TRANSIENT ANALYSIS OF A PIPED WATER NETWORK USING HAMMER SOFTWARE: A CASE STUDY OF SOUTH MIZORAM

A thesis submitted towards partial fulfillment of the requirements for the degree of

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All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

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ABSTRACT

The case study belongs to a Transient analysis of a piped network system using HAMMER software. A pipe network system situated at South Mizoram has been taken for this case study. Generally hydraulic transient in a water supply line is usually caused by sudden power failure, pump failure, valve failure etc. Here, the thesis analyses the surge and water hammer concerns the generation, propagation and reflection of pressure waves in the liquid filled pipeline, due to sudden power failure.

The hydraulic modeling of the pipe network has been done using the HAMMER software. Then, in case of sudden power failure, the transient analysis of the pipe network has been modeled by using the same software. Then, the corresponding data of that transient analysis has been analyzed, and it was found that the pressure in the pipe network has been above the permissible limit of safe operation. Then, a suitable surge protection device has been incorporated with the pipe network at risk prone point, and again the network has been analyzed with the HAMMER software, to reduce the pressure in the pipe network for safe operations.

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CHAPTER - 1

1. General Introduction:

1.1Background:

A hydraulic transient is a flow condition where the velocity and pressure change rapidly with time. The occurrence of transience can introduce large pressure forces and rapid fluid accelerations into a water distribution system. When flow velocity changes rapidly because a flow control component changes status (for example, a valve closing or pump stop), it causes the change to move through the system as a pressure wave. Hydraulic transient can cause hydraulic equipment's in a pipe network to fail, if adequate transient control measures are not in place to overcome the transient (if the pressure wave is strong enough).

Due to the devastating effects that a hydraulic transient can cause, its analysis is very important in determining the values of transient pressures that can result from flow control operations and to establish the design criteria for system equipments and devices so as to provide an acceptable level of protection against system failure due pipe collapse or bursting.

Numerical models are used to analyze hydraulic transients due to the complexity of the equations needed to describe the transients. An effective numerical model allows the hydraulic engineer to analyse potential transient events and to identify and evaluate alternative solutions for controlling hydraulic transients, thereby protecting the integrity of hydraulic system.

1.2 Objectives:

The objectives of this work is to

- Model the Piped water network, situated at South Mizoram, in HAMMER software platform.
- Perform transient analysis of the network under different condition by HAMMER software.
- Check maximum transient pressure developed in the network.
- Select appropriate surge protection device/s, required if any, according to the simulated results.

1.3. Study Area:

For the fulfillment of the thesis, a Piped Water supply system, situated at South Mizoram, has been considered.

1.4. Literature Review:

Fluid structure interaction is one of the major studies in water hammer analysis:

Tijsseling (1996) carried out a very detailed review of transient phenomena in liquid-filled pipe systems. He dealt with water hammer, cavitations, structural dynamics and fluid-structure interaction (FSI). His main focus was on the history of FSI research in time domain.

Das *et al*. (2013) investigated that with the increased demand of water in an urban area it becomes necessary to increase the capacity of the water pipeline networks by keeping the pipes and valves elements unchanged as it is quite hazardous work to change those in an urban area. This paper presents a study on characteristics of mainly Hammer Head at increased flow demand in pipeline networks using HAMMER software. For modeling the pipeline distribution networks, the parameters of the pipes, junctions and other elements were inserted in the above software according to the layout of distribution network of dhapa, water treatment plant, KMC. The flow capacity of the pipeline networks were increased in the order of 25%, 50%, 75%, and 100% more than the existing flow capacity of the above networks and the transient analysis were done accordingly. Increasing trends of hammer head, pressure and circumferential stress with respect to increased flow, demand were observed for all the zones which satisfy with vide validation with basic equation for water hammer theoretically. T was also checked whether the pipes are safe for taking the load for increased flow demand.

Wiggert and Tijsseling (2001) attempted to succinctly summarize the essential mechanisms that cause FSI, and present relevant data that describe the phenomenon. In addition, the various numerical and analytical methods that have been developed to successfully predict FSI has been described.

Heinsbroek (1996) compared two different ways, MOC and finite element method for solving structural equation. Thos study showed that the FSI in pipeline system can adequately be investigated by application of MOC and FEM for hydraulic and structure of piping system, respectively. Tijsseling illustrated the MOC approach for obtaining exact solution of FSI four equation models and it is generally referred in most of the latest papers for validating the results with benchmark examples.

Wiggert *et al*. (1986) used a one dimensional wave formulation in both the liquid reaches and the piping structure resulting in five wave components and fourteen variables. MOC approach is introduced in this paper.

Le *et al*. (2002) has independently solved the main FSI equation analytically. In both studies only junction coupling is considered but only for an unrestrained valve. In addition to the time domain analysis many researchers have studies the theoretical and experimental aspects in frequency domain.

Ahmadi and Keramat (2010) studied the analysis of water hammer with fluid–structure interaction (FSI) to investigate junction coupling effects. Junction coupling effects were studied in various types of discrete points, such as pumps, valves and branches. The emphasis was placed on an unrestrained pump and branch in the system and the associated relations were derived for modeling them. Proposed relations were considered as boundary conditions for the numerical modeling which was implemented using the finite element method for the structural equations and the method of characteristics for the hydraulic equations.

Mahmoodi *et al*. (2011) determined the position of loss of coolant accident in nuclear power plants using the transient vibration signal from a pipe rupture. A finite element formulation is implemented to include the effect of fluid-structure interaction. The coupled equations of fluid motion and pipe displacement are solved.

Kermat *et al*. (2012) investigated water hammer with FSI and viscoelasticity concerns pipes made of plastic, where FSI effects are more significant than in steel pipes, simply because they are more flexible (although with thicker walls, their modulus of elasticity is lower and their Mechanical Engineering 08-12 6 Poisson's ratio is higher). This makes FSI analysis necessary to reliably estimate the ultimate pipe stresses, elbow displacements and anchor forces, especially for designs with flexibly supported pipes. It was found herein that in the early moments of the transient event FSI is significant.

Olson and Bath (1985) have formulated finite element procedure by establishing direct symmetric model based on fluid velocity potential. Sandberg (1988) has proposed a symmetric finite element model for coupled acoustic vibration between fluid and structure and impact of eigen value shifting in complex system. Lee and Park (2006) presented a methodology to transform coupled pipe dynamics equation into linear form about steady state value of fluid pressure and velocity. Spectral element model is used and compared with finite element model. Xiaodong (2008) in his book described the fundamental procedure for solving FSI effect by use of virtual work method and establishing formulation of displacement-Velocity potential and displacement- velocity potential- Pressure method. Elghariani (2007) in his thesis has discussed formulation of equations considering effect of FSI and solving it with MOC with friction coupling as a major source of investigation. Other works in literature mentioned the finite element formulation for the fully coupled dynamic equations of motion to include the effect of fluid–structure interaction (FSI) and applied to a pipeline system used in nuclear reactors.

