Surge Analysis Program Version 2R

SAP2R

User Manual

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Important instructions in the use of SAP2R

1. Open the result file SAP2.RES using Notepad or Word directly from the folder C:\iisc. The icons on the VB screen may not work in some PCs due to variations in OS and OS updates. Similarly, open the plot file SAP2.XLS directly from the folder C:\iisc.

2. Use only Type B project option. Avoid the simple Type A option, which lacks flexibility.

3. In designing surge protection system, all the air valves should not be considered in surge analysis. The air valves may not function as ideal vacuum breakers and hence design based on air valves should be taken up with caution. In general, when design based on air valves alone is proposed, it may be necessary to verify that the surge picture will not be severe even if the air valves fail to function as vacuum breaker.

4. Whenever the minimum head profile indicates pressures below –10 m over a stretch, water column separation analysis is necessary for determining the maximum head profile. Analysis must be repeated considering water column separation effect at different critical locations.

5. When analysis is done with water column separation effect at one or two locations as allowed in SAP2, the minimum head profile has no relevance and hence the minimum head profile may be removed from the plot (prepared from macros with short cut key ctrl + g etc.) and only the maximum head profile may be retained for such cases.

CONTENTS

1. BACKGROND TO THE SOFTWARE

There has been an increasing awareness in the country on the importance of surge or hydraulic transient analysis, while designing pumping stations and transmission mains. The writer, during and after his service at the Indian Institute of Science, has played a pioneering role in the country in this area over the last 35 years. He has been associated with surge analysis and design of surge protection systems for more than 300 projects in this period, involving more than 450 pumping stations. The projects span municipal and industrial water supply systems, lift irrigation schemes and condenser cooling water systems. These projects covered widely varying parameters, with discharge varying from 0.02 to 16.0 m^3/sec, transmission main size varying from 125 to 3600 mm, transmission main length varying from 0.2 to 200 km and pump head varying from 20 to 900 m, for various types of pipes (steel, ductile iron, cast iron, AC, GRP, PSC and HDPE pipes).

The design of surge protection system is an iterative process in which a particular protection is proposed, waterhammer analysis is made for that choice for power failure condition, the resulting surge pressures are evaluated, the protection system is modified based on the evaluation and the process is repeated until an adequate and economical protection system is arrived at. Surge or waterhammer analysis is made for each option by numerical analysis using the method of characteristics. A software is required for such an analysis, as it involves simultaneous solution of two nonlinear, first order partial differential equations.

The first version of SAP was released in July 1999. Its scope was restrictive with a lumped single pumping station, uniform size transmission main delivering water to one terminal reservoir. The second version SAP2 was released in 2002 and its scope was much wider covering multiple pump/pumping stations, delivery of water at multiple target reservoirs, pipes of varying size, material, pressure class/wall thickness, varied options of non-return valves in the pump house and enroute along the transmission main, varied options of surge protection devices, surge in gravity main etc. The present version SAP2R incorporates some improvements in two computational modules and some changes in the output modules.

2. CONSIDERATION OF SURGES OR HYDRAULIC TRANSIENTS

2.1 Causes of Surge

Waterhammer or surge or hydraulic transients is a phenomenon occurring in closed conduit or pipe flows, associated with rapid changes in discharge in the pipe. The rapid change in discharge and the associated velocity is accompanied by a change in pressure, which is propagated through the pipe. The waterhammer wave is propagated at acoustic speed, which varies with the material and wall thickness of the pipe. Like any other wave phenomenon, the wave is transmitted and reflected at different boundaries such as reservoir or pump. It is also damped by friction as it propagates. Fig.1 presents a schematic diagram of a pumping main in a cross country alignment. In a pumping main, changes in discharge may be caused by: (a) valve closure or opening (b) starting of a pump (c) stopping of a pump (d) power failure (e) single pump failure when multiple pumps are in parallel operation. The planned starting or stopping of a pump is also associated with valve opening or closing. In general, in a pumping main carrying water, valve operations need not be very rapid and hence surge pressures due to valve operation and planned starting or stopping of a pump can be kept under control. Surge pressures due to pump starting can not exceed shut-off head of the pump (unless a valve at the downstream end is closed).

Power failure and single pump failure form the most critical surge condition in a pumping main. Power failure is critical with regard to surge pressures in the transmission main, while single pump failure may be critical with regard to surge pressures in the pump house. These two phenomena are now discussed briefly.

2.2 Surge Phenomenon Following Power Failure

When the power fails, the motor speed starts dropping rapidly, the rate of deceleration depending on the inertia of the pump and motor. As the motor speed reduces, the pump discharge and head reduce (Fig. 2), and a down surge pressure wave travels along the transmission main towards the delivery end, at a speed governed by the pressure wave velocity (approximately 1 km/sec). When the wave reaches the delivery reservoir, it gets reflected as an upsurge wave, which in turn, travels towards the pump end. Within a short interval following power failure, the motor speed reaches a level at which no forward pumping is possible. At this stage, flow reversal takes place, and the non-return valve at the pump end closes. It is possible that the valve has allowed some reverse flow to develop before it closes. If the closure of the valve is relatively slow (such as for valves with external dash-pot arrangement), reverse rotation of the pump may also develop.

The above phenomenon may cause the following problems. When the non-return valve closes, depending on the magnitude of reverse flow already established, a pressure rise occurs, which may exceed the design/test pressure of the pipe (A in Fig. 2). Prior to that, during the initial down surge phase, the magnitude of pressure drop may be such that, at a peak along the alignment, vapour pressure occurs (B in Fig. 2). As this now forms a pressure control at the location, it functions as a pseudo-reservoir, segregating the flow upstream and downstream of the location. This is termed as water column separation, with inflow velocity at the location being different from the outflow velocity. Initially, the outflow velocity is more than the inflow velocity, increasing the cavity size. Later, the inflow velocity becomes more shrinking the cavity. At some instant, the cavity fully collapses, creating a shock pressure rise, and thereafter the inflow and outflow velocities are the same at the location. The shock pressure rise travels on both sides and may cause the pressure to exceed design/test pressure. For large diameter steel pipes, the occurrence of vapour pressure may also be a problem. In systems where extensive occurrence of vapour pressure is indicated, analysis considering column separation effect is to be treated as approximate. Hence predictability of the behaviour of such a system under surge condition is not good, unless suitable protection system is designed.

2.3 Surge Phenomenon Following Single Pump Failure

In a pump house where multiple pumps are in parallel operation, one pump may fall suddenly due to a fault. This condition can create severe local surge pressures in the delivery pipe line of the failing pump (Fig. 3). These high surge pressures occur in the small length between the non-return valve on the pump delivery line and the delivery manifold or header. This phenomenon is a common cause of failure of non-return valves and butterfly/sluice valves in the pump house.

When a single pump fails with multiple pumps in parallel operation, the speed of the failing pump rapidly drops, along with the discharge from this pump. The other running pumps get slightly overloaded to partly compensate the reduced discharge. The pressure at the delivery manifold or header reduces, but this reduction is not very significant in view of the head generated by the running pumps. The more the number of running pumps, the less the pressure reduction in the manifold. In view of this, reverse flow occurs very rapidly through the failing pump. Typically, flow reversal may take place in 1-3 sec. The rate of reverse flow builds up very rapidly, with water being short circuited from the running pumps to the failing pump. Under such condition, any non-return valve which functions mechanically, may have a small delay in closure, by which time significant reverse flow may be built up. If the valve closes suddenly under such a reverse flow, very high surge pressures may result. The reason for this is that even a very small delay in the reflux valve closure (0.25-0.5 sec) is relatively quite significant, in relation to the pressure wave travel time from the pump to the delivery manifold (which is of the order of 0.01 sec). On the other hand, if the valve closes slowly, such as for hydraulically operated pump discharge valve or valve with dash-pot arrangement, the pressure rise is controlled, but significant reverse rotation of the pump may be developed.

A surge protection system designed for the transmission main protection (ex: air vessel) cannot take care of the local surge pressures in the pump house, resulting from single pump failure. Generally, one or more of the following three approaches may be used to handle this problem:

1. Use a conservative pump delivery pipe size, so that the velocity through the delivery pipe is not large, resulting in reduced surge pressures; 2. Use special types of non-return valves on pump delivery pipes; 3. Specify conservative values of test pressures for the pump house pipes and valves.

In regard to item 3 above, it must be noted that the choice of a conservative test pressure is not merely related to the working pressure. This is in view of the fact that the surge pressure due to single pump failure is essentially dependent on delivery pipe velocity, type of non-return valve and number of working pumps. In a low head scheme, this surge pressure may exceed the pump head by several times, while in a high head scheme, the factor will be lesser. In particular, when air vessel is used as surge protection device, the local surge pressure in the pump house may be accentuated.

2.4 Hydraulic Transients in a Cooling Water System

Fig. 4 presents a schematic diagram of a condenser cooling water system. Fig. 4a presents the sketch for a once-through system, while Fig. 4b presents the sketch for a re-circulation system with cooling towers. The hydraulic grade line (HGL) elevation for the system in Fig. 4a will be such that even under steady state or working condition, there will be sub-atmospheric pressure in the downstream half of the condenser. In view of this, under power failure condition, the possibility of water column separation occurrence at the condenser is very high. Typically, the condenser inlet and outlet pipes are twin pipes of the same size as shown in Fig. 4a. The procedure for modeling the condenser is discussed in Section 15.

2.5 Water Supply System with Multiple Delivery Reservoirs

While major transmission mains generally carry bulk water from the pumping station to a single delivery reservoir, there may be pumping stations which transmit water to more than one delivery reservoir. Fig. 5 presents a schematic diagram of a pumping station with delivery to more than one reservoir. In some systems within a city, there may be transmission mains carrying water to several delivery reservoirs. In general, surges in a network are relatively not as strong as in a pump house-single transmission main-single delivery reservoir system, unless some pipes in the network are designed with a relatively large flow velocity. Surge analysis for a tree type network as shown in Fig. 5 has to take into account the possibility that the distribution of water among the different reservoirs may not be always as per design. In view of this, two factors are to be kept in view: a) The steady state HGL may vary depending on the distribution of water among the different reservoirs. b) The pumps may not always operate under rated condition, as the operating discharge and head may vary with variation in the distribution of water.

2.6 Surges in a Gravity Main

As the scope of SAP2R covers surge analysis in a gravity main also, a brief description of surges in a gravity main associated with shutdown of flow is presented. Fig. 6 presents a schematic diagram of a gravity main. When the flow is shutdown in a gravity main, if it is desired to prevent draining of water from the pipe line to obviate the need for refilling of the pipe line, it is necessary to close the valve at the delivery end. This closure of valve induces an upsurge or pressure rise behind the valve and this pressure rise propagates towards the source reservoir. The more gradual the closure of the valve, the lesser the pressure rise, but the amount of water drained until the valve closure is completed increases. In long length gravity mains, the closure time required to keep pressure rise moderate may be unduly large. In such cases, some surge control measures are desirable. The options available in SAP2R with regard to surge analysis in gravity main will be discussed further in Section 4.

3. CONTROL OF SURGES IN A PUMPING MAIN

3.1 Principles of Surge Control

Control of surge involves control of down surge or pressure drop and control of upsurge or pressure rise. As the critical surge condition is power failure, down surge occurs as the primary surge and upsurge follows as the secondary surge. Hence there are protection devices which aim at controlling the primary down surge and hence indirectly control the upsurge also. There are protection devices which do not control the down surge, but control the upsurge or pressure rise which follows the down surge. Such devices are of use in situations where pressure rise is the main problem and not pressure drop. There are also control devices which can control both down surge and upsurge, depending on the system requirements. The options of surge protection devices within these broad principles are now presented.

3.2 Surge Protection Devices

3.2.1 Air vessel

Air vessel is a surge protection device which can control both upsurge and down surge. It is also referred as surge vessel or air chamber. Fig. 7 presents a schematic diagram of an air vessel oriented horizontally. There are two types of design, termed Type 1 and Type 2 designs. The distinction between these two types of design will be discussed presently.

The air vessel can be an effective surge protection system to control both down surge and upsurge. It is a closed pressure vessel, with water in the lower part of the vessel and compressed air at working pressure in the upper part. The relative proportion of water and compressed air is a design variable. When power fails, the pump head reduces rapidly, while the pressure in the air vessel reduces much more gradually, accompanied by expansion of air. As a result, the non-return valve located just upstream of the air vessel or on the delivery pipes of pumps closes. Now water is supplied in the transmission main from the air vessel, at a gradually diminishing rate, as the air expands. Essentially, the compressed air functions as a stored energy, cushioning the rate of velocity reduction in the transmission main, and hence controlling the surge pressures. As the air expands, the forward flow velocity reduces, and soon flow reversal takes place. Now water enters the air vessel, compressing the air.

The surge protection depends on the initial volume of air under working conditions. The associated design parameter is defined by the air vessel size parameter KAV given by,

$$KAV = \frac{2C_0 a_0}{Q_0 L_0} \qquad (1)$$

where C_0 = air volume under working condition, Q_o = reference discharge, L_0 = length of the transmission main for reference pipe, and a_0 = pressure wave velocity for the reference pipe. The reference quantities Q_0, L_0 and a_0 are the design discharge, transmission main length and pressure wave velocity in the transmission main, for a single pipe system as handled by the first version of SAP. For a complex system, these reference values are set inside the software based on the system data, but knowledge of these quantities is not necessary for the user, though they are available in one of the result files.

The design of the air vessel should be such that there is enough compressed air, C_o in the vessel, that is, sufficiently high value of KAV to control the surge pressures, and enough water in the vessel so that some water is still left in the vessel, when the air expands fully at the instant of maximum down surge. With such a design, when the pump is restarted, the water level automatically reaches the normal level in the air vessel and no recharging of the vessel is required.

In the design of air vessel, there are two important parameters, the volume of compressed air under working conditions and the inflow/outflow loss parameter in the connecting pipe. In designing the connecting pipe, it is desirable to have a lower loss for flow out of the vessel, compared to flow into the vessel. For this, two types of design may be used, one where a differential orifice is provided in the connecting pipe and the orifice is so shaped that there is a lesser head loss for flow out of the vessel compared to flow into the vessel. This type of air vessel design is referred here as Type 1 design (Fig. 7). By reducing the size of the orifice, upsurge comes down significantly. However, there is a limit to this approach as undue throttling will result in deterioration of down surge and also the velocity through the orifice will increase considerably. To avoid this problem, an independent two way control with a non-return valve-bypass connection is possible.

In the second type of design, a non-return valve is provided in the main connecting pipe to the air vessel and for inflow into the vessel, a bypass of smaller size is provided. This type of air vessel design is referred here as Type 2 design. In the Type 2 design, it is possible to choose the head loss parameter for inflow and outflow to/from the air vessel independently and hence it provides an option to control down surge by sizing the air vessel and control the upsurge by reducing the size of the bypass. However, the design has the serious limitation that it requires a relatively large size non-return valve to be provided in the connecting pipe, which may be costly. Also, the performance of the vessel depends on proper operation of the non-return valve. The air vessel for Type 1 design is likely to be larger in size than for the Type 2 design, in situations where both upsurge and down surge play an important role in deciding the size of the vessel. However, the cost increase due to increase in volume is neutralised by the simpler connection without the non-return valve. Hence in making the final decision, an overall view has to be taken rather than merely going by the size of the air vessel alone.

The water level in the air vessel has to be maintained over a specified band. As some compressed air may be lost due to leakage and dissolution, and also due to air volume changes associated with temperature variations, it may be necessary to replenish small quantities of compressed air periodically, when the water level crosses the upper control level. For this, and also for initial charging of the air vessel, a compressor is required as an accessory. A periodic monitoring of the water level in the air vessel, and correction through charging (occasionally bleeding), is required. Typically, such monitoring is required once a day, and the correction may take just a few minutes. Surge analysis is used only for determining the size of the air vessel, the initial air volume and the connecting pipe details. The details of accessories such as compressor and pneumatic plumbing are to be decided from other considerations.

3.2.2 One way surge tank

The one way surge tank is a surge protection device intended for control of down surge. It is also referred as feed tank or discharge tank. Figs. 8 and 9 present a schematic diagram of a one way surge tank. The one way surge tank is generally located at relatively elevated points along the alignment. These are the locations which are vulnerable to down surge. The one way surge tank is a surge protection device, essentially intended to control down surge and prevent occurrence of water column separation. As water column separation is prevented or minimised, it indirectly controls upsurge also. It can be an economical protection system if the alignment is such that a suitable location is available in the upstream half of the pumping reach. The one way surge tank generally does not protect the line upstream of it fully.

In using one way surge tank as surge protection device, even if analysis may indicate that a ground level tank is suitable, it is preferable to use elevated tank with staging height. When power failure occurs, the system pressure reduces rapidly. When the pressure in the transmission main drops below the water level in the tank, the non-return valve in the connecting pipe opens (Figs. 8 and 9), and water flows out of the tank moderating further pressure drop in the transmission main. If, due to upsurge later, a pressure rise occurs, the non-return valve closes preventing inflow into the one way surge tank. It is for this reason that the tank is referred as one way surge tank.

Under working conditions, when the tank is full, the valve on the inlet line to the tank is kept closed. Two types of filling arrangement may be used. The bypass filling arrangement (Fig. 8) requires an operator to be stationed at the tank location. This arrangement is commonly used when the one way surge tank is located near the pump house. In the float valve filling arrangement (Fig. 9), the filling rate may be slow depending on the local pressure at the tank location. If adequately large size float valve is available, this problem may not arise. The float valve filling arrangement is most commonly used for one way surge tank located enroute along the alignment.

3.2.3 Surge control valves

Surge control valves may be broadly categorised into three types: 1. Valves belonging to the non-return valves category; 2. Valves belonging to the pressure relief valve category; and 3. Valves belonging to the air valve category. It may be noted that though common terminology such as non-return valve, pressure relief valve, and air valve are used above, the surge control valves may be of special types within these broad categories. Valves of the first type are fitted in-line, while valves of the other two types are fitted on a tee junction. The first two types are essentially intended to take care of upsurge or pressure rise, and the third type is intended to take care of down surge or pressure drop.

An example of the surge control valve of the non-return valve category, is a spring loaded non-return valve with axial disc motion. The valve is generally provided with a bypass. The springs are mounted behind the disc. The disc, which remains open during normal working, starts closing with reduction of forward velocity following power failure. The valve closure is to be completed when the velocity becomes zero, thus preventing reverse flow occurrence and associated pressure rises. An alternative to this type of valve is the dual plate check valve, with two semi circular discs which also close by spring force. When these types of spring loaded valves are located downstream of a location where water column separation occurs, it may control the pressure rise due to rejoining of the separated water columns. With regard to the use of these valves for surge protection, the following points are to be noted: 1. They are devices essentially intended to control upsurge or pressure rise; they are not suited for control of down surge or pressure drop. 2. The flow reversal time following power failure depends on the hydraulic parameters associated with the pipe line and the pump. In several systems, this time may be very short and it must be ensured that the valve can respond with full closure within the required time. 3. In long pumping mains, a swing or tilting disc non-return valve with a bypass may serve the same purpose as these spring loaded valves. This is in view of the fact that any small delay in closure of the non-return valve has an insignificant effect in view of the larger time scale of the system (which is the pressure wave travel time over the transmission main length).

Normal spring loaded pressure relief valves of the direct type may not function as effectively as a surge relief valve due to sluggish action. However, special types of pilot controlled pressure relief valves can be used as a surge relief valve. Valves with a separate low pressure pilot and a high pressure pilot enable opening of the valve when the line pressure drops below a set limit or rises above a set limit. When the line pressure comes to the normal range, the valve again closes. The opening under surge conditions is generally very rapid, while the closing is gradual.

Surge control valves of the air valves category are essentially used as vacuum breakers to prevent column separation and subsequent deleterious effects. Double kinetic air valves, special types of spring loaded air valves and special types of vacuum breakers may be used for controlling the occurrence of sub-atmospheric pressures. It must be noted that surge analysis considering the effect of air valves as vacuum breakers is approximate, as two phase flow effects are ignored. Hence use of air valves as surge control devices should be restricted to isolated locations along the transmission main, and they must not be relied upon for control of extensive occurrence of sub-atmospheric pressures, except under expert advice.

4. SCOPE OF THE SOFTWARE

The essential scope of the software, SAP2R is to conduct surge analysis for power failure or pump failure situation in a pumping system, though it can be used for analysis of surges in a gravity main also. The software can deal with multiple pump houses, multiple pumps in the same pump house, multiple delivery reservoirs, multiple pipes, pumping-cum-gravity main, gravity main, condenser cooling water system, cooling water system for combined cycle power plant, booster pumps with on-line suction etc. In fact, subject to the limitation that the steady state flow direction in each pipe should be known, there is practically no other restriction with regard to scope.

The software does the surge analysis for failure of one or more pumps, including power failure. It provides results for minimum and maximum pizeometric heads at identified chainages along the pumping system and also graphical plots of minimum and maximum pizeometric heads along with the longitudinal alignment and HGL, for pre-specified flow paths along the system. The output file will contain additional results which will be directly useful for the design. For example, if analysis is done for air vessel protection option, the output file will give results of maximum expanded air volume which helps in deciding the size of the air vessel. If analysis is made for one way surge tank protection option, the output file will give results for the extent of draining of the tank which helps in fixing the capacity of the tank. Results will also be available for maximum velocity through the connecting pipe, which will help in fixing the optimal size of the connecting pipe, as this pipe with associated valves form a costly component of the one way surge tank protection. Depending on the case of analysis, supplementary graphical plots will be available to help the process of decision making in the design.

It is envisaged that the program may be used under two types of situations. A common situation will be one where the pumping main details are finalised and hence the data about the pumping main are fully known, but the data about the pumps may not be available, except for the specifications of discharge, head, speed and approximate HP. Specifically, data for pump characteristics and GD^2 values of pump and motor will not be available. In such situations, the software provides an option for choosing one of three standard pump characteristics for the analysis. The GD^2 values of the pump and motor are computed based on an empirical formula in-built in the software, based on data for pumping machinery for several projects in India. In the second situation, order for the pumps may have been finalised, hydraulic layout of pump house may also have been finalised, and hence complete data about the system is available. The software SAP2R can be used for analysis in both these situations.

The scope of the software covers a wide range of surge protection options available in the country at present. These include: a) air vessel b) one way surge tank c) Zero velocity valve d) dual plate check valve e) intermediate non-return valve f) air valve g) Air cushion valve h) stand pipe and i) surge relief valve. Where multiple number of the same device or a combination of devices can be used, the software provides option for it.

Some restrictions are imposed on the choice of protection devices, with regard to certain combination of protection devices. There are two such restrictions: a) A combination of air vessel and surge relief valve is not permitted as both are located near the pump house and the discharge through the surge relief valve will significantly affect the efficacy of the air vessel. b) For upsurge control through spring loaded non-return valves located along the transmission main, either Zero velocity valve or dual plate check valve may be used, but not a combination of both. This restriction is placed from practical considerations including cost factor, as there is no advantage in mixing both the types of valves in the same scheme. However, this restriction does not apply to the use of dual plate check valve within the pump house. The details regarding protection options available are given in Section 9.

The scope of the software allows for a wide range of choice for pump house non-return valves. This is a distinctive feature in the software. Generally, the choice of non-return valves in the pump house is closely related to indications from surge analysis and hence it is important to be able to consider different types of valves before final selection is made. Details regarding pump house non-return valves covered by the software are given in Section 10.

An additional protection option included is a valve with/without bypass outlet. This option is intended for use in gravity main and the details will be discussed in Section 9.9. It can also be used a surge analysis simulation option in a pumping main (not as a protection option) for studying the effect of accidental closure of an intermediate valve, as discussed in Section 7. For gravity main, surge analysis can be done for the case of closure of a valve at the downstream end. This option is available only for the case one delivery reservoir.

5. METHOD OF ANALYSIS

The basic equations for surge analysis are a set of two simultaneous, first order partial differential equations in two unknowns (piezometric head and velocity) in two independent variables (distance along the pipe and time). These equations are derived based on momentum and continuity principles, taking into account pipe material elasticity and compressibility of water. The solution of the two partial differential equations requires specification of initial condition at time t=0 before the onset of surge, and boundary conditions at external boundaries such as pump and delivery reservoir, and internal boundaries such as air vessel and one way surge tank.

The analysis problem may be mathematically posed as follows. The two dependent unknown variables are piezometric head, H and flow velocity, V. In general, H and V vary with distance along the pipe, x and time since the onset of surge, t (ex: power failure). At time t = 0, that is just before the onset of surge, H and V are known all along the pipe line, that is all x values, based on working conditions. The problem is to determine H and V values in the x-t domain, for x varying from start chainage to end chainage and t varying from 0 to any specified value upto which solution is sought. In a tree type network, H and V values are to be obtained along all the pipe paths.

