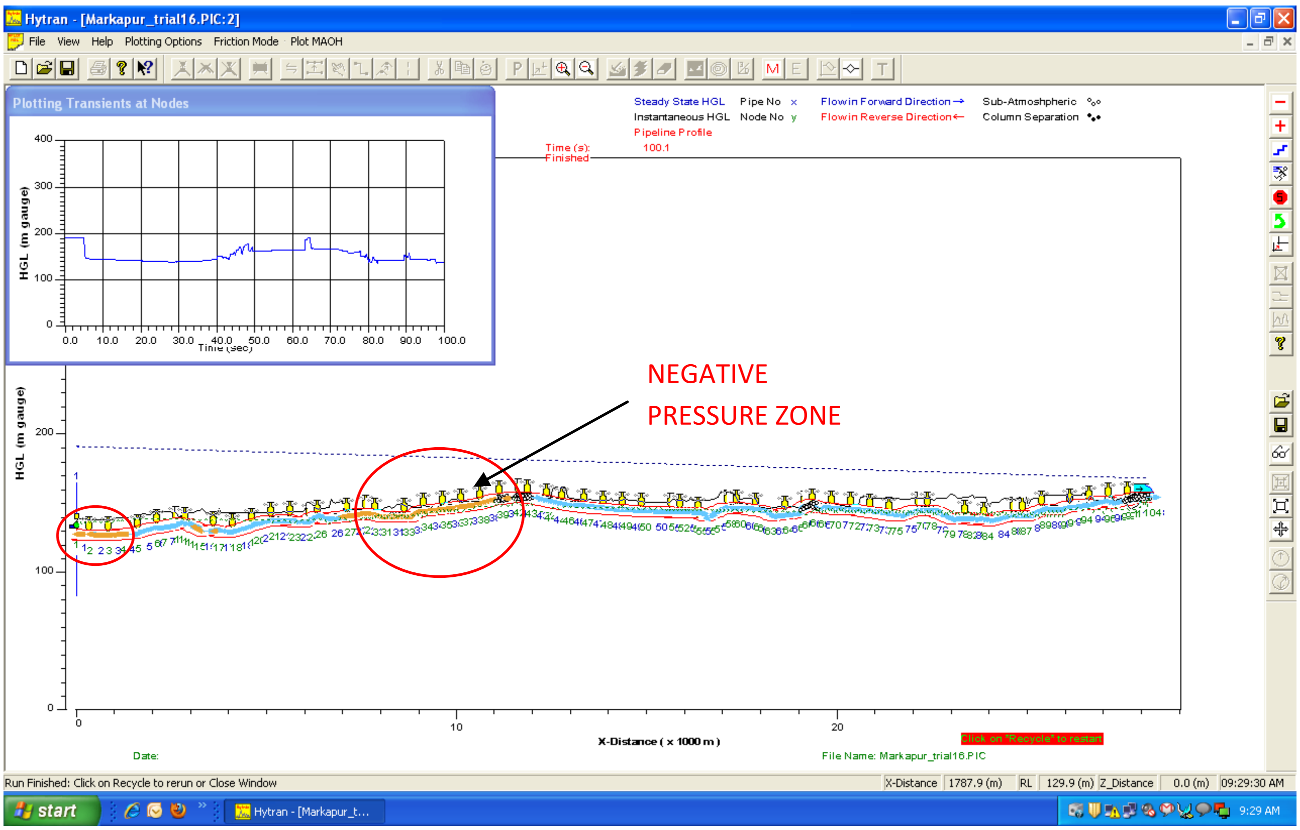


Fig 4.9 Transient analysis of Markapur Water Transmission main in Hytran software.

From the Fig 4.9 it is evident that during running of the pumps transient flow comes into play in the pipeline, which creates fluctuating pressures in the pipeline. From the results obtained from the analysis it is observed that the pipeline is subjected to maximum pressure of 6.4 kg/cm2 and a minimum pressure of - 0.45kg/cm2. From the Fig 4.8 it can also be observed that negative pressure zones are formed at few locations along the pipeline.

As a conclusion it can be inferred that the reason for failure of the pipeline can be for the following;

- GRP pipes which are composite pipes are more susceptible to negative pressures and hence the failure occurred at such negative pressure zones.

- Proper embedment of the pipe is an important feature during laying of GRP pipes. The strength of the pipe is greatly enhanced by proper compaction of the surrounding soil embedding the pipeline. Inadequate compaction of the embedment soil may lead to failure of such pipe at different locations.

4.4 Case Study No 2: JC Nagi Reddy Drinking Water Supply Scheme, Ananthapur, Andhra Pradesh.

In this project DN 1000mm diameter GRP pipes were used as transmission main to carry water from Ground Level Service Reservoir (GLSR) to feed to a network of pipelines located at approximately 30 kms from the source. The elevation of the GLSR is 92 metres above the supply zone. Hence, the pipeline was designed for gravity flow.

