COMPUTATIONAL ANALYSIS OF WATER SURGE PHENOMENON AT POWER STATION

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RESEARCH REPORT SUBMITTED TO THE FACULTY OF ENGINEERING UNIVERSITI MALAYA. IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MECHANICAL ENGINEERING

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Field of Study: Water Surge

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ABSTRACT

In such confined system for water pipeline, a sudden displacement of flow that causes large pressure destabilize or back pressure is called water hammer. The called is given due to the sound that occurs during the back flow of water. It is most important consideration of many hydraulic design structure due to extreme variation of pressure cause by the pump. The compressibility of water and the elasticity of pipes, pressure waves will then spread in the pipe until they are decreased at certain velocity, which is dependent on the pipe material and wall thickness. Through the effects of the water hammer changing, range from slight changes in pressure and velocity to sufficiently high pressure or vacuum through to failure of fittings, and burst pipes. Figure 1 shows burst mild steel pipe due to water hammer pressure. This pipe thickness and pipe material is not sufficient to sustain the water hammer pressure. Therefore, pipe burst and suitable mathematical modeling of the different ingredient in hydraulic system is necessary to get, useful results, which help fulfill these objectives. In this paper mathematical modeling used to develop computer program to simulate the hydraulic transient in simple pipe. There was no need to consider cases of unsteady flow, either in open channels or in closed pipes and conduits. The action of waves on shore 1ines, in bays and ports, and a1ong canals, was the only prob1em simi1ar to water-hammer known in early times, and the mathematical and physical knowledge in those days was unable to cope with this problem except by construction of breakwaters for protection of harbors and shipping. This branch of hydrau1ics, now designated as coastal engineering, which deals with tida1 and surface waves, has become a very important field, particularly in this 20th century. Because of the rapid flow changes, a pressure wave is propagated while a negative down surge travels down the pipeline to the discharge outlet where it is reflected. The reflected wave will in turn creates a positive surge along the pipeline. Unlike some aspect of the system behavior that are conservative when

neglected, this phenomenon cannot be neglected as it increases the severity of water hammer. Column separation is the discontinuity in the water column caused by excessive tension when the pressure is reduced to the vapor pressure of water. Large diameter thin walled pipelines are particularly vulnerable to shell collapse under this condition. On the other case, if the adverse pressure is not acceptable, suitable surge suppression device shall be recommended to limit the pressure to acceptable levels.

ABSTRAK

Dalam sistem terkurung untuk saluran paip air, aliran tiba-tiba aliran yang menyebabkan tekanan yang tidak stabil atau tekanan belakang dipanggil tukul air. Yang dipanggil diberikan kerana bunyi yang berlaku semasa aliran belakang air. Ini adalah pertimbangan yang paling penting bagi banyak struktur reka bentuk hidraulik kerana variasi tekanan yang keterlaluan oleh pam. Kemampatan air dan keanjalan paip, maka gelombang tekanan kemudian akan tersebar di dalam paip sehingga ia menurun pada halaju tertentu, yang bergantung kepada bahan paip dan ketebalan dinding. Melalui kesan tukul air yang berubah-ubah, dari sedikit perubahan tekanan dan halaju ke tekanan yang cukup tinggi atau hampagas ke kegagalan kelengkapan, dan paip pecah. Rajah 1 menunjukkan paip keluli yang pecah kerana tekanan tukul air. Ketebalan paip dan bahan paip ini tidak mencukupi untuk mengekalkan tekanan tukul air. Oleh itu, paip pecah dan pemodelan matematik yang sesuai bagi ramuan yang berbeza dalam sistem hidraulik adalah perlu untuk mendapatkan, hasil yang berguna, yang membantu memenuhi matlamat ini. Dalam makalah ini pemodelan matematik digunakan untuk membangunkan program komputer untuk mensimulasikan fasa hidraulik dalam paip mudah. Tidak perlu mempertimbangkan kes-kes aliran tidak mantap, sama ada dalam saluran terbuka atau dalam paip dan saluran tertutup. Tindakan ombak di pantai 1in, di teluk dan pelabuhan, dan terusan a1ong, adalah satu-satunya masalah yang berlaku pada tukul air yang diketahui pada masa-masa awal, dan pengetahuan matematik dan fizikal pada masa-masa itu tidak dapat mengatasi masalah ini kecuali dengan pembinaan pemecah bagi perlindungan pelabuhan dan perkapalan. Cawangan hidrau1ik ini, yang kini ditakrifkan sebagai kejuruteraan pantai, yang berkaitan dengan tida1 dan gelombang permukaan, telah menjadi medan yang amat penting, terutamanya pada abad ke-20 ini. Kerana perubahan aliran pesat, gelombang tekanan disebarkan sementara gelombang turun negatif menurunkan saluran paip ke saluran pelepasan yang dicerminkan. Gelombang

yang tercermin akan menghasilkan gelombang positif sepanjang saluran paip. Tidak seperti beberapa aspek tingkah laku sistem yang konservatif apabila diabaikan, fenomena ini tidak boleh diabaikan kerana ia meningkatkan keparahan tukul air. Pemisahan lajur adalah pemotongan dalam lajur air yang disebabkan oleh ketegangan yang berlebihan apabila tekanan dikurangkan ke tekanan wap air. Talian berdinding nipis berdiameter besar sangat terdedah kepada keruntuhan shell di bawah keadaan ini. Dalam kes lain, jika tekanan buruk tidak dapat diterima, peranti penindasan lonjakan yang sesuai hendaklah dicadangkan untuk menghadkan tekanan ke tahap yang boleh diterima.

ACKNOWLEDGEMENTS

First, I wish to express my deepest gratitude to my supervisor Prof. Ir. Dr. Nik Nazri Bin Nik Ghazali for offering me to conduct this research project and his exemplary guidance, constant encouragement and monitoring throughout my research project. Every time I came across something that I do not understand, he will always available to advise me and discuss with me in precise details. I learnt a lot about the fundamentals and core knowledge about water surge.

Moreover, I could not do it without the support from my family which helped me acquire my strength to accomplish my project successfully. I am grateful to my friends as well who always stood by me in case of any kind help I sought for. I would like to express sincere appreciation to every party that had given support and shared their priceless knowledge with me. Special thanks to Hytran software Ms Yoon Li that been helpful in providing all the knowledge on expertise using the software.

Lastly, I hope that this document will benefit its readers, in providing additional data related to the research of water surge in protection of power station for future references and studies.

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LIST OF SYMBOLS AND ABBREVIATIONS

DATUM	:	Data from Sea Level
SPAN	:	Suruhanjaya Air Negara
JBA	:	Jabatan Bekalan Air
UTG	:	Uniform Technical Guidlines
LRA	:	Loji Rawatan Air
SSP3	:	Sungai Selangor Plant 3
NPSH	:	Net Positive Suction Head
FSI		Fluid Structure Iteration
DLF	:	Dynamic Load Factors
MOC	:	Method of Characteristic

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CHAPTER 1: INTRODUCTION

1.1 Background

Water hammer in a system of water pipeline are transient flow from one transition to steady state in watery flow system. This transient occurs within all confined and unconfined system. This allow by a commotion to the fluid flow. In such confined system for water pipeline, a sudden displacement of flow that causes large pressure destabilize or back pressure is called water hammer. The called is given due to the sound that occurs during the back flow of water. It is most important consideration of many hydraulic design structure due to extreme variation of pressure cause by the pump. For example, the increasing pressure in the piping system combine with high pressure wave, there are the negative wave which are likely to be missed but can cause contaminant intrusion. It will apply to stress and cause damaging the existing on pipes, joint and valve and the noise that triggered can be notified.

The effect of water hammer on piping system can change the pressure and resulting of rapid changes in current. Normally it were occur in a piping system after emergency pump off or normal operating pump shut-off, although it may also during the pump soft start or at valve opening or closing. The compressibility of water and the strength material of pipes, pressure waves will then spread in the pipe until they are decreased at certain velocity, which is depend on the pipe material and wall thickness. Through the effects of the water hammer changing, range from minor changes in pressure and velocity to sufficiently high pressure or vacuum through to failure of connector, and burst pipes. Figure 1 shows burst mild steel pipe due to water hammer pressure. This pipe thickness and pipe material is not sufficient to sustain the water hammer pressure. Therefore, pipe burst and appropriate calculation of modeling in the different ingredient in hydraulic system is necessary to useful results, which help can be fulfill these objectives. In this data modeling used to develop computer program to simulate the hydraulic transient in simple pumping system. The simulation is typically very time-consuming and depending on characteristics of the system implementation.

In the larger field of hydraulics, early development was based on problems of transportation of water, and on the measurement of flow for irrigation and for domestic use in the centers of population. This invo1ved devices for pumping, for delivery along canals and conduits, and for the measurement of quantities used by individuals. The theory and designs had to do with hydrostatic pressures, friction losses, and discharge coefficients, most of which could be handled by experimental studies. There was no need to consider cases of unsteady flow, either in open channels or in closed pipes and conduits. The action of waves on shore 1ines, in bays and ports, and a1ong canals, was the only prob1em simi1ar to water-hammer known in early times, and the mathematical and physical knowledge in those days was unable to cope with this problem except by construction of breakwaters for protection of harbors and shipping. This branch of hydrau1ics, now designated as coastal engineering, which deals with tida1 and surface waves, has become a very important field, particularly in this 20^{th} century.

Figure 1.1: Pipe burst cause of water hammer

(Source: https://www.thestar.com.my)

In water supply pumping schemes involving transferring of water from suction tank to elevated reservoir, it is often assumed that sudden power failure to the pump motors will produce the maximum and minimum transient in the pipeline. If there are multiple pumps in the station, then it is assumed that the extreme transient generated will be caused by all pumps failing simultaneously. In majority cases, the pressure caused by simultaneous power failure to multiple pumps is the main consideration that governs the design of the pipeline.

In pumping system where check valve or one-way valve is installed at the downstream of the pumps, when power supply fails, the pump energy is implementing to rotate the impeller pump that use energy available to drive the pumping system to kinetic energy of the rotating mass of the pump, motor and the entrained water in the pump. Since the energy is usually small compared to the energy required to maintain the flow against the discharge head, the pump speed slows down quickly resulting in a rapid reduction in the pump discharge. Because of the rapid flow changes, a pressure wave is propagated while a negative down surge travels down the pipeline to the discharge outlet where it is reflected. The reflected wave will in turn creates a positive surge along the pipeline.

During this transient cycle, the pressure may fall below atmospheric pressure and if it further drops to the vapor pressure of water at any point in the pipeline, cavitation will occur forming a vacuum at that point. Unlike some aspect of the system behavior that are conservative when neglected, this phenomenon cannot be neglected as it increases the severity of water hammer. Column separation is the discontinuity in the water column caused by excessive tension when the pressure is reduced to the vapor pressure of water. Large diameter thin walled pipelines are particularly vulnerable to shell collapse under this condition.

It is the purpose of this surge analysis to reveal if there is any adverse pressure (Maximum or minimum) occurs during transient, if no adverse pressure is encountered, no surge suppression device is needed. On the other case, if the adverse pressure is not acceptable, suitable surge suppression device shall be recommended to limit the pressure to acceptable levels.

In these recent event on march 2018, there are one of the water treatment plant, LRA (Loji Rawatan Air) the Sungai Selangor Plant 3 (SSP3) at Bukit Badong that was outrage with two (2) major pipes size 1,100mm and three (3) small pipe size 400mm was burst that involve 5 people are injured cause by the water surge at the Surge vessel tank during the pump operational.

1.2 Problem Statement and significance of the Research

1.2.1 Positive Pressure

It occurs as the modelling the surge performance of a pipeline, peak positive pressures are one of the key aspects to review. The rated pressure of a pipeline is a maximum pressure which the pipe can be subject to, as specified by the pipe manufacturer. As rising mains are subject to varying degrees of water hammer, it is common practice to design a pipeline so that the normal operating pressure is well below that of the rated pressure of the pipe material used. If specific water hammer modelling is not done, the hydraulic engineer cannot be certain of the magnitude of peak pressures within the pipeline. It should the rated pressure be exceeded, the rising main's useful life could be reduced, leading to failure.

1.2.2 Negative pressure

Negative pressures within a pipeline cause buckling of the pipeline and/or cavitation. A pipeline can buckle if the negative pressures experienced within the line are greater than the structure of the pipe can tolerate, and the pipe will collapse in on itself. This usually only occurs with high negative pressure and relatively thin walled pipes. If surge modelling of a pipeline shows that significant negative pressures are likely, it is prudent to conduct a specific buckling calculation.

Cavitation occurs when the pressure within a pipeline approaches negative 10m head. It is very important that negative surge vacuums of this magnitude be avoided. If cavitation is left to occur often, the fluid can vaporize and condense very rapidly. This will lead to unnecessary degradation to the surrounding pipe and fittings. If cavitation does occur, excessively high positive pressure can be generated when the water columns re-join.

1.2.3 Fatigue loading

When some pipe materials are subjected to repeat cyclic loading, which occurs with water hammer, the material can weaken due to fatigue. This type of failure should be checked for, during the design phase, when a large number and/or high amplitude of stress cycles are anticipated. The amplitude or pressure range considered when checking for fatigue loading is defined as the maximum pressure minus the minimum pressure, experienced within a pipeline, during its day to day operation.

For pipeline design, if a large pressure range is observed during transient modelling and a pipe material susceptible to fatigue failure is being used, then a fatigue calculation should be done.

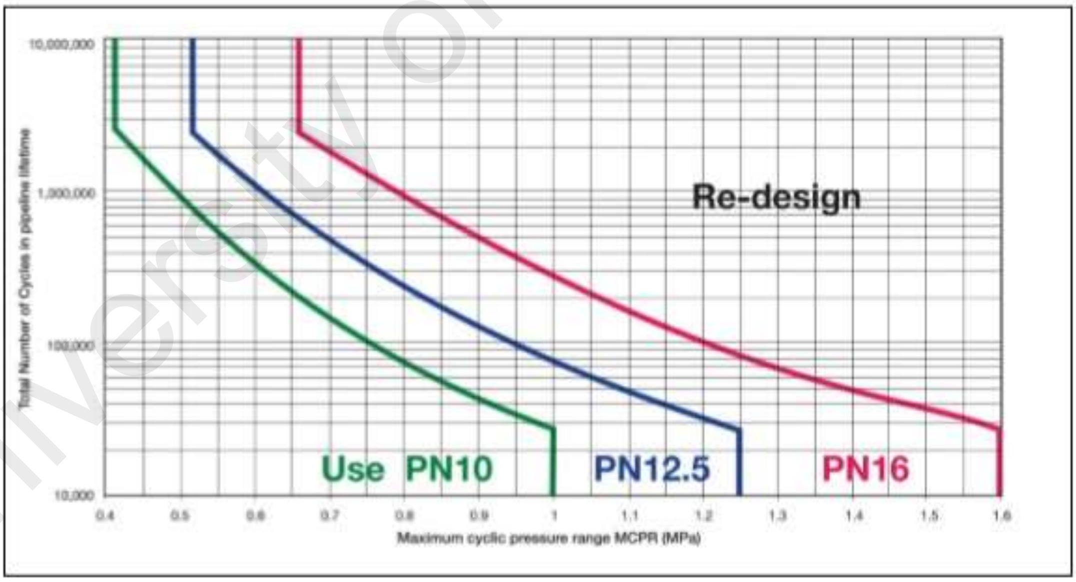


Figure 1.2: Re-rated performance of PVC piping under Cyclic Loading

(Source: http://www.iplex.com.au)

1.3 Objective of the Research

The objective of the present research project are: -

1. To investigate water hammer phenomenon on pumping station

2. To simulate water surge phenomenon according to actual pumping station

3. To suggest various method to minimize water hammer

4. To analyze and recommend prevention on water hammer

CHAPTER 2: LITERATURE REVIEW

The study of water-hammer has now assumed a broader world-wide aspect, carried by engineers and concerned mainly with its practical importance. Fields of study have become more specialized and the methods are more accurate and in greater detail, with experimental test and the determination of the system characteristic of the various component playing an important role.