Mukherjee *et al.* (2015) worked on transient analysis of pipeline network for drinking purpose in Assam, India is to study the transient behaviour of the proposed raw water pipeline for drinking purpose which is linked between intake well at Brahmaputra river to Jalukbari water treatment plant (WTP).

1.5. Structure of Thesis:

Chapter 1 describes the background, objectives, study area and structure of thesis.

Chapter 2 is dedicated to the Transient flow concepts. Due to the transient flow, water hammer occurs in the system. The water hammer concept and the causes of water hammer are explained. Then, equations in study are derived.

Chapter 3 introduces the HAMMER software which is used for the transient analysis under the present study.

Chapter 4 is dedicated to brief description of the Pipe network system, transient analysis of the Pipe network using HAMMER software under different conditions.

In Chapter 5 conclusion of the case study is discussed.

Chapter 6 contains the references.

CHAPTER - 2

2. Transient flow:

This chapter reviews the fundamental concept and principles of transient flow.

Firstly, definition of transient flow is given. Then the fundamentals of water hammer are developed on the basis of basic conventional relationships of physics or fluid mechanics.

2.1. Definition of transient flow:

In steady flow there is no change in flow conditions such as pressure, discharge, and velocity at any locations in the pipeline system with time. If flow conditions at a point are changing with time, flow is called unsteady flow. Steady flow is special case of unsteady flow. In other words, unsteady flow equations are valid for steady flow conditions, too. Transient flow definition is used to describe unsteady flow of fluids in pipeline. Transient flow is an intermediate- stage flow, i.e. it is observed when the flow conditions are changing between two successive steady state conditions. Transient flow develops in pipeline system when there are changes in the hydraulics system or the surrounding environment which affects the flow.

In general, transient flow can be divided into two types. The first type of transients is called as quasi – steady flow. The main characteristics of that type of transient flow are the gradual variation of discharges and pressure with time. Hence, the flow appears as steady over short time interval. Drawdown in the large reservoirs or in large tanks is a gradual process, so this situation is typical example of quasi-steady flow. The other type of transient flow is called as true transient flow. The main factors that affect the development of true transient flow are the fluid inertia and/ or the elasticity of the fluid and pipe. If pipe and fluid elasticity effects are negligible while the inertial effects of pipeline systems are significant, true transient flow is referred as rigid-column flow. On the other hand, if elasticity effects of pipe and fluid are under considerations in addition to the internal effects, true transient flow is referred as water hammer.

2.2. Impacts of Transients:

A wave is a disturbance that propagates energy and momentum from one point to another through a medium without significant displacement of the particles of that medium. A transient pressure wave, subject's system piping and other facilities to oscillating high and low pressures, and cyclic loads and these pressures can have a number of adverse effects on the hydraulic system.

Hydraulic transients can cause hydraulic equipments in a pipe network to fail if the transient pressures are excessively high. If the pressures are excessively higher than the pressure ratings of the pipeline, failure through pipe or joint rupture, or bend or elbow movement may occur. Conversely, excessive low pressures (negative pressures) can result in buckling, implosion and leakage at pipe joints during sub atmospheric phases. Low pressure transients are normally experienced on the downstream side of a closing valve.

After pump stops in a pipeline with a check valve just downstream of the pump, the system flow reverses its direction towards the pump. Normally, in fairly long pipelines, the check valve will close when the flow just reverses (water velocity equals zero). However, in some situations the inertia of the valve causes it to delay its closure and the reverse flow causes it to close very rapidly through the remaining portion of its closure operation. This very fast, hard valve closure is known as valve slam. When the check valve is fully closed, it stops the reverse flow instantaneously, causing sometimes a loud noise (water hammer) in the pipeline. The noise associated with the slam is due to the impact of the disc into its seat. Surprisingly, a resilient-seated check valve can make the same metallic slam sound as a metal-seated valve (Val-Matic Valve and Manufacturing Corp, 2003). To prevent check valve slam, a check valve must either close very rapidly before appreciable reverse flow occurs or very slowly once reverse-flow has developed. In order to close rapidly, studies indicate that:

- The disc should have low inertia and friction,
- The travel of the disc should be short, or
- The motion should be assisted with springs

To close slowly, a check valve needs to be equipped with external devices such as oil dashpots and the pump must be capable of withstanding some backspin. Dashpots devices have been proven to be effective (Val-Matic Valve and Manufacturing Corp., 2003).

Sub atmospheric (low) pressure conditions increase the risk of some pipeline materials, diameters, and wall thickness to collapse (implode). Although the entire pipeline may not collapse, it can still damage the internal surface of some pipes by stripping the interior lining of the pipe wall. Even if the pipeline does not collapse, column separation (cavitations) could occur in a section of the pipeline, if the pipeline’s pressure is reduced to the vapor pressure of the liquid. This column separation is caused by the differential flow in and out of a section of the pipeline. There are two distinct types of cavitations that can result and these are gaseous and vaporous cavitations.

Gaseous cavitations involve the formation of bubbles (dissolved air) and their collapse (coming out of the water). Gaseous cavitations cause small gas pockets formation in the pipe which could have the effect of dampening transients if these gas pockets are sufficiently large because they tend to dissolve back into the liquid slowly.

Vaporous cavitations is the boiling (vaporization) of the water itself in the pipeline. Even liquid oxygen will boil and no one would ever call that hot. Fluids boil when the temperature of the fluid gets too hot or the pressure on the fluid gets too low. If you lower the pressure on the water it will boil at a much lower temperature and conversely if you raise the pressure, the water will not boil until it gets to a higher temperature. In vaporous cavitations, a vapour pocket forms and then collapses in the pipe when the pipeline pressure increases due to more flow entering the region than leaving it. Collapse of the vapour pocket can cause a dramatic high pressure transient if the water column rejoins very rapidly, which can in turn cause the pipeline to rupture. Vaporous cavitations can also result in pipe flexure that damages pipe linings.

Cavitations can and should be avoided by installing appropriate protection equipment or devices in the system. To counteract vaporization problems you must either decrease the suction head, lower the fluid temperature, or more generally slowdown velocity changes. The pipeline profile could also be important for the risk of cavitations.

Cyclic load occurs when the pressure fluctuations in the pipeline are very rapid, as in the case of water hammer. A large number of cyclic loads can results in pipe burst due to fatigue and pipeline fittings (bends and elbows) to dislodge, resulting in a leak or rupture. The occurrence of water hammer can release energy that sounds like someone pounding on the pipe with a hammer. This sound is due to the collapse of a large vapour cavity.

Causes of Hydraulic Transients:

Hydraulic transients occur at flow changes (rapid) in pressurized conduits and this is due to:

- Start and stop of pumps, especially stop due to power failure.
- Load changes in hydropower plants.
- Valves operations (shut-off valves).
- Check valve closure.
- Air pockets in pipelines, especially at pump start.
- Discharge of air through air vent, valves.