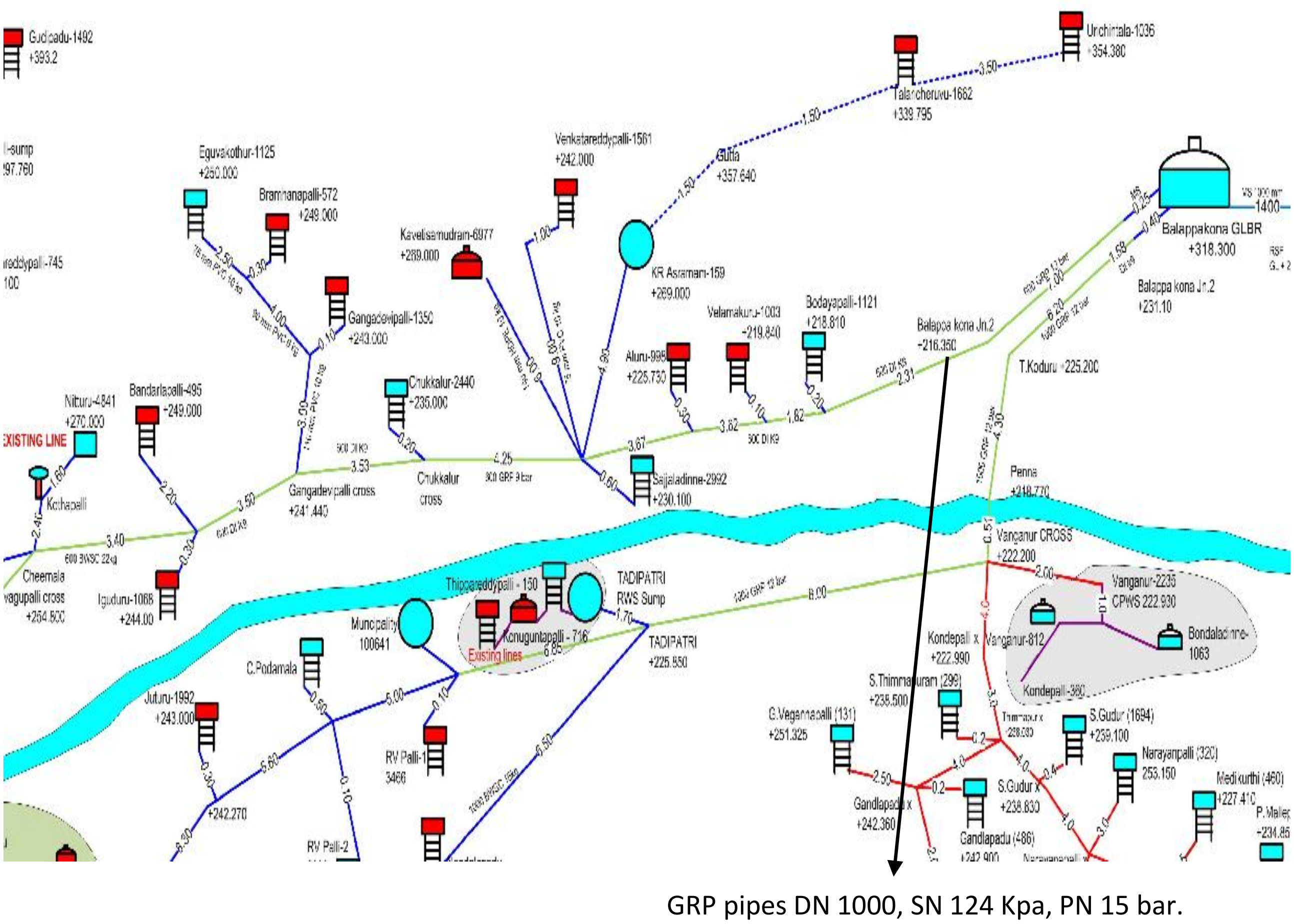


Fig 4.10 Schematic diagram of JC Nagi Reddy drinking water supply scheme.

From the Fig 4.10 it can be seen that twin GRP pipes marked in green has been laid to supply water from the Ground Level Service Reservoir (GLSR) to Elevated Service Reservoir (ESR) constructed at different locations in the supply zone. The available head of approximate 92 meters has been utilized to design the system for gravity flow.

Table: 4.5 Salient features of the transmission main (JC Nagi Reddy WSS).

Srl No	**Features of the pipeline**	**Values**
1	Length of the pipeline	30000 meter
2	Nominal Diameter of the pipeline	1000mm
3	Type of pipeline proposed	GRP
4	Class of pipeline	PN = 15 bar
5	Stiffness of pipeline	SN 124 Kpa
6	Flow	Gravity

From the Table 4.5 it can be seen that the stiffness of the pipe and the pressure class of the pipe chosen is adequate to accommodate the water pressures developed during gravity flow. With the absence of pumping system, it can be safely assumed that the pipeline was not subject to transient forces.

However, during site visit it was observed that the transmission pipe stretch could not be commissioned because of failure of the pipeline. It is mentioned that the pipeline which had been laid in the year 2010, could not be commissioned because of regular failures in the pipeline.

Fig 4.11: Photograph showing disintegration of GRP fibres.

From the Fig 4.11 it can be inferred that the failures of the pipe has occurred because of material deterioration over a period of time. On further investigation it has also been observed that buckling of the pipe has also occurred due to overburden pressure, leading to leakage from the joint. Hence it can be concluded that inspite of low pressure in the pipeline, failures can occur due to poor quality material selection and improper design of the pipeline (in this case the stiffness of the pipeline). The adequacy of the joints also needs to be ascertained to prevent joint failures.