2.1 Phenomenon of water surge

The first scientist Joukowski, that describe the water hammer effect was proved that both theoretically and experimentally that there are maximum pressure can be produced, known now as the “Joukowski head” or “Joukowski pressure” depending on the units of its expression. It is given by the formula;

$$h = \frac{v \times c}{g} \tag{2.1}$$

Where;

$c = speed\ of\ the\ sound\ wave\ in\ the\ pipe, known\ as\ the$ wave celeric, m/s

$v = initial\ velocity\ of\ the\ liquid, m/s$

$g = 9.81\ m/s^2$

$h = Joukowski\ head, m$

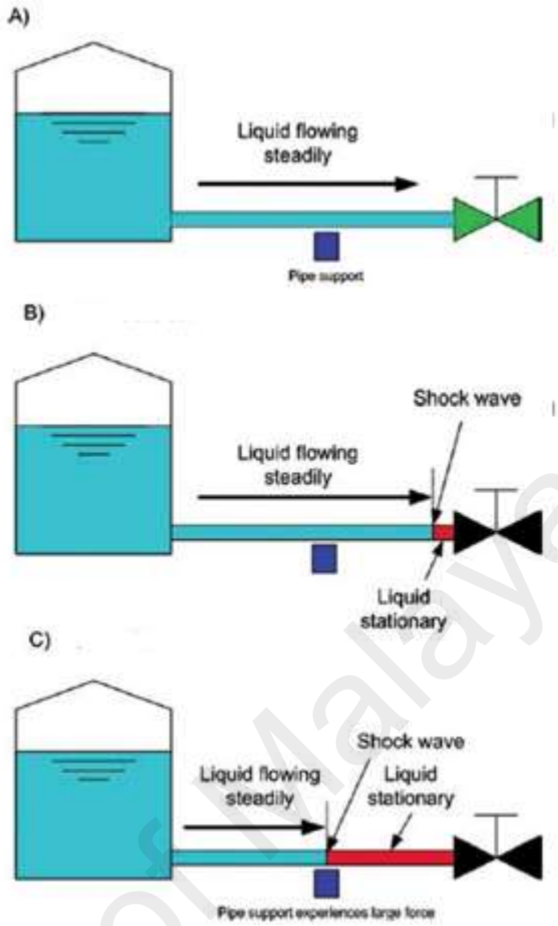


Figure 2.1: Liquid flowing through a value, (a) Valve open, (b) Valve closed suddenly, and (c) A time later

The forces and pressures calculated are specified and fast event. The Joukowski event and a gradual change in fluid speed that gives no perceptible surge forces. In many cases, more complicated analysis must be done to ascertain the pipe risk. This usually involve the transient modelling of the pipe profile in greater and lesser details to see how large the surge pressures will become. This will be ability to calculate the maximum and minimum value of pipe pressure experiences during transient event.

In any current situation for forces on different material pipes and their pipe support (such anchor block) getting complex even when analysis of transient is performed. The dynamics response to the pipe works must be considered. It shows on vibration theory and it consideration of the time for which forces implement.

If the rigid pipework, vibration theory shows that maximum forces can reach twice the value event and for flexible pipework the forces may transmitted to anchors and be very small. If the pipes are short but the vibration are taking longer than the pressure wave passes through the section of pipe quickly. The transient can be gone before the pipe has time to move enough sustain damage, if the converse is true then the harmonic motion of the pipe is double to be safe.

Rising on water hammer due to downstream of valve on positive pressure increase in front of the valve, however for pipes with valve not close to the pipe end, it is more likely that problem occurs positioning downstream of the valve. The pressure can fall to the vapor pressure condition of liquid, and boiling can be produced. If boiling occurs, then the cavity forms. In a typical situation are shown at figure 2.2 (A), the liquid down stream of cavity return and increase the same velocity as the liquid water had when the cavity started to form. However, if it returns to the valve of remaining before the cavity as show in figure 2.2 (B), the collision become an equivalent to valve closing in minimum time fraction of second can harm in water hammer.

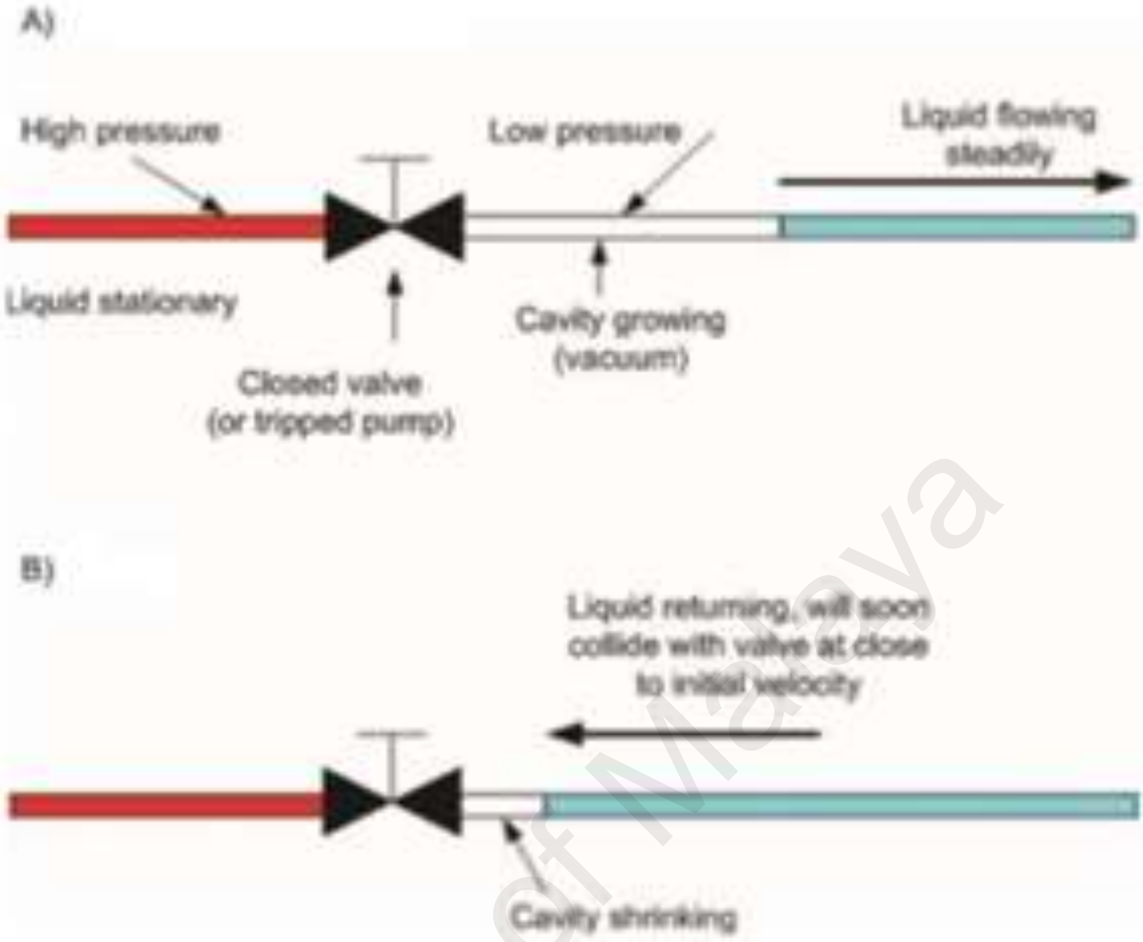


Figure 2.2: Cavity growing downstream of the value, (a) Soon after the valve close, and (b) Later

Pump trip is the same sort of situation occurs downstream of a pump that has tripped. If the pump slows the liquid sufficiently quickly, then cavitation will occur downstream of the pump, and the vapor collapse gives rise to severe water hammer. Immediately after a trip, the fluid drives a centrifugal pump like a turbine, and the dynamic behavior is complex. For positive displacement pumps, the run-down is largely independent of the fluid conditions. In either case, a cavity can form in the low-pressure area and lead to a cavity collapse and subsequent pressure shock.

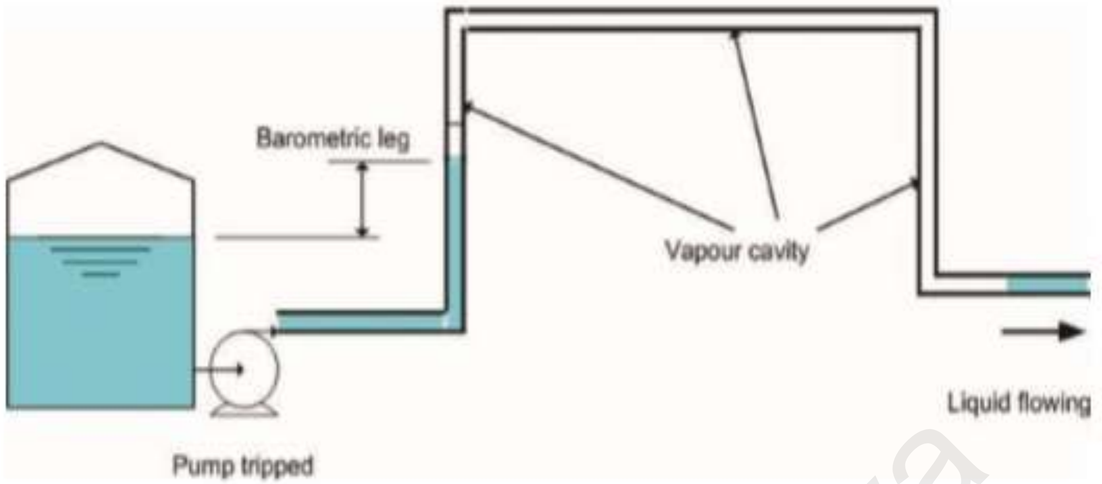


Figure 2.3: Cavity forming in a pipe bridge

Highpoints Cavitation can also happen in elevated high places such as on pipe bridges. In some situation shown in Figure 2.3, the liquid is vulnerable to cavitation on pump trip as the down coming liquid a pull suction on the elevated section. This can cause a problem even when the elevated section is less than a barometric leg above the destination tank. However, if the pipe high point is more than a barometric leg above the destination tank, then unless valves are used to prevent it, there will always be a cavity formed. As a result, when the pump restarts, the liquid columns will collide, again creating severe water hammer if the velocity is high. If non-condensable gases come out of solution in the cavity, the subsequent collapse will be cushioned, reducing the surge pressure and forces. However, this cannot be relied on for surge protection.

The restrictor orifice occurs as flow is limited by a restrictor orifice that is close to the end of a piping system, a problem can occur on pump startup. The system depicted transported a boiling liquid from one storage tank to another. A control valve was needed in the pipe to regulate the flow, but to prevent flashing across it a restrictor was placed in the pipe downstream, close to the inlet of the destination tank.

So the Joukowski pressure is

$$p = v \times v \times \rho \tag{2.2}$$

Where $\rho =$ fluid density

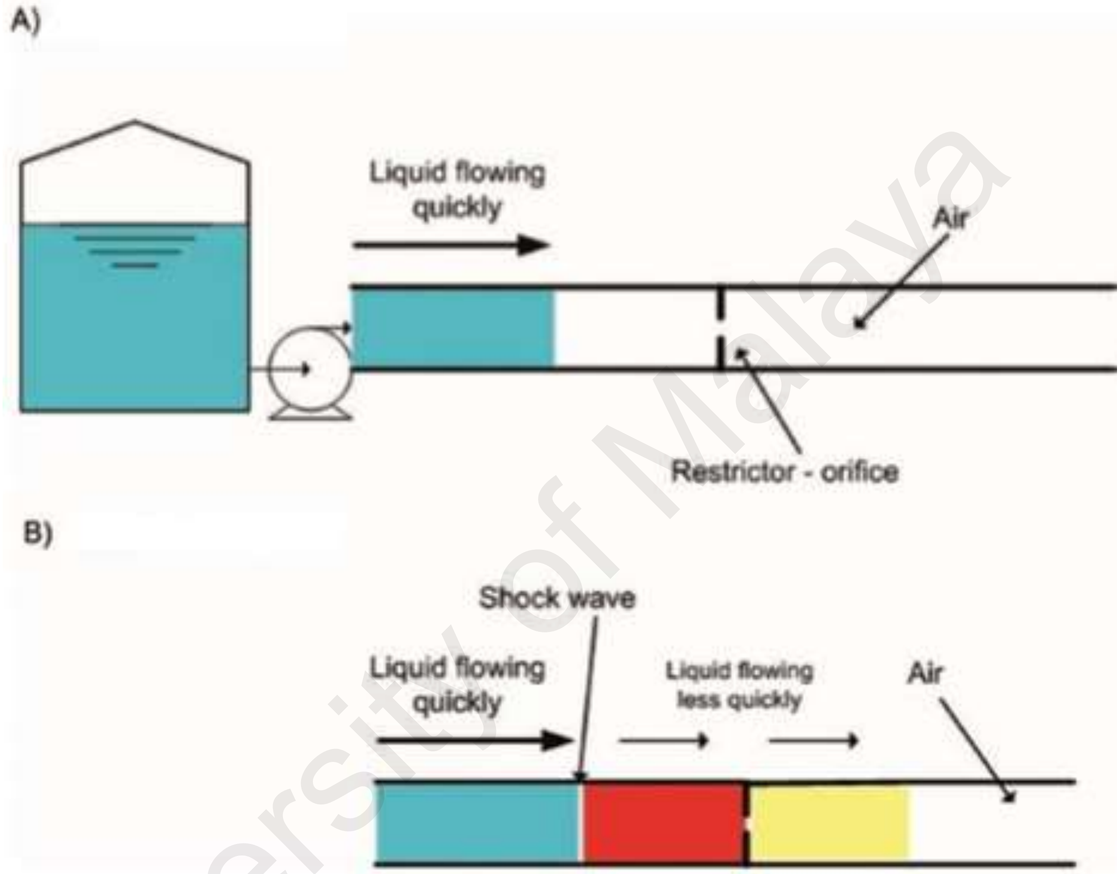


Figure 2.4: Flow hits an RO, (a) Just before strike, and (b) Just after strike

Under normal running conditions, the pressure drop across the restrictor causes a back-pressure that prevents flashing across the control valve and hence allows it to operate correctly. However, on pump startup, as the piping system is empty, the water liquid runs at high rate until it reaches the restrictor, when its flow in sudden current it falls. This causes a surge phenomenon event with the velocity being the change by the passage of water liquid through the restrictor. In a case studied, this was quite significant, and the pipework system had to be designed to withstand the forces produced.

With rigid pipework system, vibration theory shows that the maximum force can reach twice the value calculated. For flexible pipework, the force transmitted to anchors can be small. If the pipe is short and its period of vibration is long, then the pressure wave passes through that section of pipe quickly. Hence the transient can be gone before the pipe has time to move enough to sustain damage. However, if the converse is true, then the harmonic motion of the pipe is such that the forces calculated previously need to be doubled to get the correct result. Thus, if harmonic motion of the pipe is not to be studied, then the result should be doubled to be safe. This factor modifying the force conclusion that is known as the Dynamic Load Factor (DLF), so the full equation for force is:

So the dynamic Load Factor (DLF) is

$$F = \frac{\pi}{4} \times D^2 \times v \times c \times \rho \times DLF \qquad (2.3)$$

The non-return valves can be the pressure surge problem. Normally, such valves are held open by the fluid flow, and are closed either by a spring, or by the drag of the fluid as it flows in a reverse direction, e.g. after a pump trip. The problem is that unless correctly chosen, these valves can have unfavorable characteristics, in that they suddenly slow the liquid as they reach the closed position. So, if the valve is slow to operate, a significant reverse flowrate can build up, and then the valve slams shut – exactly the conditions to get a pressure surge.

Fortunately, some manufacturers have recognized this problem and make non-return valves that close quickly and prevent the reverse flow building up. These should be used whenever reverse flow is likely in long pipelines. Selection of a suitable valve can be based on the deceleration of the liquid expected.