2.3. Factors Affecting the Hydraulic Transients:

The magnitude of the transient pressure peaks depends on many factors, and some of these factors are:

- Pipeline length, configuration. The longer the pipeline the stronger the hydraulic transients. Branched pipeline configuration is better in handling transients.

- Pipeline profile.

- Rate of change of the flow. The more rapidly the flow changes, the higher are the generated hydraulic transients. Flow change depends on the valve operation, pump characteristics.

- The elastic properties of the water and the pipes. Less elastic pipes are disadvantageous.

- Possible contents of dissolved or gaseous gases in the water. Gas bubbles normally reduce transients.

- Formation and appearance of vapour pockets (cavities) in the water.

- Protective measures applied. These include surge chambers, air vessel, air valves, frequency-controlled pumps, etc.

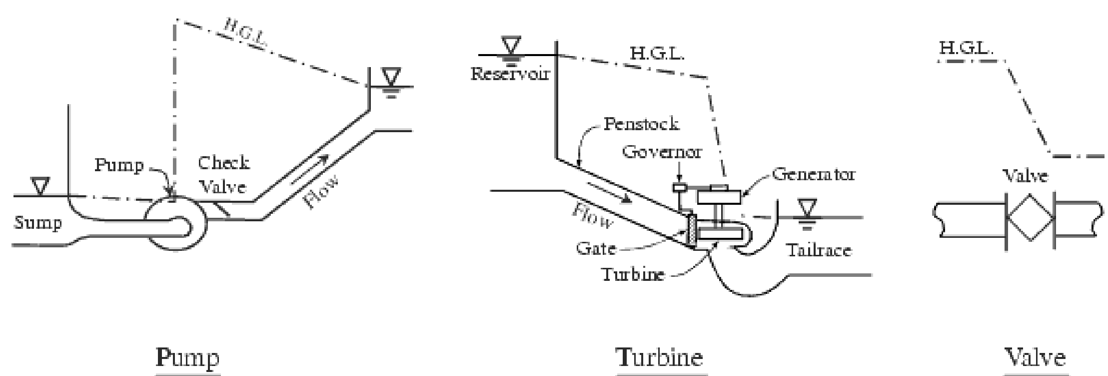


Fig 2.1: Common Causes of Hydraulic Transients

2.4. History of Transient Analysis Methods:

Various methods of analysis were developed for the problem of transient flow in pipes. They range from approximate analytical approaches whereby the nonlinear friction term in the momentum equation is either neglected or linearised, to numerical solutions of the nonlinear system. These methods can be classified as follows:

2.4.1. Arithmetic Method:

This method neglects friction (Joukowsky, 1904)

2.4.2. Graphical Method:

This method neglects friction in its theoretical development but includes a means of accounting for it through a correction.

Generally, the graphical method is considered to be one of the simplest and effective ways to calculate the hydraulic transient. Basically there are some simplifications which must be done to make it possible to apply the graphical method. The transients are normally obtained only at the end points of the pipeline and the frictional losses are assumed to be concentrated to only one point (either the inlet or outlet of the pipeline depending on the problem), also the energy losses in the entire pipeline during the transient phase are thus approximated by means of the water velocity in one point (inlet or outlet) although the velocity in reality varies along the pipeline. The graphical method can be done by free hand or by the use of drawing software (for example AutoCAD), and that of course affects the results because it always depends on the person's accuracy.

2.4.3. Method of Characteristics:

This method is the most popular approach for handling hydraulic transients. Its thrust lies in its ability to convert the two partial differential equations (PDEs) of continuity and momentum into four ordinary differential equations that are solved numerically using finite difference techniques The graphical method is also based on the method of characteristics.

2.4.4 Algebraic Method:

The algebraic equations in this method are basically the two characteristic equations for waves in the positive and negative directions in a pipe reach, written such that time is an integer subscript (Wylie and Streeter, 1993).

2.4.5. Wave-Plan Analysis Method:

This method uses a wave-plan analysis procedure that keeps track of reflections at the boundaries.

2.4.6. Implicit Method:

This implicit method uses a finite difference scheme for the transient flow problem. The method is formulated such that the requirement to maintain a relationship between the length interval Δx and the time increment Δt is relaxed.

2.4.7. Linear Methods:

By linearising the friction term, an analytical solution to the two PDEs of continuity and momentum may be found for sine wave oscillations. The linear methods of analysis may be placed in two categories: the impedance method, which is basically steady-oscillatory fluctuations set up by some forcing function, and the method of free vibrations of a piping system, which is a method that determines the natural frequencies of the system and provides the rate of dampening of oscillations when forcing is discontinued (Wylie and Streeter, 1993).

2.5. Physics of Transient Flow:

A hydraulic transient is generated when the flow momentum of the transported liquid changes due to the rapid operation of the flow control device in the hydraulic system. Mathematically hydraulic transient is analysed by solving the velocity $V(x, t)$ and pressure $P(x, t)$ equations for a well-defined elevation profile of the system, given certain initial and boundary conditions determined by the system flow control operations. In other words, the main goal is to solve a problem with two unknowns, velocity (V) and pressure (P), for the independent variables position (x) and time (t). Alternatively, the equations may be solved for flow (Q) and head (H).

The continuity equation and the momentum equation are needed to determine (V) and (P) in a one-dimensional flow system. Solving these two equations produces a theoretical result that usually reflects actual system measurements if the data and assumptions used to build the numerical model are valid.

2.6. Water Hammer:

Water Hammer is a pressure surge or wave that occurs when there is a sudden momentum change of a fluid (the motion of a fluid is abruptly forced to stop or change direction) within an enclosed space (Water Hammer). This commonly occurs in pipelines when a valve is closed suddenly at the end of a pipeline where the velocity of the fluid is high. The pressure wave created will propagate within the pipeline.

2.6.1. Cause and Effect:

Water hammer is caused by a change in fluid momentum. The most common cause of this change in momentum is sudden closure of a valve on a pipeline. When this occurs, a loud hammer noise can be produced and vibrations can be sent through the pipe (Water Hammer). The pressure wave produced from this event can cause significant damage to pipe systems. The large increase in pressure can cause pipes to crack and in some cases burst. It also causes cavitations within pipe lines and if is severe enough can cause the pipe line to implode (Water Hammer).

Fig: 2.2. Damaged pipeline due to water hammer phenomena.

Another instance that produces a water hammer effect is pump and turbine failure. When a pump fails, the sudden halt in flow will produce the momentum change causing the water hammer effect. This can also be seen in home plumbing systems when faucets are turned on and off suddenly. A loud hammer noise will be produced, and the plumbing will vibrate in most cases.