4.5 Case Study No 3: Failure of Ductile Iron main at UNA, Himachal Pradesh.

The Ductile Iron pipeline of size 250mmhas been laid in a hilly terrain. On site inspection it was found that the alignment of the pipe traverses through deep troughs and crests, forests and streams. The accessibility to the site was difficult and as such pipe had to be transported by beasts of burden.

The profile of the pipe suggests that the pumping station is located at a RL of 530.68m and discharged water at the rate of 45.44 litres per second to a hill top reservoir located at RL 709.69m at a distance of 5.3 kms. From the hill top reservoir the transmission main discharged water through gravity to a secondary reservoir located at an RL of 683.40 m.

Leakages in the pipeline were observed on the rising mains at three locations.

Fig 4.12 Photograph showing leakage of Ductile Iron pipe at the joint.

From the Fig 4.12 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.

In another location of the rising main it has been observed that profuse leakage from the joint is taking place.

Fig 4.13: Photograph showing leakage of Ductile Iron pipe from the joint.

On careful inspection of the leakage point as shown in Fig 4.13, it can be observed that the gasket of the ductile iron had been damaged due to excessive deflection of the joint.

The reasons for the failure of the pipe in this project can be attributed to joint failures in the pipeline. The failures of the joints have occurred because of the following reasons;

i) Use of poor quality rubber gasket (in this case SBR gasket) for jointing of Ductile Iron pipes.

ii) The laying of pipelines in a hilly terrain is difficult. Hence every precaution has to be taken to lay the pipe in proper alignment and grade. Moreover support of the pipelines during river crossings has to be provided at the adequate position so that deflection of the joint does not occur beyond permissible limit (3 degrees).

4.6 Case Study No 4: Failure of Ductile Iron main in Simnar Water Supply Scheme, Maharashtra.

The Simnar water supply scheme had been designed to pump water at a high head (208.8m). From the profile it is found that the slope of the pipe gradually rises upto the discharge end. Precautions in laying of the pipe had been taken so that the deflection of the joint does not exceed the permissible limits.

Table: 4.6 Salient features of the transmission main (Simnar WSS).

Srl No	**Features of the pipeline**	**Values**
A	PIPELINE DETAILS	
1.	Length of the pipeline	15093 meter
2.	Nominal Diameter of the pipeline	700mm
3.	Type of pipeline used.	Ductile Iron pipe
4.	Class of pipeline	Class K9
5.	RL at pump end	543.11m
6.	RL at discharge end	725.0 m
B	PUMPING DETAILS	
1.	Discharge through pipe	0.25 cumec
2.	Rated Head of pump	208.8 MWC
3.	Rated pump speed	1420 rpm
4.	Efficiency of pump	80%
5.	No of pumps	2 Working + 1 Standby.

From Table: 4.6 it is observed that high head pumps with a standby arrangement has been used. It is therefore essential to provide surge protection devices to prevent pipe failure, in case of sudden failure of pumps. In the water supply scheme, air valves had been installed at a spacing of 500 meters. Apart from the precautions taken against surge, it has been observed that failure of the pipeline has occurred. Hence, it was imperative to analyse the pipeline on flow conditions it is subjected to. Hytran software has been used for the purpose.

On detailed analysis of the steady flow and transient flow conditions of the pipeline, it is observed that the pipeline was subjected maximum pressure of 32.9 kg/cm^2 and a minimum pressure of - 0.10 kg/cm^2.

Fig 4.13 shows development of negative pressure zones along the entire length of the pipeline. It is also been observed that Steady State HGL falls below the highest point of the pipeline.

Fig 4.13: Transient analysis in Hytran software showing negative pressure zones in red (Simnar WSS)

From the results obtained from the analysis of the pipe line it is evident that Ductile Iron pipe of Class K9 is strong enough to withstand the positive pressure of 32.9 kg/cm2 but it is weak in negative pressure zones. In negative pressure zones, mainly failure from the joint occurs in Ductile Iron pipe.

4.7 Discussion on procedure to be adopted for selection of pipe (transmission mains).

From the case studies mentioned in the previous sections it is therefore necessary to formulate a criterion for selection of different pipe materials considering the site conditions and the flow conditions the pipe is subjected to. Different approaches have been formulated by different organizations to guide engineers to make proper decision in pipe selection.

4.7.1 CPHEEO guidelines - Ranking of pipe material on different parameters.

CPHEEO in its Manual for Water Supply and Treatment has recommended a 10 point scale, ranking of pipelines based on twenty one parameters. The main aim of the exercise is to ensure judicious use of pipe material so that the pipe can serve the design requirement.

In this study, all the pipe materials are compared on the basis of twenty one parameters as recommended in the guideline. The values of the parameters are compared from authentic source (like mechanical strength from relevant BIS standards of different pipelines).

Table 4.7: Matrix showing Comparative Analysis of different pipe materials.