Longer piping system with pumps can run down in any length of time from less than a second to tens of seconds depending on their inertia and internal friction. The duration rate of slow-down decreases as the speed velocity is decreases, but a typical pump will run down to under 50% of its initial speed in 2 to 3 seconds, causing a similar slower in flowrate. The effect of this can be estimated as if it were a valve close. If the pump is a positive displacement pump located at the end of a long suction pipe, it is like a valve closing at the end of a long pipe.

The common problem with pumps is cavitation in the delivery line, if the cavity can subsequently collapse. It is not possible to give typical figures here, because whilst there is only 1 Bara of atmospheric pressure, frequently the static pressure in the pipe system can be high and thus prevents cavitation. Hence the situation needs careful analysis. Changes in elevation, particularly pipe bridges, are danger areas as it is here that static heads can be lower, and cavitation is more likely Fluid structure interaction (FSI).

There was among to do an exceptionally exhaustive survey of transient wonders in fluid filled pipe frameworks managed water pump, cavitation, auxiliary progression and liquid structure cooperation (Tijsseling, A.S.,1996). The fundamental concentration was among history of FSI investigate in time zone.

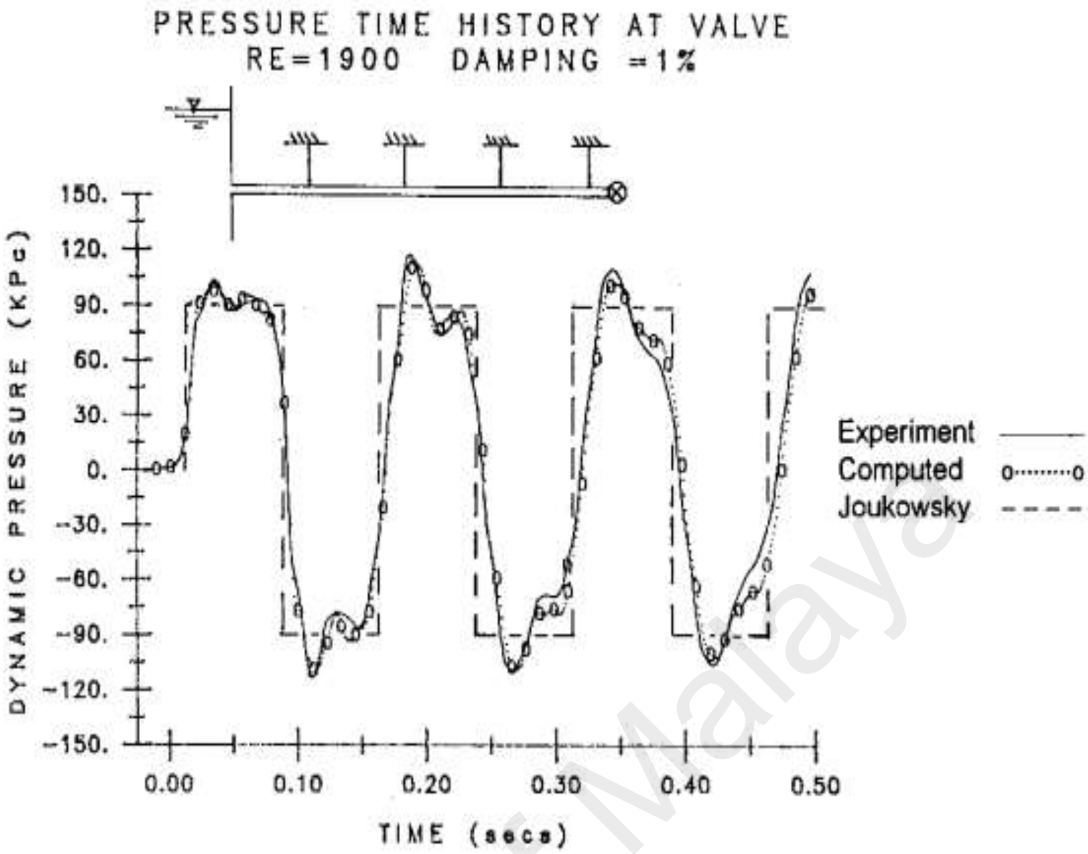


Figure 2.5: Pressure Vs time

At that point where endeavored to succinctly abridge the basic components that reason FSI, and present huge information that depict the peculiarity (Wiggert, D.C, Tijsseling A.S.,2001). What's more, different numerical techniques and investigative strategies that have been created to effectively foresee FSI has been characterized.

The two changed courses, strategy for trademark (MOC) and limited component technique (FEM) for unraveling the basic condition (Heinsbroek A, 1996). In this way examine demonstrated that the FSI in pipeline framework can satisfactorily be explored by utilization of MOC and FEM for water driven and structure of funneling framework, individually. Tijsseling exhibited the MOC approach for acquiring precise arrangement of FSI four condition model and it is by and large alluded in the greater part of the most recent papers for approving the outcomes with standard cases (A.S. Tijsseling,2003).

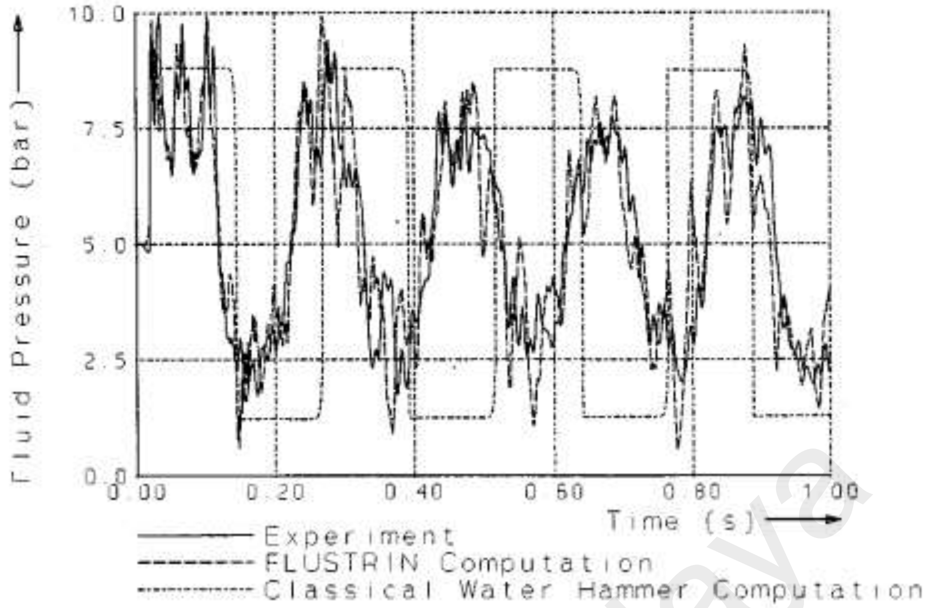


Figure 2.6: Measured and computed dynamic pressure near the shut-off valve

In different terms, utilized a one-dimensional wave plan in equally the fluid liquid compasses and the funneling structure bringing about five wave parts and fourteen factors (Wiggert et al, 1987). MOC approach was presented in the condition.

In the examined to limited component perform investigations with plan of Finite distinction technique (FDM) and strategy for attributes to show the parts of water pounding (Murat, E.,1996).

Settling the fundamental FSI condition scientifically. In the two investigations just, intersection coupling are considered yet just for an over the top valve (Lee.U and Park.J, 2006). An expansion to the time area investigation, numerous scientists have thinks about the hypothetical and test viewpoints in recurrence space.

The examination of water pound with fluid structure cooperation (FSI) start to explore intersection coupling impacts. Intersection coupling impacts were considered in different sorts of focuses, for example, pumps, valves and connectors. The significance was put over the top pump and connection in the framework and the related relations were determined for demonstrating. Anticipated relations were measured as limit conditions for the numerical displaying which was connected utilizing the limited component strategy for the basic conditions and the technique for attributes for the pressure driven conditions (Ahmadi,A. and Keramatn, A.,2010).

As the coupled condition of smooth movement and pipe relocation are illuminated by Mahmoodi et al. unflinching the situation of misfortunes of coolant mischance in atomic influence plants utilizing the transient vibration motion from a pipe crack. A limited component plan is executed to incorporate the impact of liquid structure association (Mahmoodi.R, Shahriari.M, Zolfaghari.A, Minuchehr, 2012).

An examination by Kermat et al. at water pumps with FSI and viscoelasticity concerns funnels made of plastic, where FSI impacts are demonstrated more huge than in steel channels, just in light of the fact that they are more adaptable ("in spite of the fact that with thicker dividers, their modulus of versatility is lower and their Poisson's proportion is higher" in materials graph). This making the aftereffects of FSI examination important to dependably gauge a definitive pipe stresses, elbow removals and grapple powers, all the more precisely to center the outlines with adaptably upheld channels. It was discovered thus that in the early discoveries of the transient occasion FSI is generous.

Liquid speed are potential found by Olson and Bathe that have detailed limited component system by building up coordinate symmetric model.

Sandberg has proposed a symmetric limited component show for coupled acoustic vibration amongst liquid and structure and effect of Eigen esteem moving in complex framework while after that Lee and Park displayed an approach to change coupled pipe elements condition into direct shape about enduring state estimation of liquid weight and speed. Ghostly component demonstrate is utilized and contrasted and FEM (Olson and Bathe, 1985).

It has been 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 by the Xiaodong, 2008. While by Elghariani in the thesis state has discussed formulation of equations considering effect of FSI and solving it with MOC with or without friction coupling as a major source of investigation. On other terms as prescribe 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 (Elghariani,S.K.,, 2007).

2.2 Pipe Friction

Pipe friction was founded by Darcy-Weisbach, where the equation has a long history of development, it all started from the 18th century and continues through this day, while it is named after two (2) great engineers of the 19th century, many others have also assisted in the effort of improving. There are many of the names and dates are well known, but there are some have slipped from shared recognition. As in any past work, others may well find it is still uncompleted.

In finalization, it is to minimize too many variable of confusion, therefore it come out to standardized equation forms and variable symbols are used instead of each researcher's specific terminology. Simple replacements, such as diameter for radius, are made without extra additional note. The History of the Darcy-Weisbach Equation for Pipe Flow Resistance.

In the 21st century where there is the energy consumption. An example can be fluorescent lamps compared to more efficient than Tungsten lamps since they consume lesser electricity but provided same amount of light. While transporting liquid in pipes, energy loss due to friction between pipe wall and liquid molecules and within the liquid due to its viscous effects can be seen in considerable amount. Therefore, researches are performed to decrease the frictional force and ultimately decrease the energy loss.

Conditions in the pipelines are characteristically non-uniform over the flow cross section and any given length. The flowing water fluid within pipelines is not isothermal in the radial direction because of the very dissipation that is quantified by the Darcy-Weisbach equation. Certainly, any given length of pipe for which the fully-developed flow requirement is approximated must be connected to entry and exit systems within which this is not the case. When the flow is turbulent, vortices form and collapse relentlessly over time.

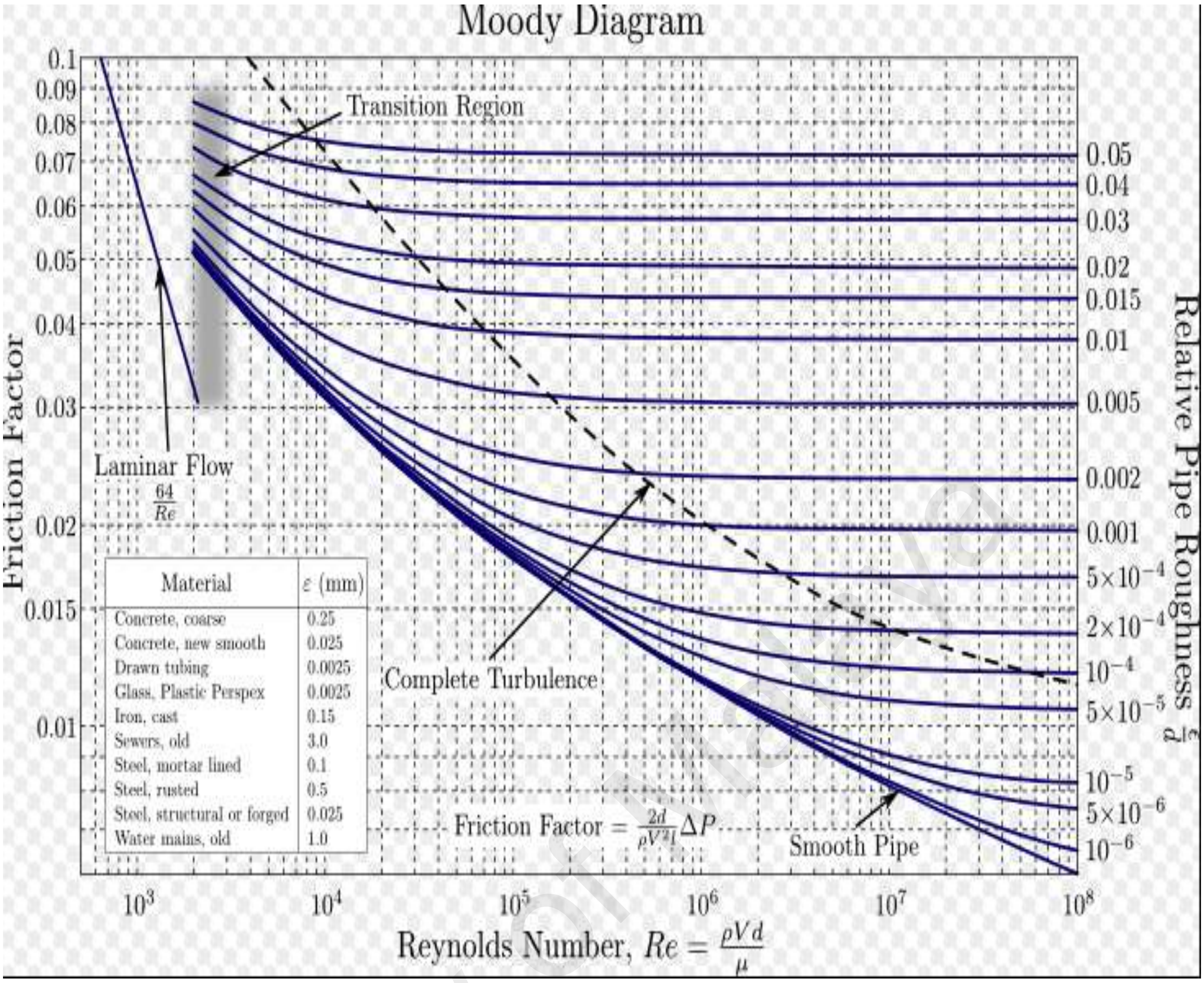


Figure 2.7: Moody Diagram

(Source: https://www.engineeringtoolbox.com)

CHAPTER 3: METHODOLOGY

To perform the proposed project, there need a method or step to ensure that there will be no mistake during performing the analysis. These are the step and explanation on what is the step required.

There will be two (2) study cases for water surge phenomenon.

- Case no.1: Normal pumping flow to reservoir (Steady State condition)

  The simulated results are then analyzed and used to determine if any surge suppression device is needed. If the surge suppression device is found to be necessary, simulation of the pumping system with the recommended surge suppression device is carried out to check the resultant surges. The result of the simulation will be included as case no.2 as follow;

- Case no.2: Normal pumping flow to reservoir with surge suppression device (Transient State condition)

  After the simulation in steady state condition, the result will be of one (1) pump running with the surge suppression system to gather the result and one (1) pump standby.

3.1 Data collection

Before starting any of the analysis design, data collection is major in the beginning, it is a survey to collect all the information needed to pursue each of the task, it starts from the literature review that been done in the past of the similar purpose project. It's also gather information such as the materials that been used, the type of method that were suitable for the water hammer, how many past experiences, etc. This is the entire question that will be asked during the survey to ensure that the amount of data is complete to collect and resume to the project.

3.1.1 Pump Specification

The power station plant is designed to lift treated water from the suction tank to high reservoir through new 2000 mm diameter steel pipelines. There will be two (2) horizontal multi stage. A single main delivery header pipe collects the water from individual pumps and deliver the treated water to high level reservoirs.