Besides satisfying the two governing partial differential equations, the solution should also satisfy the boundary conditions. For example, at a reservoir boundary, H value is constant corresponding to the delivery level or reservoir water level, depending on the nature of delivery (free or submerged). At a pump, the boundary conditions are more complex, defined by the speed-discharge-head characteristics and speed-discharge-torque characteristics of the pump, and the pump-motor inertia equation governing the rate of reduction of speed. Associated with such multiple boundary conditions, there are additional local unknowns, in this case, pump speed and torque.

Boundary conditions are relevant not only at the two extreme boundaries, but also at other devices/fittings located along the transmission main. For example, continuity equation forms the boundary condition at a junction (ex: manifold or header). For a one way surge tank, the continuity equation related to outflow from the tank and the head loss equation for connecting pipe between the one way surge tank and the transmission main provide the boundary conditions.

Surge phenomenon being a wave motion, the analysis problem is best solved by tracking the solution along the path of the wave motion. The path of the wave motion in the x-t plane (solution domain formed by distance along the pipe and time axes) is called the characteristic. There are two sets of characteristics corresponding to wave motions in the positive x direction and negative x direction. The method of tracking the solution along the paths of these two sets of characteristics, is called the method of characteristics. The analysis procedure used in the present software is based on the method of characteristics. The theory and computational methodology for solution by the method of characteristics are given in standard references (Wylie, E.B. and Streeter, V.L., Fluid Transients, McGraw Hill International Book Co., 1978).

In the SAP2R software, the core part of the program wherein the analysis by the method of characteristics is done, uses the non-dimensional form of the governing equations. All the dimensional inputs given are converted to the required non-dimensional form in the software, before entering the analysis module. There are two advantages in working with non-dimensional variables: a) The variables used in the computations remain within the same order for widely varying physical problems and this facilitates improved numerical processing. b) Working with non-dimensional variables improves generalised understanding of the problem, in the long range.

6. TYPES OF PROJECTS

Analysis projects are classified into two types in SAP2R, namely Type A and Type B projects. Type A refers to a simple system of a pump house, with identical multiple pumps in parallel operation, with a transmission main of constant diameter, discharging water to a delivery reservoir (Fig. 1). This option corresponds to the scope of the first version of SAP. Type B projects correspond to more complex systems not covered by the simple Type A project. This option can be used for systems with: a) pumps operating under non-rated conditions, b) multiple pipes, c) delivery to multiple reservoirs, d) multiple pump houses, e) pumps of different types in parallel operation, f) on-line booster pumps, g) junctions, both combining and dividing types, h) condenser as in cooling water system, i) local obstructions, such as a partially open valve or an orifice or a filter and j) source reservoir associated with a gravity main. Both types of projects allow a wide choice of surge protection devices and type of closure for pump house non-return valves. **It is strongly**

advised that only Type B option be used even for simple systems. Simulation based on Type A project lacks flexibility and also does not enable an assessment of local surge pressure in the pump house, which is an important factor. Hence even though the software retains the Type A option, further discussion in the manual is restricted to Type B projects only so as to discourage the use of Type A option.

7. OPTIONS FOR SIMULATION

Type B projects are intended for use in complex systems with multiple pipes, multiple pump houses (or each pump in a pump house treated separately), multiple delivery reservoirs etc. Type B projects cover both pumping mains and gravity mains and in both cases, it is the pump/power failure or shutdown option that is provided in SAP2R. For a pumping main, option is available to specify for each pump, whether it is running or failing. This is achieved by treating each pump in a pump house as a separate pump. Hence in Type B projects, the option of analysis for all pumps running is also available. This is an useful option to check the data validity and to detect possible errors, as with the option of all pumps running, there is no surge and hence the steady state HGL, the maximum piezometric head profile and the minimum piezometric head profile should all coincide. For on-line booster pump pumps also, the option to specify running or failing condition is available.

In addition, for cases with one delivery reservoir, an option to consider the effect of closing a valve at the delivery end is available. This is essentially intended for analysis of surge in a gravity main for the shutdown condition, where the valve at the delivery end is closed to prevent the draining of water. One additional protection option provided in SAP2R, is a valve with a bypass option at any intermediate location (including at the delivery reservoir end), closing as per the specified pattern. This option is essentially provided as a simple protection option for a gravity main, but it can be used as a simulation option for a pumping main, to consider the effect of accidental or deliberate closure of a valve at any intermediate location.

Details of all the available system options and associated data are discussed in Section 12.

8. DATA STRUCTURE FOR TYPE B PROJECTS - PIPES AND NODES

As Type B projects are normally associated with multiple pipes and possibly complex piping systems, the principal data structure is based on the concept of pipes and nodes. Fig. 10a presents the nomenclature of pipes and nodes for the system presented in Fig. 5. In Fig. 10a, the pump house is represented by one node, with all the working pumps lumped together as in the case of simulation in Type A projects. Fig. 10b presents the schematic of pipes and nodes with each working pump treated separately as a node. It is strongly advised that each pump may be modelled separately, as in Fig. 10b. A pipe in a Type B project has two end nodes, the upstream and downstream nodes as defined by the steady state flow direction. In addition, associated with a pipe, the other data are: a) discharge, b) diameter (ID), c) length, d) start chainage and e) details of pipe material (material, wall thickness, lining etc.). The information in (e) is used for the calculation of pressure wave velocity.

The data associated with nodes are: a) type of node, b) number of upstream pipes and the corresponding pipe numbers and c) number of downstream pipes and the corresponding pipe numbers. The information in (b) and (c) establish the connectivity of the network. SAP2R provides the following 9 options for the type of node: 1) ordinary node, 2) combining junction where two or more pipes join together (ex: manifold junction or header, Node 3 in Fig. 10b), 3) dividing junction where two or more pipes branch from a single pipe (ex: the pipes branching at Node 4 in Fig. 10b), 4) delivery reservoir (ex: Nodes 5 and 6 in Fig. 10b), 5) source reservoir associated with a gravity main, 6) condenser in a cooling water system, 7) an obstruction with concentrated local head loss (ex: a partially throttled valve), 8) pump with sump (Nodes 1 and 2 in Fig. 10b) and 9) on-line booster pump.

SAP2R allows the option of modelling a condenser in a cooling water system in alternate ways. The node option referred in item (6) above is a simple one and may be used for preliminary analysis. However, it is strongly recommended that for analysis of a condenser cooling water system, the condenser may be modelled as an equivalent pipe. It is possible to model the condenser even as two or three pipes if preferred. Details in this regard are given in Section 15. The obstruction node in the model may be used only at locations of significant local head loss in the system. For example, a full open isolation valve along the alignment can, in theory be modelled as an obstruction, but such refinement does not add any value and only distracts attention from the main aspects of the analysis. If, in a system, for discharge control, a valve is heavily throttled with a significant head loss, the location may be made a node of obstruction type. If in a pumping main, there is a variation in the pipe size or material along the alignment, such locations can be modelled using nodes of ordinary type. Fig. 11 presents a schematic diagram illustrating the different types of nodes.

It must be noted that the nodes referred above are only the nodes with regard to user interface. The computational nodes are one or more orders of magnitude larger in number than these user interface nodes. The computational nodes are set inside the software.

9. OPTIONS FOR PROTECTION DEVICES

9.1 Air Vessel

The two key design parameters for the air vessel are: a) the size parameter of the air vessel, KAV (eqn .1) and b) details of the connecting pipe between the air vessel and the transmission main. There are two types of connecting pipe system possible for the air vessel and based on this, the designs are catagorised as Type 1 or Type 2 design. In Type 1 design, a rounded orifice is installed in the connecting pipe, in such a way that the head loss for inflow into the air vessel is much larger than for outflow from the air vessel. This is intended to achieve some control on the upsurge without significant deterioration in the down surge. In the Type 2 design, a non-return valve is provided in the connecting pipe, with a bypass of smaller size for allowing inflow into the air vessel. This design provides for an independent two way control for inflow and outflow, but at the additional cost of a non-return valve.

The software handles both the design options. For Type 1 design, the orifice size is to be provided along with connecting pipe size, and for Type 2 design, the bypass size is to be provided along with connecting pipe size.

The air vessel is assumed to be located near the pump house. The software fixes the elevation of the air vessel based on ground level near the pump house, that is, at the air vessel location.

In air vessel design, it may be decided to provide a non-return valve on the transmission main just upstream of the air vessel. This is particularly so if the number of working pumps is large and the required size of non-return valve on the transmission main is not unduly large. If this non-return valve is not provided, the function of the air vessel will depend on the proper functioning of all the non-return valves on the individual pump delivery pipes. The software provides an option to include or not to include the non-return valve on the transmission main.

9.2 One Way Surge Tank

Figs. 8 and 9 present schematic diagrams of one way surge tank. Normally, one way surge tank is located at a relatively elevated point along the alignment of the transmission main. In systems with low to moderate pump head, one way surge tank located near the pump house may also prove to be of advantage. One way surge tank may be a ground level tank or an elevated tank (over head tank), though the writer prefers to use only elevated tank. The tank drains partly or fully following power failure and on restart of the pumps, the tank has to be refilled. In the arrangement shown in Fig. 9, refilling is done through the inflow line with the float valve. If a one way surge tank is located near the pump house, it may be convenient to have a bypass filling arrangement (Fig. 8) avoiding the float valve. The pump house staff can refill the tank after pump start by opening the valve on the bypass line. The choice of the size of the inflow pipe, whether of float valve filling arrangement or bypass filling arrangement, is not based on surge analysis. It is based on available pressure at the location of the tank and allowable or desired filling time. The software allows for multiple number of one way surge tanks, provided at different locations along the transmission main.

9.3 Dual Plate Check Valves

The dual plate check valve is also a spring loaded non-return valve, with torsion springs instead of compression springs as in the case of Zero velocity valve. Fig. 12 gives a schematic diagram of the dual plate check valve. The dual plate check valve is also intended to close with reduction in velocity. The software considers dual plate check valve in two aspects: a) dual plate check valve on the individual pump delivery pipes within the pump house, b) dual plate check valve used in the transmission main at intermediate locations along the alignment. The use of dual plate check valve within the pump house on individual pump delivery pipes is discussed in Section 10. In this section, the use of dual plate check valves in the transmission main is only considered.

When dual plate check valve is used in the transmission main, it may be of the same size as the transmission main. Normally, dual plate check valves are not provided with a bypass. However, if dual plate check valves are to be used at some intermediate locations along the alignment, it is desirable to provide a bypass. If, due to the slim structure of the valve, provision of a bypass integral with the valve is not economical, a bypass may be provided in the pipe around the valve. It may be noted that when dual plate check valve is used in the pump house for individual pump delivery pipes, no bypass need be provided.

9.4 Zero Velocity Valves

Zero velocity valves are special type of spring loaded non-return valves intended for upsurge control (Fig. 13). The valve closure occurs gradually with the reduction in velocity following power failure, reaching full closure at zero velocity. The Zero velocity valve is provided with a bypass which allows a small amount of reverse flow. The size of the Zero velocity valve is normally the same as the transmission main size. The software allows for multiple number of Zero velocity valves.

9.5 Intermediate Non-return Valves

There are pumping mains in which at some intermediate locations along the alignment, swing check valves are provided. The software allows for these valves assuming that the valve closes instantaneously, with a delay following flow reversal. The delay can be zero or a specified small duration (say, 0.5 or 1.0 sec). The valve may or may not be provided with a bypass.

9.6 Air Valves and Air Cushion Valves

The software includes air valves and Air cushion valves as vacuum breakers. In the analysis, air valves are assumed to start functioning as vacuum breaker at (-) 3 m pressure, while Air cushion valves are assumed to start functioning as vacuum breaker on the onset of sub-atmospheric pressure. Total reliance on air valves/Air cushion valves for surge control should be done with great care and under expert advice.

9.7 Stand Pipes

At locations along the alignment where the hydraulic grade line is within a few metres of pipe elevation, it may be occasionally advantageous to use a stand pipe for control of down surge. Such locations are usually likely to occur towards the delivery end. Fig. 14 gives a schematic diagram of a stand pipe. The program allows multiple number of stand pipes.

9.8 Surge Relief Valves

Surge relief valve (also referred as surge anticipating valve) is a piloted pressure relief valve, with a low pressure pilot and a high pressure pilot. When the pressure goes below the low pressure pilot setting or above the high pressure pilot setting, the valve opens, and when the pressure comes back within these limits, the valve closes. The opening of the valve is rapid, while the closure is slow to avoid secondary surges due to closure. The surge relief valve is normally provided near the pump house. More than one valve may be provided on the same branch or on separate branches to improve the reliability of function. Though the software allows flexibility in location of the surge relief valve, these valves are usually located near the pump house.

9.9 Valve With/Without Bypass Outlet

The option of valve with/without bypass outlet is intended for use in surge control in gravity mains and is available for Type B projects only. Fig. 15 gives a schematic diagram of the option as it is intended for normal use in a gravity main. In this case, the valve will be located at the delivery end. For shutting down the supply in the gravity main, first the bypass is opened, then the main line valve is closed gradually (during which time the bypass valve is kept open), and then the bypass valve is closed. This helps in reducing the closure time of main line valve without undue deterioration in the upsurge, which in turn minimises the quantity of water drained during the shutdown process.

10. OPTIONS FOR PUMP HOUSE NON-RETURN VALVE

The software provides for a wide range of options for non-return valves on the delivery pipes from individual pumps. Six options are provided which can be used practically to cover any type of non-return valve. As the industry terminology in describing different types of non-return valves is not very well standardised, in the following discussion, the focus is essentially on the type of closure of the valve. In the output presentation, a numerical code from 1 to 6 is assigned for each type of closure and the associated closure characteristics are now described. Guidelines for modelling procedure for standard types of valves are given in Section 15.

10.1 Code 1 type closure

Code 1 type closure refers to a rapidly closing swing check valve, assumed to close instantaneously with or without delay, following flow reversal. This closure pattern is shown in Fig. 16a. The closure pattern is ideal when there is no delay. However, the surge picture may deteriorate if the valve is assumed to close with delay. A delay of 0.5 to 1.0 sec may be usually considered. The effect of such a delay may be significant or otherwise depending on the time scale of the system.

The data requirement for this type of closure is only specification of delay in closure. If the delay is specified as 0, it refers to ideal closure.

10.2 Code 2 type closure

Code 2 type closure refers to a swing check valve closing with uniform speed, with closure starting on flow reversal with or without delay. This closure pattern is shown in Fig. 16b. Generally, a large size swing check valve takes a small finite time (less than 1 sec) for the full disc movement and such closure may be represented by this type of closure. For example, a non-return valve closing in 0.5 sec with 0.5 sec delay refers to a valve closing fully in 1 sec after flow reversal. Alternately, a non-return valve whose closure is slowed down by an external mechanism can also be represented by Code 2 closure, provided the rate of closure is uniform.

The data requirement for this type of closure is as follows:

Time of closure (sec)

Delay in closure (sec)

The delay can be specified as 0 if desired.

10.3 Code 3 type closure

Code 3 type closure refers to a non-return valve closing in two speed, with closure starting on flow reversal with or without delay. This type of closure corresponds to a valve wherein the first 90% closure occurs relatively rapidly, while the remaining 10% closure takes place slowly. Generally, the delay for this type of closure may be ignored and specified as 0, though the program provides an option for specifying a non-zero delay. The closure pattern for Code 3 type closure is shown in Fig. 16c. Non-return valves with an external counter weight and dash-pot arrangement generally fit in with this type of closure.

Another type of non-return valve for which Code 3 type closure may be used is internally cushioned swing check valve. While in valves with external dash-pot arrangement, the total closure time may be 10 sec to even 60 sec, for an internally cushioned swing check valve, the closure time is likely to be less than 2 sec. However, within this closure time, the first 90% closure occurs relatively rapidly. For example, a closure time of 0.6 sec for first 90% closure and 0.9 sec for remaining 10% closure may represent an internally cushioned swing check valve.

The data requirement for Code 3 type closure is as follows:

Time of first 90% closure (sec)

Time of next 10% closure (sec)

Delay in closure (sec)

The delay may be specified as 0 if desired.

10.4 Code 4 type closure

Code 4 type closure refers to non-return valve closing with uniform speed, with closure starting from instant of pump trip. This type of closure requires transmission of a signal on pump failure and operation of the valve through electrical or hydraulic or pneumatic control. A motorised butterfly valve, closing with uniform speed on pump failure, is represented by this type of valve. The closure pattern for Code 4 type closure is shown in Fig. 16d.

The data requirement for Code 4 type closure is only the time of closure in seconds.

10.5 Code 5 type closure

Code 5 type closure refers to non-return valve closing in two speed, with closure starting from the instant of pump trip. The first 90% closure takes place relatively rapidly, while the remaining 10% closure may be more gradual. This type of closure pattern is shown in Fig. 16e. Code 5 type closure also requires transmission of a signal to identify pump/power failure and power pack arrangement with external counter weight and dash-pot assembly to achieve two speed closure.

The data requirement for Code 5 type closure is as follows:

Time of first 90% closure (sec)

Time of next 10% closure (sec)

10.6 Code 6 type closure

Code 6 type non-return valve refers to dual plate check valve. The use of dual plate check valve in the pump house should be distinguished from the application referred in Section 9.3, where the dual plate check valve is located in the transmission main at intermediate locations along the alignment. The closure pattern of dual plate check valve is shown in Fig. 16f. Here, the closure depends on the rate of deceleration of flow following power failure or single pump failure. Dual plate check valve is normally a rapidly closing non-return valve and hence the possibility of reverse flow developing through the valve may be small. However, if the deceleration rate is too rapid, the effect of Code 1 or Code 2 type closure with delay may also be studied while using dual plate check valve. This may be particularly useful in estimating the local surge pressure in the pump house for deciding the test pressure of the dual plate check valve.

There is no special data requirement for dual plate check valve.

10.7 No closure of non-return valve

In order to simulate no closure of non-return valve, Code 1 type data may be used, giving data for delay as 10000 sec.

11. ANALYSIS OF WATER COLUMN SEPARATION

During the surge condition following power failure, it is possible that pressure at a location reaches vapour pressure. This generally occurs at peak locations along the alignment and in situations where there are no devices for control of down surge. When vapour pressure occurs at a location, there is pressure control at the location, which functions as a pseudo constant head location until the cavity collapses. There is separation of water column and the velocity upstream and downstream of the location differ. Initially, the downstream velocity is higher causing enlargement of the cavity and at a later time, the upstream velocity becomes higher causing shrinking of the cavity. At the instant when the cavity fully vanishes, a shock pressure rise is created at the location and its effect travels in both directions. This phenomenon is called water column separation.

The software allows analysis for the case of water column separation. However, in each analysis, water column separation at one or two locations only can be considered. The option of two locations can be used to model simultaneously column separation in two symmetric, parallel pipes (ex:

condenser inlet or outlet pipes, Fig. 4). There are inherent limitations in analysing situations where there is extensive occurrence of vapour pressure. This aspect is discussed further in Section 17.2.

12. GUIDELINES FOR DATA INPUT

12.1 Main Menu

The main data input is done in Windows environment through an user friendly interface. In designing the data input module of the software, the following principles are used: a) The data requirement should be self explanatory for a pipe line engineer. b) To the extent possible, data which is of uncertain nature and does not have a sensitive impact on the results of analysis, should be incorporated in the software itself, as hard data. c) The chances of wrong usage of the software due to ambiguity in the data interface should be minimised.

The main menu comprises of the following options: a) File, b) View, c) Run (the Help option shown on the menu bar is not used). The main menu is supported by a tool bar to provide added convenience. Under File menu, the normal options of initiating a new project, opening and closing a project and saving a project are provided. The saved project files of SAP2R are given the extension .SAP, while saving. The .SAP files contain all the system data, longitudinal alignment data and pump characteristics data.

In starting a new project, two options are available, namely Type A project and Type B project. As it is already indicated that it is desirable to use only Type B option, the guidelines for data input are now provided for Type B projects. Most of the data are self explanatory, but as and where some explanations are required, they are provided in the following sections.

12.2 Data Input for Type B Project

For Type B projects, there is a redundancy in the data input, in terms of establishing the pipe connectivity and ensuring the condition of continuity in discharge. This is deliberately introduced to avoid ambiguity in data input, as well as to minimise logical complexity in the program. The data is validated to avoid inconsistency arising from the redundancy and any inconsistency is reflected through an error message.

Form: Details of transmission main

- Number of pipes

  Pipe details

  - Pipe number
  - Upstream node number
  - Downstream node number
  - Discharge
  - Diameter (ID)
  - Length
  - Start chainage (the start chainage of any pipe can be a continuous chainage from a previous pipe or a local chainage, such as 0 for each pipe)

- Number of nodes

  Node details

  - Node number
  - Type of node (ordinary or combining junction or dividing junction or delivery reservoir or source reservoir or condenser or obstruction or pump with sump or on-line booster pump)
  - Number of upstream pipes followed by upstream pipe numbers
  - Number of downstream pipes followed by downstream pipe numbers

Form: Specific details at nodes

This form seeks data for all the nodes depending on the type of node, among the 9 types. For each type, a set of specific data is required. This is now explained for each type of node.

Ordinary node

- HGL at the node (based on the steady state condition)

Combining junction type node

- HGL at the node (based on the steady state condition)

Dividing junction type node

- HGL at the node (based on the steady state condition)

Delivery reservoir type node

- Water level in the reservoir (discharge level)
- Discharge

Source reservoir type node

- Water level in the reservoir
- Discharge

Condenser type node (use of this may avoided by treating the condenser as equivalent pipe)

- HGL elevation upstream of condenser
- HGL elevation downstream of condenser

Obstruction type node

- HGL elevation upstream of obstruction
- HGL elevation downstream of obstruction

Pump with sump type node

- Number of pumps (a pump house with multiple pumps in parallel operation can be represented by a single pump node. In such a case, the number of pumps will be the number of working pumps in the pump house. Alternately, each pump can be treated as a separate pump node, in which case, the number of pumps will be 1. SAP2R can also model spatially distributed multiple pump houses with each pump house represented by one or more pump nodes).
- Discharge (operating discharge per pump)
- Head (operating head)
- Speed
- Sump water level
- Type of non-return valve

    - Details associated with the closure pattern (Section 10)
- Pumping machinery finalised (Yes or No)

If Yes:

  - GD^2 value of the pump
  - GD^2 value of the motor
  - Rated discharge of the pump
  - Rated head of the pump
  - Rated efficiency of the pump
  - Shut-off head of the pump
  - Non-reverse rotation ratchet provided (Yes or No)
  - Discharge, head, efficiency data (either directly entered on the table or got from a file; if data is from a file, the last row should contain a $ to mark end of data and the file should have .PMP extension name)

If No:

  - Choose type of pump characteristics (Radial or Mixed or Axial)

On-line booster pump type node

- Number of pumps
- Discharge (operating discharge per pump)
- Head (operating head)
- Speed
- Suction side HGL elevation (based on steady state condition)
- Type of non-return valve
    - Details associated with the closure pattern (Section 10)
- Pumping machinery finalised (Yes or No)

If Yes:

  - GD^2 value of the pump
  - GD^2 value of the motor
  - Rated discharge of the pump
  - Rated head of the pump

- Rated efficiency of the pump
- Shut-off head of the pump
- Non-reverse rotation ratchet provided (Yes or No)
- Discharge, head, efficiency data (either directly entered on the table or got from a file; if data is from a file, the last row should contain a $ to mark end of data and the file should have .PMP extension name)

If No:

- Choose type of pump characteristics (Radial or Mixed or Axial)

Form: Wave velocity and trip code

- Type of pipe (pipe material)
    - If steel, wall thickness, c.m. lining thickness and guniting thickness, if provided
    - If ductile iron, pressure class and c.m. lining thickness
    - If cast iron, pressure class
    - If BWSC (bar winded steel cylinder pipe), steel cylinder thickness, concrete thickness and percentage reinforcement by volume
    - If PSC, core thickness, coat thickness and percentage reinforcement by volume
    - If AC, wall thickness
    - If GRP or PVC or HDPE, pressure wave velocity

The pressure wave velocity for a pipe carrying water is given by,

$$a = \frac{1450}{\sqrt{1 + \frac{K}{E}\frac{D}{e}}} \qquad (2)$$

where a = pressure wave velocity (m/sec), K = bulk modulus of elasticity of water (kgf/cm^2), E = modulus of elasticity of pipe material (kgf/cm^2), D = pipe diameter (mm), e = pipe wall thickness (mm). Strictly, in the denominator, the second term is to be multiplied by a factor depending on the fixity condition of the pipe, but its effect is usually very small and may be neglected. For thick walled pipe such as concrete encased steel cylinder pipes as may be used in condenser cooling water system, there are special formulae derived for more precise calculation of the pressure wave velocity. In such cases, if the pressure wave velocity is calculated by the user, he may input it as data by choosing GRP or PVC pipe and directly entering the calculated pressure wave velocity. This ruse can be used as the output file gives only pressure wave velocity data and not the pipe material.

For GRP/PVC/HDPE pipes, there is an uncertainty in estimating the Young's modulus of elasticity. The value of the modulus of elasticity may be obtained from the pipe supplier in these cases. Hence it is specified that the value of pressure wave velocity may be calculated separately and provided as input.