Water hammer can be induced intentionally for various applications. A hydraulic ram can be created using a water hammer, and is commonly used in mining practices to break through rock. In addition, the water hammer effect creates an increase in pressure within a pipe line and is then used to detected leaks within the pipe line. The increased pressure causes water to shoot out of the pipe at a leak site, which is then easily spotted. Despite water hammer being useful at time, it is generally an undesired phenomenon that must be considered when designing pipe lines (Water Hammer).

2.6.2. Mathematical Modeling:

This chapter deals with mathematical modeling of physics present in Water hammer analysis. The formulation will give details of classical water hammer and change in equation if effect of FSI is considered.

Classical Water Hammer Theory:

We consider following assumptions for the study of classical water hammer theory:

1. One dimensional model is considered with average cross sectional velocity and pressure.
2. Friction is considered to be constant in our study.
3. The pipe is assumed to be fully filled in due course of study and any possibility of column separation or cavity formation is avoided.
4. There is no fluid other than water in pipe.
5. The density and other structural property as well as thermodynamic property remain constant.
6. The pipe is assumed to be straight, thin walled, linear elastic and of circular cross-section containing a weakly compressible fluid.
7. Additional effect of damping, friction and gravity are ignored in our study.

To generate equations describing the water hammer phenomenon, the unsteady momentum and mass conservation equations are applied to flow in a frictionless, horizontal, elastic pipeline. First, the momentum equation is applied to a control volume at the wave front following a disturbance caused by downstream valve action. The following equation may be developed, which is applicable for a wave propagating in the upstream direction:

$$\Delta p = -\rho a \Delta V \text{ or } \Delta H = -\frac{a}{g}\Delta V \qquad (2.1)$$

where,

Δp = change in pressure, (Pa)

ρ = fluid density, (kg/m^3)

a = characteristic wave celerity of the fluid, (m/s)

ΔV = change in fluid velocity, (m/s)

ΔH = change in head, (m)

It can be seen from the equation that a valve action causing a positive velocity change will result in reduced pressure. Conversely, if the valve closes (producing a negative ΔV), the pressure change will be positive.

By repeating this step for a disturbance at the upstream end of the pipeline, a similar set of equations may be developed for a pulse propagating in the downstream direction:

$$\Delta p = \rho a \Delta V \quad \text{or} \quad \Delta H = \frac{a}{g}\Delta V \tag{2.2}$$

These equations are valid at a section in a pipeline in the absence of wave reflection. They relate a velocity pulse to a pressure pulse, both of which are propagating at the wave speed a. Assume that an instantaneous valve closure occurs at time t = 0. During the period L/a (the time it takes for the wave to travel from the valve to the pipe entrance), steady flow continues to enter the pipeline at the upstream end. The mass of fluid that enters during this period is accommodated through the expansion of the pipeline due to its elasticity and through slight changes in fluid density due to its compressibility.

The following equation for the numerical value of "a" is obtained by applying the equation for conservation of mass.

$$a = \sqrt{\frac{\frac{E_v}{\rho_v}}{1 + \frac{E_v}{E_p}.\frac{D}{e}.C}} \tag{2.3}$$

where,

Ev and *Ep* are the volumetric modulus of elasticity of the fluid and the pipe material (Pa) respectively. ρ_v is the density of the liquid (Kg/m^3), *D* and *e* are the internal diameter and the wall thickness (m) of the pipe respectively, and *C* = constant, which depends on the axial movement of the pipe. In practical calculations, $C \approx 1$

2.6.3. Full Elastic Water Hammer Equations:

The water hammer equations are one-dimensional unsteady pressure flow equations given by (Wylie and Streeter, 1993):

$$\frac{\partial H}{\partial t} + \frac{a^2 \partial Q}{gA \partial x} = 0 \tag{2.4}$$

$$\frac{\partial Q}{\partial t} + gA\frac{\partial H}{\partial x} + \frac{fQ|Q|}{2DA} = 0 \tag{2.5}$$

In order to model the transient situation in a system, one has to solve these equations for a wide variety of boundary conditions of that system and its topologies. The full elastic water hammer equations cannot be solved analytically except by some approximate methods.

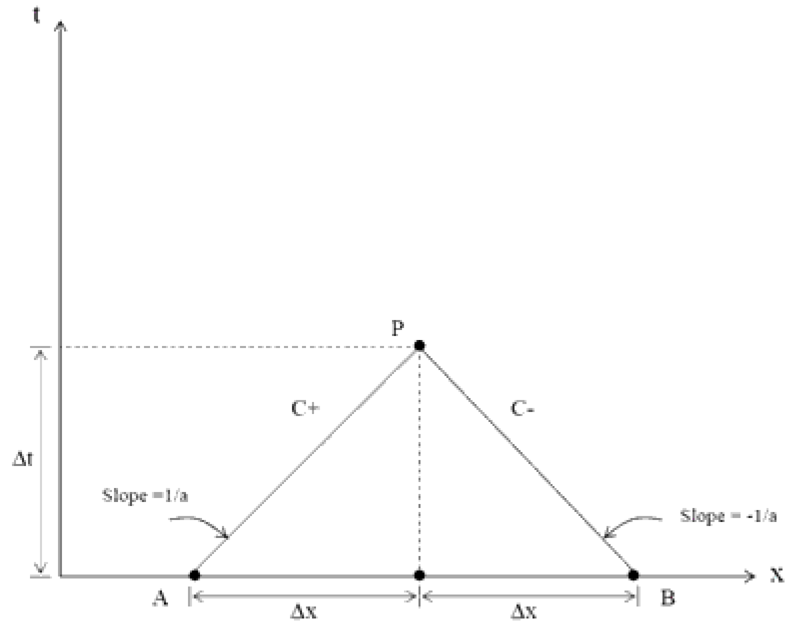
2.6.4. Method of Characteristics (MOC):

HAMMER uses the most widely used and tested method, known as the Method of Characteristic (MOC), to solve governing equations and for unsteady pipe flow. Using the MOC, the two partial differential equations can be transformed to the following two pairs of equations:

$$\left.\begin{aligned} &\frac{g}{a}\frac{dH}{dt} + \frac{dV}{dt} + \frac{fV|V|}{2D} = 0 \\ &\frac{dx}{dt} = +a \end{aligned}\right\} \quad C^{+} \tag{2.6}$$

$$\left.\begin{aligned} &-\frac{g}{a}\frac{dH}{dt} + \frac{dV}{dt} + \frac{fV|V|}{2D} = 0 \\ &\frac{dx}{dt} = -a \end{aligned}\right\} \quad C^{-} \tag{2.7}$$

Equations and cannot be solved analytically, but they can be expressed graphically in space-time as characteristic lines (or curves), called characteristics, that represent signals propagating to the right (C+) and to the left (C-) simultaneously and from each location in the system, as shown in the figure below.