Table 3.1: Pump Specification

Manufacturer	KSB
Country of Manufacturer	India
Model	Multitec A 100/2-8.1 11.167
Type	Horizontal Multi Stage
Pump Capacity	144 m^3/hr
Total Head	120 m
Speed	2982 rpm
Motor	75 kW

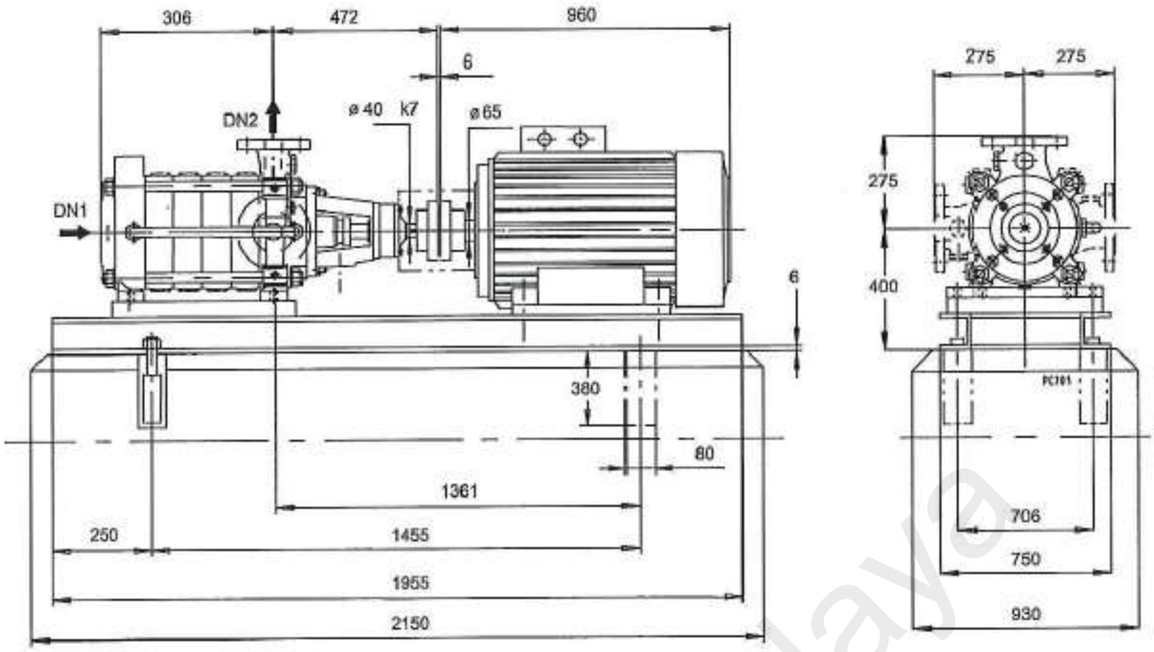


Figure 3.1: Pump Design

This design is casing type pump is more inexpensive for higher rate water liquid flow applications, and the impeller is supported by bearings on both sides (Non-Drive-End, NDE and Drive-End DE). It is an advantage for larger and higher flow pumps.

The horizontal multi stage casing pump has both the suction and discharge connections in the lower half of the casing, opposed to each other. The impeller is mounted on a shaft which is supported by bearings on both sides, therefore maintenance is done accordingly.

These pump design are Benefits of the in term of flexible in ideal of adjustment the suction and discharge nozzles to the system. The low NPSH (Net Positive Suction Head) value will give extra to the pump delivery discharge with it special suction impeller. It reliability in wear-resistant, self-aligning plain bearing that made of silicon carbide and excellent suction performance. The high availability in balancing the axial thrust for a longer hour service life. Maintenance services are easier by dismantling of bearing assembly and mechanical seal, lastly it is low on operating costs.

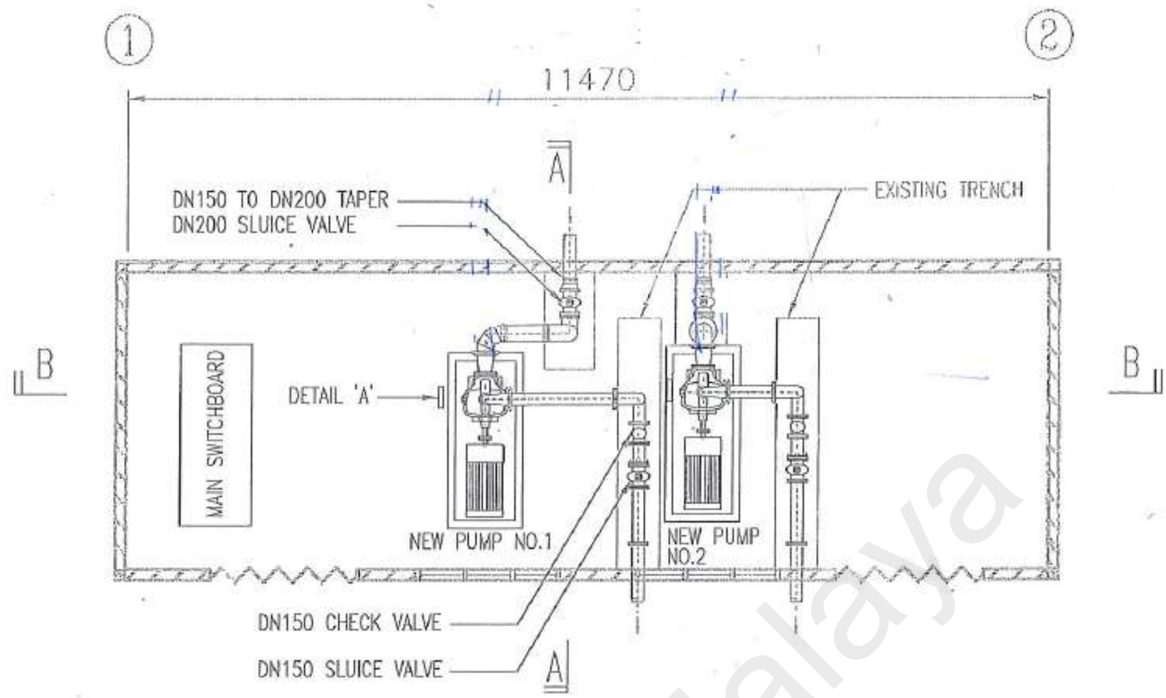


Figure 3.2: Pump set layout

3.1.2 The pipeline layout

The pipeline modeled consists of a 200 mm in diameter steel pipe 2250 m long. The pipeline is very long and running at an up gradient to the receiving reservoir. The surge suppression criteria will be preventing the maximum upsurge pressure exceeding the pressure rating of the pumping system at sixteen (16) bars. The pump station had operating one (1) pumps running and one (1) pump standby.

Figure 3.3: Pipe layout from power station to reservoir

(Source: Google Earth)

In Figure above show the direction of the current pump house to the reservoir. It is located at Sg Merab, Bandar Baru Bangi housing area. The housing area are starting to develop and there is more demand in water distribution to the new develop housing area. The current pump at the pump house is running 24 hours to sustain water level at the reservoir. Therefore, in upgrading the pump capacity will increase the lifespan of the pump and reduced the running hours for each pump. The status of the pipe lay from the pump house to the reservoir remain the same as it will not affect the new pump upgrading. However, the water surge needed to be upgrading to sustain with the new pumps.

Figure 3.4: Piping profile from power station to reservoir

The elevation profile along the pipeline to reservoir are uphill and across the housing area. The data is collected from google earth and verified on site with depending margin plus (+) and minus (-) 1.0 m from DATUM. The piping is installed with referred to SPAN (Suruhanjaya Air Negara) guidelines the UTG (Uniform Technical Guidelines) that been enforced in Malaysia to ensure that all water production and water distribution meet the standard. Some trial pit is performed near the pump house to determine the materials of the current pipe and the depth. This pipeline and the pump house was built during the times of (JBA) Jabatan Air Selangor in the earliest 90s. Therefore, during the time SPAN and UTG was never set the requirement. After the trial pit and site verification, it was found that the piping system is using Mild Steel pipe rather than Cast Iron pipe or Galvanize pipe that most piping system are used during that early years.

The pump is proposed to improve the supply, by pumping more water to a high-level tank, protection of the pumping system from adverse effect of surge is important. Usually after sudden shut down of the pump, flow decay rapidly at the pump discharge end. This phenomenal has caused a water column separation at the pump discharge end, which causes the pressure in the pipe to drop and creating the down surge pressures.

This pressure reduction is transmitted along the pipeline at the wave velocity, and when this pressure wave is reflected, an up-surge pressure is generated. The magnitude of surge pressure is related to the rate of change of flow in the pipe. The faster the change in flow rate, increasing or decreasing, the higher will be the surge pressure.

3.2 System Modelling

This analysis was carried out by the water hammer analysis computer program, HYTRAN using data provided. The pipeline was analyzed for transient case 1 to 2 as outline in when one (1) pump running with one (1) standby. Runs were carried out to ascertain that the transient pressures induced in the pipelines during power failure are at acceptable level.

3.2.1 Setup scale

The set-up scale is to contain the distance and elevation. As Started the scale to contain X-Distance and Y-Elevation coordinates. Then it is to draw the pipeline along the distance from the pump house to the reservoir. In this case, there are only needed around 7 pipes nodes with distance.

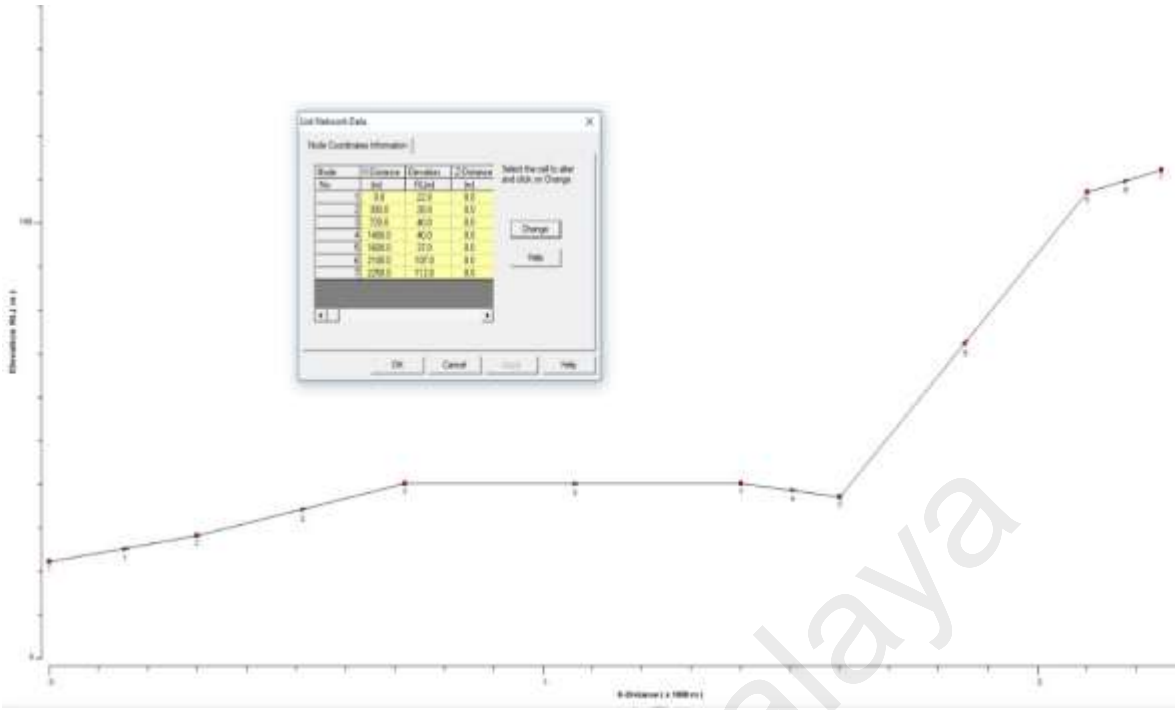
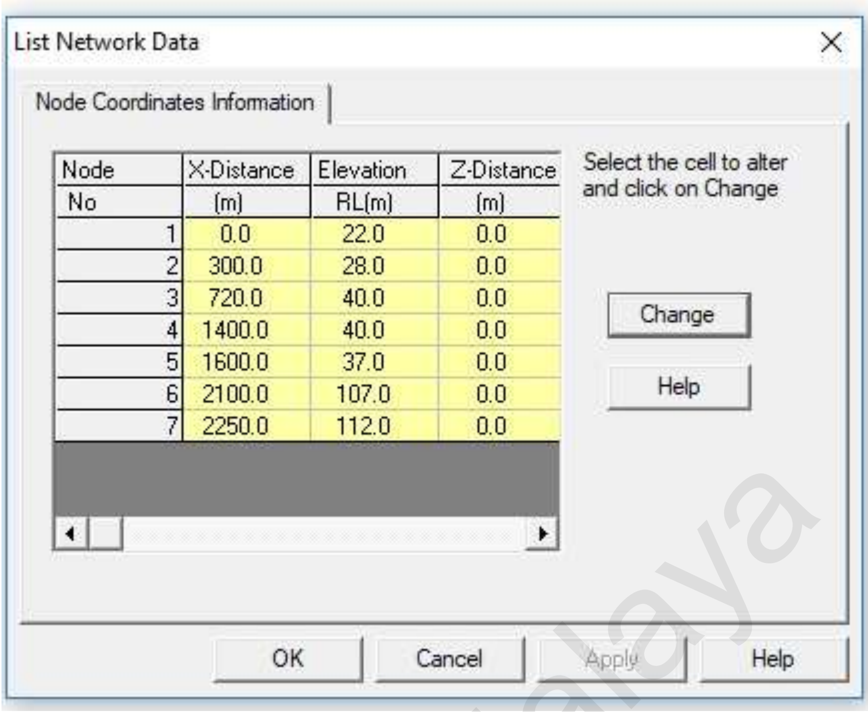


Figure 3.5: Pipes are drawn

The pipe is draw with 6 pipeline point randomly as it not needed to be accurate on site base cause the length and elevation can be alter after the sketch is completed. The nodes that been highlight is the most critical path, as it the major number of length and elevation that are significantly increase from the DATUM. Although the length of the pipeline is about 2250m, there are only required 7 nodes to run the simulation and enter the most crucial path. From along the length, it can be determined at the figure 3.5 where the elevation most highly increase. The first elevation is at the starting point node 1 where the pump house is and the highest point elevation is at the node 7 where the reservoir are place. Most of water distribution reservoir are place in high places so that it can distribute to consumer by gravity. It does not required pump to distribute to the housing area near the location radius.



Node No	X-Distance (m)	Elevation RL(m)	Z-Distance (m)
1	0.0	22.0	0.0
2	300.0	28.0	0.0
3	720.0	40.0	0.0
4	1400.0	40.0	0.0
5	1600.0	37.0	0.0
6	2100.0	107.0	0.0
7	2250.0	112.0	0.0

Figure 3.6: Pipe distance and elevation

After the sketch is completed, then it is time to select the pipe node position. The length and elevation are choose at most critical path were it needed to most drastically increase. As bases on site, the node that been choose are as figure above. It can indicate that in the beginning node 1, the start point at the pump house elevation RL (m) is 22.0 as from DATUM level was taken. At the node 7, where the reservoir are is at distance 2,250m from the pump house and increasing of elevation profile at 112.0m from DATUM level.