- Trip code for each pump (Running or Failing)
- Trip code for each booster pump (Running or Failing)
- For single delivery reservoir case only:

  Valve closing at delivery reservoir to be considered (Yes or No)

  If Yes:

  - Delay in closure
  - Time of closure

The option of valve closure at delivery end is available only for the case of single delivery reservoir. This option is essentially intended for surge analysis in a gravity main associated with the closure of valve at the delivery end following stoppage of supply. However, the option can be used for a pumping main with one delivery reservoir, for studying the effect of a rare possibility of closing the valve at the delivery end. A more general option of valve closure at an intermediate location is available through the protection option form, which will be discussed subsequently.

Form: Type of analysis

- Column separation effect considered

  If Yes:

  - Number of locations of column separation (1 or 2)

    For each location:

  - Pipe number of location

    - Chainage (location)
    - Pipe invert level
- Analysis with protection (Yes or No); If Yes details of protection

  Air vessel

  - Pipe number
  - Ground elevation at air vessel location (near pump house)
  - Size parameter of air vessel, KAV
  - Connecting pipe size
  - Non-return valve provided on transmission main (Yes or No)
  - Type of air vessel (1 or 2); for Type 1 orifice size, for Type 2 bypass size

  One way surge tank

  - Number of one way surge tanks

  For each tank:

  - Pipe number
  - Chainage (location)
  - Ground level
  - Staging height
  - Diameter
  - Storage depth
  - Connecting pipe diameter

  Zero velocity valve

  - Number of Zero velocity valves

  For each valve:

  - Pipe number
  - Chainage (location)
  - Bypass size

  Dual plate check valve

  - Number of dual plate check valves

  For each valve:

- Pipe number
- Chainage (location)
- Bypass size

Intermediate non-return valve

- Number of intermediate non-return valves

For each valve:

- Pipe number
- Chainage (location)
- Bypass size
- Delay in closure

Air valves

- Number of air valves

For each valve:

- Pipe number
- Size
- Chainage (location)
- Pipe invert level

Air cushion valves

- Number of Air cushion valves

For each valve:

- Pipe number
- Size
- Chainage (location)
- Pipe invert level

Stand pipe

- Number of stand pipes

For each stand pipe:

- Pipe number
- Chainage (location)
- Diameter

- Pipe invert level
- Top level of stand pipe

Surge relief valve

- Number of locations of surge relief valves

For each location:

- Pipe number
- Chainage (location)
- Number of surge relief valves
- Size of valve
- Pipe invert level at the valve (normally near pump house)
- Low pressure pilot setting
- High pressure pilot setting
- Closure time

Valve with/without bypass outlet

- Pipe number at valve location
- Chainage of valve location
- Delay in start of valve closure
- Time of closure of valve
- Bypass outlet provided (Yes or No)

If Yes:

  - Bypass outlet discharge level
  - Size of bypass outlet
  - Delay in bypass valve opening
  - Time of opening
  - Duration of open position
  - Time of closure

The idea behind this protection option is as follows. When a gravity main flow is to be shutdown, first the bypass valve is opened, then the main line valve is closed (during which time the bypass valve will remain open), then the bypass valve is closed slowly (Fig. 15). This may control the surge without allowing undue drainage of water. Such a protection option may be useful for long length gravity mains. In other cases, a gradual closure of valve without bypass may be adequate. In this case, surge analysis is required only to fix the valve closure time.

Form: Output control

- Chainages for printing heads (pipe number and chainage)
- Pump number for plotting speed (time vs speed of rotation, following power failure or single pump failure can be plotted for any one chosen pump).
- Details of paths for plotting pressure
  - Number of paths (upto 6 paths are allowed for plotting surge pressure picture)

  For each path:
    - Number of pipes in the path
    - Pipe numbers in the path
- Pipe number, chainage and pipe invert level for plotting pressure drop rate (at 3 locations, pressure drop rate following power failure can be plotted)
- Simulation time specified (Yes or No); If Yes:
  - Simulation time after power failure or pump failure

With this, the main data entry is over. However, before execution, data of longitudinal alignment are to be given. For this, use the "view data" icon on the tool bar (or view option on the menu bar). Select the "alignment data" in the "view data" menu, which brings up the alignment data form.

Form: Alignment data

- Data of pipe number, chainage and elevation (pipe invert or centre line or ground level)

  (Either directly entered on the table or got from a file; if data is from a file, the last row should contain a $ to mark end of data and the file should have .ALN extension name. In a complex pipe network, alignment data may not be available for all pipes. In such a case, alignment data for some pipes may be omitted, provided such pipes are not in the plot paths. For all pipes in the plot paths, alignment data is a must).

This completes all the data. When a **new** project is created, before the **first execution**, the **save** option in the menu is to be used. This restriction does not apply for subsequent outputs in the project.

13. OUTPUT FILES AND GRAPHICAL PLOTS

The design of output modules is based on the following principles: a) The results presented should be so as to facilitate the design process for surge protection system. b) Results which are of an uncertain nature and do not directly help in the design process need not be documented. With regard to the design of surge protection system, the first principle above stresses the importance of graphical plots. The results are available in two text files. Besides, several files are prepared with a specific view to obtain results in a graphical form.

The basic output file is SAP2.RES and for opening the file, "view result" icon is provided on the tool bar. However, due to variations in operating system, this icon may not work and it is advised that SAP2.RES, which is available in C:\iisc folder, may be directly opened through Notepad or Microsoft Word. In this file, the system data is provided, along with summary of results relating to the pumps and minimum and maximum pizeometric heads at the locations specified by the user. Instead of the exact chainage, results are available at the nearest nodal chainage as per the discretisation of the pipe. The difference between these two chainages are very small and is not of significance. For Type B projects, there is a variation in the way data is input and how it is presented in the output file. In data input, the network connectivity is established through specification of upstream and downstream node numbers of pipes, and giving data of upstream and downstream pipes for each node. In the output file, the connectivity is presented through upstream and downstream node numbers of the pipes, along with pipe numbers of predecessor (upstream) and successor (downstream) pipes for each pipe.

In addition to the basic results, SAP2.RES provides specific results concerning the following details, where relevant: a) details at water column separation location b) details at an air vessel c) details at a one way surge tank d) details at a surge relief valve. In planning the details to be printed, their utility in design is kept in view. For example, for air vessel, the maximum expanded air volume in the air vessel, which is necessary for deciding the size of the air vessel, is made available. For one way surge tank, the extent of draining of the tank or in case of full draining, the time of draining are made available to decide the size of the tank. As the cost of a one way surge tank protection depends critically on the connecting pipe size, the maximum velocity through the connecting pipe is made available to facilitate the design of the pipe size. Similarly, in regard to surge relief valve, the output is intended to help in setting the low and high pressure pilots and the closure time, besides the choice of valve size. For a gravity main, the outflow at the reservoir end till valve closure is given, which indicates the extent of draining till valve closure. Example outputs for different cases are presented in Appendix.

The second output file in text form is TABLE.RES. In this file, a summary of results for minimum and maximum flows, minimum and maximum heads and associated times of occurrence is provided in a non-dimensional form. These results are intended for users interested in understanding the details of the surge process and some experience is required to use these results as a learning tool. The following explanation of TABLE.RES is provided, for which the results of TABLE.RES presented for Example 1 in the Appendix may be referred. In the table, the following notations are used:

NP - pipe number

IN – computational node number (local in the pipe)

HUMIN - non-dimensional minimum head just upstream of the node

TUMIN - non-dimensional time associated with HUMIN

HUMAX - non-dimensional maximum head just upstream of the node

TUMAX - non-dimensional time associated with HUMAX

HDMIN - non-dimensional minimum head just downstream of the node

TDMIN - non-dimensional time associated with HDMIN

HDMAX - non-dimensional maximum head just downstream of the node

TDMAX - non-dimensional time associated with HDMAX

VUMIN - non-dimensional minimum velocity just upstream of the node

TVUMN - non-dimensional time associated with VUMIN

VUMAX - non-dimensional maximum velocity just upstream of the node

TVUMX - non-dimensional time associated with VUMAX

VDMIN - non-dimensional minimum velocity just downstream of the node

TVDMN - non-dimensional time associated with VDMIN

VDMAX - non-dimensional maximum velocity just downstream of the node

TVDMX - non-dimensional time associated with VDMAX

The reference quantities for non-dimensionalisation are given in the table. The dimensional time is obtained by multiplying the non-dimensional times by the reference time. The dimensional velocity is obtained by multiplying the non-dimensional velocity by the reference velocity. The dimensional piezometric head is obtained by multiplying the non-dimensional head by the reference head and adding the value of datum.

In addition to the presentation of the results in the two files, SAP2.RES and TABLE.RES, more importantly, results can be obtained in graphical form which are very helpful in the design process. **For viewing the results in graphical form, "view graph" icon on the tool bar is provided. Again, as in the case of SAP2.RES. due to variations in operating system, this icon may or may not work. Hence the excel file SAP2.XLS, which is available in the folder C:\iisc, may be directly opened through Microsoft Excel. Once SAP2.XLS is opened, access to graphical plots is available as long as Excel application is not closed.** Once SAP2.XLS is opened, the graphical plots can be obtained by using different short-cut keys, as follows:

(1) ctrl + g: Plot of minimum and maximum piezometric heads along with longitudinal alignment of the pipe line for Path 1.

(2) ctrl + h: Plot of minimum and maximum piezometric heads along with longitudinal alignment of the pipe line for Path 2.

(3) ctrl + i: Plot of minimum and maximum piezometric heads along with longitudinal alignment of the pipe line for Path 3.

(4) ctrl + j: Plot of minimum and maximum piezometric heads along with longitudinal alignment of the pipe line for Path 4.

(5) ctrl + k: Plot of minimum and maximum piezometric heads along with longitudinal alignment of the pipe line for Path 5.

(6) ctrl + l: Plot of minimum and maximum piezometric heads along with longitudinal alignment of the pipe line for Path 6.

(7) ctrl + r: Plot of pressure with time at the three identified locations

(8) ctrl + s: Plot of pump speed with time for the specified pump

(9) ctrl + v: Plot of velocity through air vessel connecting pipe with time (for Type 2 air vessel, reverse flow velocity corresponds to velocity through the bypass pipe)

(10) ctrl + a: Plot of velocity through connecting pipe to first one way surge tank, with time

(11) ctrl + b: Plot of velocity through connecting pipe to second one way tank, with time

(12) ctrl + c: Plot of velocity through connecting pipe to third one way tank, with time

(13) ctrl + d: Plot of velocity through connecting pipe to fourth one way tank, with time

The scales and titles of the plots are automatically set in the software itself, but the user can modify these as per his requirements based on options available under Excel chart option. In particular, he may edit the title to describe the case completely before saving or printing the graph. Similarly, for pressure drop rate plots, he may enlarge a small part to highlight the rate of pressure reduction in the first cycle of down surge.

Examples of different types of plots are presented in the Appendix.

14. CHECK LIST FOR TROUBLE FREE USAGE

1) The software will be loaded in the directory C: \ iisc and the result files (text files) and the result file for plots will all be available in this directory only. The file SAP2.XLS for preparing plots is also available in this directory.
2) When a **new** project is created, before the **first execution**, use the **save** option in the menu. This restriction does not apply for subsequent outputs in the project.
3) Ensure that all the data are entered, before execution. If a screen has OK command, it must be clicked before going to the next screen.
4) For Type B project, ensure consistency of data for network connectivity and discharge continuity. **Preparing a schematic diagram of the model such as in Fig. 10 will be beneficial in this regard.**
5) For all data, attention is required to ensure that the dimensional values are as per specified dimensions. For example, discharge is in m^3/sec and pipe diameter is in mm (these are indicated on the relevant data entry screens). The software does not provide for different options for dimensions.
6) The alignment data may be directly entered on the data entry form or can be imported from a file. The file option is preferable from convenience point of view. When the file option is used, the file name should have extension .ALN. The project name abbreviation followed by .ALN may be used. The .ALN file should terminate with a $ in the last row. **It is suggested that the alignment data may be first prepared in 3 column Excel file with pipe number, chainage and elevation. Using Notepad and copy and paste, the data is converted to text format. The $ may be added in the last row. The file may be saved with .ALN extension.**
7) Where pump characteristics are available, the data may be directly entered on the data entry form or can be imported from a file. Here also,

the file option is preferable from convenience point of view. When the file option is used, the file name should have extension .PMP. The project name abbreviation with pump node number followed by .PMP may be used. The .PMP file should terminate with a $ in the last row.

8) Before trying a new execution, close the text files SAP2.RES and TABLE.RES (if open) and also close any graphical plots that may be open. The Excel application itself (SAP2.XLS) need not be closed.
9) In a sequence of analyses for different cases, first open the SAP2.XLS once and keep it open. As long as the EXCEL application is not closed, the graphical plots can be obtained for different analyses, by using the short cut keys mentioned in Section 13.
10) In the data input, location in terms of chainage is required for the following options: a) water column separation b) one way surge tank c) Zero velocity valve d) Dual plate check valve e) Intermediate non-return valve f) air valve g) Air cushion valve h) stand pipe and i) surge relief valve. In the analysis model, a particular node as per discretisation can consider only one type of boundary condition. Hence, the same chainage should not be specified for two types of options given above. The software gives a warning of such a clash in the output file (SAP2.RES), for the user to modify the data and re-execute. The warning message may be used for relocation of relevant chainages.
11) If, on opening the results file after execution, an empty file is found, execute the program SAPF2.EXE in DOS mode, by using the command SAPF2. Any insufficiency in data will be indicated by an error message.
12) In some cases, after execution, the results file SAP2.RES may contain only the data part, without results. In such cases, if in DOS mode, SAPF2 is executed (as in item 10), math error (ex: floating divide check) may be indicated in execution. The most likely cause of such error will be in the data, mostly incomplete data or some unrealistic data entry. In particular, ensure chainages and invert levels, where required are correct. The staging height and storage height of one way surge tank

should be such that the water level (ground level + staging height + storage height) should be clearly lower than the hydraulic grade line level at the location of one way surge tank. For a stand pipe, the height of top of the stand pipe (in RL) should be at least 1 or 2m above the hydraulic grade line elevation at the stand pipe location.

13) Where the pressure drop rate plot is stored for future reference, in the Excel plot (for macro ctrl + r), the labels Location 1 etc. may be replaced by the actual chainages as given in the input data screen. Similarly, where the surge pressure plots are saved for future reference, the title of the figure may be edited to give a complete description of the analysis case.

14) In case where multiple number of the same device (ex: three one way surge tanks) occur, it is a good practice to give the data in ascending order of chainage. Similarly, for plots of pressure drop rate, the three chainages may be preferably in ascending order of chainage. The chainages for printing minimum and maximum piezometric heads are sorted in ascending order in the software itself.

15) Any non-trivial software requires some familiarisation before it can be used without troubles. A convenient way to achieve such a familiarisation is to execute the example problems in the Appendix and compare the results with the results in the Appendix.

15. GUIDELINES ON MODELING

1) As stated earlier, use only Type B Project option, that is avoid Type A project option for analysis.

2) The alignment data may be first prepared in Excel file and then transported to a text file through Notepad or Word, as it always facilities easy editing subsequently in case of any change.

3) Even though, multiple parallel pumps may be modelled by lumping them and in the Pump Details form, the number of pumps may be indicated, it is clearly preferable to model each pump separately, by providing one node for each pump. The software allows upto 5 pumps in parallel operation and if the

number of parallel pumps are more than 5, then model 4 pumps separately and lump the remaining pumps under 5^{th} pump node. In such a case, the corresponding pipe size must be made √Nxd, where N is the number of pumps lumped and d is the diameter of individual pump delivery pipe. Similarly for the lumped pipe, the thickness in Wave velocity and trip code form should be made √Nxt, where t is the thickness of individual pump delivery pipe.

4) The manifold or header from multiple parallel pumps may be represented by "combining junction" and the HGL elevation at this node is given by (sump water level + pump head – head loss in pump house).

5) Usually, at the time of surge analysis, the length of delivery pipe from individual pump upto the manifold (header) may not be available. For this data, based on pipe size, approximate length between 5 m and 20 m may be provided.

6) The following suggestions are made for modelling the pump house non-return valve: i) For swing check valves of size 350 mm and less, Code 1 type valve may be chosen with 0/0.5/1 sec delay. The analysis with delay 0.5/1 sec are useful for estimating local surge pressure in the pump house, while the analysis with delay 0 may be used for the design of surge protection system. ii) For swing check valves of size 400 mm and more, Code 2 type valve may be used with closure time of 0.5 sec and delay of 0/0.5 sec; the case with delay is useful for estimating local surge pressure in the pump house. iii) For non-return valves with counter weight and dash pot arrangement, Code 3 type valve may be used with delay 0 and time for 90% and balance 10% closure as per data obtained from valve vendor. This option may also be used for internally damped swing check valve. iv) For butterfly valve which is programmed to close in specified time of closure on pump trip, Code 4 type valve may be used, with closure time as specified. If the valve is electrically actuated and will stay open on power failure, Code 1 type valve with delay of 10000 sec may be used to indicate no closure. It is to be noted that such large delay data may be given only for Code 1 type valve. If such large delay is given for Code 2 or Code 3 type valve, the computational time would be very large, as the simulation time

is decided based on delay also for Code 2 and Code 3 valves. v) For hydraulically operated pump discharge valve (HOPDV), Code 5 type valve may be used with 90% and balance 10% closure time as per design. vi) For dual plate check valve, Code 6 type valve may be used. The surge protection design may be done with Code 6 valve. However, for estimating the local surge pressure in the pump house, depending on the size of the valve, Code 1 or Code 2 with delayed closure must be used as sensitivity study for dual plate check valve.

7) In some cases, there may be a model node which is at once both combining and dividing junction. An example is manifold from multiple parallel pumps feeding water in two parallel transmission mains. SAP2R does not have provision to give such hybrid node type. In such a case, make the node "combining junction" and provide a small length of pipe (say 10 m long) with pipe size as $\sqrt{2}$xD, where D is the diameter of the twin parallel transmission mains. Again for this small length pipe, the thickness should be $\sqrt{2}$xt, where t is the thickness of the transmission main. At the end of this small pipe, a "dividing junction" node may be specified.

8) In a cooling water system, the condenser may be modelled as an equivalent pipe, instead of using the "condenser" type node option. The condenser may be modelled as an equivalent pipe with the diameter equal to $\sqrt{N}$ times the diameter (ID) of the condenser tubes (where N is the number of tubes), with length equal to the individual tube length and discharge equal to the total discharge through the condenser. The wall thickness of the equivalent pipe should also be specified as $\sqrt{N}$ times the wall thickness of the individual tubes to provide correct D/t value, so that the pressure wave velocity of the equivalent pipe will be the same as for the individual tubes. When the condenser is modelled as a pipe, interpretation of sub-atmospheric pressure may be made conservatively based on the condenser top elevation.

9) If it is found convenient or necessary, any two parallel pipes of same size and type may be modelled as a single pipe with diameter equal to $\sqrt{2}$xD and thickness equal to $\sqrt{2}$xt.

10) The surge due to closure of valve at any intermediate location in the pipeline may be modelled by using the “protection” option of “valve with/without bypass outlet”. The option without bypass outlet may be chosen and the valve closure time may be specified (delay in valve closure may be made 0).

11) In a system where the available pump head exceeds the required head by a significant margin, the system may be operated with throttling of valves at the upstream end near the pump house. Such a case may be modelled by simply giving the value of HGL at the “combining junction” (manifold/header) after including the additional loss due to valve throttling in pump house loss.

12) The option of column separation at two locations is provided mainly to deal with two identical parallel inlet/outlet pipes at the condenser in a cooling water system. There is a possibility of vapour pressure occurrence at the start of twin outlet pipes and this option may be used to indicate column separation in both the twin pipes.

13) In modelling situations for the case of no surge protection or protection based on upsurge control devices only (ex: Zero velocity valve, surge relief valve), extensive occurrence of vapour pressure may be indicted. In such case, the following conservative modelling approach is recommended. First, analysis may be done with “NO” for column separation. The minimum head profile from this analysis may be used to assess the severity of down surge. Then, a number of repeated analysis may be made with column separation considered at one location in each analysis. In these cases, the minimum head profile has no relevance and may be deleted from the plot. The locus of maximum of the maximum head profiles from these multiple analyses (with water column separation considered at one location in each analysis) may be used to assess the severity of upsurge. The maximum pressure obtained form this approach will generally provide conservative estimate of maximum pressure. **When zero velocity valves or surge anticipating vales are used as protection option, this approach must be adopted for estimating the maximum pressure**

ignoring the vacuum breaker function of the air valves and Air cushion valves.

14) SAP2R requires that the steady state flow direction in all the pipes is known. There is one special situation where the steady state flow direction is ambiguous, but still the software can be used with slight adaptation in modelling. This concerns two parallel transmission mains, with an inter-link provision. When analysis is required with inter-link in open position, the flow direction in the inter-link pipe is not clear. In fact, ideally, there will be no flow through the inter-link pipe, for symmetric parallel pipe line system. The model can not handle a pipe with zero steady state discharge. This difficulty can be got over, by assuming a small flow through the inter-link pipe (say, 1 or 2 lps), and adjusting the discharges in the two parallel systems by this small quantity to keep the balance of continuity. The HGL elevations on either ends of the link pipe is estimated based on the loss coefficient of the link pipe. The two values of HGL on either ends of the link pipe will differ by a very small magnitude and this should be given in the data correctly.

15) The situation of shutdown of flow in a gravity main with closure of valve at the delivery end may be modelled either through consideration of closure of valve at the delivery reservoir (in data entry form titled wave velocity and trip code), or choosing valve with/without bypass outlet option in the protection device (in the data entry form titled protection devices). In the latter case, there is the option of providing a bypass to the delivery reservoir. In this case, the bypass outlet discharge level must be made the same as the delivery reservoir water level.

16. EXAMPLES OF APPLICATION

Appendix presents 8 examples of application. These examples are provided to assist in getting familiar with the use of the software. In each case, only select results are presented, for illustration. An interpretation of the results presented in these examples is beyond the scope of the User Manual. However, in interpreting the profile of minimum head, the points mentioned in section 17.1 may be kept in view. While the presentation of the examples is such that it is generally self explanatory, some supplementary details necessary to ensure clarity are presented below.

For each example, the names of the reference file which provides the consolidated data are provided. If these files are loaded in the directory C:\iisc (or any other directory), they can be opened from SAP2R and all the data gets loaded automatically. In addition, the alignment and pump characteristics files (the latter where relevant), are also provided, in case the user desires to create the project file for the example afresh. However, it must be noted that "ex*.sap" file has to be referred through the data entry forms, for the details of the pipes regarding pipe material and wall thickness, as the output file SAP2.RES gives only the pressure wave velocity as calculated using the data regarding pipe material and wall thickness. Some specific details with regard to individual examples are now presented.

The reference figure for Example 1, with two delivery reservoirs, is given in Fig. 10b. The figure gives the node and pipe numbers as per which data is provided. The plot for minimum and maximum piezometric heads are presented for two paths (using ctrl+g and ctrl+h short cut keys) corresponding to the paths 1-3-4 and 1-3-5 (Fig. 10b).

Example 2 deals with the case of air vessel protection for single pump failure condition with a view to estimate local surge pressure in the pump house. For one pump, the trip code is 1 (failing pump) while for the other two pumps, the trip code is 0 (running pump).

Example 3 presents surge analysis for a condenser cooling water system. A schematic diagram of the cooling water system is shown in Fig. 4b and the corresponding model diagram is shown in Fig. 17. In the model, the two identical parallel pipes for condenser inlet pipes and condenser outlet pipes are modelled as a single pipe with the diameter being $\sqrt{2}$ times the individual pipe diameter. While modelling parallel pipes as a single pipe, where the pipe wall thickness is given as data for the calculation of pressure wave velocity, the data should be adjusted so as to maintain the D/t value as for the original pipe (vide item 1 in section 15). In Example 3 the condenser is modelled as an equivalent pipe as described in item 4 of Section 15. In the example, It is found desirable to give data of pressure wave velocity directly for pipes 3, 4, 5, 6 and 9 (Fig. 17). Pipes 3 and 6 are steel lined concrete ducts for which the pressure wave velocity is to be calculated as applicable for a thick walled pipe. Pipes 4 and 5 are condenser inlet and outlet pipes with some variations in wall thickness and it is decided to provide a calculated mean value for the pressure wave velocity. Such an option can be exercised by choosing GRP pipe for the pipe material, which prompts the direct input of pressure wave velocity. This is only a ruse to exercise the option of providing data for pressure wave velocity directly, instead of providing data for pipe material and wall thickness (Section 12.2).

Example 4 is a project with an on-line booster. While this example is presented to illustrate the applicability for an on-line booster case, the interpretation of results and the design of the surge protection system for a project with a major on-line booster station as in Example 4, has to be done under expert supervision. Fig. 18 presents the schematic diagram for Example 4.