Wave Characteristics in x-t Plane

2.7. Transient Control:

Ideally a hydraulic system design process will include an adequate investigation and specification of equipment and operational procedures to avoid undesirable transients. However, in reality, transients will still occur despite the design parameters; hence, remedial measures are required to keep transient conditions from seriously disturbing the proper functioning of an existing system. Unexpected sources of unsteady flow also appear in some newly constructed systems (Wylie and Streeter, 1993).

Two possible strategies for controlling transient pressures exist:

1. Focus on minimizing the possibility of transient conditions during project design by specifying appropriate system flow control operations and avoiding the occurrence of emergency and unusual system operations.

2. To install transient protection devices to control potential transients that may occur due to uncontrollable events such as power failures and other equipment failure.

Systems that are protected by adequately designed surge tanks are generally not adversely impacted by emergency or other unusual flow control operations because operational failure of surge tank devices is unlikely. In systems protected by hydropneumatic tanks, however, an air outflow or air compressor failure can occur and lead to damage from transients. Consequently, potential emergency situations and failures should be evaluated and avoided to the extent possible through the use of alarms that detect device failures and control systems that act to prevent them.

Water usage and leaks in a distribution system can result in a dramatic decay in the magnitude of transient pressure effects

2.8. Protection Devices:

To the extent possible, the engineer would like to design flow control equipment such that serious transients are prevented. Using a transient model, the engineer can try different valve operating speeds, pipe sizes, and pump controls to see if the transient effects can be controlled to acceptable levels. If transients cannot be prevented, specific devices to control transients may be needed. A brief overview of various commonly used surge protection devices and their functions is provided in Table

Some methods of transient prevention include:

2.8.1. Slow opening and closing of valves:

Generally, slower valve operating times are required for longer pipeline systems. Operations personnel should be trained in proper valve operation to avoid causing transients.

2.8.2. Proper hydrant operation:

Closing fire hydrants too quickly is the leading cause of transients in smaller distribution piping. Fire and water personnel need to be trained on proper hydrant operation.

2.8.3. Proper pump controls:

Except for power outages, pump flow can be slowly controlled using various techniques. Ramping pump speeds up and down with soft starts or variable-speed drives can minimize transients, although slow opening and closing of pump control valves downstream of the pumps can accomplish a similar effect, usually at lower cost. The control valve should be opened slowly after the pump is started and closed slowly prior to shutting down the pump.

2.8.4. Lower pipeline velocity:

Pipeline size and thus cost can be reduced by allowing higher velocities. However, the potential for serious transients increases with decreasing pipe size. It is usually not cost-effective to significantly increase pipe size to minimize transients, but the effect of transients on pipe sizing should not be ignored in the design process.

To control minimum pressures, the following can be adjusted or implemented; Pump inertia, Surge tanks, Air chambers, One-way tanks, Air inlet valves, and Pump bypass valves. To control maximum pressures, the following can be implemented; Relief valves, Anticipator relief valves, Surge tanks, Air chambers, and Pump bypass valves. These items can be used singly or in combination with other devices.

2.8.5. Pump Inertia:

Pump inertia is the resistance of the pump to acceleration or deceleration. Pump inertia is constant for a particular pump and motor combination. The higher the inertia of a pump, the longer it takes for the pump to stop spinning following its shutoff and vice versa. Larger pumps have more inertia because they have more rotating mass. Pumps with higher inertias can help to control transients because they continue to move water through the pump for a longer time as they slowly decelerate. Pump inertia can be increased through the use of a flywheel. For long systems, the magnitude of pump inertia needed to effectively control transient pressures makes this control impractical due to the mechanical problems associated with starting high inertia pumps. Therefore, increasing pump inertia is not recommended as an effective option for controlling transient pressures for long piping systems.

Fig 2.3: Typical arrangement of fly disc.

2.8.6. Air Chambers:

Air chambers and surge tanks work by allowing water out of the system during high-pressure transients and adding water during low pressure transients. They should be located close to a point where the initial flow change is initiated.

An air chamber is a pressure vessel that contains water and a volume of air that is maintained by an air compressor. During pump stop, the pressure and flow in the system decreases and as a result the air in the air chamber expands, forcing water from it into the system.

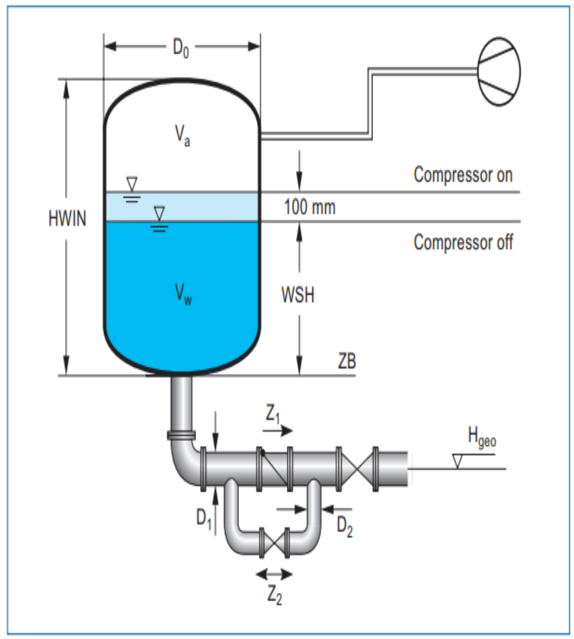


Fig 2.4: Schematic layout of a compressor-type air vessel

2.8.7. Surge Tanks:

A surge tank is a relatively small open tank connected to the hydraulic system. It is located such that the normal water level elevation is equal to the hydraulic grade line elevation. During pump stop, the surge tank substitutes the pump and by gravity feeds the system with water. This controls the magnitude of the low pressure transient generated as a result of the pump stop.

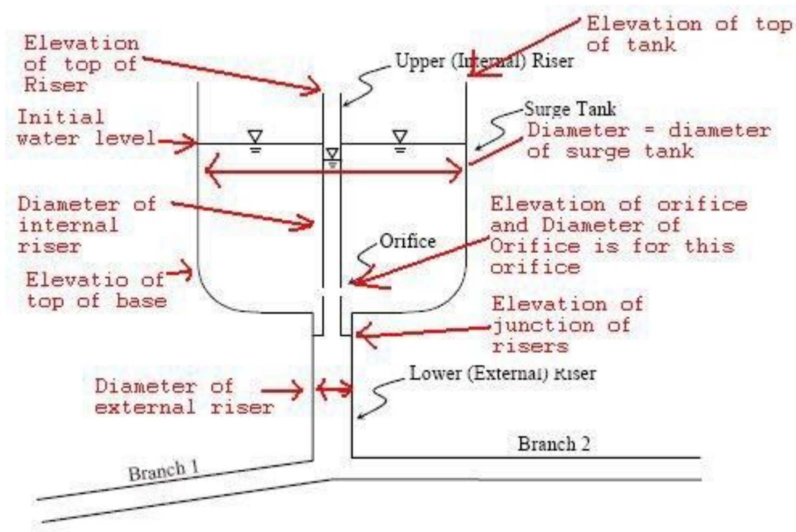


Fig 2.5: Schematic Diagram of Surge Tank

2.8.8. One-Way Tank:

This is a storage vessel under atmospheric pressure that is connected to the hydraulic system. It has a check valve (normally closed) connected to it which only allows water from the tank into the system. One-way tanks are primarily used in conjunction with pumping plants (Wylie and Streeter, 1993). The significant advantage of using a one-way tank rather than a surge tank is that the check valve allows the one-way tank to have a much lower height.