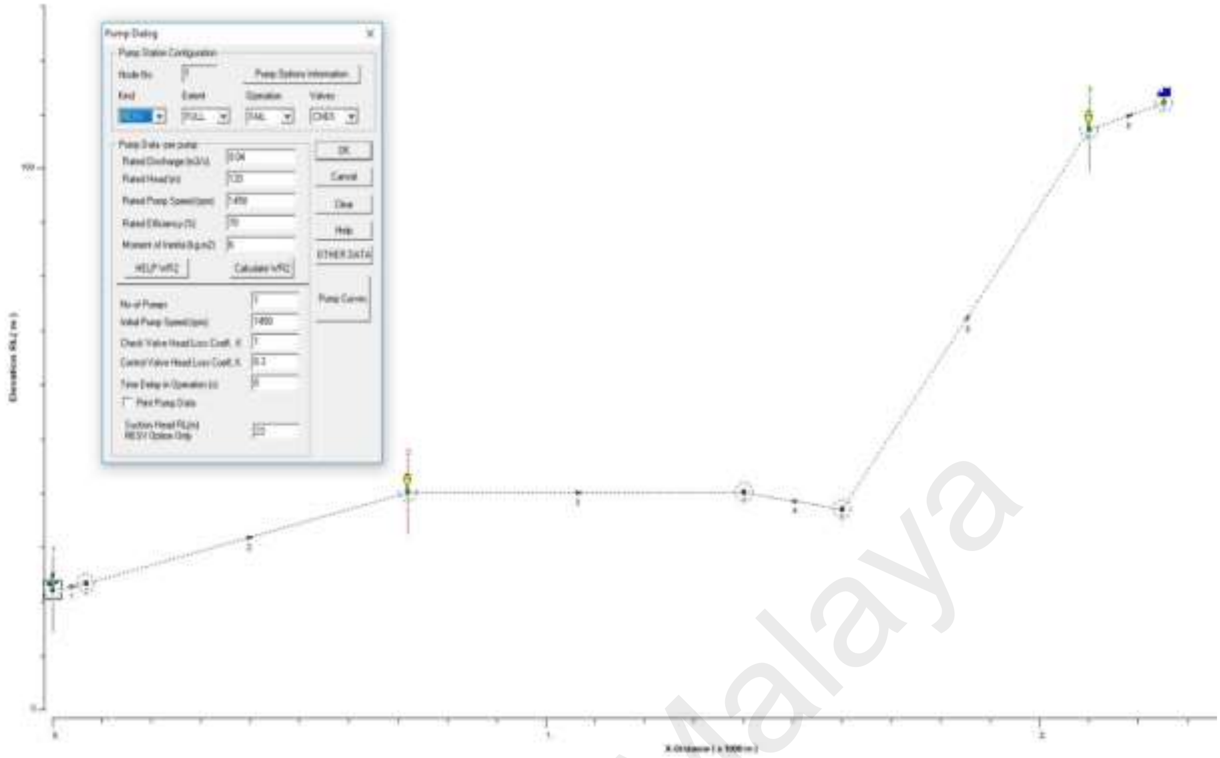


Figure 3.7: The pump data insert

The pump design of horizontal multi stage data are taken from the supplier. These pumps figure are only needed to place one (1) pump cause the pump house philosophy is one (1) pump running and (1) pump standby. The maximum pumping running hours is at 10 hours per day and it will rotate to the pump on the standby mode to operate another hour. The pumping will stop during the reservoir at full capacity and both pumps one (1) and two (2) will on standby mode.

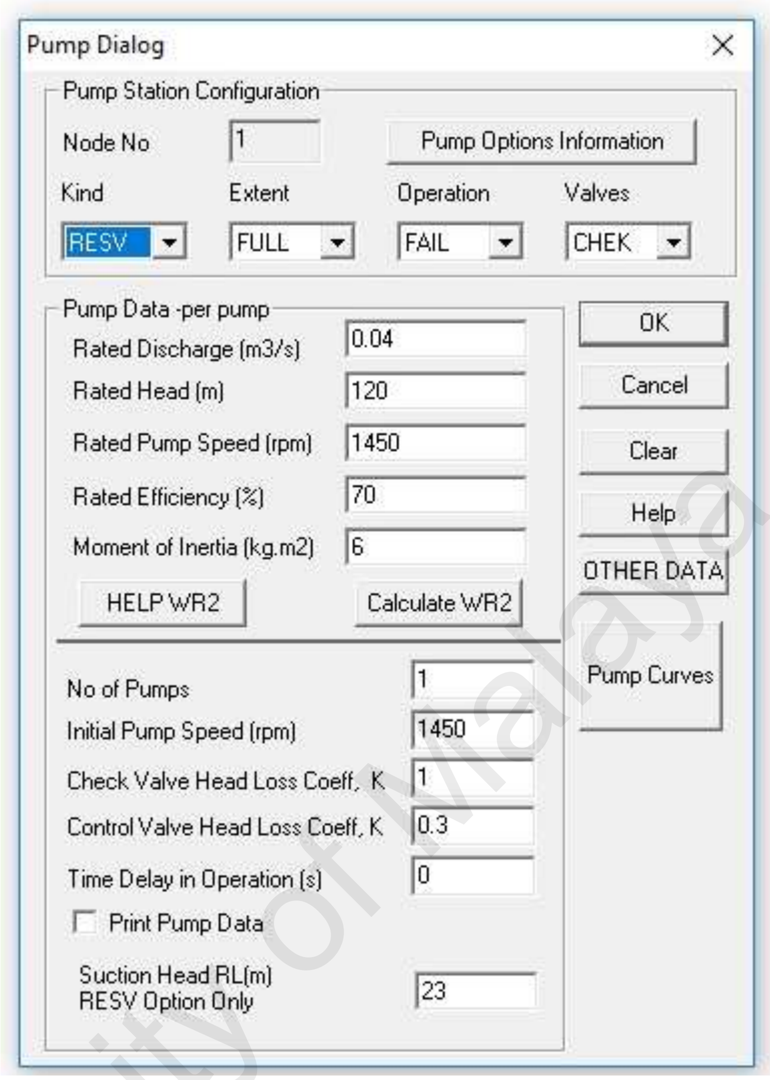


Figure 3.8: Pump data

The pump data dialog is placed in the simulation. The moment of inertia (kg.m2) are based pump curves, Hytran software uses a conservative equation tending to lower value. This simulation is set on "operation" mode of fail in case there are power disruption on the pump house. The suction head RL (m) RESV option only is the water level from which the water is pumped for the reservoir.

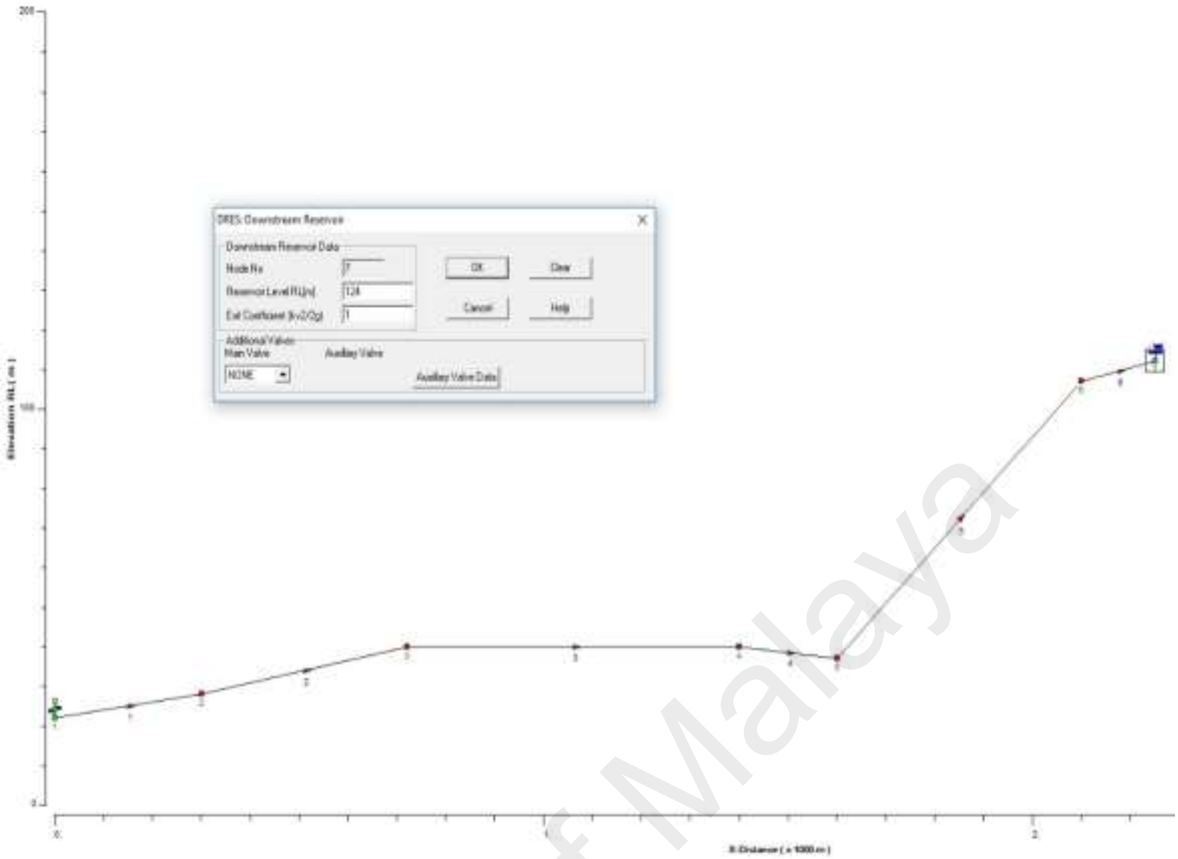


Figure 3.9: Reservoir data

The reservoir data is placed at the node 7 where the end of node. As the elevation level is at peak with 125m from DATUM. The exit coefficient (kv2/2g) is equal to one (1) is based on the Hytran software minimum of pressure outlet.

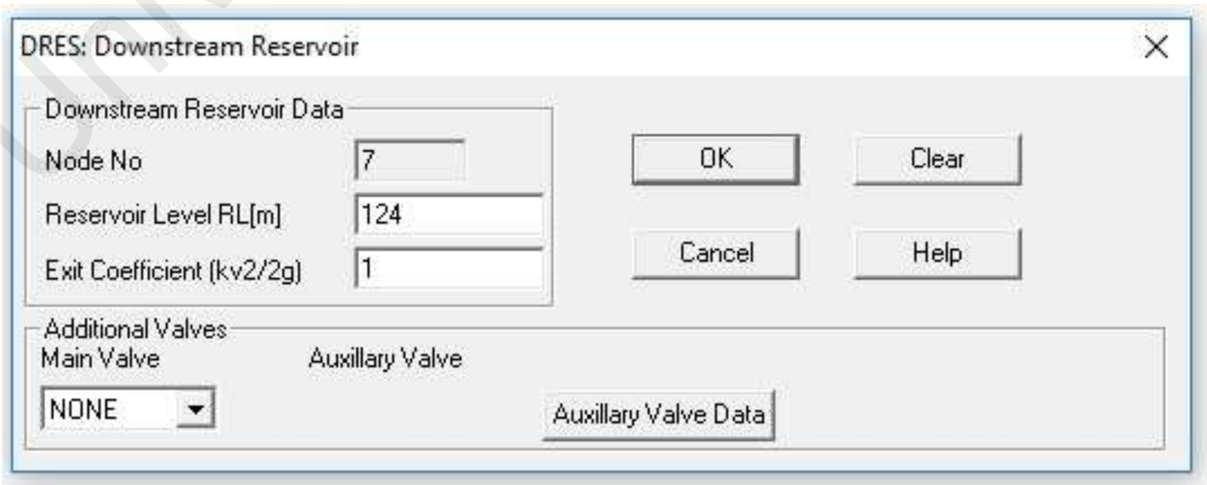


Figure 3.10: Reservoir data

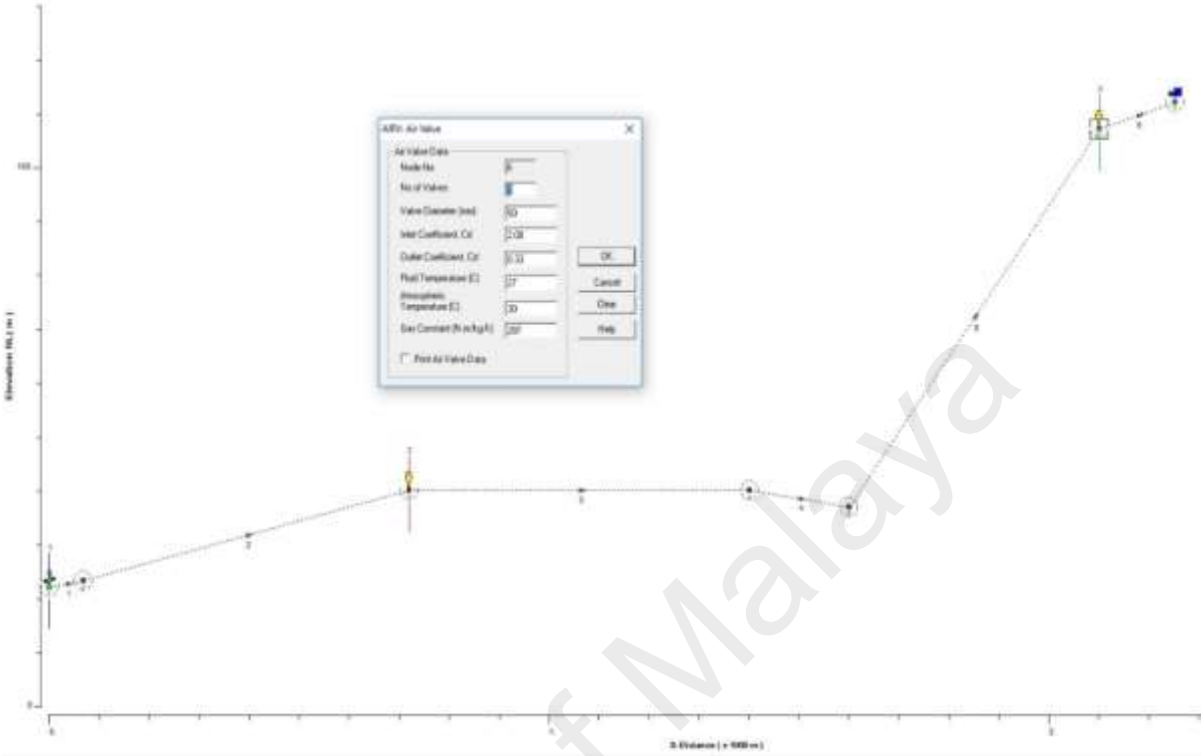


Figure 3.11: Air valve

Air valve is commonly use to release air in the pipeline to atmospheric pressure to minimize pressure in the pipe. The air valve are currently placed with two (2) units along the pipeline when on site visit. These air valve is secondary in protect system operation including start-up, shutdown and critical condition such as power failures or line breaks.

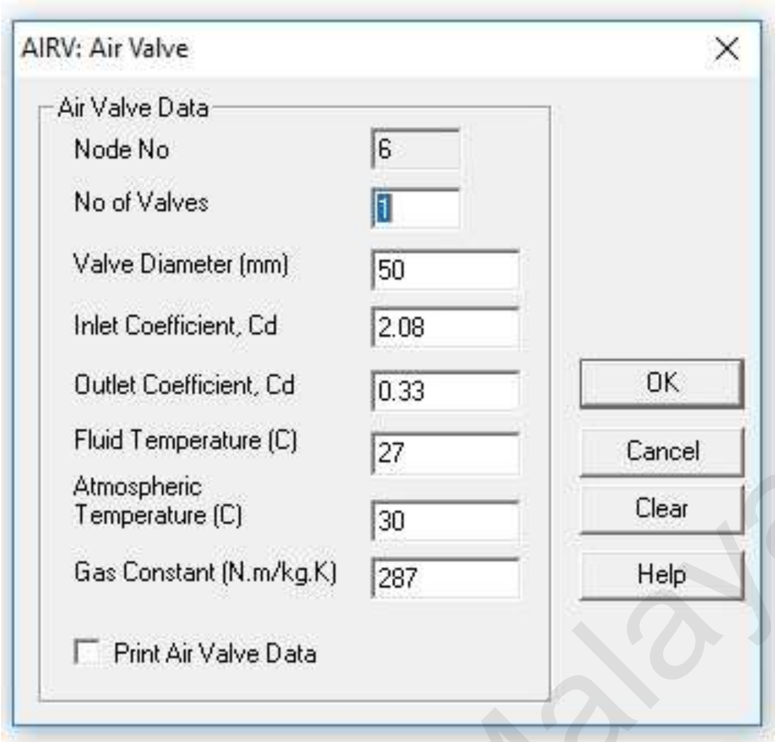


Figure 3.12: Air valve value dialog

The above Air valve dialog is inserted as the data is receive from the supplier. The size that been installed on site is 50mm diameter and the brand is AVK air release valves that can be installed to any highest on a pipeline where the pressure is more than 0.1 bar and up to the maximum working pressure. The high inflow rate is to prevent damaging vacuum pressure from developing. When water in pipeline is drained or empty, air enters pipe quickly in such a way that it will flows throughout the piping system.