Example 5 is a case with two one way surge tanks as surge protection system. There are two working pumps. Example 5 is case illustrating the difference between SAP2 and SAP2R. If this example is run with SAP2, spurious oscillations in minimum head profile and maximum head profile will be indicated, as shunting of non-return valve on one way surge tank connecting pipe (for fraction of a second), from close to open position, is not prevented in SAP2.

Example 6 is a case where air vessel is used as surge protection system, along with an intermediate non-return valve for upsurge control. There are four working pumps in parallel. The output file gives the maximum expanded air volume, which is required for deciding the capacity of the air vessel.

Examples 7 and 8 represent applications for a gravity main. Fig. 6 presents the schematic diagram of a gravity main. The project considered is a very long length transmission main of 200 km length. In the example presented, there is a change in pipe diameter after 178.5 km. Example 7 presents the results of analysis for the case of closure of valve at the downstream end in a time of 900 sec. The output file also provides results for the total outflow at the reservoir till completion of the valve closure. This indicates the extent of draining of the pipe. Example 8 presents a case where a valve at 2 km from the source reservoir is throttled to provide a local head loss of 16.45 m (from a HGL elevation of RL 95.95 m to RL 79.50 m). This is modelled by providing an obstruction node at 2 km. This breaks the 1875 mm pipe reach into two pipes, of length 2 km upto the obstruction node and 176.5 km downstream of it.

17. LIMITATIONS OF ANALYSIS

Like in any theoretical analysis, the results of the analysis should be interpreted with an understanding of the limitations of the analysis. The principal limitations of the analysis are related to the occurrence of sub-atmospheric pressure and vapour pressure in the system. There will be several practical cases for which surge analysis without protection may indicate extensive occurrence of vapour pressure (approximately - 9 m) over the length of the transmission main. In such situations, there is no well established method of analysis and different software may handle the situation differently. If air valves are used to control the occurrence of such extensive sub-atmospheric pressures, an uncertainty is introduced in the method of analysis. These aspects are discussed in this section.

17.1 Minimum pressure results

When the profile of minimum piezometric head goes below vapour pressure limit at multiple locations along the alignment, different software use different approaches in presenting the associated results. Two common approaches are used: a) The minimum pressure will be limited to -10 m in the surge pressure plot, wherever analysis indicates a lower value. b) The minimum pressure profile will be plotted without placing any lower limit. In the latter case, spurious minimum pressures with negative values in excess of -10 m will be indicated. While the first approach appears theoretically more correct, the second approach has some practical advantages and hence, it is adopted in the present software.

When computations are done without placing any lower limit on minimum pressure (that is, analysis without consideration of water column separation effect), the magnitude of the "spurious" negative pressure values gives a very good indication of the severity of the down surge problem, the likely impact of water column separation, and an indication of the type of protection system required. When the minimum pressure profile is limited to - 10 m in the pressure plot, the indications with regard to above aspects are relatively less effective.

Hence, in the present software, when minimum piezometric head profile shows minimum pressures lower than - 10 m, the results are to be treated as of qualitative value. However, these qualitative results play an important role in taking further decisions regarding the required surge protection system.

17.2 Effect of water column separation

When occurrence of vapour pressure is indicated, analysis may be done considering the effect of water column separation at the location. However, the problem is that such analysis is reliable if the occurrence of vapour pressure is limited to one or two locations. In practice, particularly for cases without surge protection or with only upsurge control devices (Zero velocity valve or surge relief valve), extensive occurrence of vapour pressure may be indicated. In such cases, there are no well established analysis procedures and different software may handle the situation differently. In any case, in such situations, the results of analysis should be treated as approximate and interpreted with caution.

In the present software, water column separation effect can be considered at one or two locations in each analysis. At this location, the pressure control with lower limit at vapour pressure is imposed, but at other locations, there is no such control. By repeating the analysis for several cases, considering water column separation effect at different locations in each case, an approximate picture of the maximum pressure profile along the alignment can be obtained. A conservative modelling approach to deal with this situation is indicated in Section 15, item (13).

17.3 Effect of air valves and Air cushion valves

Another situation where uncertainties are introduced in the analysis is in the use of air valves (and Air cushion valves) as vacuum breaker. When air valves are used as vacuum breaker at locations where severe sub-atmospheric pressure is expected, some air is let into the system through the air valve. The important aspects which govern this process are: a) time lag in the vacuum breaker function of the air valve b) air inlet capacity of the air valve, c) air exhaust characteristics of the air valve and d) the movement of air along the pipe. Among these factors, analysis procedures focus particular attention on (b) and (c), while items (a) and (d) introduce maximum uncertainty. Besides, related to (d), two phase flow effects pose another problem. In view of these reasons, analysis where air valve and Air cushion valve effect as vacuum breaker is used, should be treated as approximate. The present software does not consider two phase flow effects.

More than relative merits of different modelling techniques, the evaluation of reliability of air valve function based on pressure drop rate picture (in the absence of air valve) is a crucial factor. It is specifically for this reason, option for plotting pressure variation rate at three specified locations (through ctrl+ r short cut key) is provided. These locations may be chosen as proposed air valve locations. If pressure drops from sub-atmospheric pressure to vapour pressure in less than 1 sec (in the absence of air valve), the air valve function as vacuum breaker will be uncertain. If the drop in pressure from sub-atmospheric pressure to vapour pressure takes a few seconds (3 seconds or more), air valve function as vacuum breaker may be considered reliable.

Surge protection design relying exclusively on air valves/Air cushion valves for down surge control should be done with great care, taking pipe strength to withstand buckling and collapse into account. Such design should preferably be done under expert advice.

17.4 Effect of data uncertainties

So far, the discussion in this section is in relation to uncertainties resulting from the method of analysis. There may also be uncertainties related to data.

One of the principal reasons for such uncertainties is the non-availability of actual pump data, as the order for pumping machinery may not have been finalised. In particular, the actual pump characteristics and GD^2 values of pump and motor may not be available. The software allows for the option of using standard pump characteristics (of chosen type), if actual pump characteristics are not available (vide Section 12). Generally, the surge picture is not very sensitive to some variations in the non-dimensional form of pump characteristics. Anyhow, the effect of this uncertainty can be studied by repeating the analysis for an alternate choice of standard pump characteristics. Regarding GD^2 value, when data is not available, an empirical relation in terms of motor power and speed, embedded in the software, is used for the estimation of GD^2 value.

Another source of data uncertainty is in regard to head loss characteristics of non-return valve at different openings and coefficient of discharge value for air valves/Air cushion valves. For non-return valves, the software uses data base using standard curves for loss coefficients (Miller, D.S., Internal Flow Systems, BHRA Fluid Engineering Series, 1978). In any case, availability of reliable data for non-return valve loss coefficients at various openings, particularly under dynamic conditions, is uncommon. The uncertainty due to this aspect is unlikely to be a significant factor.

The coefficient of discharge of air valves and Air cushion valves is also built into the software. In analysis with air valves, there are larger uncertainties due to reasons other than discharge characteristics of air valves, as discussed in Section 17.3.

Sensitivity studies may be made to consider the effect of any other uncertainty in data (ex: closure time of non-return valve).

18. LIMITATIONS OF SOFTWARE

The limitations discussed in Section 17 pertain to limitations arising from method of analysis and uncertainties in data. Besides this, there are limitations which essentially arise from restrictions imposed in the scope of the software. The principal limitations of SAP2R with regard to scope, are: (a) The software requires that the steady state flow direction in each pipe is known. (b) It is not applicable for looped networks such as street level pipes in an urban water supply network. The software can be used in loops formed of parallel pipe lines, such as in Fig. 4, where the steady state flow direction is known. (c) The scope of the software is limited to flow shutdown such as power failure, one or more pumps failure and closure of the delivery end valve in a gravity main. The scope does not cover start-up surge, whether in a pumping main or in a gravity main. However, in most cases, the most critical surge pressures are associated with the shutdown conditions, principally power failure for pumping mains. It is only in an exceptional situation where the start-up surge may be more critical.

There is one special situation where the steady state flow direction is ambiguous, but still the software can be used with slight adaptation in modelling. This concerns two parallel transmission mains, with an inter-link provision. The technique for dealing with this situation is outlined in item (14) in Section 15.

With regard to size limitation, the following points may be kept in view: i) Upto 80 number of pipes and 80 number of nodes are allowed; ii) For each pipe, upto 800 data points are allowed in the alignment data file; iii) Upto 5 number of pumps and 5 number of booster pumps are allowed for parallel operation. If the number of pumps are more, pumps more than 4 number may be modelled by lumping, as indicated in Section 15, item (3); iv) Air vessel is allowed only at one location, while for other protection devices, sufficiently large number is allowed such that it is most unlikely to pose any restriction from practical angle. For example, for one way surge tanks, upto 10 tanks is allowed, which is too many as more than 2 or 3 tanks is never likely to be used.

19. CONCLUSION

This manual provides guidance for the use of the revised second version SAP2R, for surge analysis in pumping mains and gravity mains. The manual covers the following aspects: a) background to the software, including governing principles used in the software design b) brief description of the surge phenomenon c) brief description of the principles of surge control and surge protection devices d) brief description of the method of analysis e) details of the scope of the software covering all the options available f) guidelines for data input g) options of output files and graphical plots h) check list for trouble free usage i) guidelines on modelling techniques j) examples of applications k) limitations of analysis and l) limitations of the software. This is essentially a user manual, intended to help the user in completing the surge analysis for the case chosen for analysis. This should be distinguished from a manual on design guidelines, though several ideas discussed in the manual may be helpful in the design.