2.8.9. Pressure Relief and Other Regulating Valves:

A pressure relief valve is a self-operating valve that is installed in a system to protect it from over pressurization of the system. It is designed to open (let off steam) when safe pressures are exceeded, then closes again when pressure drops to a preset level. Relief valves are designed to continuously regulate fluid flow, and to keep pressure from exceeding a preset value.

An anticipator relief valve can be used instead of a pressure relief valve to control high pressure transient peaks. It is essential for protecting pumps, pumping equipment and all applicable pipelines from dangerous pressure surges caused by rapid changes of flow velocity within a pipeline, due to abrupt pump stop caused by power failure. Power failure to a pump will usually result in a down surge in pressure, followed by an up surge in pressure. The surge control valve opens on the initial low pressure wave, diverting the returning high pressure wave from the system. In effect, the valve has anticipated the returning high pressure wave and is open to dissipate the damage causing surge. The valve will then close slowly without generating any further pressure surges (M&M Control Service, INC).

Fig 2.6: Surge Anticipatory Valve

Fig 2.7: Surge relief Valve

Air inlet valves are installed at high points along the pipeline system to prevent vacuum conditions and potential column separation. Air enters the pipeline system during low pressure transient, and this air should be expelled slowly to avoid creating another transient condition. Before restarting the pumps, an adequate time should be allowed for the air that entered the pipeline to be expelled. There are varieties of valves that allow air to enter and leave a system, and their names depend on the manufacturer. These valves include air inlet valves, air release valves, vacuum relief valves, air vacuum valves, and vacuum breaker valves.

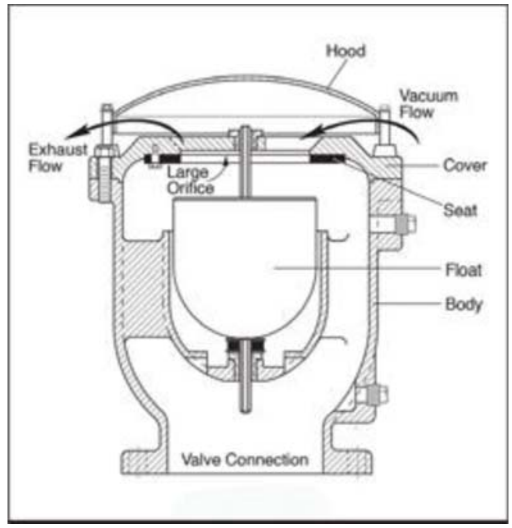


Fig 2.8: Air Valve

Fig 2.9: Swing check valve equipped with a hydraulic actuator and counterweight

2.8.10. Booster Pump Bypass:

Pump bypass with a valve is another protective device against pressure transients. Two pressure waves are generated as a result of reduction in flow due to booster pump stop; the wave travelling upstream is a positive transient, and the wave that travels downstream is a negative transient. A check valve in a bypass line allows free flow to the pipeline to prevent low pressures and column separation (Wylie and Streeter, 1993). The effectiveness of using a booster station bypass depends on the specific booster pumping system and the relative lengths of the upstream and downstream pipelines.

2.8.11. Primary attributes and design variables of key surge-protection approaches:

Protection Approach	Primary Attributes	Decision Variables
Check valve	Limits flow to one direction Permits selective connections Prevents/limits line draining.	Size and location Specific valve configuration Antishock (dampening) characteristics.
Pump bypass line	Permits direct connection and flow around a pump Can limit up-and-down surge.	Size and location Exact points connected Check-valve properties.
Open surge tank	Permits inflow/outflow to external storage May require water circulation Can limit up-and-down surge.	Size and location Connection properties Tank configuration Overflow level.
Closed surge tank (air chamber)	As pressure changes, water exchanged so volume of pressurized air expands or contracts Needs compressor.	Location Volume (total/water/air) Configuration/geometry Orifice/connector losses.
Feed tank (one-way tank)	Permits inflow into line from an external source Requires filling.	Size and location Connection properties Tank configuration.
Surge anticipation valve	Permits discharge to a drain Has both high- and low-pressure pilots to initiate action May accentuate down surge.	Size and location High-and low- pressure set points Opening/closing times.
Combination air release and vacuum breaking	When pressure falls, large orifice admits air Controlled	Location Small and large orifice size Specific valve

valve	release of pressurized air through an orifice.	configuration.
Pressure-relief valve	Opens to discharge fluids at a preset pressure valve Generally opens quickly and closes slowly.	Size and location High-pressure set point Opening/closing times.

(**Source: AWWA, 2005**)

2.9. Valve:

A valve is a device used to control the flow of water. The control is achieved by closing, opening or partially obstructing various passageways. Valves have many applications and plumbing valves are the most commonly used valves in everyday life. Technically, valves are considered to be pipe fittings, and there are many different valve designs. Each of the many different valve designs has its own advantages and disadvantages. The gate valve slides up and down like a gate, the globe valve closes a hole placed in the valve, the angle valve is a globe valve with a 90° turn, and the check valve allows the fluid to flow only in one direction.

From a functional point of view, valves can be divided into the following groups.

1. Valves which are either completely open or completely closed (on – off function)
2. Valves which can be used for a continuous control of the flow
3. Valves which only allow flow in one direction
4. Valves for special purposes such as pressure reducing valves, safety valves, air valves.

In a hydraulic system, valves are considered to be head loss, and this loss is described as:

$$h_{valve} = K_{valve} \frac{v^2}{2.g} \qquad (2.8)$$

where

K_{valve} = valve loss coefficient

v = cross sectional average velocity in the pipe close to the valve

The loss coefficient, *Kvalve as* a function of the valve opening is normally experimentally determined for steady-state flows but is assumed to be applicable for unsteady conditions too. It has the value of $0 < K_{valve} < \infty$. The numerical value of

K_{valve} might be obtained from valve manufacturers or could be estimated using simplifying assumptions. A check valve is normally described as having a low (or zero) loss coefficient when it is open, whereas a closed check valve is described by the condition that the flow is zero.≈ 0 when the valve is fully opened, and $K_{valve} = \infty$ when the valve is completely closed.