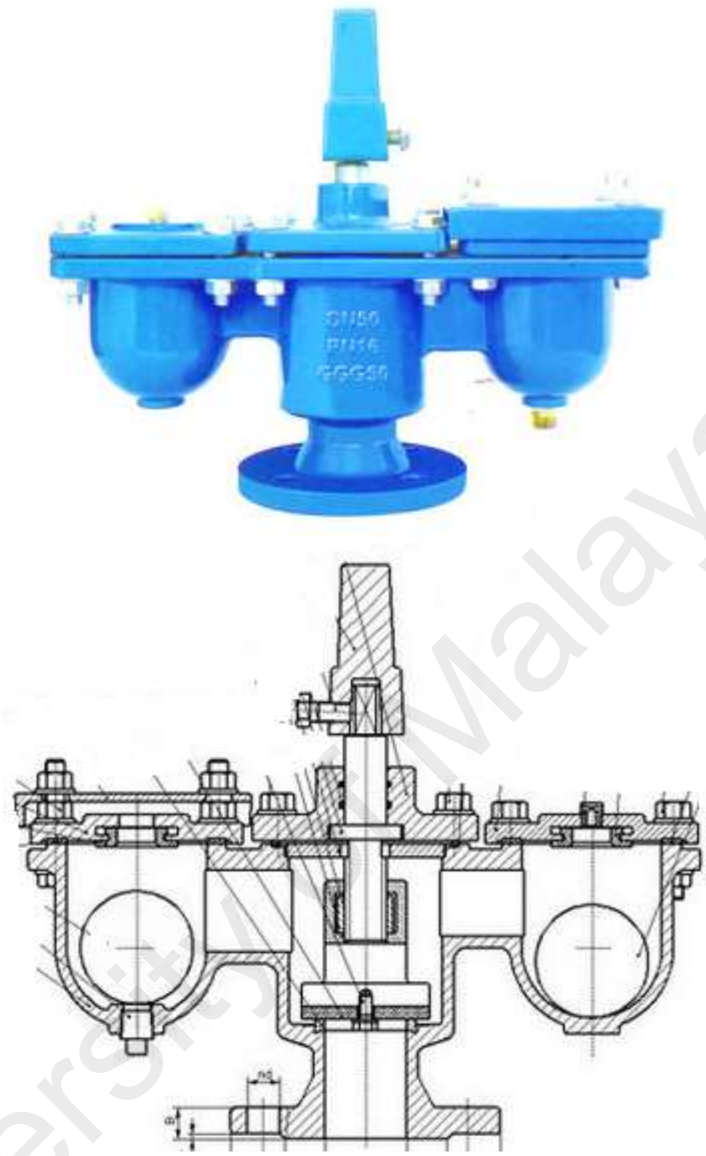


Figure 3.13: Double Orifice Air Valve

This type of air valve function as the pressure through the pipeline system is under the atmospheric pressure and the valve ball disc will start to open (drop to bottom) and allow air to discharge. When the pipeline system is with water level, as the pressure also is increase in the pipeline system the ball disc will be lift by the water that flow in the pipeline and closing the main aperture while controlled air emission that flow through the vent hole.

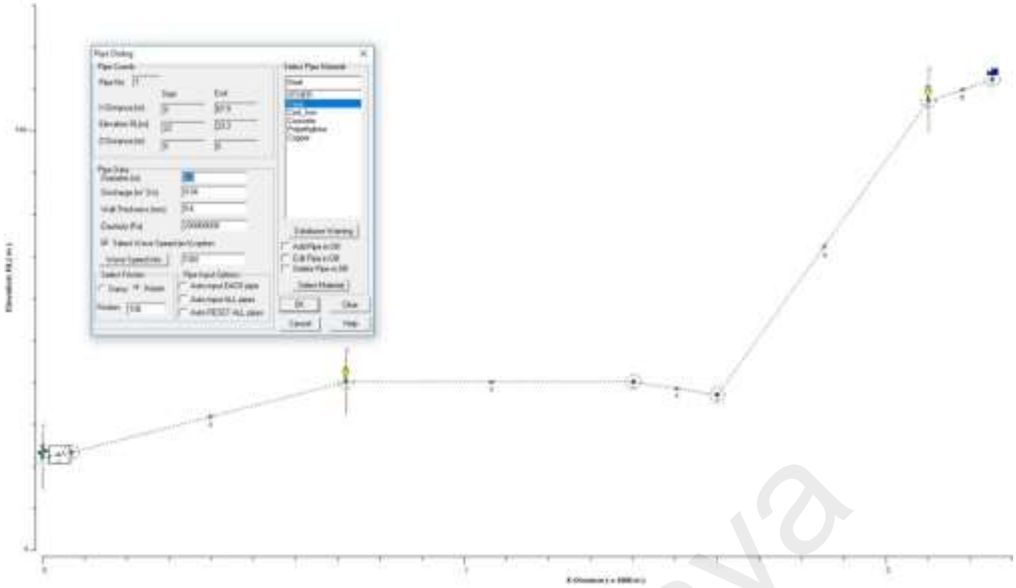


Figure 3.14: Pipe

The layout pipe that been drawn from the layout of the pump house to the reservoir is the distances about 2,250m. The pipe type is mild steel (MS) that manufactured using low carbon (less than 0.25%) steel. This type of pipe is easily welded and formed in various shapes and sizes. In clean water distribution industry, these type of new pipe is used rather than cast iron. The MS pipe is coated with powder to increase its strength and resistance when underground.

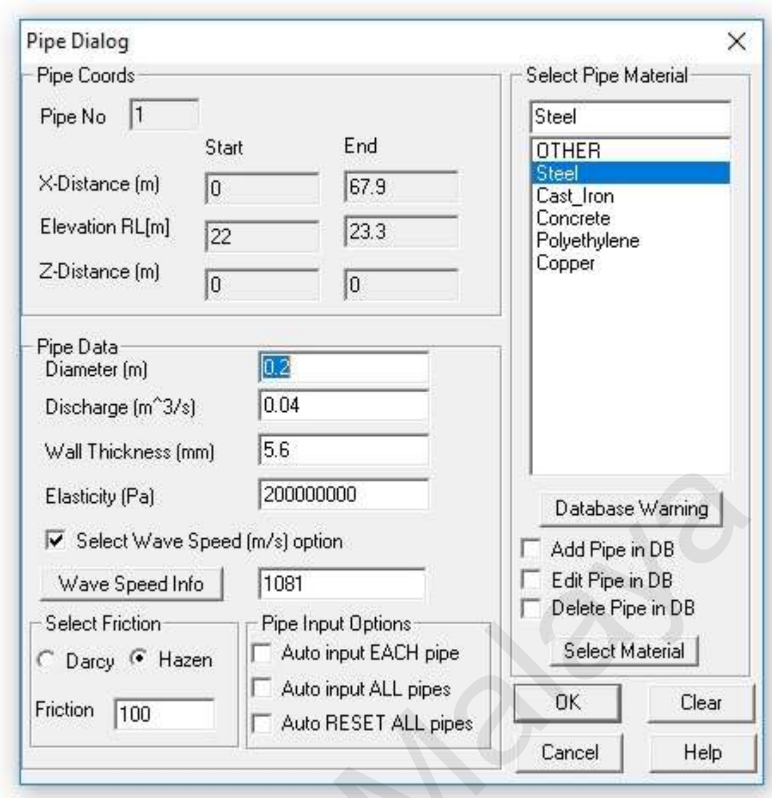


Figure 3.15: Pipe Dialog

Most of the MS pipe details are commonly used by many manufactures. The data that been placed is from the manufacture of ALL Pipes manufacturing. The pipe database holds the pipe elasticity and wall roughness. The friction factor that been used in this simulation is Hazen as it Hazen – Williams equation that proof empirical relationship that related the flow of water in a pipe with physical properties of the pipe and the pressure drop cause by friction. The value that placed is “100” as it standardizes in the Hytran Software simulation that calculated using the Moody diagram. The moody diagram describes the friction loss in the piping system. It is indicated the roughness pipe classification materials. The wave speed entry is set to default as Hytran will calculated based on the pipe elasticity, wall thickness and anchorage. This all input pipe database is implement on all nodes pipes.

CHAPTER 4: RESULTS AND DISCUSSION

After the data collection have been completed, then to run the simulation using Hytran software to see the water surge during normal pumping flow to sudden stop. This section reports the water hammer transients caused by the following scenarios or pumping configuration.

4.1 Result Case no.1: Normal pumping flow to reservoir (Steady State condition)

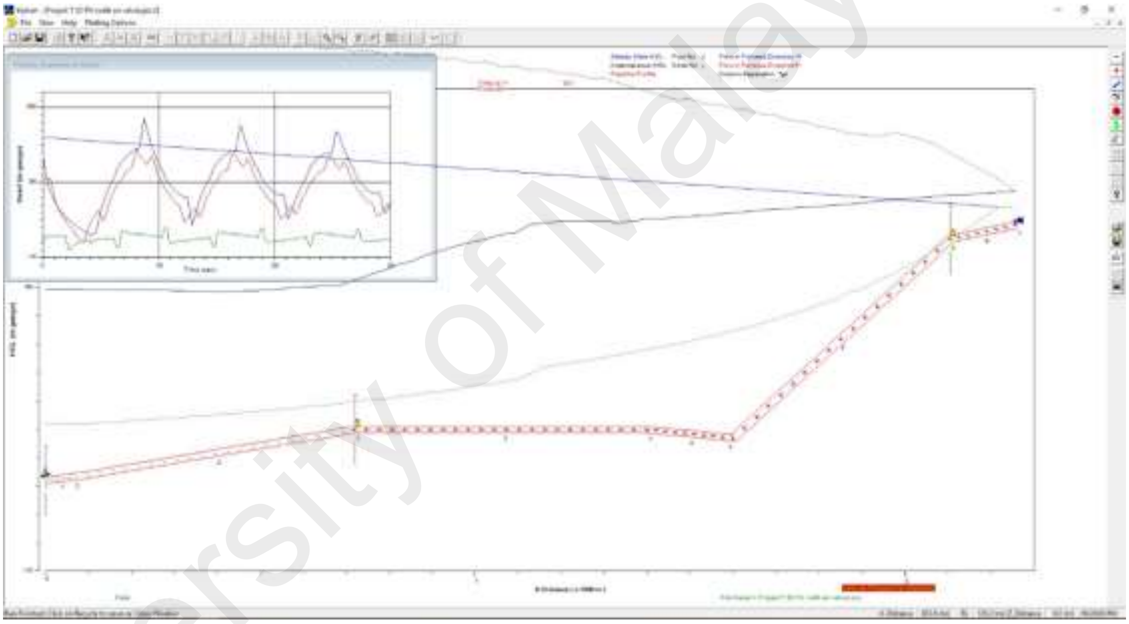


Figure 4.1: The result during steady state analysis

After the simulation was run for 30s, it shows the current wave of the water flow. The red arrow indicated down surge water which is reverse direction that flowing back to the pump house during the pump stop or power disruption. The blue arrow as in forward direction from the pump house to the reservoir. The darker the color the greater the relative speed.

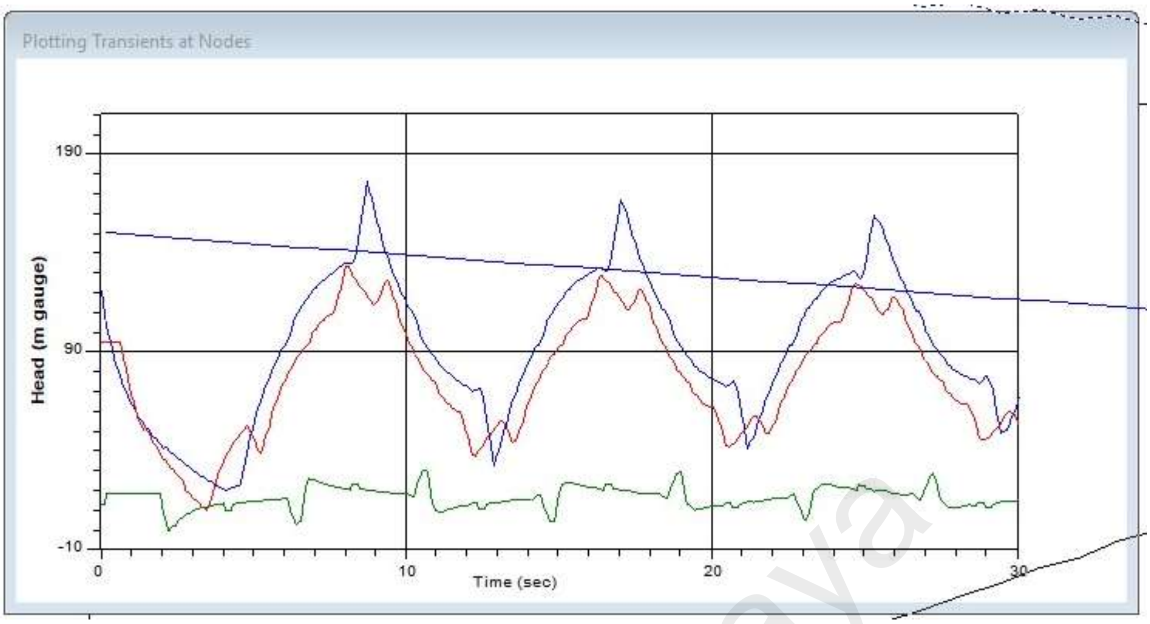


Figure 4.2: The Graph pattern on steady state

The figure above show that the full run time 30s simulation was performed, the blue line is the steady state HGL (hydraulic Grade Line) for the pipeline profile. The run time that Hytran start with the lowest upstream node number and works downstream node is detected. It is shown that the during this transient, the water surge continuous increase at its peak which is at head 170m and it continuity can cause pipe burst for a long period of time.

4.2 Result Case no.2: Normal pumping flow to reservoir with surge suppression device (Transient State condition)

Simulation of hydraulic transient due to power failure were carried out and the results include plotting of minimum and maximum pressure envelop along the pipeline and surge pressure vs time plot at the pump end (Node 1), marked as '1' in blue color and at peaks about 720m and 2100m away from the pump, marked as '2' and '3' in red color in the plots.

As shown in the plot for case 1, the maximum up surge at pump end (Node 1) is 175.28m head and minimum down surge is 0.00m. The plots also show that column separation did not occur throughout the pipeline.