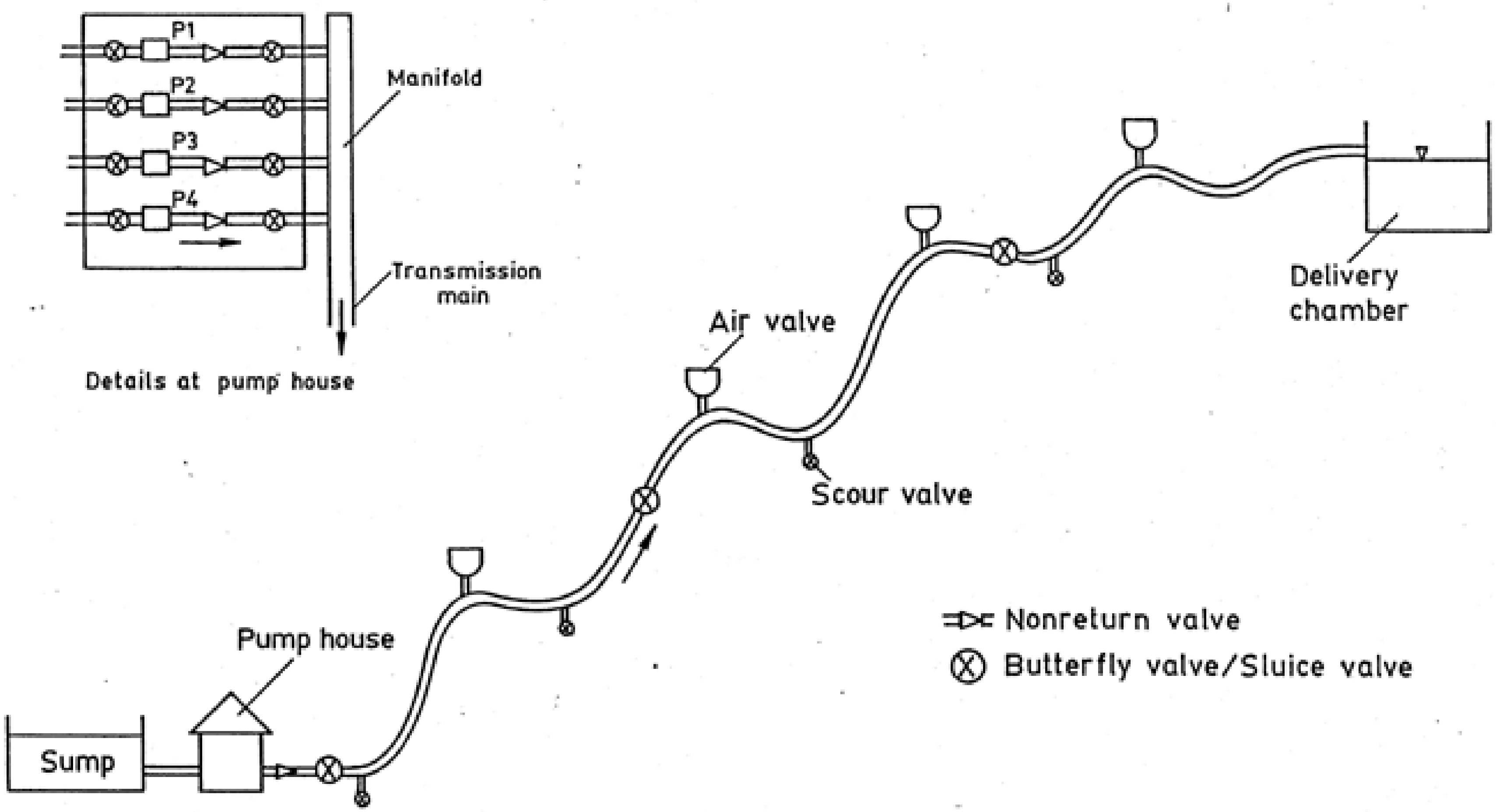


Fig.1: Schematic Diagram of a Cross Country Pumping Main

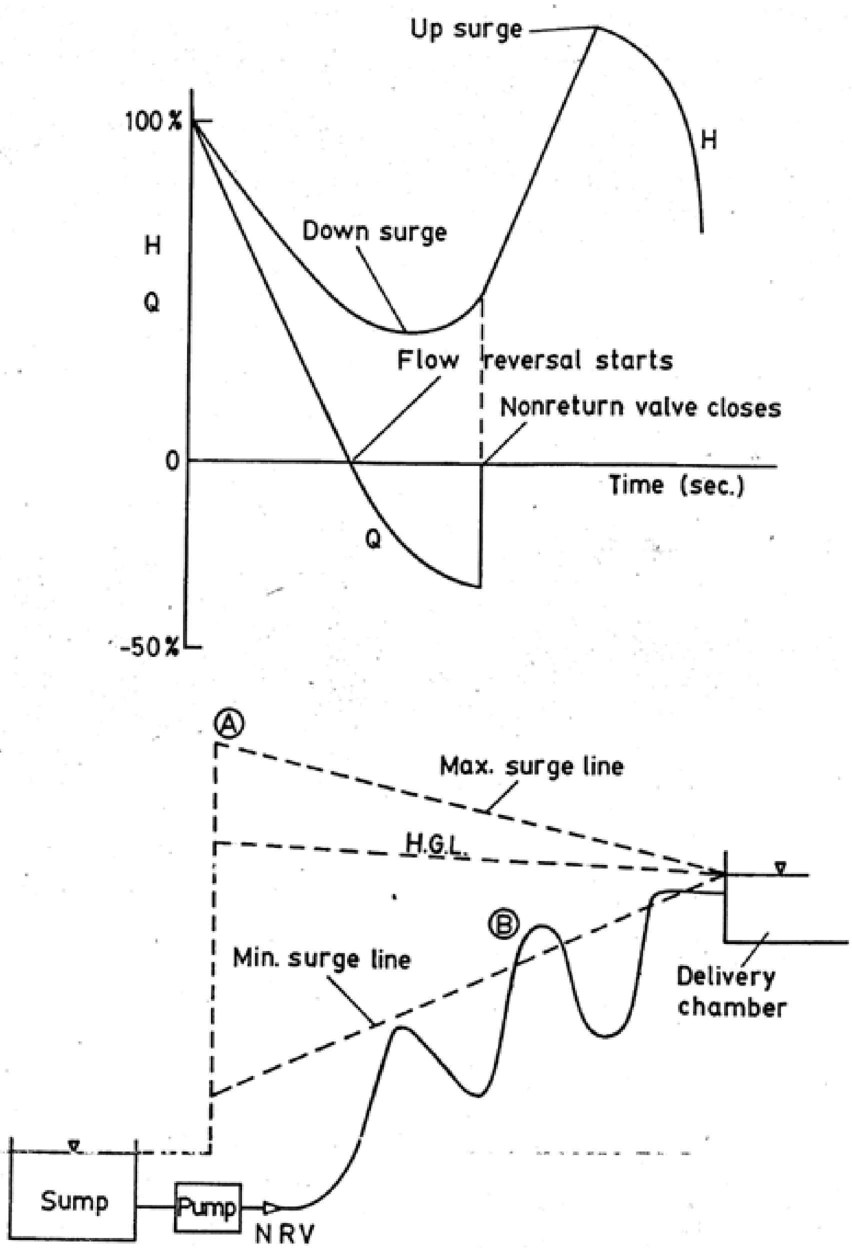


Fig.2: Surges in a Pumping Main Following Power Failure

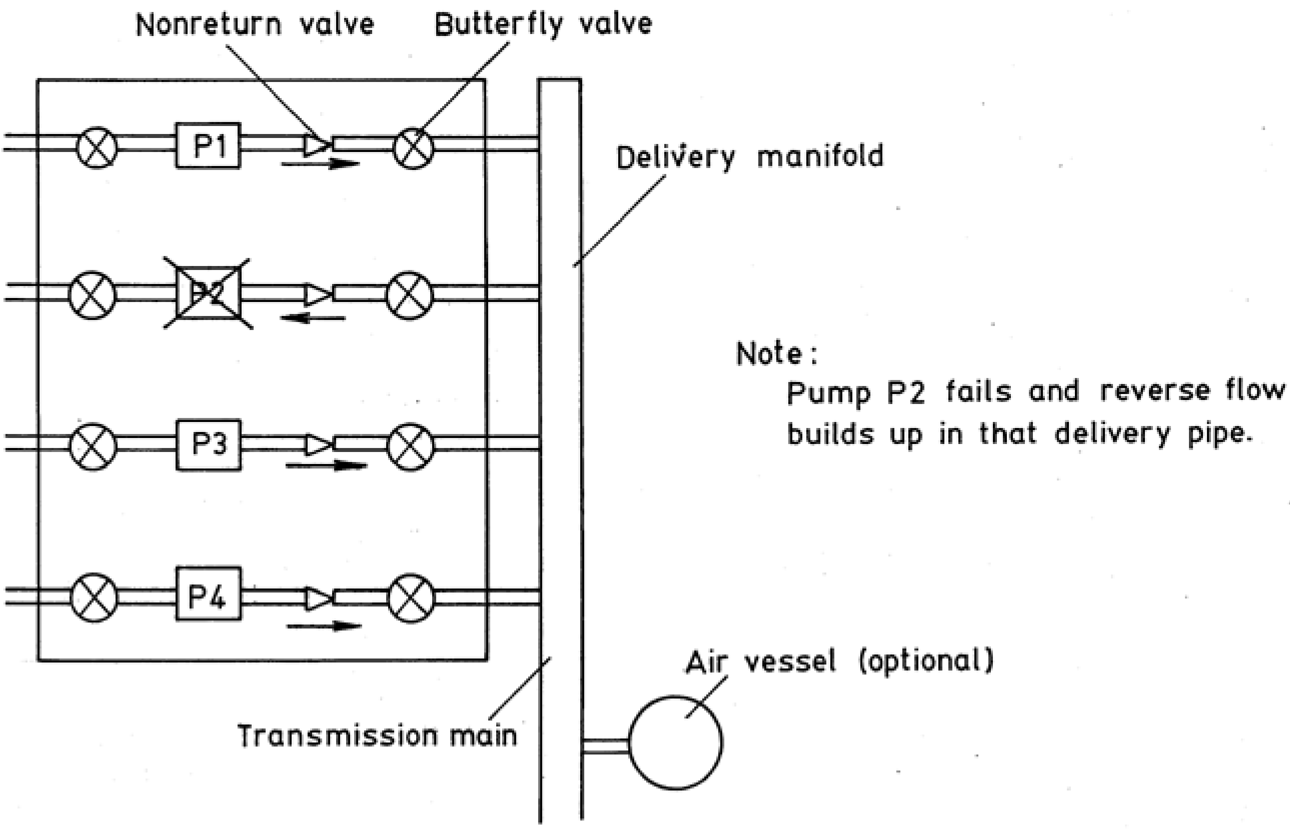


Fig.3: Schematic Diagram of Single Pump Failure

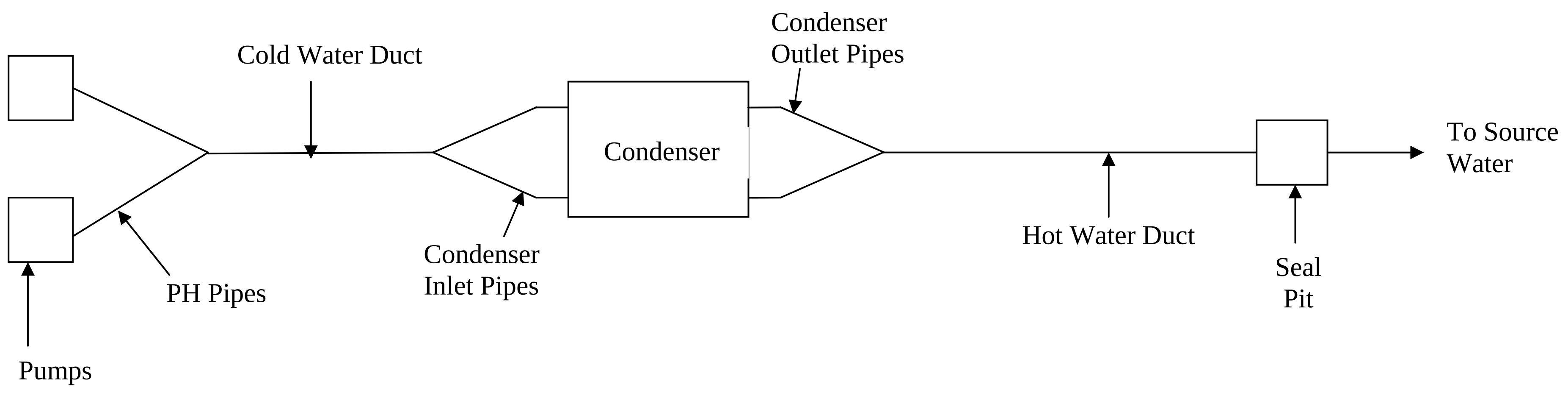


Fig. 4a: Schematic Diagram of Cooling Water System

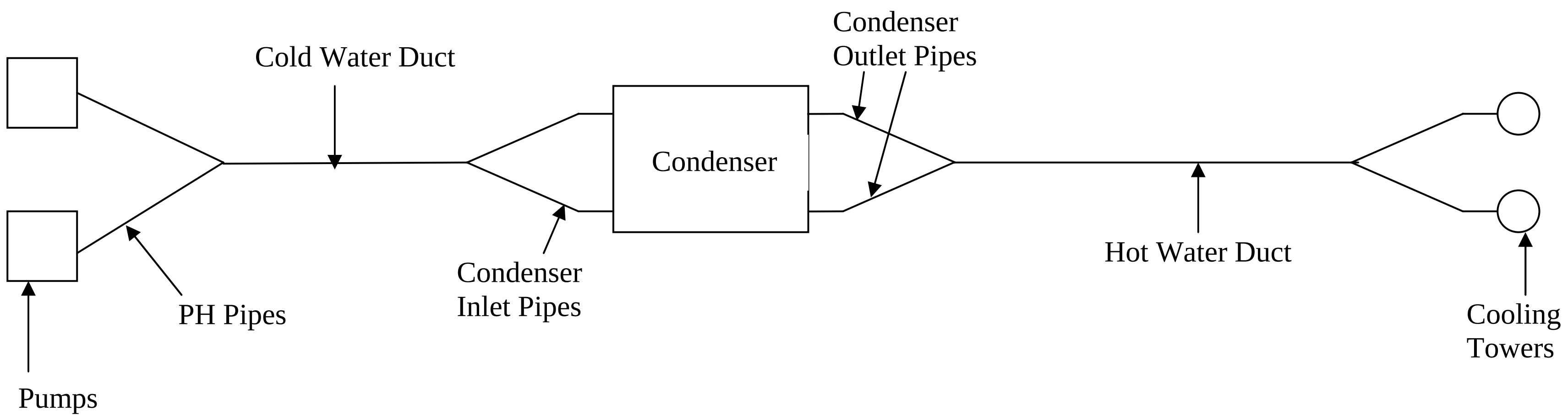


Fig. 4b: Schematic Diagram of Cooling Water System with Cooling Tower

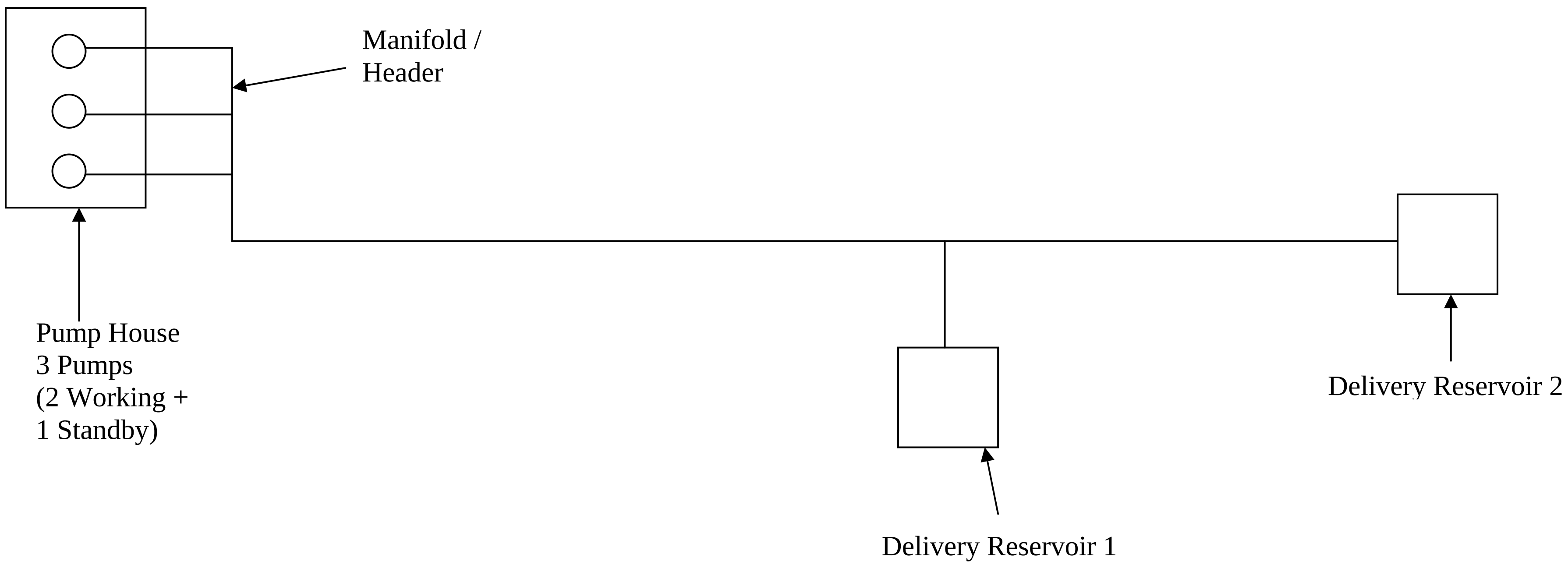


Fig. 5: Schematic Diagram of Pumping Main with Multiple Delivery Reservoirs

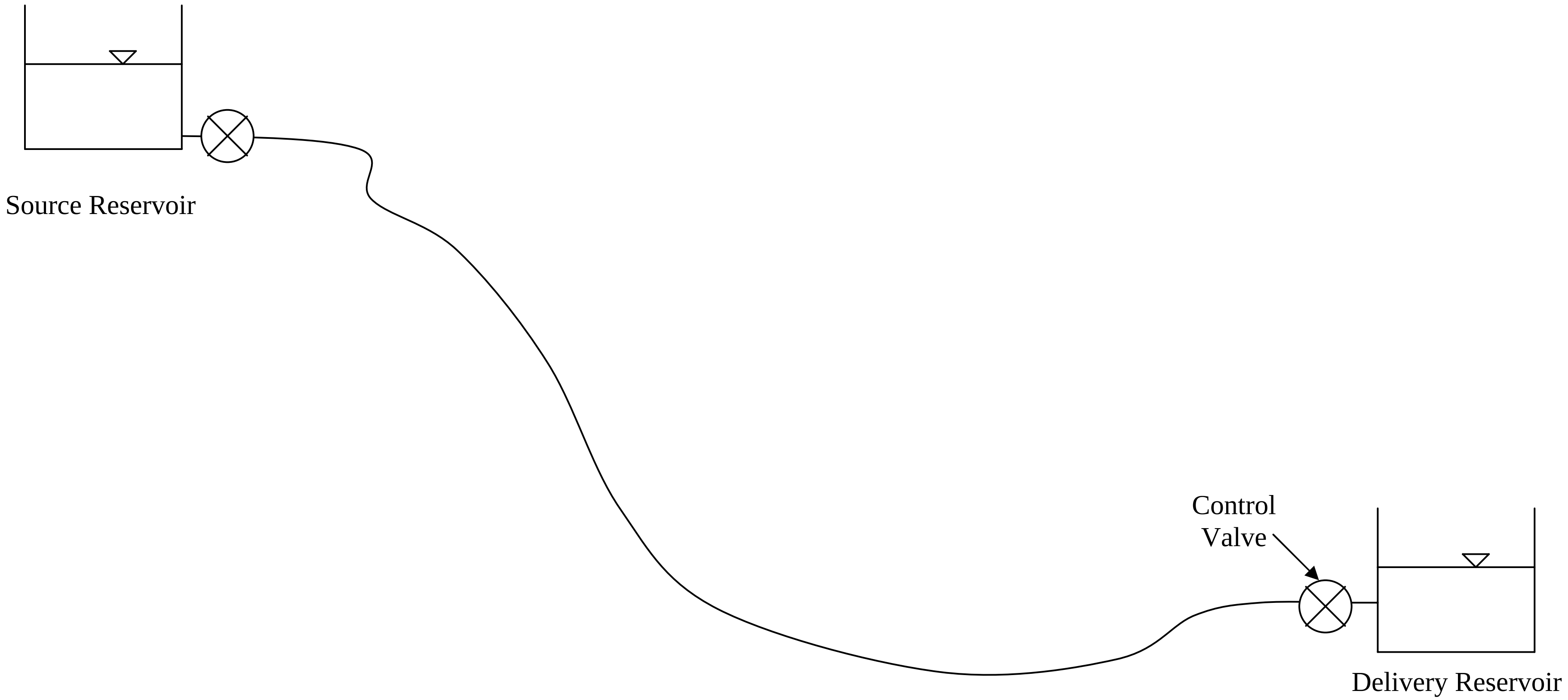


Fig. 6: Schematic Diagram of Gravity Main

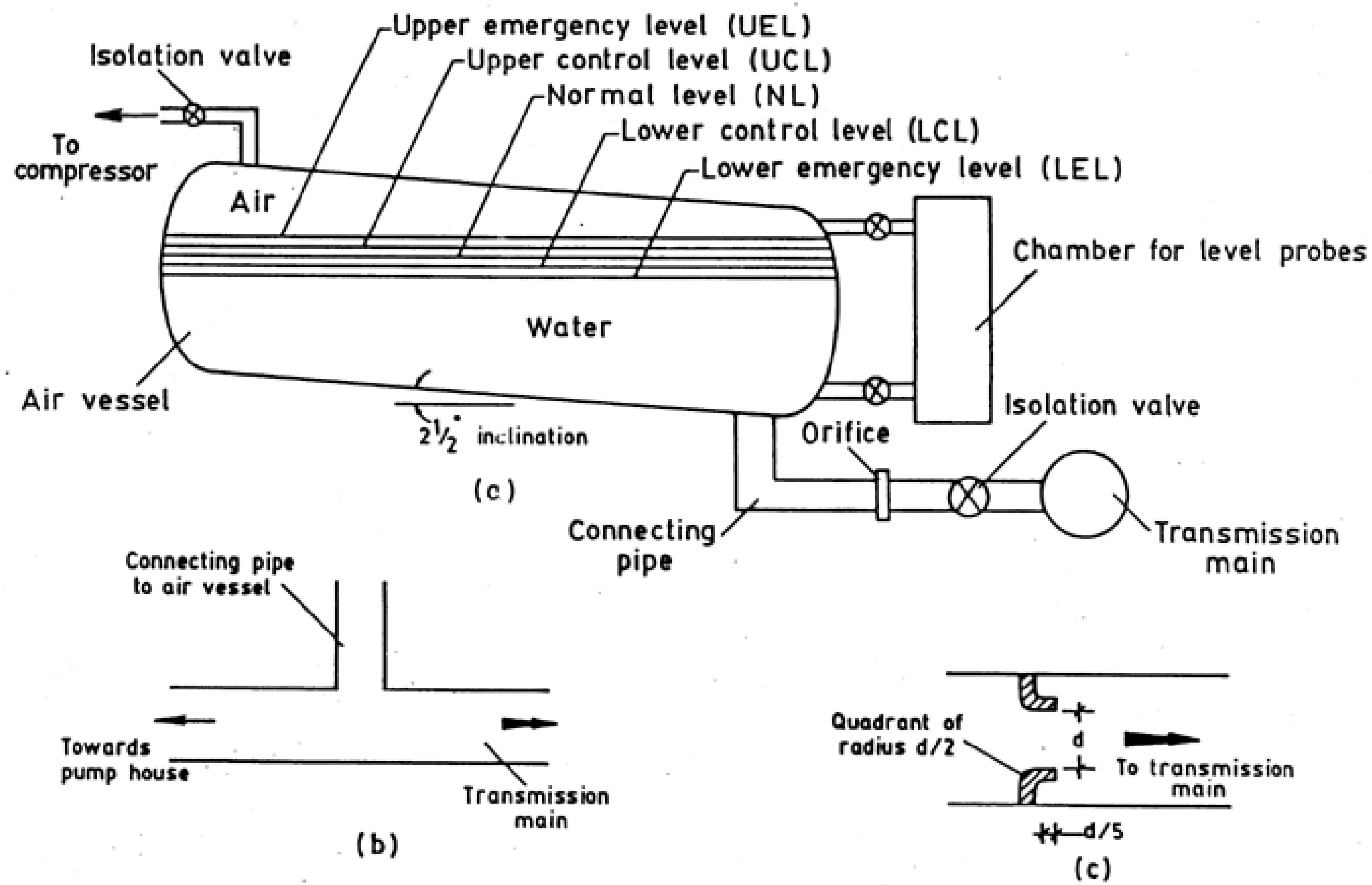
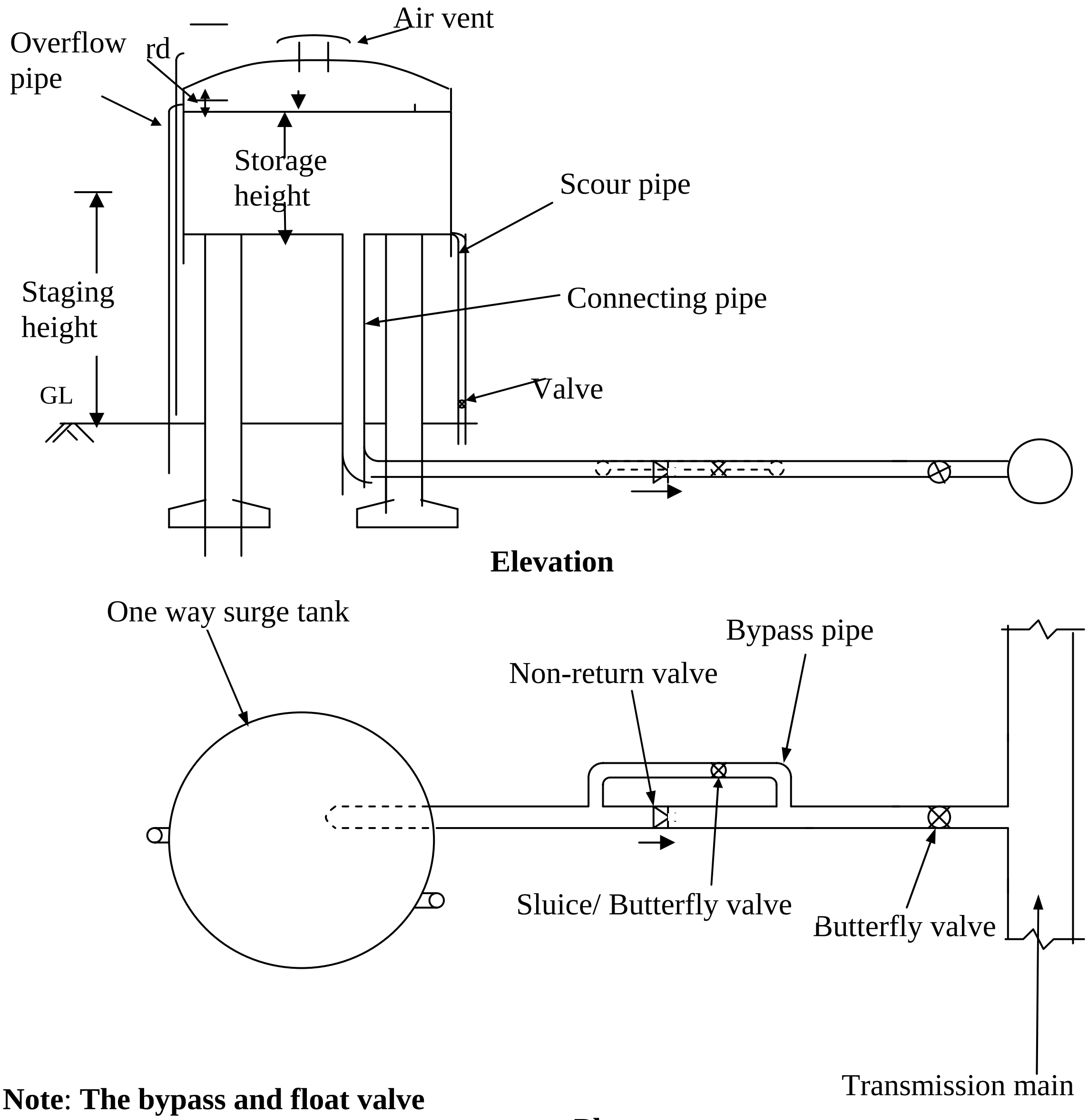
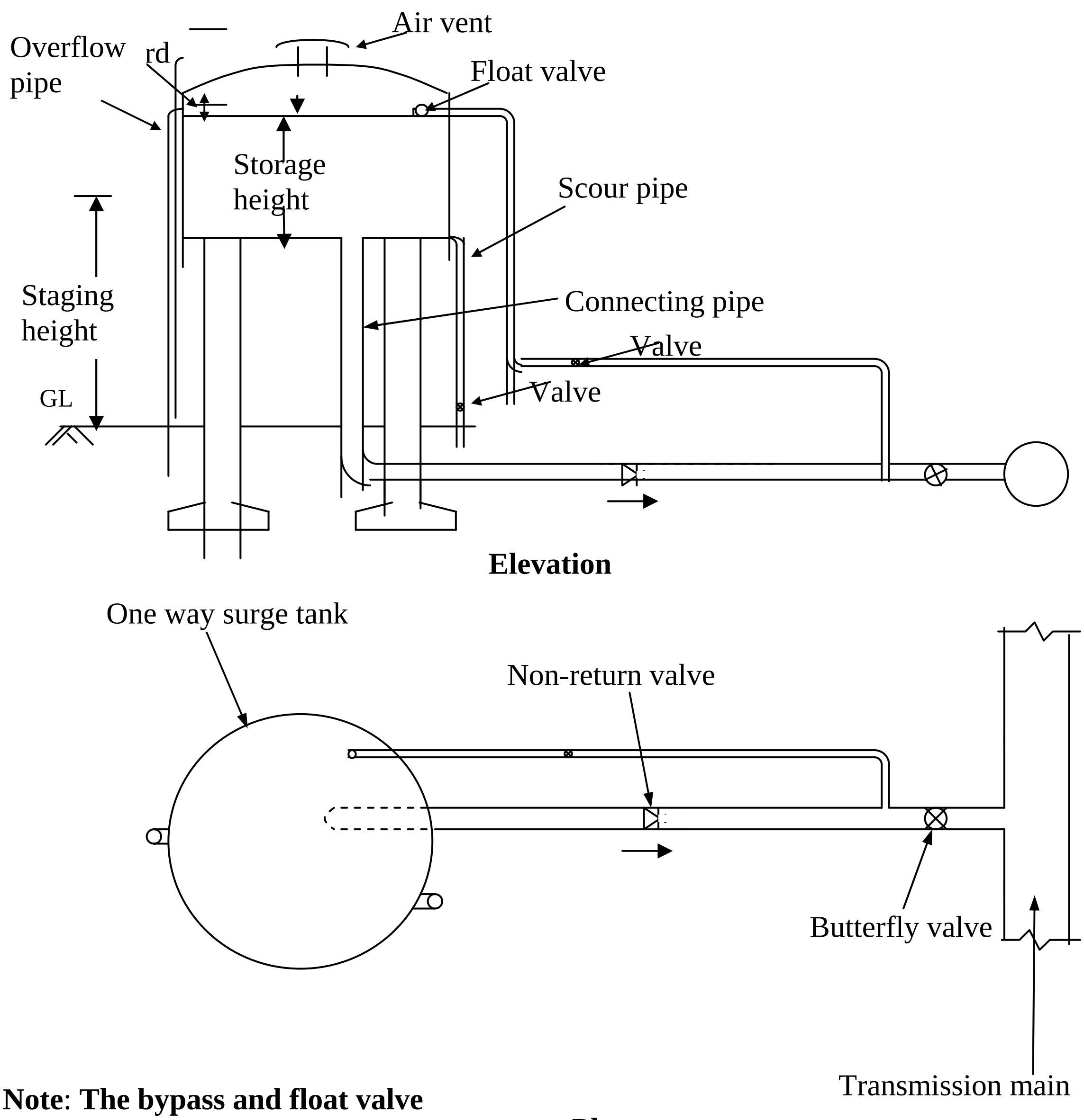


Fig. 7: Schematic Diagram of Air Vessel Installation



Note: **The bypass and float valve pipe lines are shown with lateral displacement for clarity**

Fig. 8: Schematic Diagram of Elevated One Way Surge Tank with Bypass Filling Arrangement



Note: **The bypass and float valve pipe lines are shown with lateral displacement for clarity**

Plan

Fig. 9: Schematic Diagram of Elevated One Way Surge Tank with Float Valve Filling Arrangement

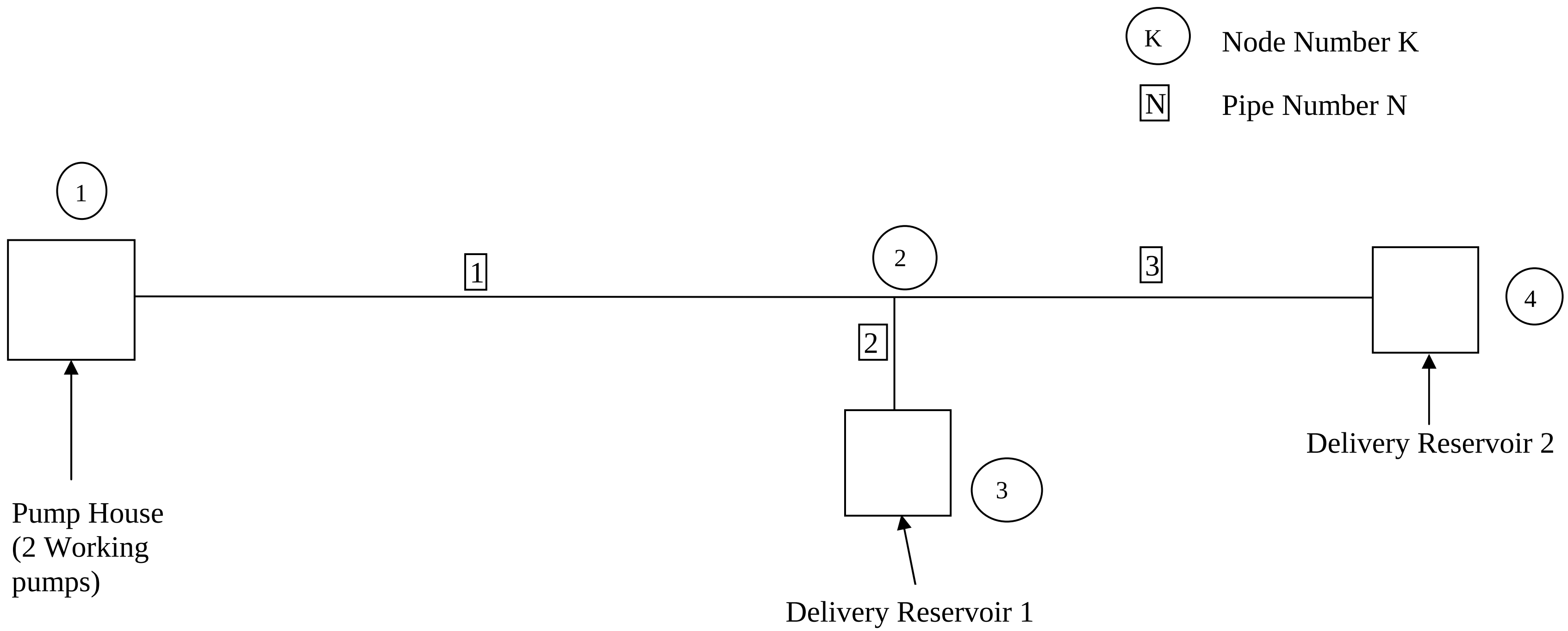


Fig. 10a: Schematic Diagram of Model of Pumping Main with Multiple Delivery Reservoirs
Note: Working pumps lumped in model

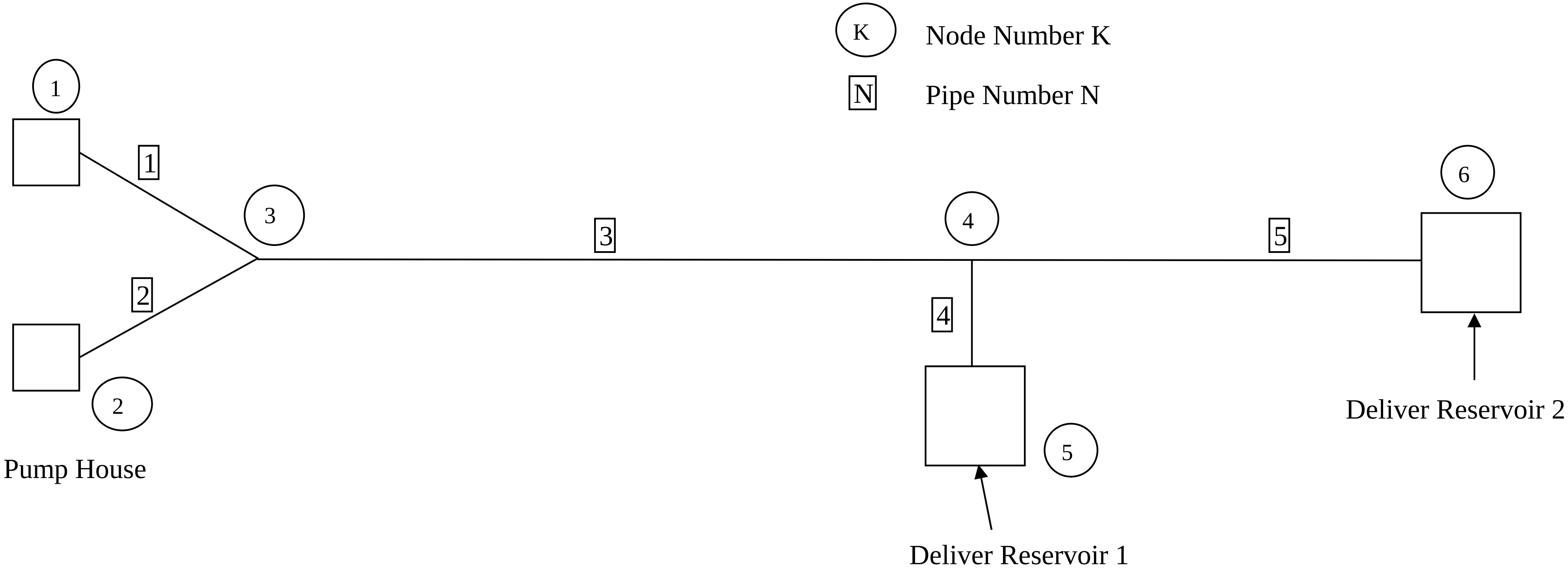
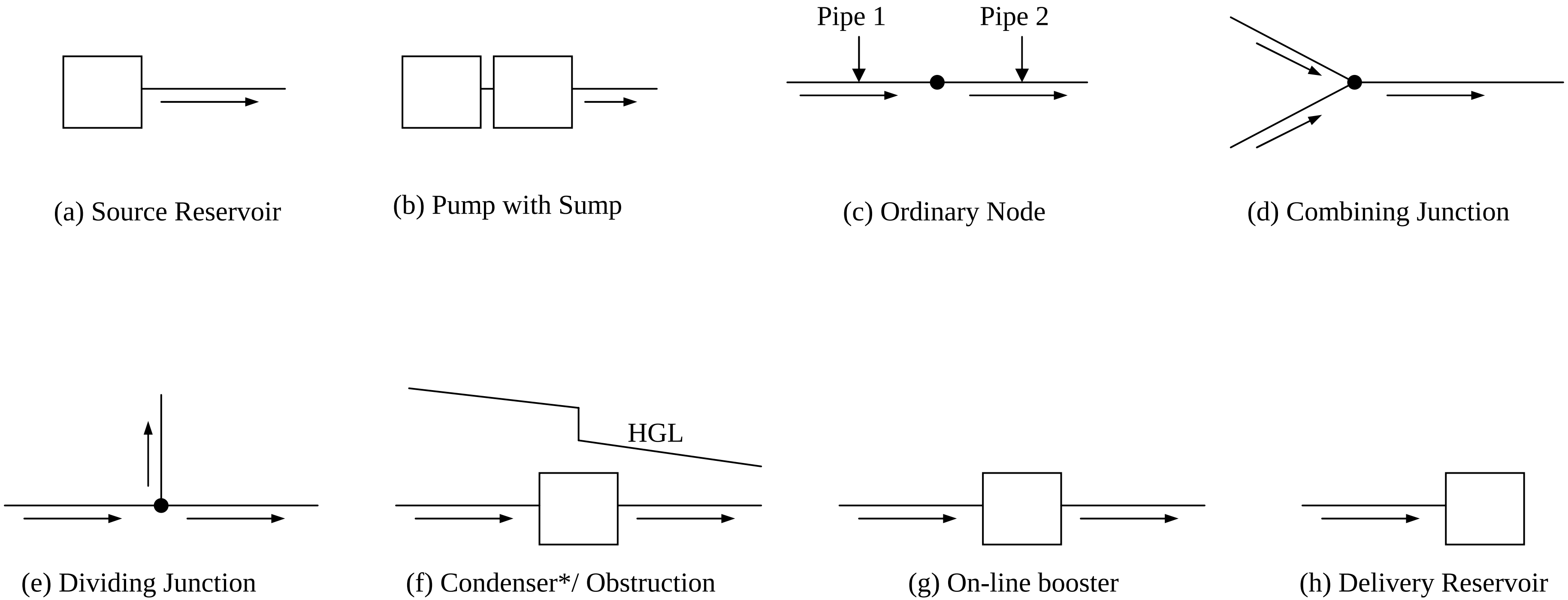