Sl No	Parameters	Cast Iron	Ductile Iron	Mild Steel	GRP	HDPE	BWSC	uPVC
1	Tensile Strength (Kg/cm^2)	1800	4200	4100	Varies in axial and hoop stress.	1600	Thin steel cylinder weak in tensile load.	140
2	Modulus of Elasticity (kg/cm^2)	7.5 x 10^9	1.7 x 10^{10}	2.1 x 10^{10}	15 x 10^5	9 x 10^7	3.5 x 10^9	3 x 10^8
3	Allowable Operating pressure (kg/cm^2)	LA- 12, A-18, B-24	K7 - 12.5, K9 - 36	Upto 50	15	16	12.5	6
4	Corrosion resistance	High	High	Moderate	Very High	Very High	Low	High
5	Life (years)	>80	> 75	30	30	50	15	15
6	Maintenance	Low	Low	Moderate	High	Low	High	High
7	Smoothness (C value)	110	140	140	145	145	110	140
8	Weight (Tonnes/m^3)	6.8 – 7.8	7.05	7.85	1.8-1.9	0.95	2.5	1.4-1.45
9	Jointing system	Lead joint, Tyton joint	Push fit, Mechanical joint	Welded	Reka Coupling	Fusion welded	Welded, pushfit	Push fit, screwed
10	Ease in Handling	Heavy	Moderately Heavy	Moderately Heavy	Light weight	Light weight	Heavy	Light weight

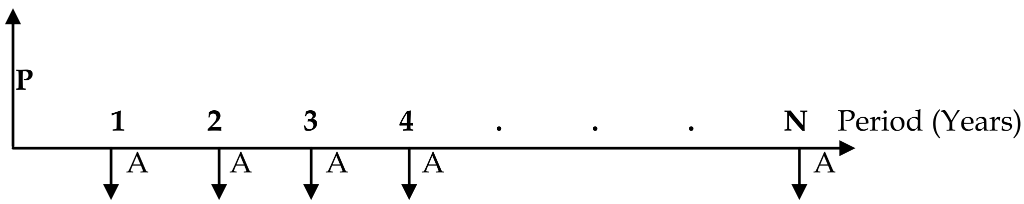
From the Table 4.7 ranking of all the pipelines to be compared can be done in a given scale. The figures in the matrix can act as a guideline for proper understanding of pipe materials.

4.7.2 Life Cycle Cost (LCC) analysis of different pipe materials:

Life cycle Cost Analysis is an approach where the net present cost of the expenditures incurred at present as well as future costs are calculated by factoring the price escalation cost.

4.8.2.1 Capitalization of Annual Cost Expenditure.

The financial flow diagram which considers a flat rate of annual charges like leakage loss or maintenance cost is presented in figure below.



The present worth in this case is calculated as

$$P = A\left[\frac{(1+i_r)^n - 1}{i_r(1+i_r)^n}\right]$$

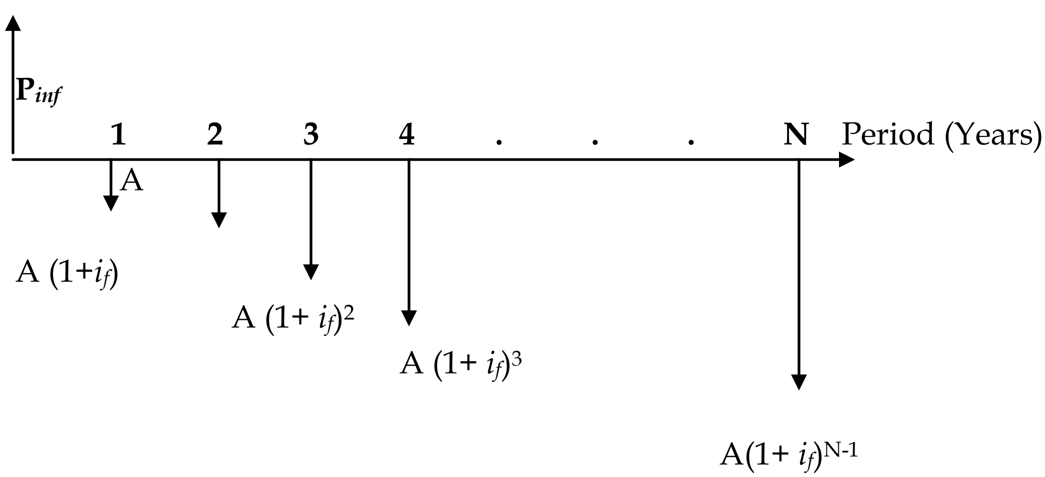
Where,

P = Present worth,

A= Annual cost,

i_r = rate of interest,

n = No of years, Project period



where, i_f, is rate of inflation.

The present worth, $P_{\inf}$, in this case is calculated as

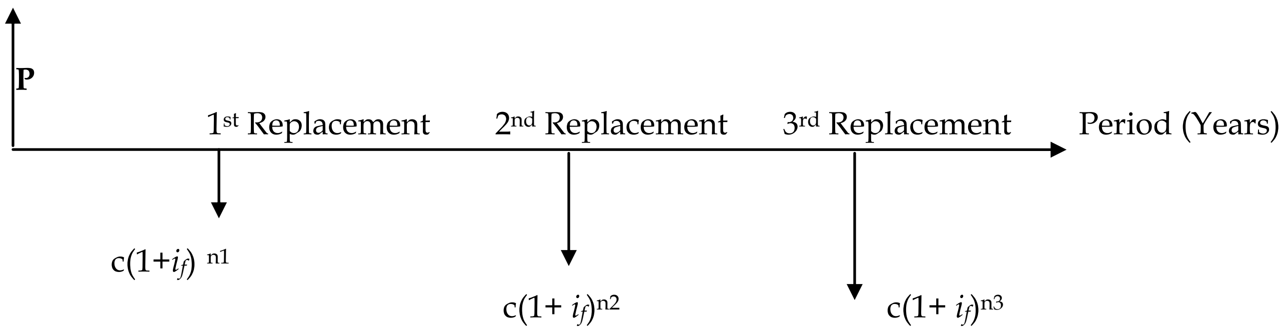
$$P_{\inf} = A\left[\frac{(1+w)^n - 1}{w(1+w)^m}\right]$$