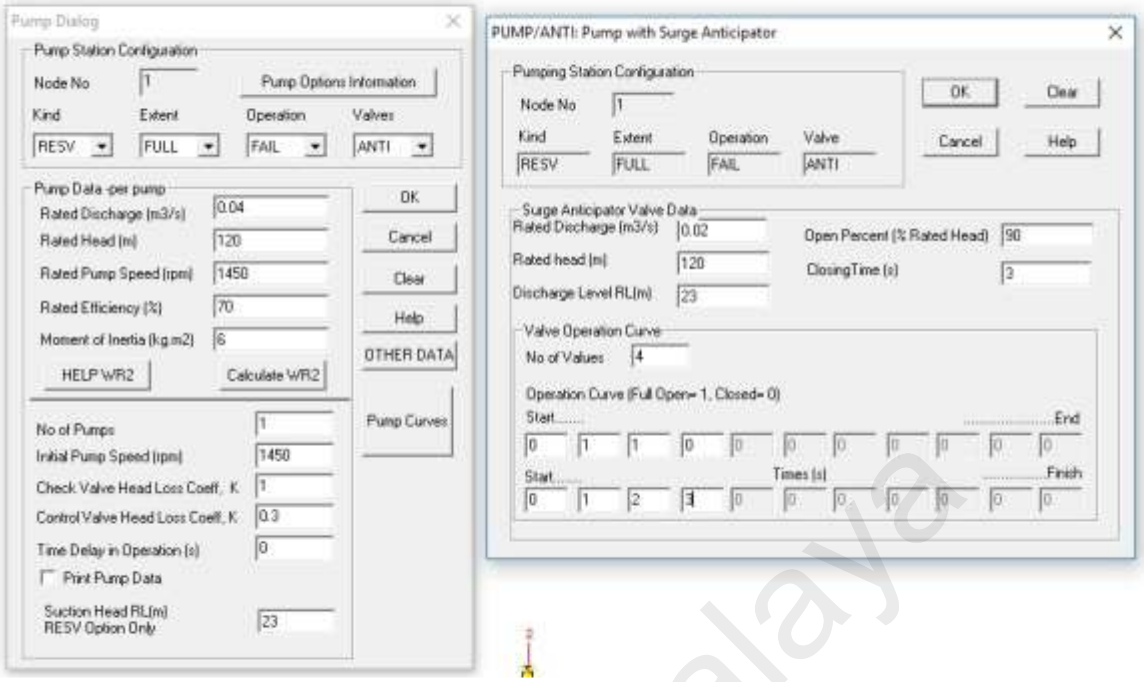


Figure 4.3: Surge anticipating data

In prevention to the water surge during steady state, surge anticipating valve are equipping to install nearest the pump house as primary surge suppression system. It will absorb the water surge that reverse direction (Red Arrow) to the pump house.

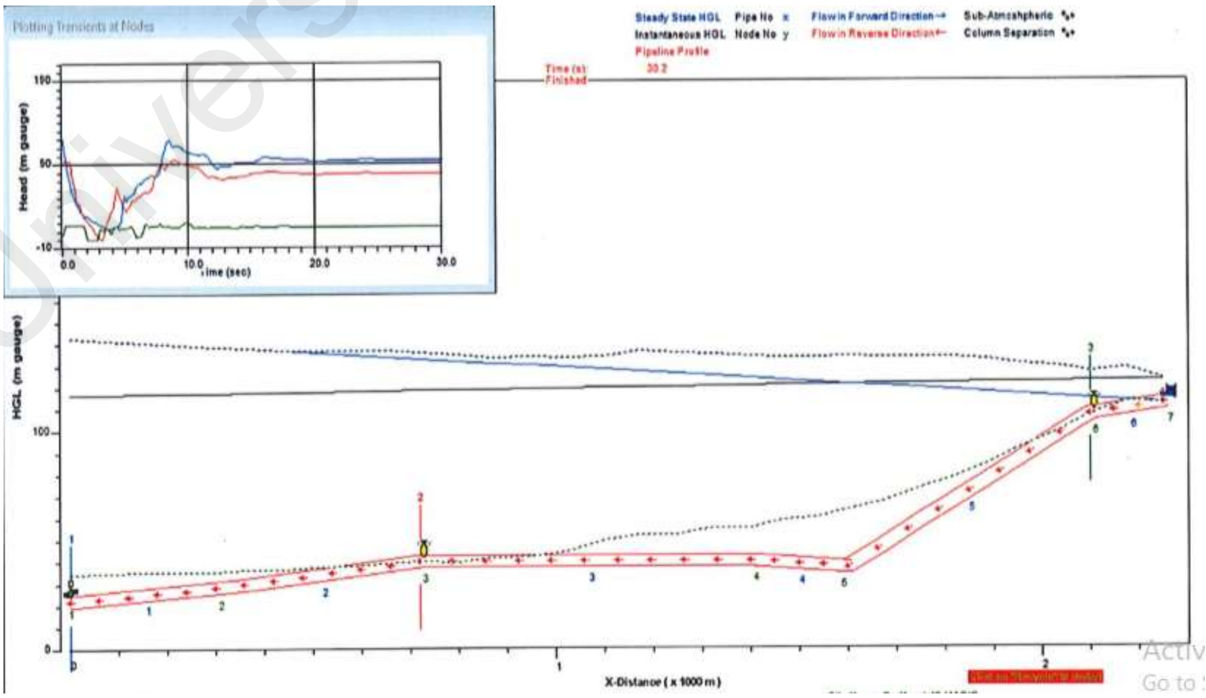


Figure 4.4: After Surge anticipating valve installed

The surge anticipating valve shall be installed at the pump end to reduce and stabilize positive surge along the pipeline. After installation of 80mm surge anticipator, the steady state flows at normal pumping flow condition with surge anticipator valve when one (1) pump running.

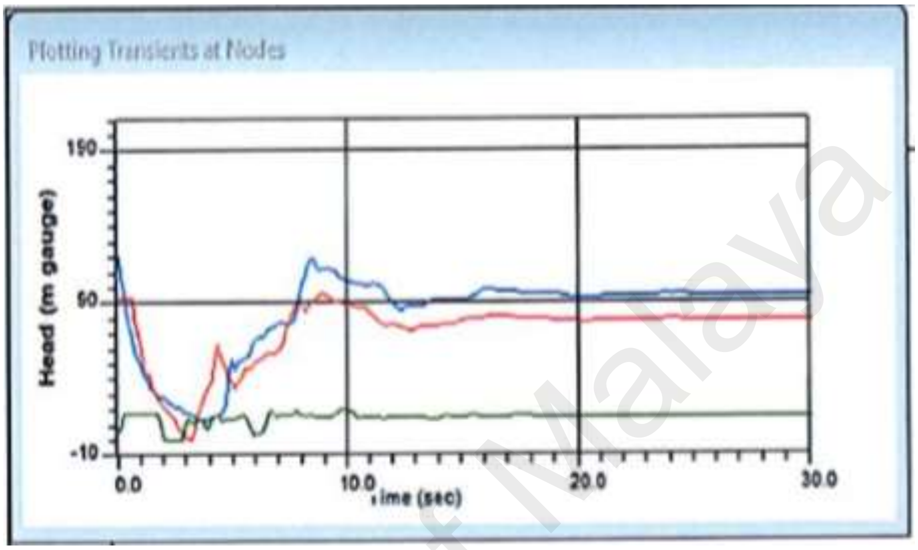


Figure 4.5: Graph of the surge result

As shown in figure above, the surge has been stabilizing and reduced to maximum up surge of 120.81m head. Minimum down surge stays around the same at -0.14m. Size of the surge anticipating valve used shall be DN 80 with recommended setting. The blue line indicates the Node at line Pump Discharge at pipe no.1 with 0%, the red line indicate at plot node line along pipe no.3 with 60% and lastly the green line indicates plot node lines at Downstream Reservoir at pipe no.7 (Reservoir) with 100%.

4.3 Surge Anticipating Valve Calculation

From the simulation, a rough calculation to determine which type of size that needed to the transient run. Here is the calculation base on the data from the pump house;

Pump Flow Rate: 144 m^3/h convert to l/s

Pump capacity: $40\ l/s$

Convert to US Gallon Per Minutes (USGPM): $40\frac{l}{s} \times 15.8503 = 634.012$

Sizing the valve is based on 50% of the maximum pumping capacity. The selected 50% maximum pumping capacity for better opening discharge, through the factory recommendation of 25% of pumping capacity

50% of the maximum pumping capacity;

$$\frac{50\ \times 634.012}{100} = 317.006\ USGPM$$

Therefore, the recommended of surge anticipating are based on the graph curve that provided by the supplier on Flow vs Pressure Drop (Model 106 – Pilot vented downstream).

From the figure below, Flow vs Minimum pressure drop, it shown that a pressure drop is about 11.20 PSI is obtained when the horizontal line is across at 317.006 USGPM and intercept at 3" (80mm) diameter surge anticipating valve.

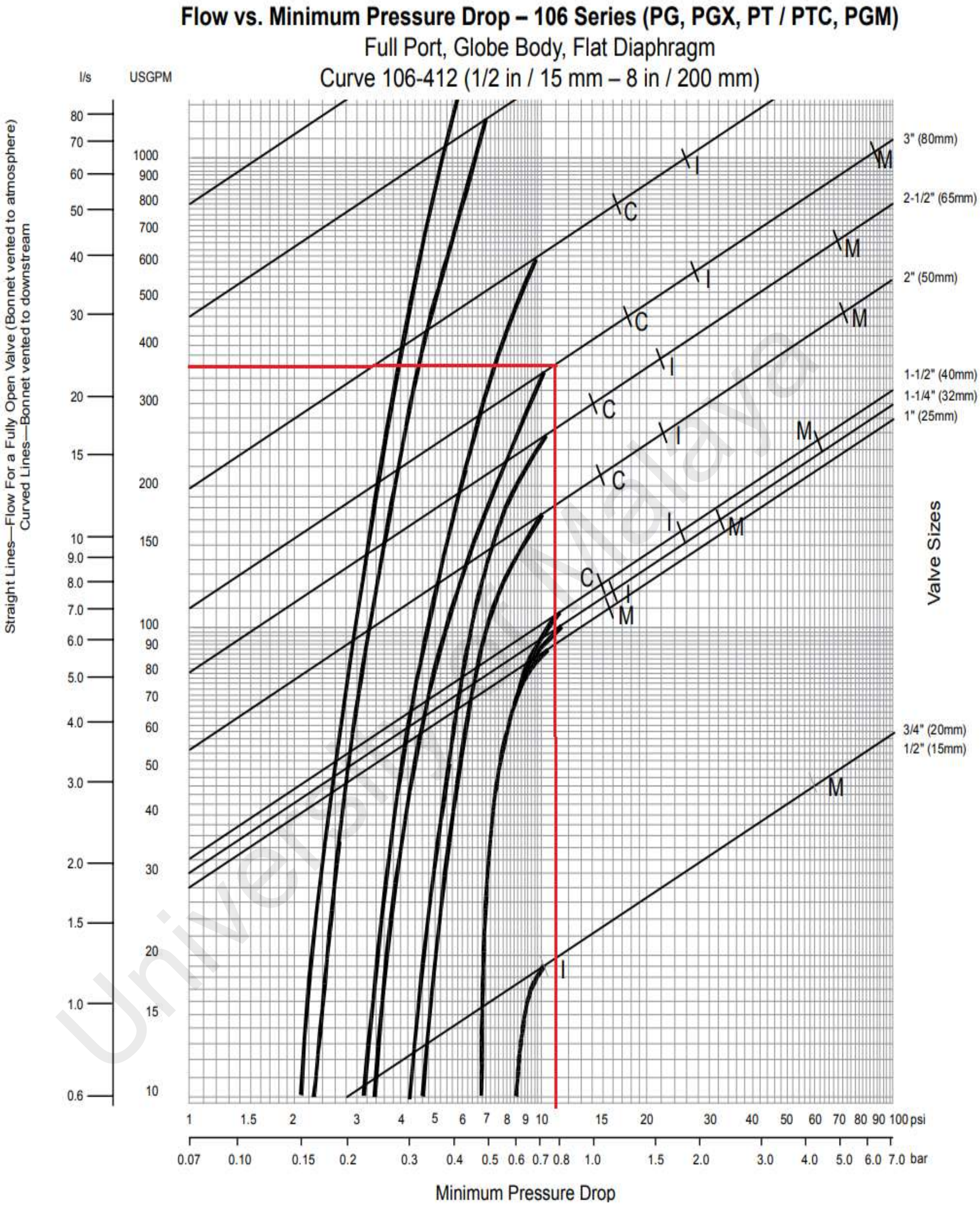


Figure 4.6: Flow vs Minimum Pressure Drop

4.4 Type of Surge Suppression System

In the pumping system, there are many type of surge suppression system, as they are to absorb water backflow as the pump in condition power failure or immediate shut-off. It main purpose is to maintain the correct pressure whilst water is transmitted to the mains networks. Uncontrolled surges can cause several issues to water companies, from leakages and water quality issues to infrastructure and network failures.

In risk management of any pumping station either it new or existing, the higher risk definition of different characteristic with different type of pumping station can be affected without the protection and costing more to repaired. Therefore, by adding a surge suppression type of system to the pumping line is the solution for helping it reduced the impact of back water hammer.

A Hydraulic Study is the beginning to assists water hammer phenomenon in pressurize piping pump system. Surge suppression frequently installed close to the pump discharge manifold throughout the reservoir. The method of characteristic was widely used to simulate the transient and steady state in piping line system that generated by hydraulic transient in water distribution system that can lead to overpressure and negative pressure, which required additional pipeline wall thickness system that can occur at duration of catastrophic failure from the surge event or fatigue failure from the repeated surge water.

4.4.1 Surge Anticipating Valve

The surge anticipating valve is dissipates surges caused by power failure or power shut-off to the pumps. It is to ensure that the valve is open when backflow of high pressure surge indicated. This type of surge valve is hydraulically operated with a single seated valve that controlled by two (2) pilot which is high pressure pilot and low-pressure pilot. The valve will have closed as the line pressure is between the set point of the two (2) pilots and the valve will open when the pipeline system pressure is drop below the setting of low pilot, but the surge valve also can fully open upon detect high pressure in the piping system that been set by the high pilot.

The operational of the surge anticipating valve condition on open is where the pressure is applied to the valve inlet with this same pressure is applied to the valve bonnet. The main valve will close tight as the area of diaphragm is greater than the valve area of seat. The pressure that above the diaphragm determine the position of the main valve are.

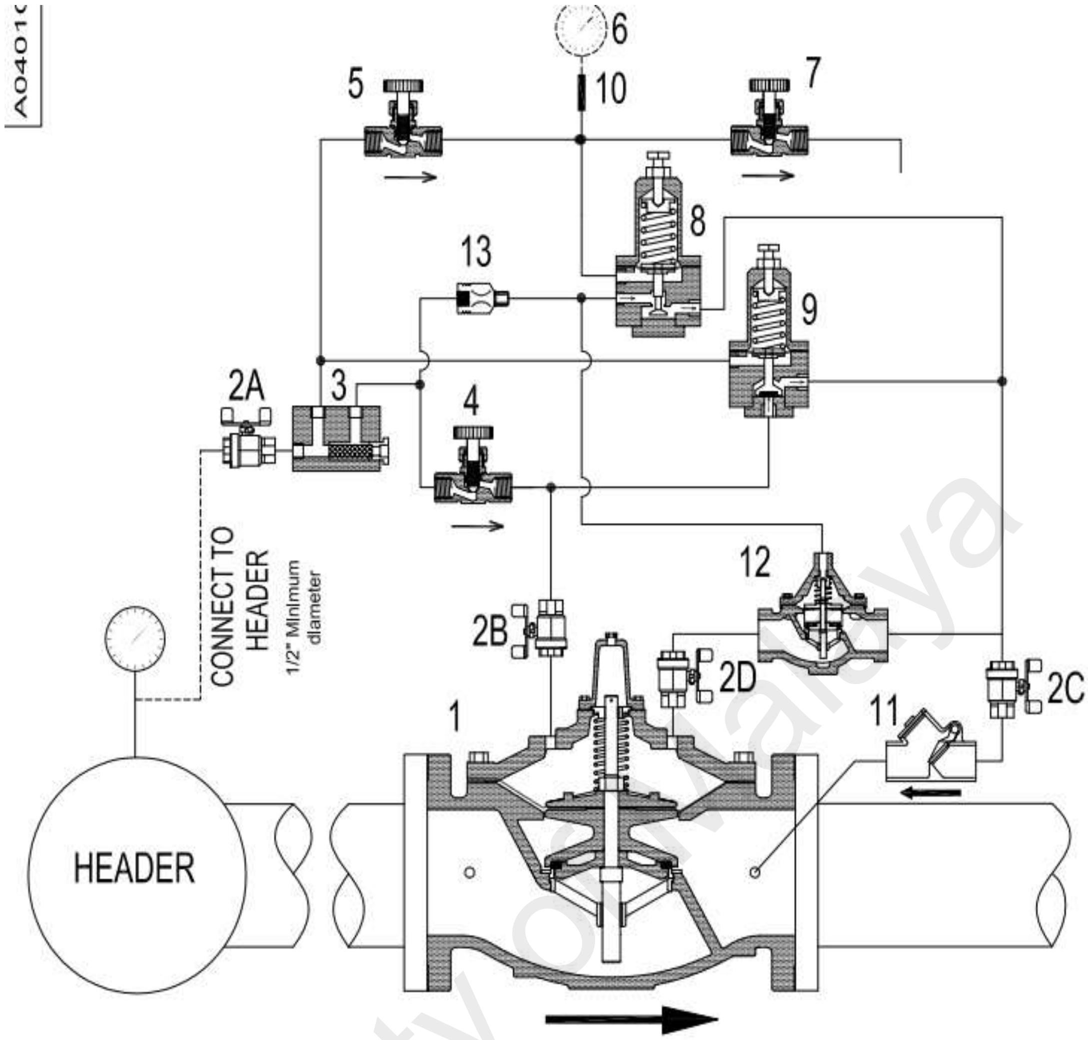


Figure 4.7: Surge Anticipating Valve

(Source: http://www.singervalve.com)