Fig. 10b: Schematic Diagram of Model of Pumping Main with Multiple Delivery Reservoirs
Note: Working pumps modelled separately



* While there is an option to model condenser as a node, it is preferable to model condenser as an equivalent pipe vide Section 15

Fig. 11: Schematic Diagram of Types of Nodes

Item No.	Part Name
1.	Body
2.	Plate
3.	Seal
4.	Stop Pin
5.	Hinge Pin
6.	Spring
7.	Stop Pin Ret
8.	Hinge Pin Ret
9.	Body Bearing
10.	Plate Bearing
11.	Spring Bearing

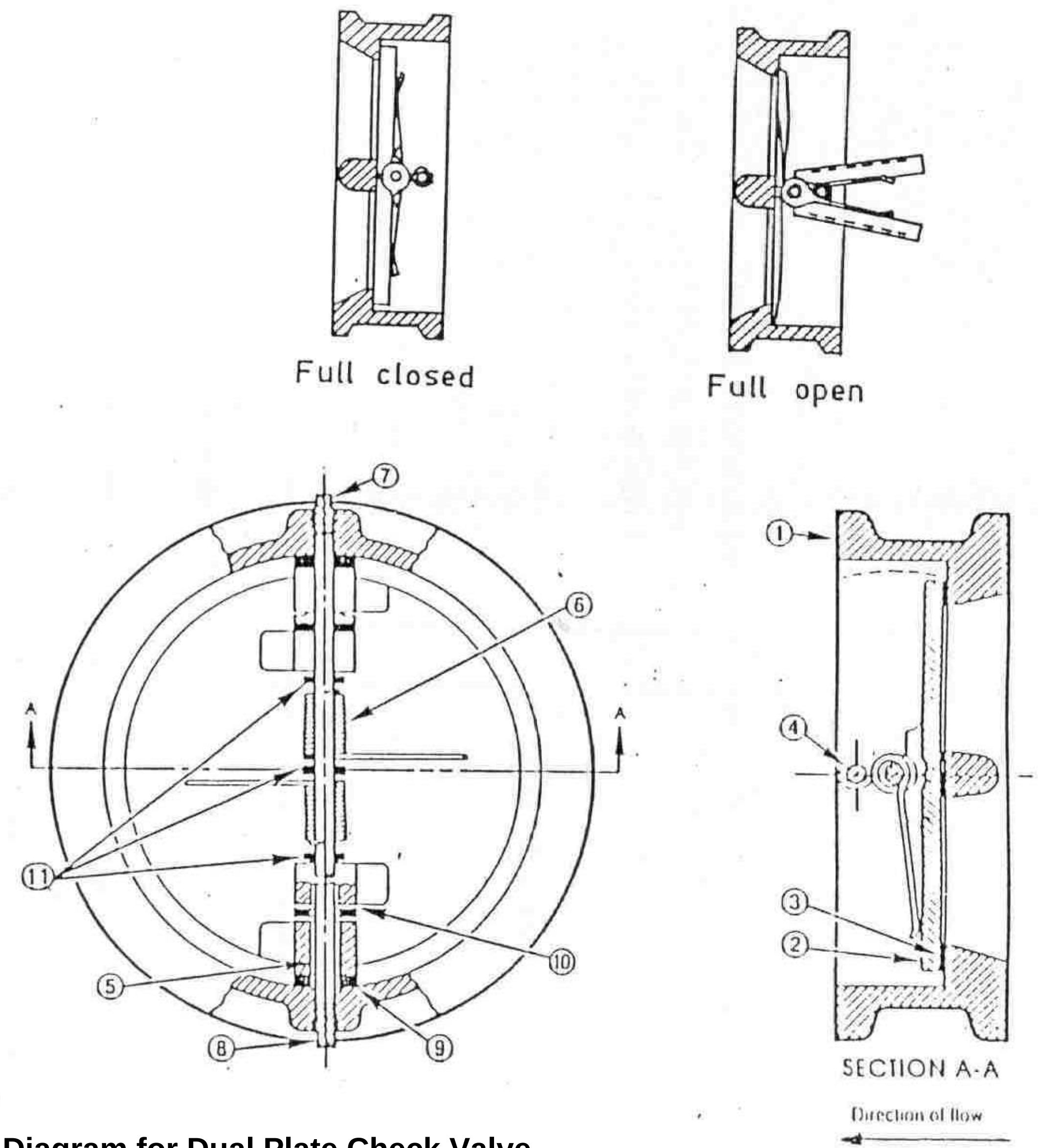
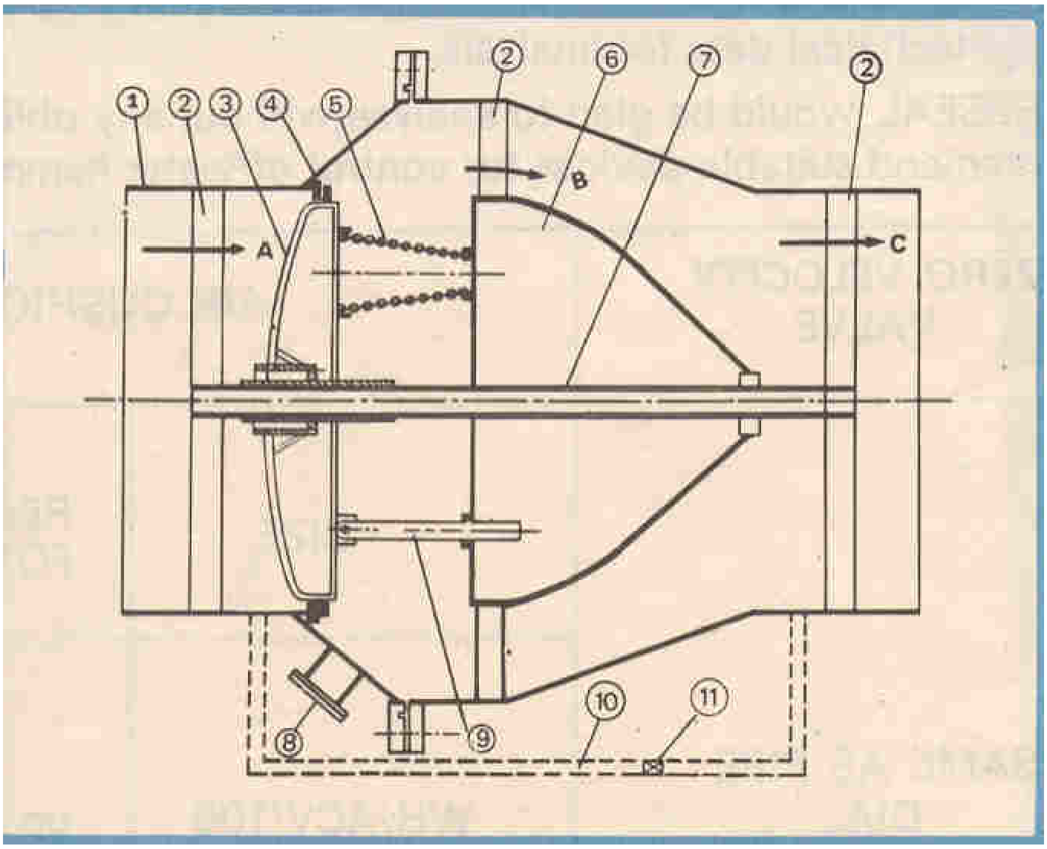


Fig. 12: Schematic Diagram for Dual Plate Check Valve

Fig.13: Zero velocity valve



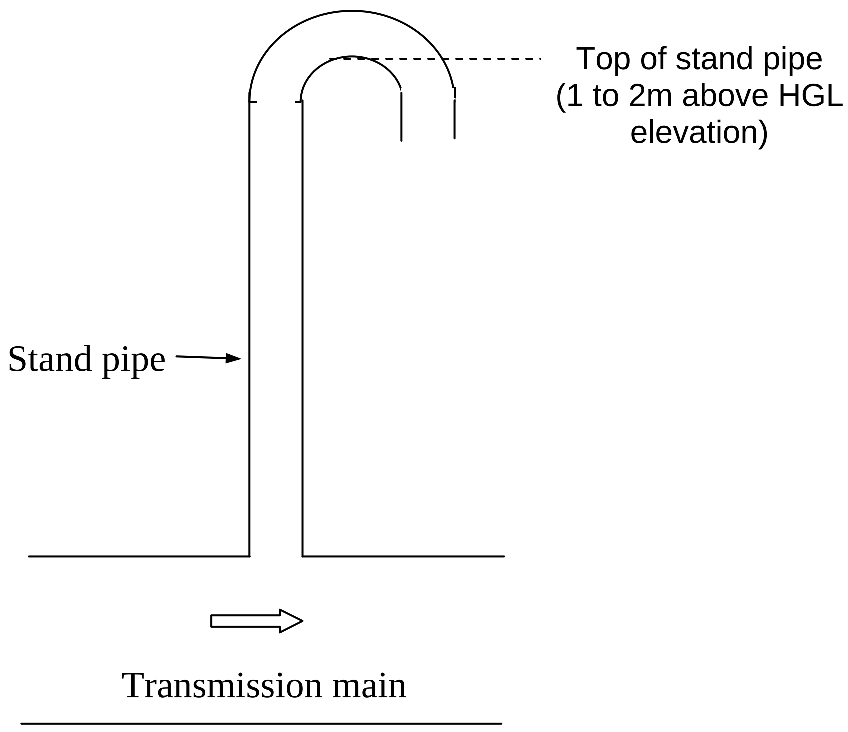


Fig. 14 Schematic Diagram of Stand Pipe

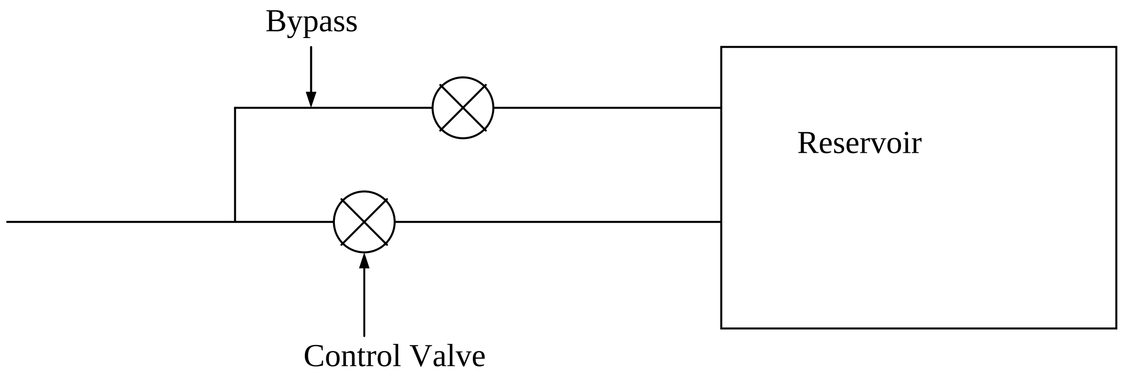


Fig. 15: Schematic Diagram of Valve With Bypass Outlet

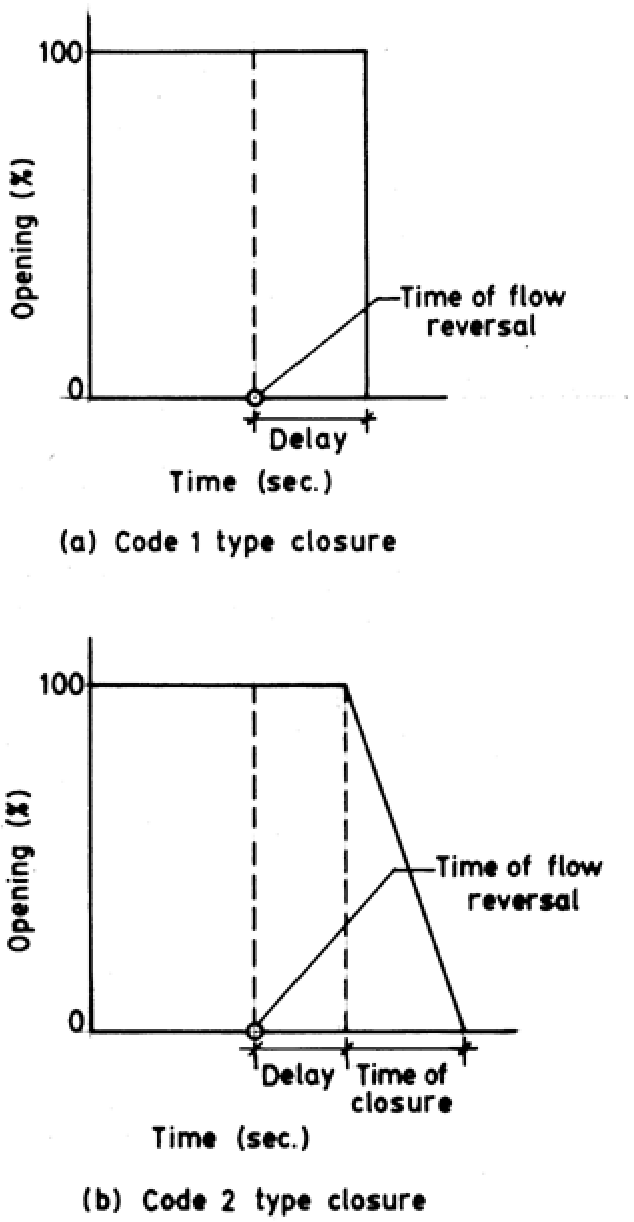
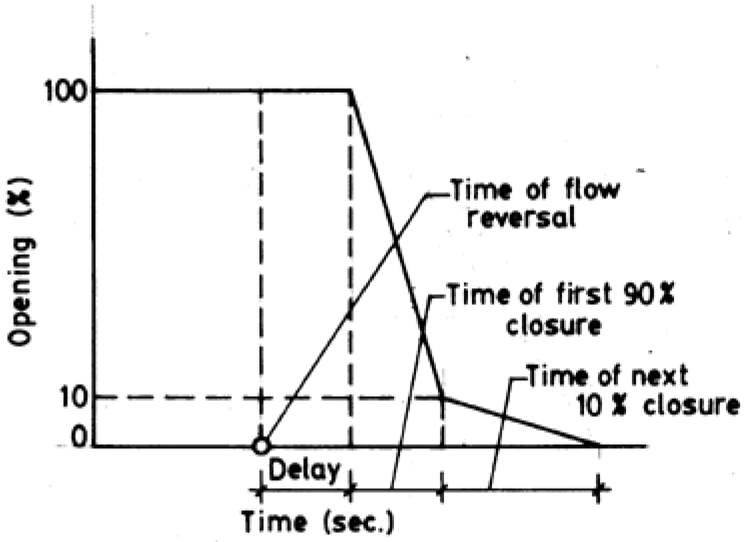
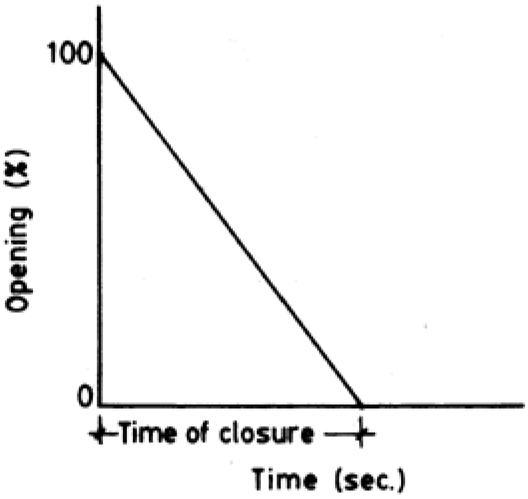


Fig. 16: Options for Non-return Valve

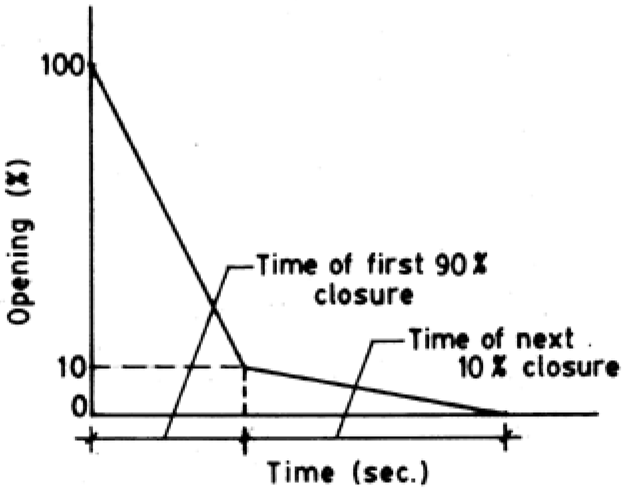


(c) Code 3 type closure

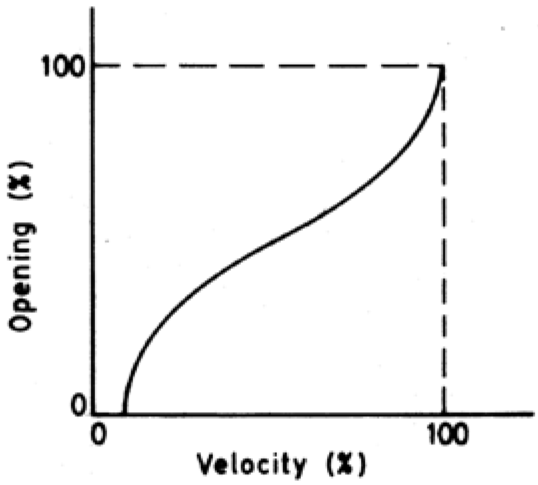


(d) Code 4 type closure

Fig. 16: Options for Non-return Valve (Contd..)



(e) Code 5 type closure



(f) Code 6 type closure

Fig. 16: Options for Non-return Valve (Contd..)

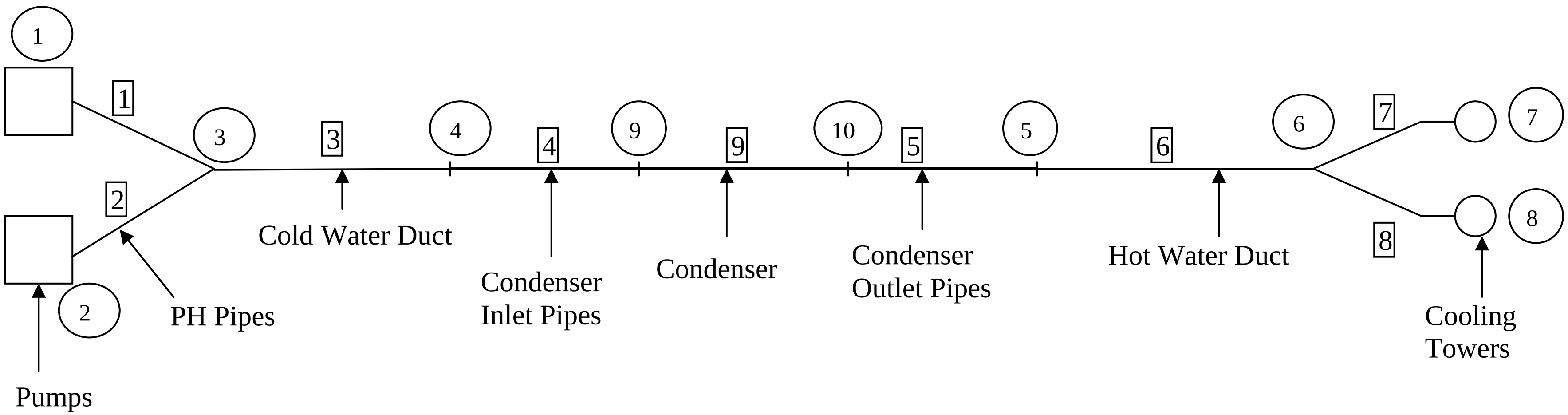


Fig. 17: Schematic Diagram of Model of Cooling Water System with Cooling Tower

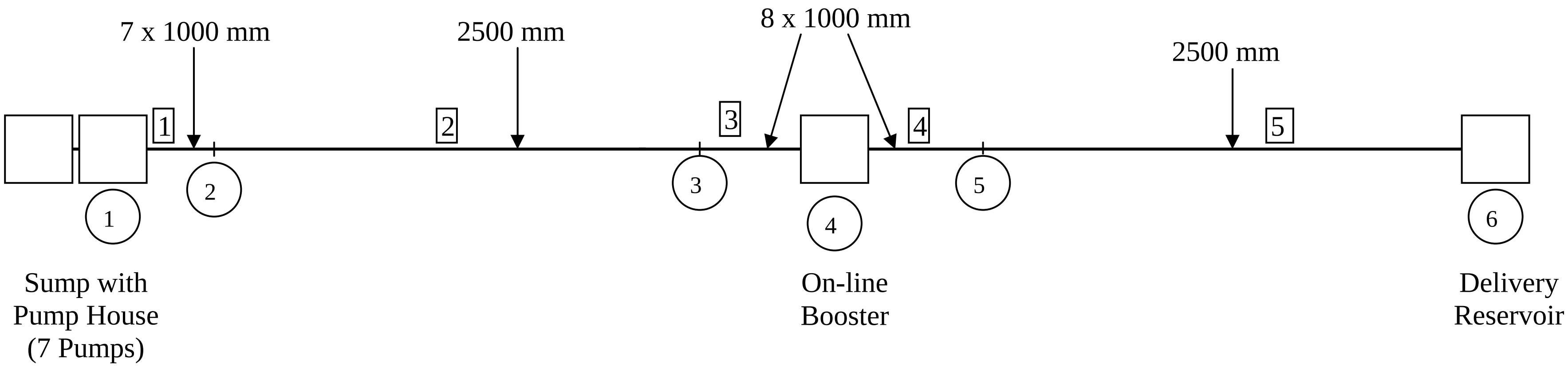


Fig. 18: Schematic Diagram of Model of On-line Booster Example

APPENDIX

EXAMPLES 1 to 8

EXAMPLE 1
MULTIPLE DELIVERY RESERVOIRS

Reference Figure : Fig. 10b
Reference File : ex1.sap

Alignment Data File Name: example1.aln

```
1 0      5.66
1 5      5.66
1 7      7.856
2 0      5.66
2 5      5.66
2 7      7.856
3 0      7.856
3 11.8   7.856
3 14.5   5.156
3 146.1  5.156
3 148.6  2.656
3 171.6  2.656
3 174.6  5.656
3 1248.7 5.656
3 1250.8 7.746
3 1466   7.746
4 0      7.746
4 1.8    7.746
4 5.5    4
4 49     4
4 56.4   11.4
4 58     11.4
5 0      7.746
5 1.4    7.054
5 717.4  7.054
5 721    3.529
5 767.4  3.529
5 773    9.129
5 1846   9.129
5 1848   7.054
5 1903   7.054
5 1905   9.129
5 2107   9.129
5 2116   17.754
5 2631   17.754
5 2634   14.5
5 2638   14.5
$
```

Pump Characteristics Data File Name : example1.pmp

```
.0139   53      6
.0278   52      11
.0556   51.5    23
.0833   51      35
.1111   50.5    45
.1389   50      55
.1667   49      63
.1944   48      71
```

```
.2222   47      79
.25     46      83
.2778   43      88
.3194   40      89
.3611   35      80
.3889   32      69
$
```