Where, w , is calculated as

$$w = \frac{(1+i_r)}{(1+i_f)} - 1$$

4.7.2.2 Capitalization of Replacement Costs

The financial flow diagram for replacements cost is as follows



The replacement costs are worked out with respect to above formulation and individually present worth are calculated with respect to prevailing interest rate, i_r , as follows,

$$Pn_1 = \frac{C(1+i_f)^{n_1}}{(1+i_r)^{n_1}}$$

4.7.2.3 Revenue Loss

Considering the economic crises around the world everyone can agree that loss of revenue due to leakages should be the most important factor that must be considered in design of pipeline. This intangible cost implication which is crucial in case of bad pipe material prone to bursts and tampering should be considered to comprehend the impact on the total life cycle cost. To facilitate the quantification of this impact, it is expressed in terms of Rs/meter/year and then it is capitalized with prevailing interest and inflation rates.

4.7.2.4 Maintenances and Repair costs

It is a well known fact that lot money apart from toil and consumer apathy need to be spent if faulty and trouble prone pipe material is used. With the field experience over many years it is very much possible to work out an average yearly expenditure on maintenance and repair cost.

For convenience of calculation purpose 0.5 % annual cost expenditure has been considered. These costs are worked out on per meter basis with respect to cost of providing and laying of pipelines and then capitalized over the project period. In fact during repairs work water authorities are committed for providing water to the affected areas through alternate source like arranging tankers. Life Cycle Analysis should also quantify this aspect in the calculation.

4.7.2.5 Replacement costs

Consideration of replacement cost is indeed essential for short life pipes. NEERI, Nagpur (14) has conducted tests on the life of some pipe materials, and have predicted Useful Service life period for such pipes. The useful service life of pipelines can also be calculated from data available with water authorities. After expressing the replacement costs for 30^{th}, 60th years, the present worth of all replacements cost shall be calculated as per the prevailing interest rates.

The approaches mentioned in the previous section can only act as a guideline; however the experience of the designer cannot be ignored. An overall approach will help in taking a judicious decision towards the selection of right pipe material. However from the study done on the transmission pipe failure in this thesis, the following conclusion can be arrived at towards selection of pipe material for different components a water supply system.

i) Raw Water Rising Main:

Since these mains are generally pressured mains and are of short distance (ie from intake station to the WTP), the supply of water through the main has to be continuous and without interruption. Total shutdown of the WTP is not desirable for such mains due to repair. Hence Metallic pipes like Ductile Iron pipes & Mild Steel pipes are suggested. The size ranges of pipes are above 600mm.

Reason: Metallic pipes can withstand high pressures. They have flexible as well as leak tight joints. They are easily repairable, especially MS pipes. They are less prone to tampering and theft. MS pipes in particular can be easily fabricated to meet the requirements of various connections at the Intake Station end as well as WTP end.

However, pipes like PSC, BWSC, and PCCP are used for long distance rising main as they are cheaper and can withstand high superimposed loads.

ii) Clear Water Transmission Main:

Clear water rising mains are generally pressured main. They are of sizes above 600mm diameter. Clear Water Transmission mains supplies water from WTP to the ESR or Booster Pumping Mains. They are laid in busy roads, subjected to heavy traffic loads.

Hence metallic pipelines like Mild Steel, Ductile Iron pipes should be preferred.

Metallic pipes are easily repairable as well as can withstand surge pressures. More importantly, metallic pipes are less prone to damage by miscreants.

iii) Water Distribution System:
Water distribution network are generally gravity mains. They are low pressure pipes having pressure class PN 6 & PN 10 (maximum). They are smaller in sizes (80mm- 300mm diameter). They are laid in narrow lanes, busy roads and are subject to traffic loads. Due to its smaller size, the overburden pressure on pipes is not so significant. The pipelines should be easy to carry and shall provide flexibility in laying, due to interferences of other underground utilities. Moreover the pipeline should also provide proper house service connection by direct tapping or through saddle connection.
Hence non metallic pipelines are preferred for distribution system.

From the above discussion, the conclusion which has been derived on the recommendations for type of pipelines to be used for different components of a water supply system has been evaluated and justified by the tools and methodologies elaborated in the study. However, the experience of the designer as well the site conditions may compel the decision makers to adopt methods and materials, which best suits for the situation. The recommendation acts as a guideline and formulates the techniques to be adopted for proper selection of the system components of a water supply system, the transmission mains in particular.