4.4.2 Surge Vessel Tank

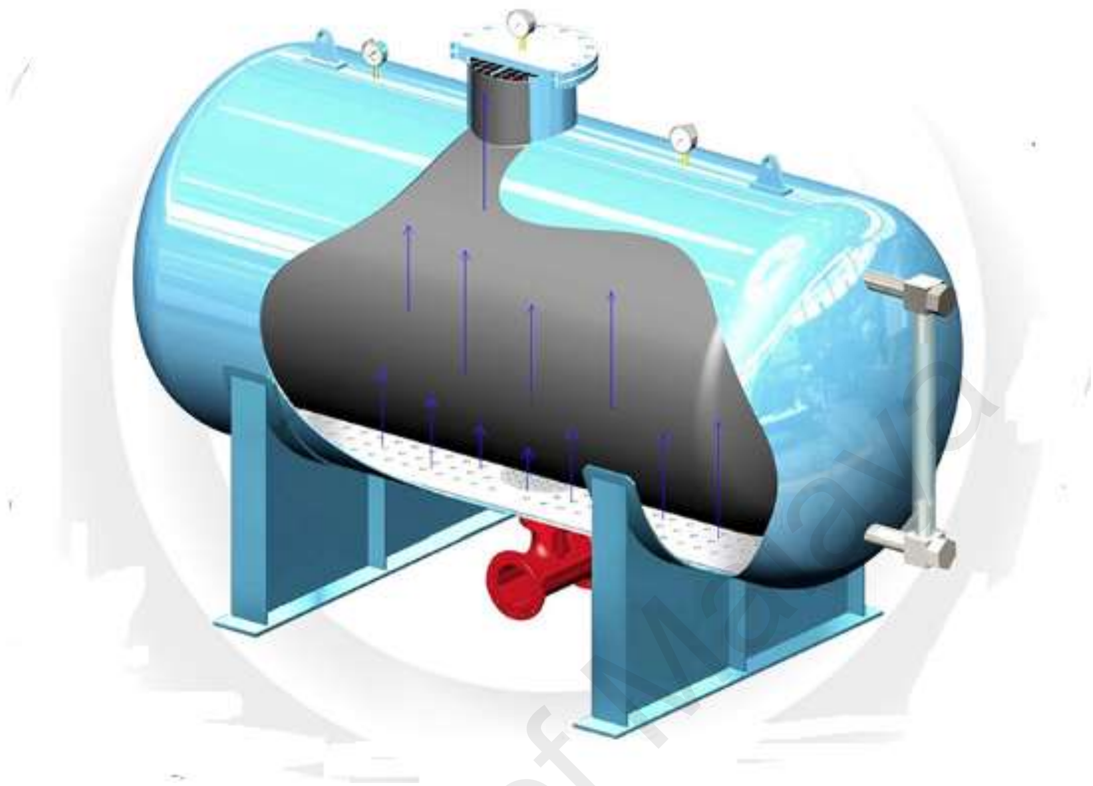


Figure 4.8: Horizontal Surge Vessel

Surge vessel tank, with its design is a additional reservoir within a pipeline system with focus to adjustable flow rates. Surge vessel tanks are used to protect and to ensure that the piping system and pumping system from the pressure waves of back flow or reverse direction of water liquid that occur when the flow rate quickly decreases. The use of common surge vessel tanks are used within pumping station or other power plants as the larger size piping is used at relatively high flow water rates, although it may be applied in various of other piping systems such as waste water management, water supplied for manufacturing, and even the automotive industry. A surge vessel tank purpose is to reduce and protect the pumping system from the effect of water hammer. For a surge vessel tank to be active, the maximum height of a surge water must be found, then the surge tank can be correctly sized for the classification.

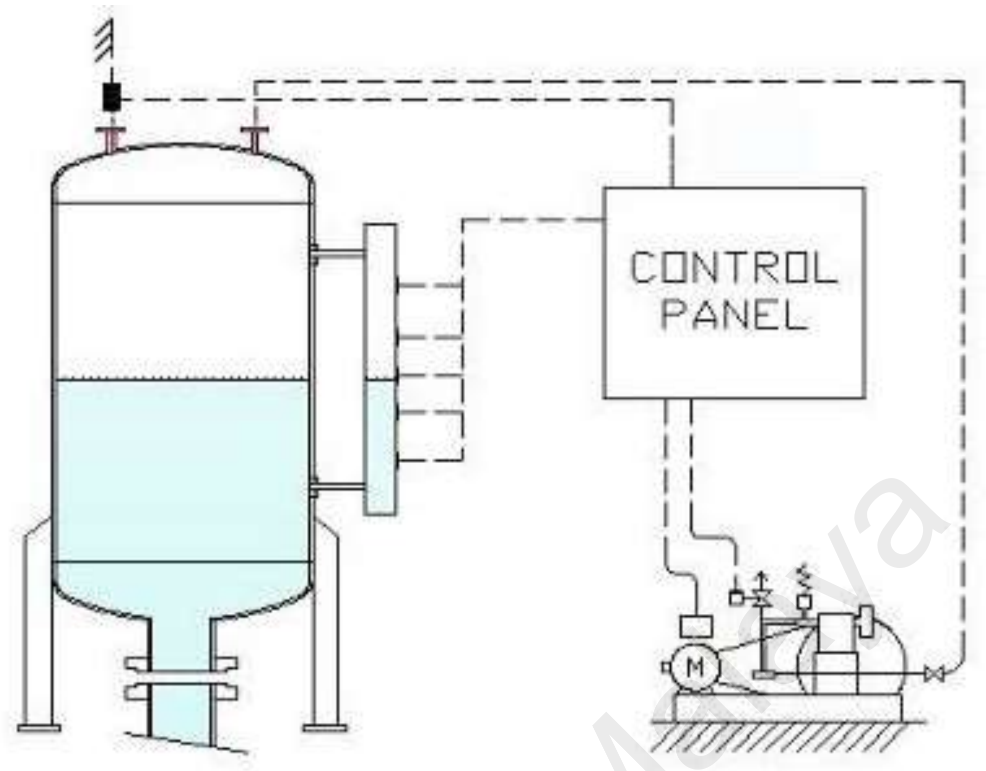


Figure 4.9: Vertical Surge vessel

This type of water surge protection is costly during installation but it is easy maintenance and cost cheaper in parts. There are always primary and secondary water surge protection, the primary are the surge anticipator valve and the surge vessel.

4.4.3 Check Valve or One-way Valve

The secondary or what it called fail switch system is the check valve or one-way valve or non-return valve that been installed after pump discharge. The check valve is used stop backflow in the piping system. These valve only can flow water in one direction as if the back water returns to the discharge pump it will not pass (immediate shut-off) through the check valve. The pressure coming from the pumps will pass through this check valve and flow through the piping line system. There are many type of check valve and depending on the operational and mechanism. The common type in any check valve is equip with a disc that operate as to open and close the valve, as the angle of the disc between the seat is about 0 to 45 degrees. It is most used to installed in arrangement with sluice valve as it provided relatively free flow mixture. In figure 4.10 is the main component that installed in swing type check valve that is a valve body, a bonnet, and a disk that is connected to a hinge that can be flexible.

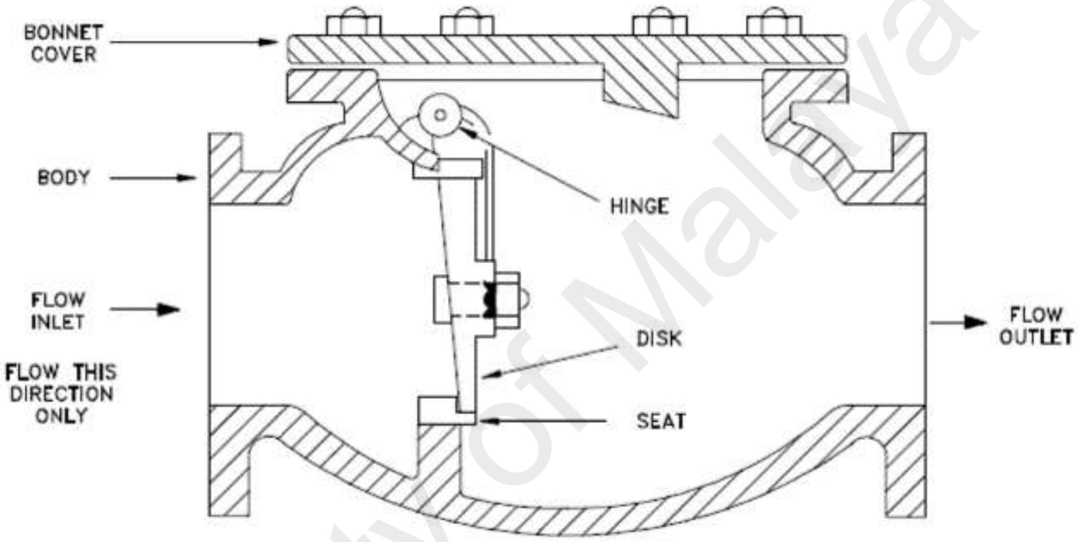


Figure 4.10: Swing Check valve

(Source: http://www.singervalve.com)

This are the last defense system of the water surge and nearly absorb what the balance water in the piping system before it reaches the pumps. In the UTG handbook it is requirement in every pumping station needed to install this type of check valve to prevent any damages to the pump. The cost to repair the pump are much expensive if it damages by the surge water. The time to repair also will affected the water disruption around the effect area due to time consuming in repair works.

Most requests for check valves take into consideration the line size and pressure class alone, as media pressure and flow can vary dramatically where pipe designs are oversized for future concerns or undersized due to lack of or incorrect information. This is not always the best way when deciding which style of valve to use in a system. Other things to consider are working pressure, flow rate, the specific gravity of the media and temperature. An analysis of the system design is highly recommended. It is necessary to understand why valves fail and the root causes. The most common failure is due to excessive wear of the internal parts of the valve. Springs, discs and stems wear prematurely by not being held steady during operation. When the disc is not stable due to insufficient flow to hold it in the full open position, chattering can occur.

There is another that consists of check valve type such as dual plate check valve. It is twin of the disc that move towards center line with the forward flow and reverse flow and when it close it will tightly place in the valve seat. This common type of valve is use in low pressure water pumping system with it lightweight and compact design that easily to place in confined area of pumping station. This cost of installation and maintenance is little bit cheaper than heavy duty valve depending on the industry used.

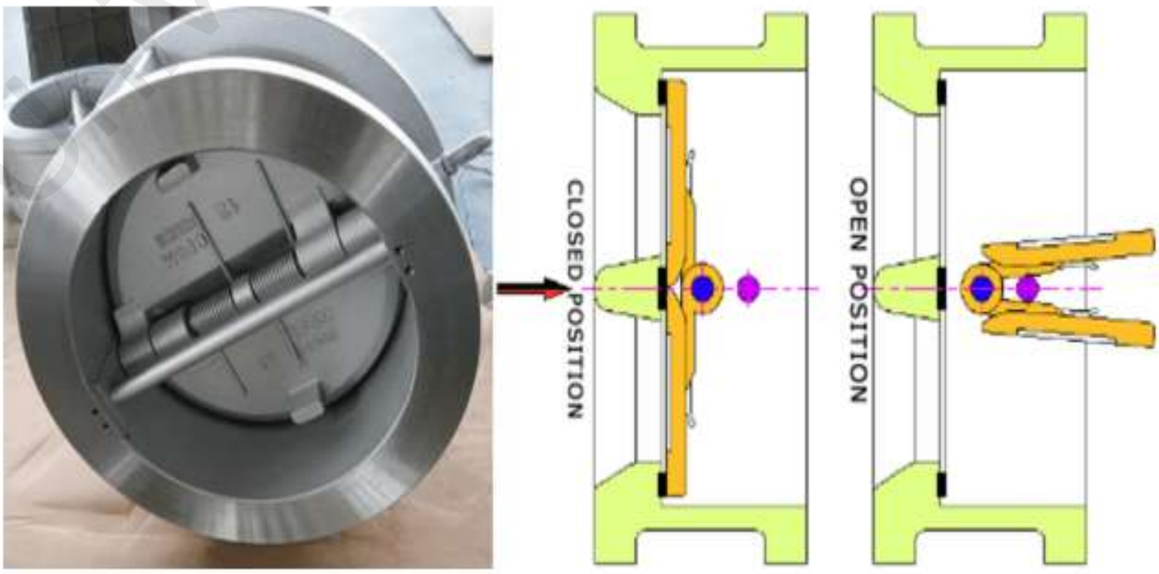


Figure 4.11: Dual Plate Check Valve

(Source: https://www.globalspec.com)

In any design of pumping station all this type equipment is crucial in addition to protect the pumping station that can cost more repaired damaged. Regardless of type or style of valve or surge system, the sized and implementation is accountable to ensure the safety and duration of every operational is on duty. If a component failure result it will affect the performance of its functionality. Therefore, water surge calculated based on every scenario depending on type of event such as power shut-off.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on both cases, it is very important to perform analysis in prevent any water surge along the pipelines. Water surge is a real phenomenon that can cause spectacular damage to the pipes and pump house. The reason for that few people aware with it present and problem to notice rapid changes. Perhaps more significant is the effect pressure during transient on the equipment that install, leading to early detection failure of joints rather than failure to the pumping system. Damages to pipe support or heavily leak can bring out Non-Revenue Water (NRW) that can cause losses to the company water industries and paid more cost to repair than prevention.

Simulation and analytically were conducted to ensure the safety and secure water flow when pumping is running. Almost every water industries trying to prevent water surge. The details result of the data is at appendix A. As it shows the surge analysis result without surge anticipating valve, it is shown that maximum head in pipe no.1 at sub-node 1 is 178.28m and the minimum head in pipe no.5 sub-node 8 is – 0.00m. It is indicating that at the node 1 impact is more than pump head which is 120m and it will heavily damage the pump even though it has secondary check valve to absorb the impact. The minimum head is decreasing at pipe no.5, 1600m distance from the pump house which is after the surge are reduced from back flow at the pump house, the water velocity become slowly decreased and return to steady state. When running the simulation with surge analysis result with 80mm surge anticipating valve, it is shown that maximum head in pipe no.1 at sub-node 1 is 120.81m and just increase 0.81m more than the actual pump head without damaging the pump house. The minimum head in pipe no.3 sub-node 2 is – 0.14m where the distance is 720.0m when it became steady state.

5.2 Recommendation

Based on the methodology and findings of this study, future recommendations can be preparing and design to ensure that the water hammer will not engaging the main pumping. In many production plant or distribution plant for pumping system, it required surge protection depending on the type and capacity of pump. In this case, the pump and piping size are intermediate and doesn't required heavy water surge protection. In some industries, there are using bigger pumps and the piping size is more than 900mm diameter therefore it uses heavy duty surge protection system and more than one. If the system carryout more load, the surge system is usually being surge vessel that run with air and water ratio in their ballast tank. The elevation and distance are also measure so that at the pumping line it will not break especially when the piping materials system use fatigue.

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