Results File for Example 1: sap2.res

```
  PROJECT          : Example 1

  ANALYSIS CASE    : Multiple delivery reservoirs

  TRANSMISSION MAIN DETAILS:

  PIPE NUMBER                             =  1
  UPSTREAM NODE NUMBER                    =  1
  DOWNSTREAM NODE NUMBER                  =  3
  NUMBER OF SUCCESSOR PIPES               =  1
  SUCCESSOR PIPE NUMBER/S                 =  3
  DISCHARGE (cum/sec)                     =  .319
  INTERNAL DIAMETER (mm)                  =  500.
  LENGTH (m)                              =    7.
  PRESSURE WAVE VELOCITY (m/sec)          = 1061.

  PIPE NUMBER                             =  2
  UPSTREAM NODE NUMBER                    =  2
  DOWNSTREAM NODE NUMBER                  =  3
  NUMBER OF SUCCESSOR PIPES               =  1
  SUCCESSOR PIPE NUMBER/S                 =  3
  DISCHARGE (cum/sec)                     =  .319
  INTERNAL DIAMETER (mm)                  =  500.
  LENGTH (m)                              =    7.
  PRESSURE WAVE VELOCITY (m/sec)          = 1061.

  PIPE NUMBER                             =  3
  UPSTREAM NODE NUMBER                    =  3
  DOWNSTREAM NODE NUMBER                  =  4
  NUMBER OF PREDECESSOR PIPES             =  2
  PREDECESSOR PIPE NUMBER/S               =  1  2
  NUMBER OF SUCCESSOR PIPES               =  2
  SUCCESSOR PIPE NUMBER/S                 =  4  5
  DISCHARGE (cum/sec)                     =  .639
  INTERNAL DIAMETER (mm)                  =  700.
  LENGTH (m)                              = 1466.
  PRESSURE WAVE VELOCITY (m/sec)          = 1049.

  PIPE NUMBER                             =  4
  UPSTREAM NODE NUMBER                    =  4
  DOWNSTREAM NODE NUMBER                  =  5
  NUMBER OF PREDECESSOR PIPES             =  1
  PREDECESSOR PIPE NUMBER/S               =  3
  DISCHARGE (cum/sec)                     =  .255
  INTERNAL DIAMETER (mm)                  =  600.
  LENGTH (m)                              =   58.
  PRESSURE WAVE VELOCITY (m/sec)          = 1086.

  PIPE NUMBER                             =  5
  UPSTREAM NODE NUMBER                    =  4
  DOWNSTREAM NODE NUMBER                  =  6
```

```
NUMBER OF PREDECESSOR PIPES              =  1
PREDECESSOR PIPE NUMBER/S                =  3
DISCHARGE (cum/sec)                      =  .383
INTERNAL DIAMETER (mm)                   =  500.
LENGTH (m)                               = 2638.
PRESSURE WAVE VELOCITY (m/sec)           = 1128.

PUMP DETAILS:

PUMP CLUSTER NUMBER                      =  1
NODE NUMBER                              =  1

NUMBER OF WORKING PUMPS                  =  1
OPERATING DISCHARGE PER PUMP (cum/sec)   =  .319
RATED DISCHARGE OF PUMP (cum/sec)        =  .319
OPERATING PUMP HEAD (m)                  =  40.0
RATED PUMP HEAD (m)                      =  40.0
RATED PUMP EFFICIENCY (%)                = 89.0
RATED SPEED OF PUMP (rpm)                = 1450
GD-SQUARE OF THE PUMP (kgf-sqm)          =  10.00
GD-SQUARE OF THE MOTOR (kgf-sqm)         =  25.00
WATER LEVEL IN THE SUMP (RL,m)           =   5.67
NON-REVERSE ROTATION RATCHET PROVIDED?   = NO
CODE FOR TYPE OF NON-RETURN VALVE        = 4
TIME OF CLOSURE (sec)                    =  45.00
PUMP TRIP CODE                           = 1
[Running Pump:0; Tripping Pump:1]

PUMP CLUSTER NUMBER                      =  2
NODE NUMBER                              =  2

NUMBER OF WORKING PUMPS                  =  1
OPERATING DISCHARGE PER PUMP (cum/sec)   =  .319
RATED DISCHARGE OF PUMP (cum/sec)        =  .319
OPERATING PUMP HEAD (m)                  =  40.0
RATED PUMP HEAD (m)                      =  40.0
RATED PUMP EFFICIENCY (%)                = 89.0
RATED SPEED OF PUMP (rpm)                = 1450
GD-SQUARE OF THE PUMP (kgf-sqm)          =  10.00
GD-SQUARE OF THE MOTOR (kgf-sqm)         =  25.00
WATER LEVEL IN THE SUMP (RL,m)           =   5.67
NON-REVERSE ROTATION RATCHET PROVIDED?   = NO
CODE FOR TYPE OF NON-RETURN VALVE        = 4
TIME OF CLOSURE (sec)                    =  45.00
PUMP TRIP CODE                           = 1
[Running Pump:0; Tripping Pump:1]

DELIVERY RESERVOIR DETAILS:

NODE NUMBER                                     =  5
DISCHARGE INTO THE RESERVOIR (cum/sec)          =  .255
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) =  11.40

NODE NUMBER                                     =  6
DISCHARGE INTO THE RESERVOIR (cum/sec)          =  .383
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) =  17.75
```

RESULTS OF ANALYSIS

NOTES:
1.Where moderate to extensive occurrence of vapour pressure is indicated by analysis, the results are to be treated as of qualitative value only.
2.Where air valves/air cusion valves are used as vacuum breaker the results are to be treated as approximate.
3.The User Manual may be referred for more details regarding limitations of analysis and for preparing results in graphical form.

DETAILS REGARDING PUMPS

FAILING PUMP

PUMP NUMBER	= 1
TIME OF FLOW REVERSAL (sec)	= 31.35
MINIMUM FLOW OF PUMP (%)	= -10.6
MINIMUM HEAD OF PUMP (%)	= -8.5
MAXIMUM HEAD OF PUMP (%)	= 100.0
MINIMUM SPEED OF PUMP (%)	= .6

FAILING PUMP

PUMP NUMBER	= 2
TIME OF FLOW REVERSAL (sec)	= 31.35
MINIMUM FLOW OF PUMP (%)	= -10.6
MINIMUM HEAD OF PUMP (%)	= -8.5
MAXIMUM HEAD OF PUMP (%)	= 100.0
MINIMUM SPEED OF PUMP (%)	= .6

MINIMUM & MAXIMUM PIEZOMETRIC HEADS AT SPECIFIED CHAINAGES

PIPE NUMBER	SPECIFIED CHAINAGE(m)	NEAREST NODAL CHAINAGE(m)	MIN HEAD (RL,m)	MAX HEAD (RL,m)
1	.0	.0	-1.24	45.54
2	.0	.0	-1.24	45.54
3	.0	.0	-1.20	44.67
3	146.0	147.8	-1.21	44.06
3	175.0	172.5	-1.21	43.96
3	1250.0	1244.3	4.16	39.57
3	1466.0	1466.0	8.30	38.66
4	.0	.0	8.30	38.66
4	58.0	58.0	11.40	11.40
5	.0	.0	8.30	38.66
5	773.0	778.2	6.43	32.49
5	1905.0	1899.4	2.96	23.60
5	2116.0	2110.4	3.06	21.93
5	2638.0	2638.0	17.75	17.75

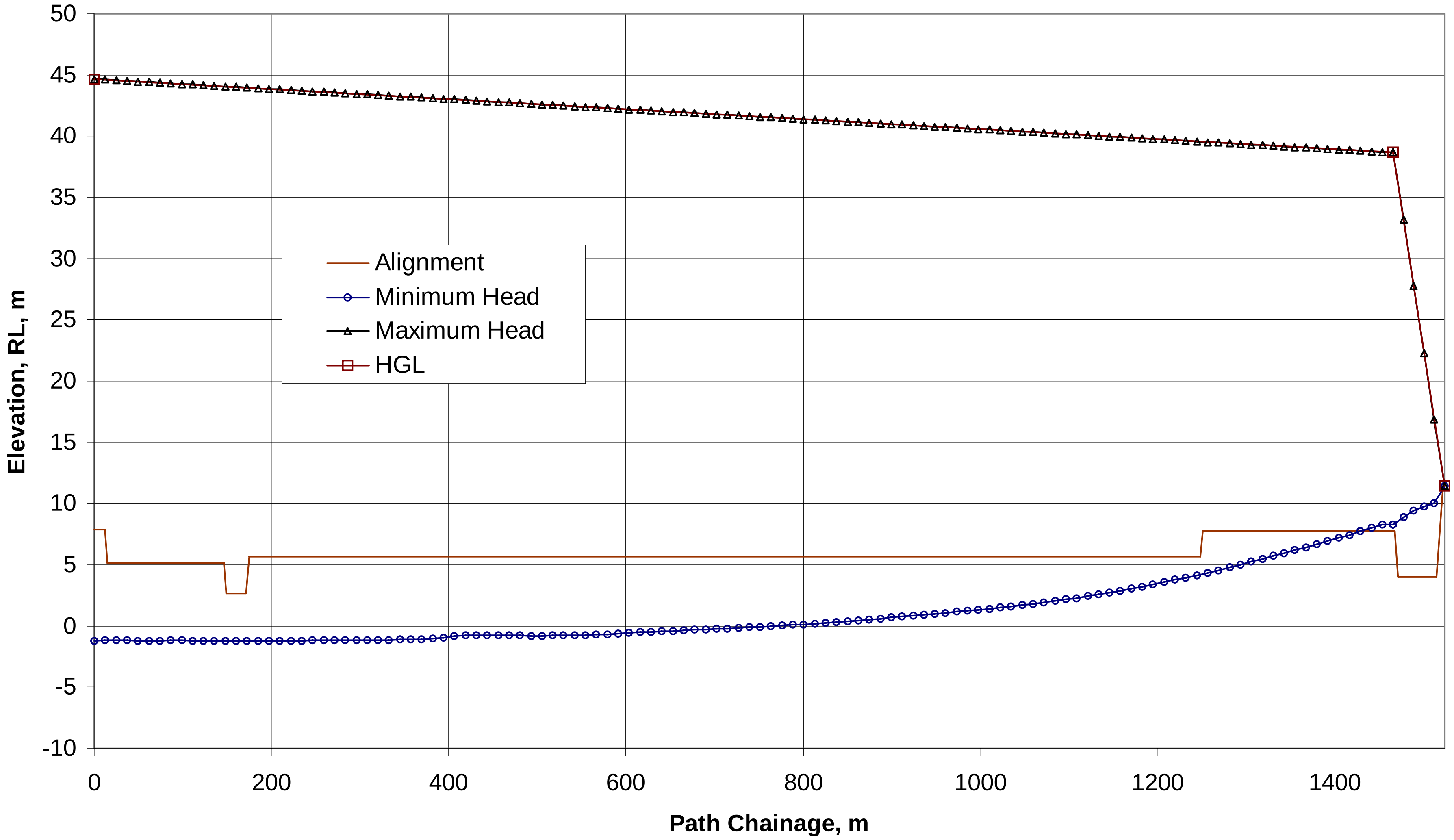


Fig.:Minimum and Maximum Piezometric Heads

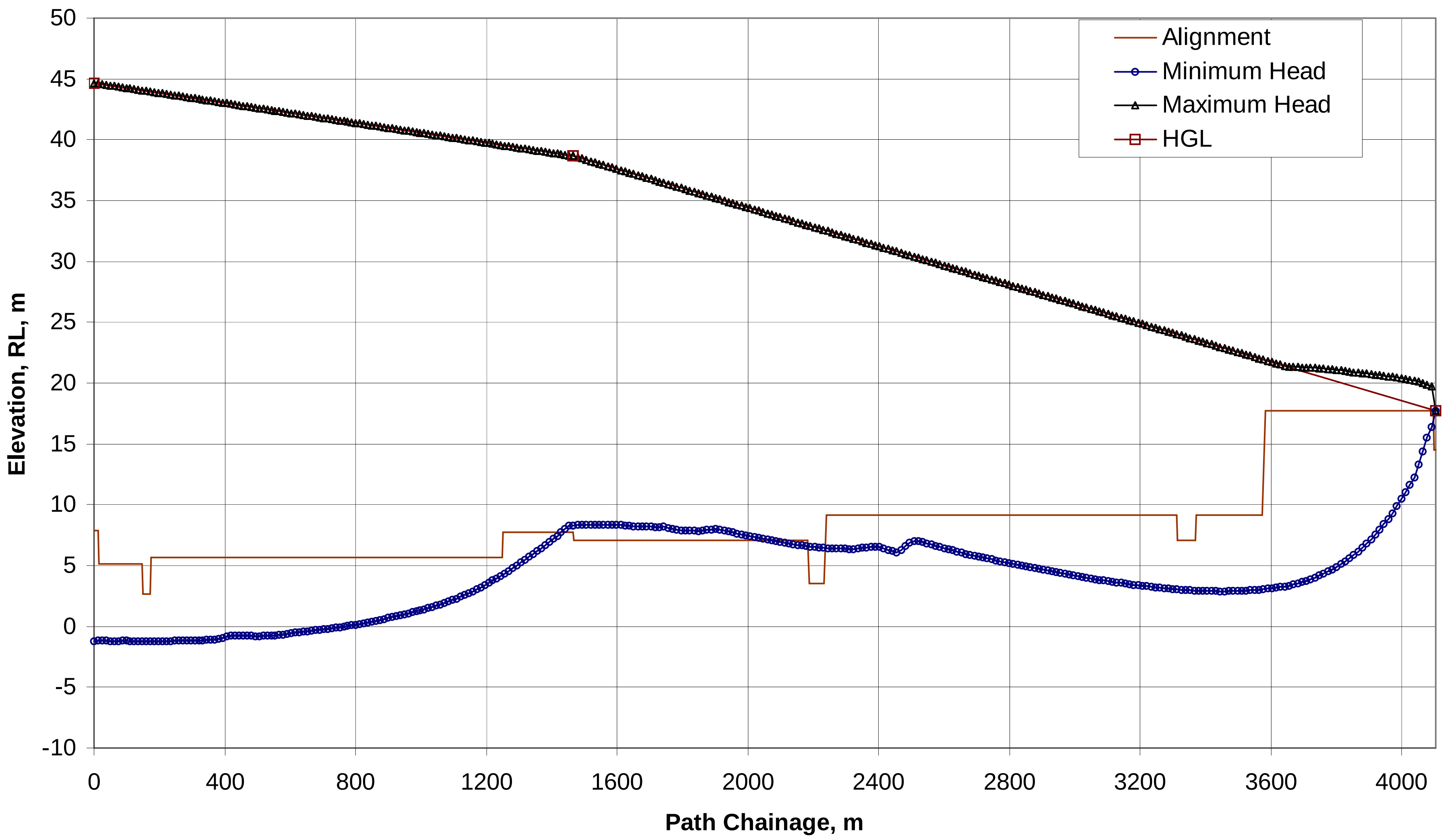


Fig.:Minimum and Maximum Piezometric Heads

EXAMPLE 2
SINGLE PUMP FAILURE WITH AIR VESSEL SURGE PROTECTION

Reference File : ex2.sap

Alignment Data File Name : example2.aln

```
1 3193 591.5
1 3205 591.5
2 3293 591.5
2 3205 591.5
3 3293 591.5
3 3205 591.5
4 3205 591.5
4 3375 591.5
4 3485 582.5
4 3730 585
4 3970 589
4 4280 612
4 4370 612
4 4480 604
4 4510 604
4 4570 610
4 4680 610
4 4790 599
4 4940 597.5
4 5100 603.82
4 5200 602.5
4 5310 602.7
4 5420 608.5
4 5490 616.5
4 6050 618.5
4 6170 637
4 6310 644
4 6350 645
4 6720 647.7
$
```

Pump Characteristics Data File Name : example2.pmp

```
0.05 106 10
0.10 105 21
0.20 102 40
0.30  98 57
0.40  94 70
0.50  90 80
0.60  86 86
0.70  80 89
0.80  71 90
0.82  70 90
0.90  62 89
1.00  48 86
$
```

Results File for Example 2: sap2.res

(example does not consider delay in closure; but conservative design needs to consider delay of the order of 0.5 sec)

```
PROJECT          : Example 2

ANALYSIS CASE    : Single pump failure + Air Vessel

TRANSMISSION MAIN DETAILS:

PIPE NUMBER                            =  1
UPSTREAM NODE NUMBER                   =  1
DOWNSTREAM NODE NUMBER                 =  4
NUMBER OF SUCCESSOR PIPES              =  1
SUCCESSOR PIPE NUMBER/S                =  4
DISCHARGE (cum/sec)                    =  .820
INTERNAL DIAMETER (mm)                 =  750.
LENGTH (m)                             =   12.
PRESSURE WAVE VELOCITY (m/sec)         = 1086.

PIPE NUMBER                            =  2
UPSTREAM NODE NUMBER                   =  2
DOWNSTREAM NODE NUMBER                 =  4
NUMBER OF SUCCESSOR PIPES              =  1
SUCCESSOR PIPE NUMBER/S                =  4
DISCHARGE (cum/sec)                    =  .820
INTERNAL DIAMETER (mm)                 =  750.
LENGTH (m)                             =   12.
PRESSURE WAVE VELOCITY (m/sec)         = 1086.

PIPE NUMBER                            =  3
UPSTREAM NODE NUMBER                   =  3
DOWNSTREAM NODE NUMBER                 =  4
NUMBER OF SUCCESSOR PIPES              =  1
SUCCESSOR PIPE NUMBER/S                =  4
DISCHARGE (cum/sec)                    =  .820
INTERNAL DIAMETER (mm)                 =  750.
LENGTH (m)                             =   12.
PRESSURE WAVE VELOCITY (m/sec)         = 1086.

PIPE NUMBER                            =  4
UPSTREAM NODE NUMBER                   =  4
DOWNSTREAM NODE NUMBER                 =  5
NUMBER OF PREDECESSOR PIPES            =  3
PREDECESSOR PIPE NUMBER/S              =  1  2  3
DISCHARGE (cum/sec)                    = 2.460
INTERNAL DIAMETER (mm)                 = 1500.
LENGTH (m)                             = 3515.
PRESSURE WAVE VELOCITY (m/sec)         =  940.

PUMP DETAILS:

PUMP CLUSTER NUMBER                    =  1
NODE NUMBER                            =  1

NUMBER OF WORKING PUMPS                =  1
OPERATING DISCHARGE PER PUMP (cum/sec)  =  .820
RATED DISCHARGE OF PUMP (cum/sec)      =  .820
```

```
OPERATING PUMP HEAD (m)                 =  70.0
RATED PUMP HEAD (m)                     =  70.0
RATED PUMP EFFICIENCY (%)               = 90.0
RATED SPEED OF PUMP (rpm)               =  750

GD-SQUARE OF THE PUMP (kgf-sqm)         = 154.00
GD-SQUARE OF THE MOTOR (kgf-sqm)        = 485.00
WATER LEVEL IN THE SUMP (RL,m)          = 583.20
NON-REVERSE ROTATION RATCHET PROVIDED?  = NO
CODE FOR TYPE OF NON-RETURN VALVE       = 2
TIME OF CLOSURE (sec)                   =    .50
DELAY IN CLOSURE (sec)                  =    .00
PUMP TRIP CODE                          = 1
[Running Pump:0; Tripping Pump:1]

PUMP CLUSTER NUMBER                     =  2
NODE NUMBER                             =  2

NUMBER OF WORKING PUMPS                 =  1
OPERATING DISCHARGE PER PUMP (cum/sec)  =  .820
RATED DISCHARGE OF PUMP (cum/sec)       =  .820
OPERATING PUMP HEAD (m)                 =  70.0
RATED PUMP HEAD (m)                     =  70.0
RATED PUMP EFFICIENCY (%)               = 90.0
RATED SPEED OF PUMP (rpm)               =  750
GD-SQUARE OF THE PUMP (kgf-sqm)         = 154.00
GD-SQUARE OF THE MOTOR (kgf-sqm)        = 485.00
WATER LEVEL IN THE SUMP (RL,m)          = 583.20
NON-REVERSE ROTATION RATCHET PROVIDED?  = NO
CODE FOR TYPE OF NON-RETURN VALVE       = 2
TIME OF CLOSURE (sec)                   =    .50
DELAY IN CLOSURE (sec)                  =    .00
PUMP TRIP CODE                          = 0
[Running Pump:0; Tripping Pump:1]

PUMP CLUSTER NUMBER                     =  3
NODE NUMBER                             =  3

NUMBER OF WORKING PUMPS                 =  1
OPERATING DISCHARGE PER PUMP (cum/sec)  =  .820
RATED DISCHARGE OF PUMP (cum/sec)       =  .820
OPERATING PUMP HEAD (m)                 =  70.0
RATED PUMP HEAD (m)                     =  70.0
RATED PUMP EFFICIENCY (%)               = 90.0
RATED SPEED OF PUMP (rpm)               =  750
GD-SQUARE OF THE PUMP (kgf-sqm)         = 154.00
GD-SQUARE OF THE MOTOR (kgf-sqm)        = 485.00
WATER LEVEL IN THE SUMP (RL,m)          = 583.20
NON-REVERSE ROTATION RATCHET PROVIDED?  = NO
CODE FOR TYPE OF NON-RETURN VALVE       = 2
TIME OF CLOSURE (sec)                   =    .50
DELAY IN CLOSURE (sec)                  =    .00
PUMP TRIP CODE                          = 0
[Running Pump:0; Tripping Pump:1]

DELIVERY RESERVOIR DETAILS:

NODE NUMBER                                    =  5
DISCHARGE INTO THE RESERVOIR (cum/sec)         = 2.460
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) = 647.90
```

```
DETAILS OF AIR VESSEL

AIR VESSEL LOCATION PIPE NUMBER         =  4
GROUND LEVEL AT THE LOCATION (RL,m)     = 591.500
SIZE PARAMETER OF THE AIR VESSEL (KAV)  =  4.00
NRV PROVIDED ON THE TRANSMISSION MAIN?  - NO
CONNECTING PIPE SIZE (mm)               = 900.
TYPE OF AIR VESSEL (1 or 2)             = 1
SIZE OF ORIFICE IN CONNECTING PIPE (mm) = 450.

RESULTS OF ANALYSIS

NOTES:
1.Where moderate to extensive occurrence of vapour pressure
  is indicated by analysis, the results are to be treated
  as of qualitative value only.
2.Where air valves/air cusion valves are used as vacuum breaker
  the results are to be treated as approximate.
3.The User Manual may be referred for more details regarding
  limitations of analysis and for preparing results in
  graphical form.
DETAILS REGARDING PUMPS

FAILING PUMP

PUMP NUMBER                                       =  1
TIME OF FLOW REVERSAL (sec)                       =   .62
MINIMUM FLOW OF PUMP (%)                          = -65.8
MINIMUM HEAD OF PUMP (%)                          =  60.0
MAXIMUM HEAD OF PUMP (%)                          = 100.0
MINIMUM SPEED OF PUMP (%)                         =  62.9

RUNNING PUMP

PUMP NUMBER                                       =  2
MAXIMUM FLOW OF PUMPS (%)                         = 117.1
MINIMUM HEAD OF PUMPS (%)                         =  78.8
MAXIMUM HEAD OF PUMPS (%)                         = 107.0

RUNNING PUMP

PUMP NUMBER                                       =  3
MAXIMUM FLOW OF PUMPS (%)                         = 117.1
MINIMUM HEAD OF PUMPS (%)                         =  78.8
MAXIMUM HEAD OF PUMPS (%)                         = 107.0


DETAILS REGARDING AIR VESSEL

AIR VOLUME UNDER WORKING CONDITION (cum)          = 18.39
MAXIMUM AIR VOLUME UNDER SURGE (cum)              = 22.50
TIME OF OCCURENCE OF MAXIMUM AIR VOLUME (sec)     =  10.7
MINIMUM AIR VOLUME UNDER SURGE (cum)              = 17.83
TIME OF OCCURRENCE OF MINIMUM AIR VOLUME (sec)    =  34.5
MAXIMUM VELOCITY THROUGH CONNECTING PIPE (m/sec)  = 1.85
MAXIMUM VELOCITY THROUGH ORIFICE (m/sec)          =  7.4


MINIMUM & MAXIMUM PIEZOMETRIC HEADS AT SPECIFIED CHAINAGES
```

PIPE NUMBER	SPECIFIED CHAINAGE(m)	NEAREST NODAL CHAINAGE(m)	MIN HEAD (RL,m)	MAX HEAD (RL,m)
1	3193.0	3193.0	605.55	719.73
2	3193.0	3193.0	638.12	657.98
3	3193.0	3193.0	638.12	657.98
4	3205.0	3205.0	629.32	664.45
4	3240.0	3240.1	637.25	655.71
4	3375.0	3380.8	637.65	655.92
4	4280.0	4277.1	639.52	655.08
4	4570.0	4575.9	639.84	654.32
4	5490.0	5489.8	641.60	651.67
4	6350.0	6350.9	643.62	649.40
4	6720.0	6720.0	647.90	647.90