CHAPTER – 5
CONCLUSION

The comprehensive study of the CPWS Gadwal project along with case studies from different parts of India, suggests that selection of pipe material is an important aspect to ensure sustained water supply system. The selection procedure should take into account the following factors;

i) Technical suitability: Pipelines should be chosen on the basis of their mechanical properties like tensile strength, bursting strength, yield strength, hoop stress and structural stiffness. The performance of the pipeline to withstand long term dynamic stresses, surge pressures as well as longitudinal stresses should be considered. To determine the forces acting on the pipeline, it is necessary to carry out analysis as per proven methods and software available for the purpose. It is also imperative to analyse the external stresses in the form of overburden pressure and impact load due to traffic. It has been observed in Ananthpur Water Supply scheme, that buckling of the pipes has occurred due to overburden pressure resulting in failure of joints. In Una Water supply project, it has been observed that failures of pipe have occurred due to poor jointing system. In case of difficult terrain like in Himachal Pradesh, it is important to take into account the constraints in carriage and haulage of pipes. Lighter weight but mechanically strong pipes should be preferred. In Simnar Water Supply scheme, it has been observed that pipes have failed due to negative surge pressures. There are many surge protection devices available in the market, which can be installed to prevent detrimental action of surge pressures in the pipeline.

ii) Operational efficiency: A pipeline is expected to run for its Design Useful life period. As such pipelines are designed for a period of 30 years but in Indian scenario, it is expected to run for at least 50 years. During the lengthy period of service, failures in pipelines are evitable. But, care should be taken during selection of a pipeline to ensure uninterrupted performance of the pipeline. Hence the maintenance aspect of the pipeline needs to be taken into account during decision making process. Availability of repair material, fixtures and fittings needs to be considered. The ease of repair work and the time taken for such repair works plays an important role in determining the type of pipe to be used. Further, it has been discussed in the study that corrosion reduces the effective life of the pipeline. Hence the effectiveness of corrosion protection coatings and linings are important factor to be considered during selection of pipe line. The energy consumption in running a transmission main contributes to the Operational efficiency of the system. The economic diameter of the transmission main is chosen amongst a family of pipes on the basis of the cost economics of the pipeline and the capitalized cost of the operating costs.

iii) Cost benefit aspect of the system: Cost economy is one of the deciding factors in deciding the type of pipeline to be used. However, the economy in basic cost of the pipeline should not be the only criteria to be considered. The concepts of Life Cycle Analysis, ie the total ownership costs to be borne by the authorities throughout the project life of the water supply system have to be evaluated. Therefore it is important to estimate the **expected useful life** of different pipe materials under different site conditions. Studies outside India, has been done on condition assessment of the pipeline on different hydraulic and site conditions, and thereby an estimation of the useful service life has been made for different pipe materials. However, such types of condition assessment studies are important to be carried out in India.

The thesis has attempted to formulate designs and programmes in Microsoft Excel software to analyse the life cycle costs of different pipe materials based on established formula. The programme shall come handy to decision makers to compare the suitability of different pipe materials on inputs provided as per their understanding and knowledge.

Finally it is reiterated that, the experience and understanding of the decision maker in implementing water supply projects cannot be ignored. An overall approach will help in taking a judicious decision towards the selection of right pipe material.

CHAPTER 6
SCOPE FOR FURTHER STUDIES

The thesis opens up a Pandora's Box on the decision making aspect for water pipelines.

The scope for future study can be summarized as following:

- Study on the performance of different pipe material on different external and internal conditions on short term and long term factors can be taken up.

- Condition assessment of existing assets of water networks, is an area where not much research has been done in India. This study gives a direction to decision making process on the basis of condition assessment /performance assessment of the assets in operation. A comprehensive assessment of the existing assets will help in effective and optimal capital investment planning.

- The thesis opens up discussions on the cost benefit aspect of the assets already under use. The replacement / refurbishment of such assets can be planned on the basis of such analysis.

- Future study can be done on failure history of large diameter water mains for effective preventive maintenance plan.

CHAPTER -7
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ANNEXURE –I
SOFTWARE USED FOR TRANSIENT ANALYSIS IN PIPELINES

A2.1 Hytran V 3.7.2

Since the study is done primarily in Hytran V 3.7.2, a brief introduction of the software is being furnished in this annexure.

HYTRAN is a computer software package developed for analyzing of HYdraulic TRANsients in pipelines. A special feature is the real time graphical representation of the transient pressure wave as propagating up and down the pipeline. The graphical display is an invaluable aid for understanding the overall transient phenomenon.

A2.1.1 Features of Hytran software.

- The software has been written completely in the C++ language on the Windows NT4, 2000 & XP environment.
- It has Intuitive Windows graphics input interface for drawing the pipeline and boundary conditions.
- The software uses Metric (SI) or English Units.
- HYTRAN software is compatible with EPANET software, widely used in the industry, available free on line.
- The software provides easy editing of the pipeline network and analysis of the network with different parameters or boundary conditions is very quick and simple.
- Pipe networks can be drawn on an elevation or plan view. A 3D view is also available for viewing the network.
- Databases for all fixtures and appurtenances can be maintained in the software.
- The interesting feature of the software is that it provides real time graphical display of the instantaneous pressure transients along the pipeline, which builds up a curiosity to understand the transient forces in great details.
- Trouble shooting has been an inherent feature in the software, where the problem areas are identified and the effect of transient control strategies evaluated immediately.
- The Output Reports are quite elaborate and exhaustive, showing the pressure transients at specified nodes, and the maximum and minimum pressures along a pipeline.