2.10. Pump:

A pump is a device used to move liquids, or slurries from one place to another. A pump moves liquids or gases from a lower pressure region to a higher pressure region. It adds energy to the system (such as a water system) to overcome this difference in pressure and friction. In general, pumps fall into two major groups and these are rotodynamic pumps and positive displacement (reciprocating) pumps of which rotodynamic pumps are the most common ones

A pump characteristics curve is a diagram supplied by the pump's manufacturer to describe the relationship between the head and the capacity of the pump using various size impellers. Each pump has its own characteristics curve, and a typical pump curve is as shown in Figure 2.10. The curve also includes information about efficiency, horse power consumption, Net Positive Suction Head Required ($N.P.S.H._R$), etc. The Net Positive Suction Head Required ($N.P.S.H._R$) is the minimum absolute pressure at the suction nozzle at which the pump can operate, and each pump has a specific $N.P.S.H._R$. To avoid pump cavitations, the $N.P.S.H._A$ of the system must be greater than the $N.P.S.H._R$ of the pump. In other words, the available N.P.S.H. must be higher than the required. Pump curves are generated by tests performed by the pump manufacturer and are based on a specific gravity of 1.0.

The system curve represents the effect of flow rate, geometric head and hydraulic losses in a system in a graphic form. Hydraulic losses in piping systems are normally composed of pipe friction losses, valves, elbows and other fittings, entrance and exit losses, and losses from changes in pipe size by enlargement or reduction in diameter. The system curve must be developed by the user based upon the conditions of service, which include physical layout, process conditions, and fluid characteristics

System curve = ΔZ + coefficient. Q^2

Where ΔZ is the pressure difference (normally geometric height difference) between the reservoirs, *coefficient* is the hydraulic losses in the system, and Q is the flow rate.

The operating point is the point of intersection of the pump curve and system curve. The head that corresponds to the operating point is the steady state head, and the flow rate corresponding to the operating point is the steady state flow rate. The flow rate of a pump increases as the required head decreases.

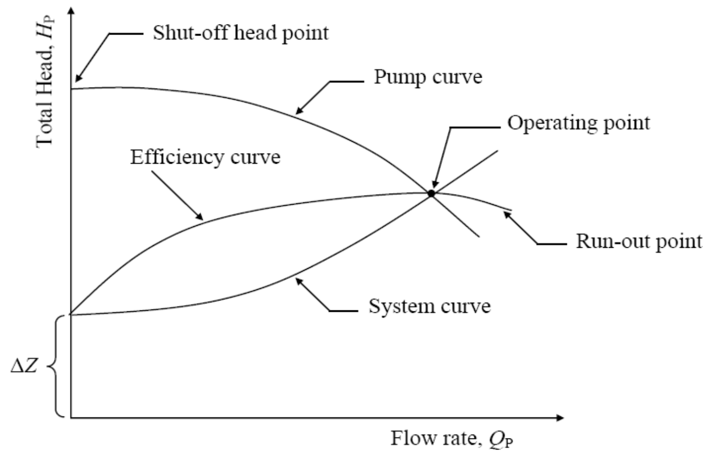


Fig 2.10. Typical system and pump characteristics curves

The shut-off head point is the head of the pump at no flow rate. The run-out point is the point where the flow rate of the pump is maximum and the head minimum, and beyond this point, the pump cannot operate. From the shut-off head point to the run-out point gives the pump's range of operation. Trying to run a pump off the right end of the curve will result in pump cavitations and eventually destroy the pump.

CHAPTER - 3

3. Introduction of HAMMER software:

HAMMER is one of the software that is able to simulate a complete system by using method of characteristics to solve differential equations of transient flow. HAMMER software is a powerful yet easy to use program that has the capability of analyzing of very complex system. It may be used for pumping system, piping networks, hydropower system etc. There are many advantages to use HAMMER software. Some of them are listed below. (HAMMER user guide 2010)

- By viewing the results, necessary precautions can be taken. Hence, the risk of transient-related damage to system can be reduced that will ensure less service introductions to customers.
- The effects of the transient phenomena on each element can be observed. Weak parts of the system can be strengthened, so the useful life of the system may be maximized.
- A hydropower plant can be modeled completely to simulate load rejection, acceptance and variation cases.
- There are many protective devices that can be modeled with HAMMER software. Therefore, it is possible to compare the results and determine the most cost-effective surge control strategy.

3.1. Interface and the toolbars of the HAMMER software:

HAMMER is user friendly software. Default workspace contains toolbars and their shortcuts, properties of the selected elements, element symbology pane, user notification pane, and the drawing pane. According to user preference, placement of the toolbars' shortcuts may be changed and some shortcuts may be added or removed.

HAMMER software includes 8 toolbars. The name of these toolbars and their functions are listed below.

- File toolbar contains opening, closing, saving and printing function.
- Edit toolbar is used for deleting, finding, undoing and redoing actions.
- Analysis toolbar contains scenarios, alternatives and calculation options. This toolbar contains analyzing functions.
- View toolbar has functions to manage the appearance of main window. Also, graphs, profiles and flex tables can be viewed by using this toolbar.
- Tools toolbar contains some useful tools such as waive speed calculator.
- Report toolbar has functions to report the results of the analysis.
- Help toolbar includes user's guide for HAMMER computer software.

3.2. Creating Model layout:

Creating a model layout is a very easy process by HAMMER software. This software has large database for modeling network system, pumping system and hydropower systems. Default workspace of the software includes layout toolbar. By clicking element, model layout can be created schematically or scaled. Properties and uses of some significant elements included in layout toolbar are listed below.

- **Pipe:** In a hydraulic system, pipe is one of the main elements. All elements included in a system must be connected to another element by pipe element. Properties of pipe material should be defined completely for successful model. The required properties of a pipe element are its diameter, material type, length, friction factor, minor loss co efficient, and wave speed which can be calculated by using wave speed calculator tool bar. Material type of the pipe element can be chosen from existing engineering library. If a new material type is required, the properties can be defined and add to the material library to assign the pipe.
- **Junction:** This element is used for connecting two or more pipes having different physical or transient properties in a hydraulic system. Furthermore, demands can be assigned to junctions to satisfy user demands especially for network system. For a successful hydropower system, the only required parameter of a junction is its elevation.
- **Reservoir:** This element refers a storage node and used for defining free water surface in a hydraulic system. Diversion weirs, dams, sump and tail waters can be defined by using reservoir elements. Water surface elevation can be defined as fixed or variable. However, water surface elevation does not change with pressure, surge during transient simulation. Its water surface and inlet/outlet elevations are required for model simulations.
- **Valves:** Valves are the control elements that open, throttle, or close to satisfy and maintain specified turbine conditions in a hydropower system. There are many types of valves defined by Bentley hammer software. These are PRV (Pressure reducing valve), PSV (Pressure sustaining valve), PBV (Pressure breaker valve), FCV (Flow control valve), TCV (Throttle control valve), and GPV (General Purpose valve). The type of the valve is selected according to purpose of uses. Also, Bentley Hammer software has not a defined element to model and impulsive turbine such as pelton Turbine. A valve may be used for modeling impulse turbine during transient analysis.
- **Pump:** A pump is an element that adds head to the system as water passes through it. This software can currently be used to model six different pump types: constant power, design point (1 point), standard (3 points), standard extended, custom extended and multiple points.
- **Tank:** Tanks are a type of storage node. A storage node is a special type of node where free water surface exists, and the hydraulic head is the elevation of the water

surface above some datum (usually sea level). The water surface elevation of a tank will change as water flows into or out of it during and extended period of simulations.