A2.2 Surge Analysis Programme (SAP) –Developed by IISC, Bangalore.

The SAP software has been built up by IISC, Bangalore, looking into the huge requirement of clients to come up with a full proof system of pipeline, especially to adopt protection system for long distance pipelines. With the depleting water resources and rapid urbanization, the dependence of permanent source of water is increasing day by day. As a result, water is being transported from far distances to meet the requirement of a city. Therefore the protection of the pipeline against transient forces has become imperative to ensure sustained water supply system of a city.

A2.2.1 Features of SAP software.

- The design of surge protection system is an iterative process in which a particular protection is proposed for say, power failure condition.
- The surge pressure is evaluated for a particular failure condition and the system can be modified on case to case basis.
- This basic software has evolved over a period of 2O years and gradually incorporated a number of design options as well as system complexities. As a result the software can analyze any complex situation with regard to surges in pumping mains.
- User friendly data input system.
- 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 output files are so structured, that they are directly helpful for the design process.
- The graphical outputs are more effective to give a proper understanding of the system pressures.

Annexure II

Glass fibre Reinforce Plastic pipes

Reference to NEERI manual (14)Glass fibre Reinforce Plastic (GRP) pipes are tubular product containing glass fiber reinforcements embedded in or surrounded by cured thermosetting resin. The composite structure may contain aggregate (silicious), fillers, and thixotropic agents. Thermoplastic or thermosetting liner and/or surface layer may be included. Fibre glass reinforced plastic (GRP) pipes is a matrix of composite of glass fibre, thermosetting polyester resin and fillers. The pipes so manufactured are light in weight and have smooth interior surface.

Fig A1.1: Photograph of GRP pipe.

A1.1 Availability

Size designation of the pipe is based on the nominal diameter, DN. Nominal diameter shall be chosen from: 200, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800 and 3000 mm.

A1.2 Manufacture

Glass fibre Reinforce Plastic (GRP) pipes are now being manufactured in India conforming to IS: 12709/1994. Standard lengths are 6 & 12 meters, however custom made length can also be made. The specials are made out of the same pipe material i.e. Glass fibre Reinforced Plastic (GRP).

GRP pipes can be classified by its construction. Two main methods used are Centrifugal casting and Filament binding.

A 1.2.1 Centrifugal casting

Centrifugally cast pipes are formed by feeding liquid resin and short lengths of chopped glass fibres into a horizontally rotating mould. Glass fibres and aggregates are compacted into resin by centrifugal force to form dense pipe wall with controlled external diameter. Random orientation of the fibres results in laminate with equal strength in both Hoop and Axial direction. Fibre orientation can be altered if required. To increase the stiffness at low cost sand and other aggregates can be incorporated.

A1.2.2 Filament binding

Filament bound pipes are manufactured by binding continuous glass fibre roving on to a mandrel resulting a pipe with a controlled dimensions. The resin is applied to either to the roving or directly to the mandrel and additional chopped fibre reinforcement can be added. The orientation of the windings and their spacing controls the final properties of the pipe. Non-circular sections can also be produced by filament winding.

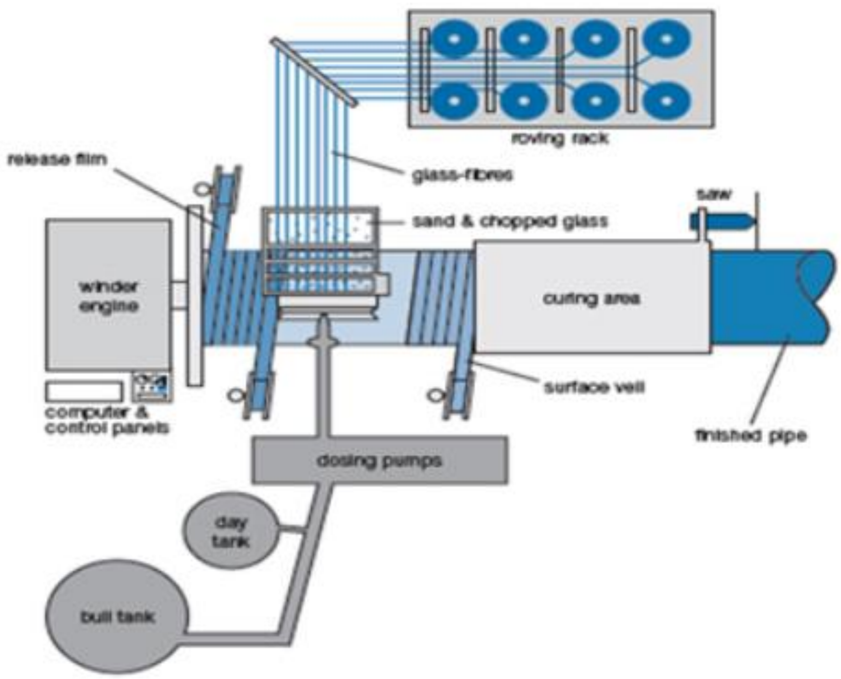

Fig A1.2: Manufacturing process of GRP pipe (Continuous Filament Winding process)

A1.3 Pipe Sizes and Classes:

GRP pipes are available from 200-3000 mm in nominal lengths of 6m, 9m and 12m. Five pressure classes of pipes namely PN3, PN 6, PN9, PN12 and PN15 are made depending on required pressure rating.