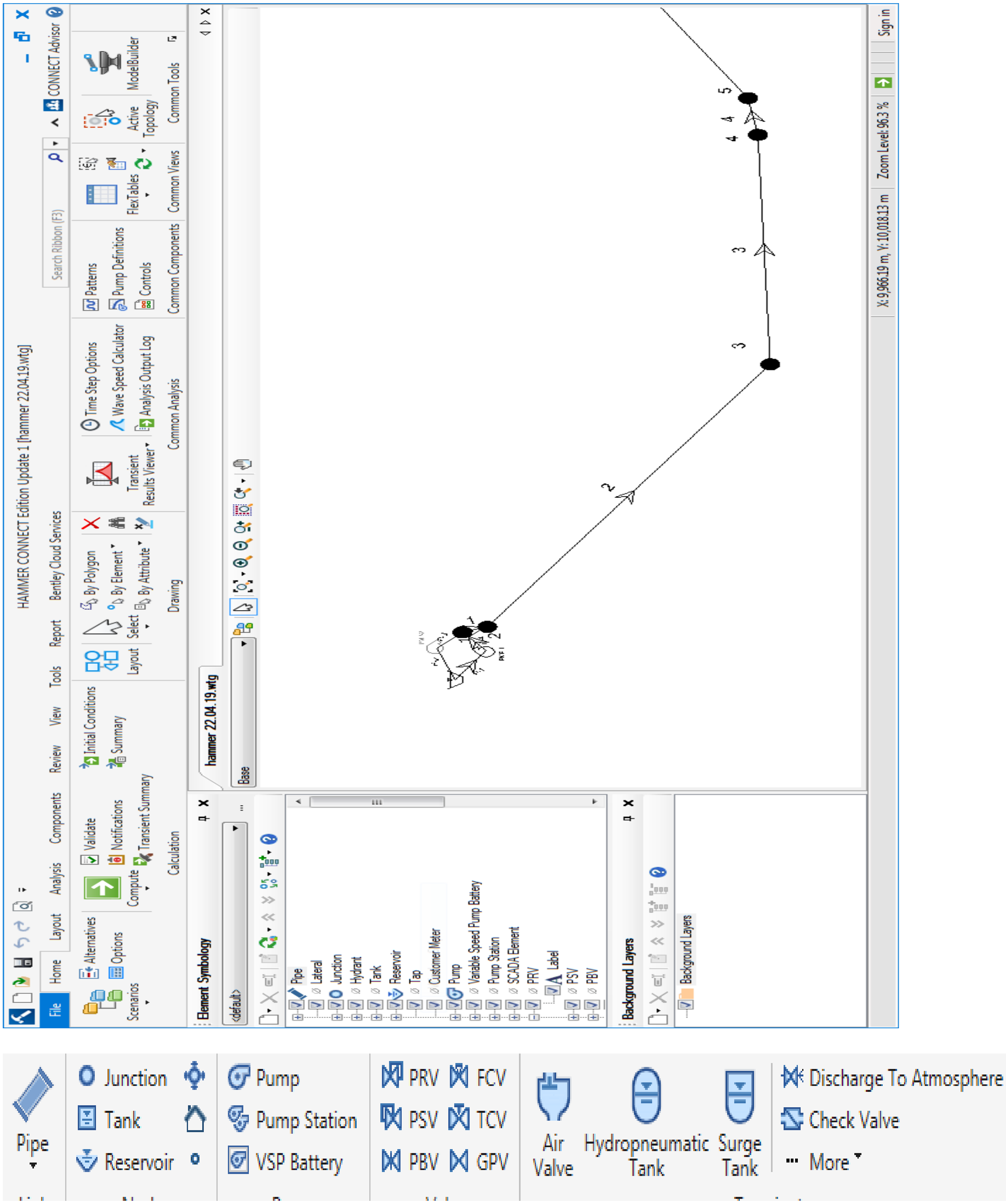


Fig 3.1: Default Workspace of Bentley HAMMER software.

3.3. Calculation options:

HAMMER software has two calculation steps. Firstly, steady state model should be created or imported. The input parameters to create a steady state model are listed below.

- Each system element such as reservoir, pipe, pump, protective devices must be placed and connected to each other.
- Nodes must be placed where characteristics of the pipeline system change.
- Elevation of each elements and nodes must be entered manually.
- Pipe lengths and diameters, material types and properties such as young's modulus, roughness height, Manning's coefficients, must be entered.
- Fluid conditions must be entered to calculate wave speed and to determine vapour pressure.
- Minor loss co efficient should be entered.
- Pump characteristics such as diameter, moment of inertia, efficiency, rotational speed, must be entered.
- Pump curve must be entered.

Second calculation option of the Bentley hammer software is transient solver. After all system characteristics entered and the steady state analysis completed, necessary data required for transient state must be entered. The main steps are listed below.

- A profile must be created to view transient results.
- The transient data for pump i.e. pump type, diameter (pump valve), time (delay until shut down), pump valve type and time (for closure of valve)
- The transient data for valve must be entered.
- The transient data i.e. wave speed of each pipe according to the pipe thickness must be calculated by wave speed calculator from the toolbar.
- The data's must be entered in the base calculation option of the transient solver of HAMMER software.
- For computing the model, initial conditions must be generated by compute initial conditions bar from analysis option.
- Finally the model is computed.

3.4. Creating scenarios and alternatives:

HAMMER is very powerful software to analyse many different operation conditions without editing or copying data. Some advantages of scenario management are listed below.

- Many alternatives may be generated with a single work file.

- Results of different alternatives may be compared directly.
- New scenarios may be created without having to re declare any data.

Especially for large schemes having hundreds or thousands of network element, the advantages listed above becomes clearer.

3.5. Viewing results:

Initial calculation summary gives some useful information such as success or failure of the calculation, status messages for elements and the system flow results (HAMMER 2010)

Transient results viewer has two alternatives. First one gives the option of viewing initial, minimum, and maximum values of hydraulic grade, pressure, velocity, air/vapour volume along the selected path. Second alternative gives the option of viewing transient time history at any selected point along the path. Also, transient time history of the selected point may be animated.

CHAPTER - 6

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