Depending on the type of installation, overburden above the crown of the pipe and the soil conditions, four types of stiffness class pipes are available. Four stiffness classes namely A, B, C & D correspond to minimum pipe stiffness values of 62, 124, 240 and 496 KPa respectively at 5% deflection.

A1.4 Joints

The pipe shall have a jointing system for fluid tightness for the intended service condition.

A1.4.1 Unrestrained

Pipe joints capable of withstanding internal pressure but not longitudinal forces. The pipes are jointed as per the techniques; Double bell coupling (GRP) for GRP to GRP; Flange Joint (GRP) for GRP to valves, CI pipes or flanged pipes.

A1.4.1.1Coupling or Socket and Spigot Gasket Joints:

Provided with groove(s) either on the spigot or in the socket to retain an elastomeric gasket(s) that shall be the sole element of the joint to provide water tightness.

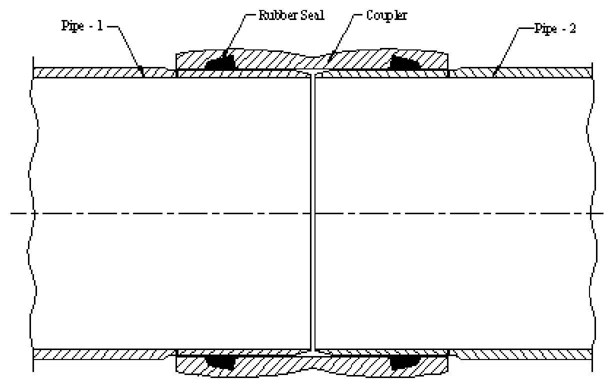

Figure A1.3 Double Bell Coupling

A1.4.2 Restrained

Pipe joints capable of withstanding internal pressure and longitudinal forces.Joints may be Butt joint with laminated overlay, socket- and -spigot with laminated overlay, socket- and -spigot with adhesive bonding, flanged or mechanical. Joints are primarily flexible systems and fittings can be made from DI, Coated steel or from GRP. It is common practice to encase fabricated fittings in concrete.

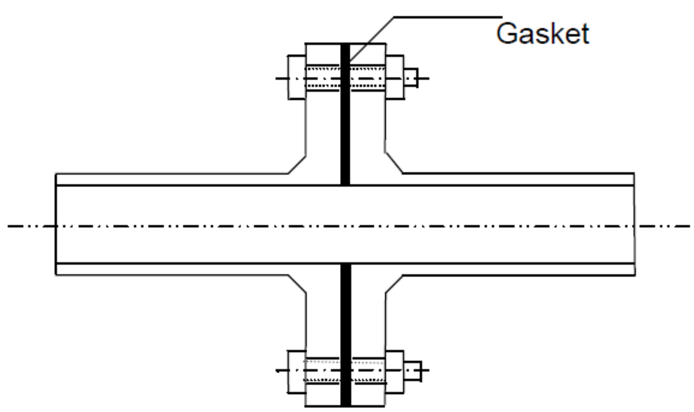

Figure A1.4 Restrained joints – Flanged type

Table A1.1 SUMMARY SHEET – Glass Fibre Reinforced Plastic Pipe

Standards	Pipe: IS:12709/1989 BS 5480
Structural Design Classification	Flexible
Pipe Dimensions Weight per meter Standard length Sizes	 600mm (diameter) : Straight length 6m, available in other lengths on request. 300mm - 2500mm (available in the UK); 25-4000mm (BS 5480)
Working Pressures Allowable operating pressure Allowable maximum operating pressure	Six classes: 6, 10, 12.5, 16, 20, 24 bar or any intermediate pressure. Equal to allowable operating pressure
Installation Standards	BS 8010 Section 2.5.
Installation Techniques	Open-Cut (traditional), conventional tunnelling, Auger boring,pipe jacking, microtunnelling.
Jointing /Fittings	Integrally spigot and socket, sleeve joints (BS 5480) non-integral clamps or bolted couplings.
Service Connections	No established methods. On-site not recommended.
Corrosion Protection Requirements	Resistant to natural ground conditions, may be degraded or permeated by organic and inorganic contaminants.
Bedding Requirements	• Prepared bedding (selected as-dug or inported) on trench bottom. • Care should be taken to avoid point loads due to rocky/stony ground or uneven loading. • Anchor blocks must be applied to non end-load resistant systems. • Where ground water table is high, take measures against flotation.
Repair Methods	• Centrifugally cast pipes: Replace affected lengths, seal cut surface. • Filament wound pipes: Special adaptors required to connect in new length. • Localised repairs: Repair clamps or patch repairs.

Advantages	• Good corrosion resistance. • Relatively lightweight • Flexible joints. • Performance can be tailored for individual pipe installations.
Limitation	• Behaviour under dynamic loading relatively poorly understood. • Susceptible to impact and accidental damage. • High standard of compaction required to limit deflection. • Risk of flotation prior to back filling. • Risk of overstraining due to subsidence or ground movement. • Vulnerable to strain corrosion attack under acidic conditions. • Permeable to certain organic and inorganic contaminants. • Leakage detection not established. • Requires metallic detector tape for pipe location.