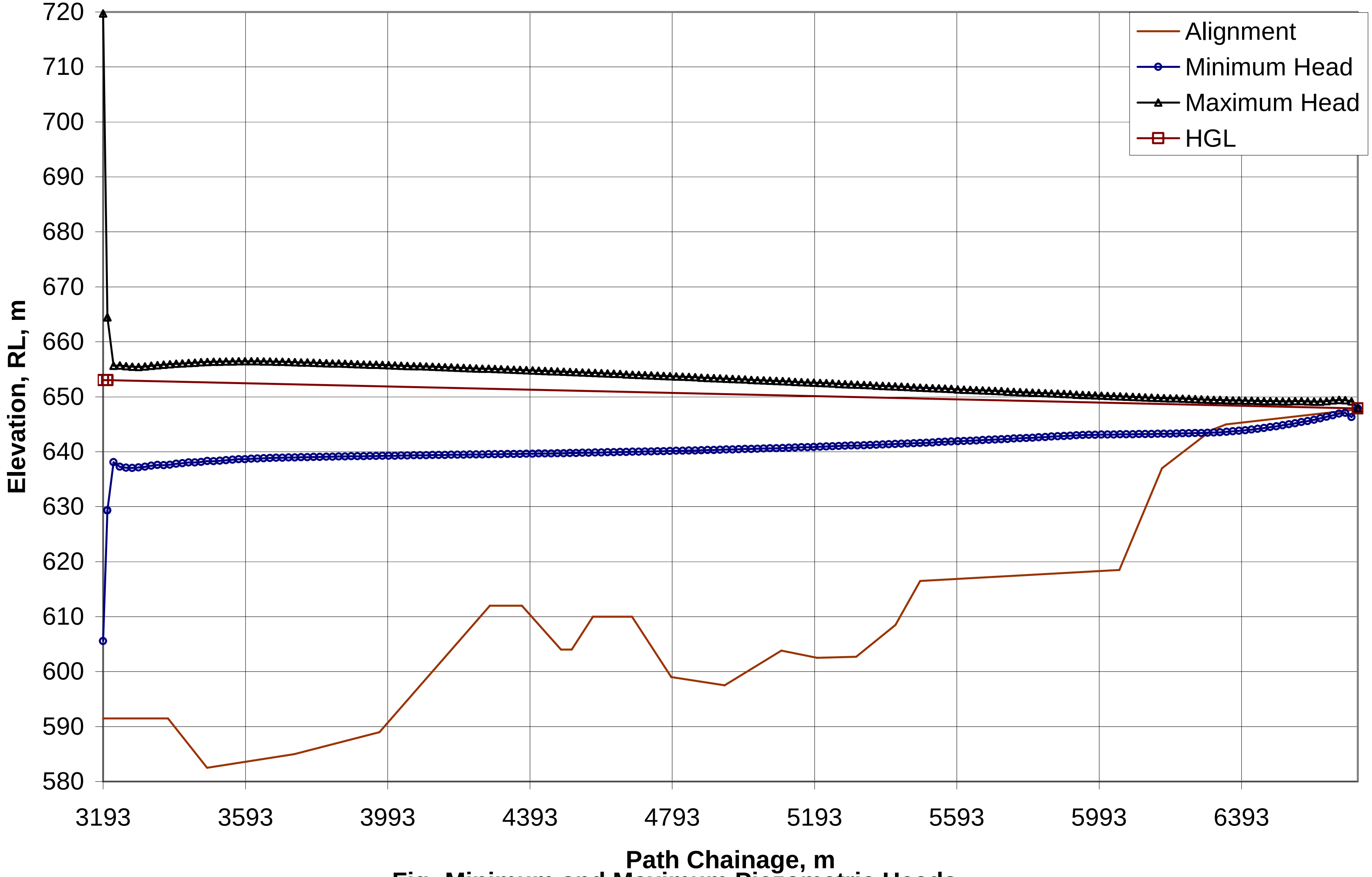


Fig.:Minimum and Maximum Piezometric Heads

EXAMPLE 3
CONDENSER CW SYSTEM

Reference Figure : Fig.17
Reference File : ex3.sap

Alignment Data File Name : example3.aln

```
1 0     93
1 10.2  93
1 19.7  86.6
1 25    86.6
2 0     93
2 10.2  93
2 19.7  86.6
2 25    86.6
3 0     86.6
3 66.5  86.6
3 74.5  81.5
3 169   81.5
4 0     81.5
4 18.7  81.5
4 20.1  82.5
4 25.2  82.5
4 35.2  92.1
4 41    92.1
5 0     86.25
5 8     82.5
5 15    82.5
5 17    81.5
5 22.3  77.7
5 32    77.7
6 0     77.7
6 56.2  77.7
6 70    86.6
6 88.5  86.6
6 939   86.6
7 0     86.6
7 15    86.6
7 20    91.6
7 33    91.6
7 37    91.6
7 86.5  91.37
7 99    91.37
8 0     86.6
8 5     91.6
8 48    91.6
8 70    91.37
8 82    91.37
9 0     92.6
9 26    92.6
$
```

Pump characteristics data :
Choose   Machinery finalised : No
           Type of pump characteristics : Mixed

Results File for Example 3: sap2.res

```
PROJECT          : Example 3

ANALYSIS CASE    : Condenser CW System

TRANSMISSION MAIN DETAILS:

PIPE NUMBER                              =  1
UPSTREAM NODE NUMBER                     =  1
DOWNSTREAM NODE NUMBER                   =  3
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  3
DISCHARGE (cum/sec)                      = 8.000
INTERNAL DIAMETER (mm)                   = 2000.
LENGTH (m)                               =   25.
PRESSURE WAVE VELOCITY (m/sec)           =  932.

PIPE NUMBER                              =  2
UPSTREAM NODE NUMBER                     =  2
DOWNSTREAM NODE NUMBER                   =  3
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  3
DISCHARGE (cum/sec)                      = 8.000
INTERNAL DIAMETER (mm)                   = 2000.
LENGTH (m)                               =   25.
PRESSURE WAVE VELOCITY (m/sec)           =  932.

PIPE NUMBER                              =  3
UPSTREAM NODE NUMBER                     =  3
DOWNSTREAM NODE NUMBER                   =  4
NUMBER OF PREDECESSOR PIPES              =  2
PREDECESSOR PIPE NUMBER/S                =  1  2
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  4
DISCHARGE (cum/sec)                      =16.000
INTERNAL DIAMETER (mm)                   = 3200.
LENGTH (m)                               =  169.
PRESSURE WAVE VELOCITY (m/sec)           = 1150.

PIPE NUMBER                              =  4
UPSTREAM NODE NUMBER                     =  4
DOWNSTREAM NODE NUMBER                   =  9
NUMBER OF PREDECESSOR PIPES              =  1
PREDECESSOR PIPE NUMBER/S                =  3
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  9
DISCHARGE (cum/sec)                      =16.000
INTERNAL DIAMETER (mm)                   = 2828.     (√2 × 2000)
LENGTH (m)                               =   41.
PRESSURE WAVE VELOCITY (m/sec)           = 1190.

PIPE NUMBER                              =  5
UPSTREAM NODE NUMBER                     = 10
DOWNSTREAM NODE NUMBER                   =  5
NUMBER OF PREDECESSOR PIPES              =  1
PREDECESSOR PIPE NUMBER/S                =  9
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  6
DISCHARGE (cum/sec)                      =16.000
INTERNAL DIAMETER (mm)                   = 2828.     (√2 × 2000)
```

```
LENGTH (m)                              =   32.
PRESSURE WAVE VELOCITY (m/sec)          = 1190.

PIPE NUMBER                             =  6
UPSTREAM NODE NUMBER                    =  5
DOWNSTREAM NODE NUMBER                  =  6
NUMBER OF PREDECESSOR PIPES             =  1
PREDECESSOR PIPE NUMBER/S               =  5
NUMBER OF SUCCESSOR PIPES               =  2
SUCCESSOR PIPE NUMBER/S                 =  7  8
DISCHARGE (cum/sec)                     =16.000
INTERNAL DIAMETER (mm)                  = 3000.
LENGTH (m)                              =  939.
PRESSURE WAVE VELOCITY (m/sec)          = 1150.

PIPE NUMBER                             =  7
UPSTREAM NODE NUMBER                    =  6
DOWNSTREAM NODE NUMBER                  =  7
NUMBER OF PREDECESSOR PIPES             =  1
PREDECESSOR PIPE NUMBER/S               =  6
DISCHARGE (cum/sec)                     = 8.000
INTERNAL DIAMETER (mm)                  = 2000.
LENGTH (m)                              =   99.
PRESSURE WAVE VELOCITY (m/sec)          =  853.

PIPE NUMBER                             =  8
UPSTREAM NODE NUMBER                    =  6
DOWNSTREAM NODE NUMBER                  =  8
NUMBER OF PREDECESSOR PIPES             =  1
PREDECESSOR PIPE NUMBER/S               =  6
DISCHARGE (cum/sec)                     = 8.000
INTERNAL DIAMETER (mm)                  = 2000.
LENGTH (m)                              =   82.
PRESSURE WAVE VELOCITY (m/sec)          =  853.

PIPE NUMBER                             =  9
UPSTREAM NODE NUMBER                    =  9
DOWNSTREAM NODE NUMBER                  = 10
NUMBER OF PREDECESSOR PIPES             =  1
PREDECESSOR PIPE NUMBER/S               =  4
NUMBER OF SUCCESSOR PIPES               =  1
SUCCESSOR PIPE NUMBER/S                 =  5
DISCHARGE (cum/sec)                     =16.000
INTERNAL DIAMETER (mm)                  = 3953.
LENGTH (m)                              =   25.
PRESSURE WAVE VELOCITY (m/sec)          = 1200.

PUMP DETAILS:

PUMP CLUSTER NUMBER                     =  1
NODE NUMBER                             =  1

NUMBER OF WORKING PUMPS                 =  1
DISCHARGE PER PUMP (cum/sec)            = 8.000
PUMP HEAD (m)                           =  20.0
SPEED OF PUMP (rpm)                     =  330
WATER LEVEL IN THE SUMP (RL,m)          =  88.35
CODE FOR TYPE OF NON-RETURN VALVE       =  5
TIME OF FIRST 90 % CLOSURE (sec)        =  20.00
TIME OF LAST 10 % CLOSURE (sec)         =  40.00
PUMP TRIP CODE                          = 1
```

[Running Pump:0; Tripping Pump:1]

```
PUMP CLUSTER NUMBER                      =  2
NODE NUMBER                              =  2

NUMBER OF WORKING PUMPS                  =  1
DISCHARGE PER PUMP (cum/sec)             = 8.000
PUMP HEAD (m)                            =  20.0
SPEED OF PUMP (rpm)                      =  330
WATER LEVEL IN THE SUMP (RL,m)           =  88.35
CODE FOR TYPE OF NON-RETURN VALVE        =  5
TIME OF FIRST 90 % CLOSURE (sec)         =  20.00
TIME OF LAST 10 % CLOSURE (sec)          =  40.00
PUMP TRIP CODE                           = 1
[Running Pump:0; Tripping Pump:1]

DELIVERY RESERVOIR DETAILS:

NODE NUMBER                                     =  7
DISCHARGE INTO THE RESERVOIR (cum/sec)          = 8.000
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) =  96.81

NODE NUMBER                                     =  8
DISCHARGE INTO THE RESERVOIR (cum/sec)          = 8.000
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) =  96.81

NUMBER OF AIR VALVES                     =  4
```

DETAILS OF AIR VALVES

SL NO.	SIZE mm	PIPE NO.	LOCATION Chainage,m	PIPE INVERT LEVEL RL,m
1	200.	1	10.	94.900
2	200.	2	10.	94.900
3	200.	3	90.	88.000
4	282.	6	74.	88.000

RESULTS OF ANALYSIS

NOTES:
1.Where moderate to extensive occurrence of vapour pressure is indicated by analysis, the results are to be treated as of qualitative value only.
2.Where air valves/air cusion valves are used as vacuum breaker the results are to be treated as approximate.
3.The User Manual may be referred for more details regarding limitations of analysis and for preparing results in graphical form.

DETAILS REGARDING PUMPS

FAILING PUMP

```
PUMP NUMBER                                        =  1
TIME OF FLOW REVERSAL (sec)                        = 21.06
MINIMUM FLOW OF PUMP (%)                           = -10.5
MINIMUM HEAD OF PUMP (%)                           =  -2.1
MAXIMUM HEAD OF PUMP (%)                           = 100.0
MINIMUM SPEED OF PUMP (%)                          =  -8.3
```

FAILING PUMP

PUMP NUMBER	= 2
TIME OF FLOW REVERSAL (sec)	= 21.06
MINIMUM FLOW OF PUMP (%)	= -10.5
MINIMUM HEAD OF PUMP (%)	= -2.1
MAXIMUM HEAD OF PUMP (%)	= 100.0
MINIMUM SPEED OF PUMP (%)	= -8.3

MINIMUM & MAXIMUM PIEZOMETRIC HEADS AT SPECIFIED CHAINAGES

PIPE NUMBER	SPECIFIED CHAINAGE(m)	NEAREST NODAL CHAINAGE(m)	MIN HEAD (RL,m)	MAX HEAD (RL,m)
1	.0	.0	87.74	108.02
3	.0	.0	87.19	106.35
3	169.0	169.0	87.82	105.85
4	.0	.0	87.82	105.85
4	35.2	34.2	87.76	105.43
4	41.0	41.0	87.77	105.35
5	.0	.0	85.47	100.35
5	32.0	32.0	85.56	99.85
6	.0	.0	85.56	99.85
6	70.0	71.7	86.84	99.66
6	939.0	939.0	91.47	98.16
7	.0	.0	91.47	98.16
7	20.0	20.8	91.66	98.14
7	99.0	99.0	96.81	96.81
8	.0	.0	91.47	98.16
8	5.0	5.5	91.84	98.15
8	82.0	82.0	96.81	96.81
9	.0	.0	87.77	105.35
9	25.0	25.0	85.47	100.35

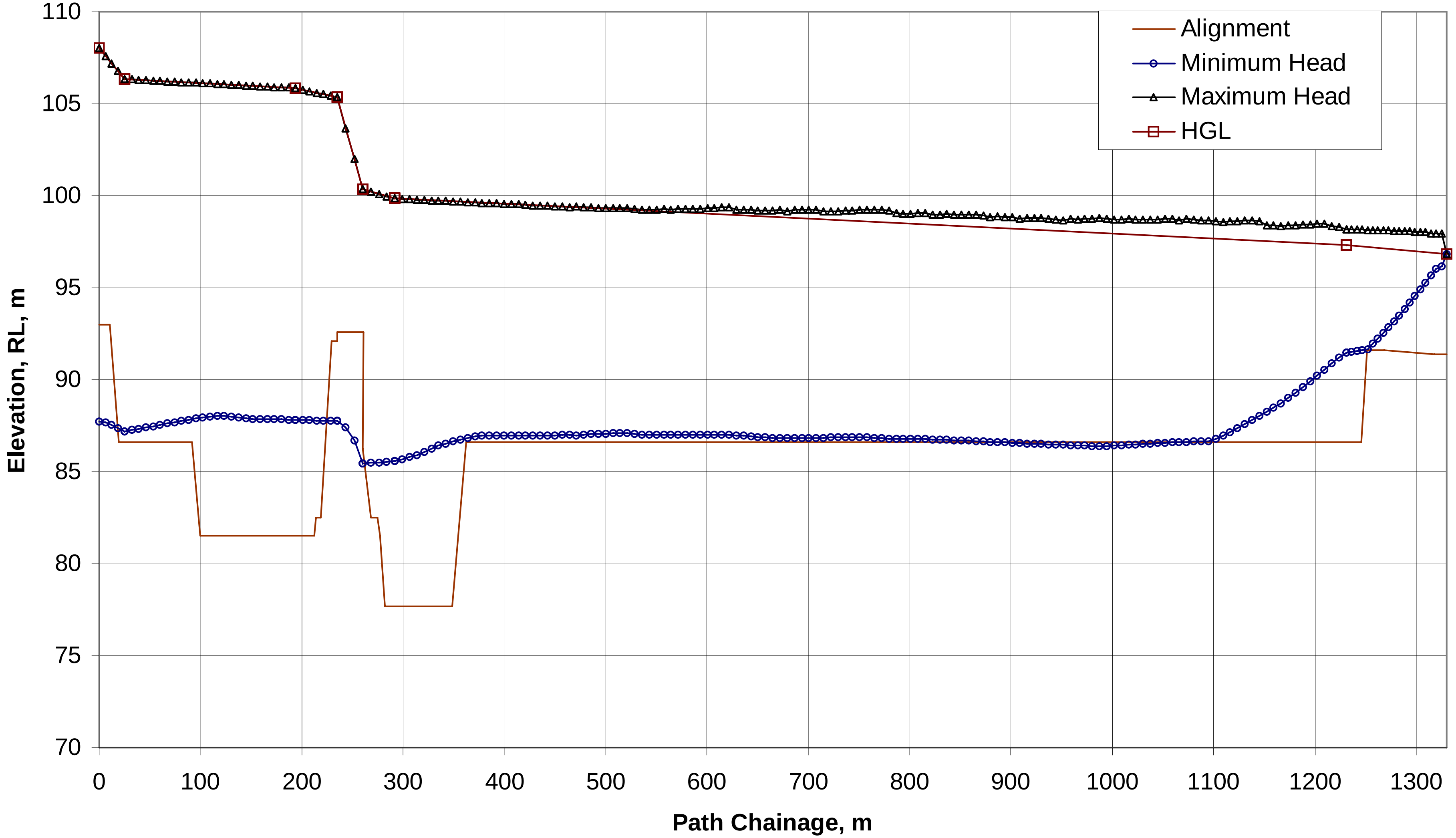


Fig.:Minimum and Maximum Piezometric Heads

EXAMPLE 4
ON-LINE BOOSTER

Reference Figure : Fig.18
Reference File : ex4.sap

Alignment Data File Name : example4.aln

```
1 0     538
1 20    538
2 0     538
2 320   530
2 1320  542
2 1537  561
3 0     561
3 20    561
4 0     564
4 20    564
5 0     564
5 500   567
5 700   564
5 1850  575
5 3200  602
5 3362  608
$
```

Pump and Booster pump characteristics data :
Choose Machinery finalised : No
Type of pump characteristics : Mixed

Results File for Example 4: sap2.res

```
PROJECT           : Example 4

ANALYSIS CASE     : On-line booster

TRANSMISSION MAIN DETAILS:

PIPE NUMBER                             =  1
UPSTREAM NODE NUMBER                    =  1
DOWNSTREAM NODE NUMBER                  =  2
NUMBER OF SUCCESSOR PIPES               =  1
SUCCESSOR PIPE NUMBER/S                 =  2
DISCHARGE (cum/sec)                     =11.880
INTERNAL DIAMETER (mm)                  = 2645.      (√7 × 1000)
LENGTH (m)                              =   20.
PRESSURE WAVE VELOCITY (m/sec)          = 1016.

PIPE NUMBER                             =  2
UPSTREAM NODE NUMBER                    =  2
DOWNSTREAM NODE NUMBER                  =  3
NUMBER OF PREDECESSOR PIPES             =  1
PREDECESSOR PIPE NUMBER/S               =  1
NUMBER OF SUCCESSOR PIPES               =  1
SUCCESSOR PIPE NUMBER/S                 =  3
```

```
DISCHARGE (cum/sec)                    =11.880
INTERNAL DIAMETER (mm)                 = 2500.
LENGTH (m)                             = 1537.
PRESSURE WAVE VELOCITY (m/sec)         =  929.

PIPE NUMBER                            =  3
UPSTREAM NODE NUMBER                   =  3
DOWNSTREAM NODE NUMBER                 =  4
NUMBER OF PREDECESSOR PIPES            =  1
PREDECESSOR PIPE NUMBER/S              =  2
NUMBER OF SUCCESSOR PIPES              =  1
SUCCESSOR PIPE NUMBER/S                =  4
DISCHARGE (cum/sec)                    =11.880
INTERNAL DIAMETER (mm)                 = 2828.      (√8 × 1000)
LENGTH (m)                             =   20.
PRESSURE WAVE VELOCITY (m/sec)         = 1016.

PIPE NUMBER                            =  4
UPSTREAM NODE NUMBER                   =  4
DOWNSTREAM NODE NUMBER                 =  5
NUMBER OF PREDECESSOR PIPES            =  1
PREDECESSOR PIPE NUMBER/S              =  3
NUMBER OF SUCCESSOR PIPES              =  1
SUCCESSOR PIPE NUMBER/S                =  5
DISCHARGE (cum/sec)                    =11.880
INTERNAL DIAMETER (mm)                 = 2828.
LENGTH (m)                             =   20.
PRESSURE WAVE VELOCITY (m/sec)         = 1016.

PIPE NUMBER                            =  5
UPSTREAM NODE NUMBER                   =  5
DOWNSTREAM NODE NUMBER                 =  6
NUMBER OF PREDECESSOR PIPES            =  1
PREDECESSOR PIPE NUMBER/S              =  4
DISCHARGE (cum/sec)                    =11.880
INTERNAL DIAMETER (mm)                 = 2500.
LENGTH (m)                             = 3362.
PRESSURE WAVE VELOCITY (m/sec)         =  929.

PUMP DETAILS:

NUMBER OF WORKING PUMPS                =  7
DISCHARGE PER PUMP (cum/sec)           = 1.697
PUMP HEAD (m)                          =  43.0
SPEED OF PUMP (rpm)                    =  740
WATER LEVEL IN THE SUMP (RL,m)         = 528.00
CODE FOR TYPE OF NON-RETURN VALVE      =  5
TIME OF FIRST 90 % CLOSURE (sec)       =  10.00
TIME OF LAST 10 % CLOSURE (sec)        =  20.00

BOOSTER PUMP DETAILS:

BOOSTER PUMP CLUSTER NUMBER            =  1
NODE NUMBER                            =  4

NUMBER OF WORKING PUMPS                =  8
DISCHARGE PER PUMP (cum/sec)           = 1.485
PUMP HEAD (m)                          =  60.0
SPEED OF PUMP (rpm)                    =  740
HGL ELEVATION ON SUCTION SIDE (RL,m)   = 562.00
PUMP TRIP CODE                         = 1
```

```
CODE FOR TYPE OF NON-RETURN VALVE       = 5
TIME OF FIRST 90 % CLOSURE (sec)        =  10.00
TIME OF LAST 10 % CLOSURE (sec)         =  20.00

DELIVERY RESERVOIR DETAILS:

NODE NUMBER                                    =  6
DISCHARGE INTO THE RESERVOIR (cum/sec)         =11.880
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) = 612.00

RESULTS OF ANALYSIS
NOTES:
1.Where moderate to extensive occurrence of vapour pressure
  is indicated by analysis, the results are to be treated
  as of qualitative value only.
2.Where air valves/air cusion valves are used as vacuum breaker
  the results are to be treated as approximate.
3.The User Manual may be referred for more details regarding
  limitations of analysis and for preparing results in
  graphical form.

DETAILS REGARDING PUMPS

FAILING PUMP
PUMP NUMBER                                       =  1
TIME OF FLOW REVERSAL (sec)                       = 12.55
MINIMUM FLOW OF PUMP (%)                          = -20.4
MINIMUM HEAD OF PUMP (%)                          =  -7.7
MAXIMUM HEAD OF PUMP (%)                          = 100.0
MINIMUM SPEED OF PUMP (%)                         = -14.8

DETAILS REGARDING BOOSTER PUMPS

FAILING BOOSTER PUMP
BOOSTER PUMP NUMBER                               =  1
TIME OF FLOW REVERSAL (sec)                       = 12.79
MINIMUM FLOW OF BOOSTER (%)                       = -26.7
MINIMUM HEAD OF BOOSTER (%)                       =  -6.6
MAXIMUM HEAD OF BOOSTER (%)                       = 100.0
MINIMUM SPEED OF BOOSTER (%)                      = -19.8


MINIMUM & MAXIMUM PIEZOMETRIC HEADS AT SPECIFIED CHAINAGES
```

PIPE NUMBER	SPECIFIED CHAINAGE(m)	NEAREST NODAL CHAINAGE(m)	MIN HEAD (RL,m)	MAX HEAD (RL,m)
1	.0	.0	513.64	608.92
1	20.0	20.0	513.76	608.77
2	.0	.0	513.76	608.77
2	20.0	20.0	514.21	608.58
3	.0	.0	522.72	608.43
3	750.0	750.0	518.94	653.95
3	1537.0	1540.0	531.71	643.87
4	.0	.0	516.77	662.36
4	20.0	20.0	515.93	662.24
5	.0	.0	515.93	662.24
5	.0	.0	515.93	662.24
5	1500.0	1500.9	532.44	643.58
5	3362.0	3362.0	612.00	612.00

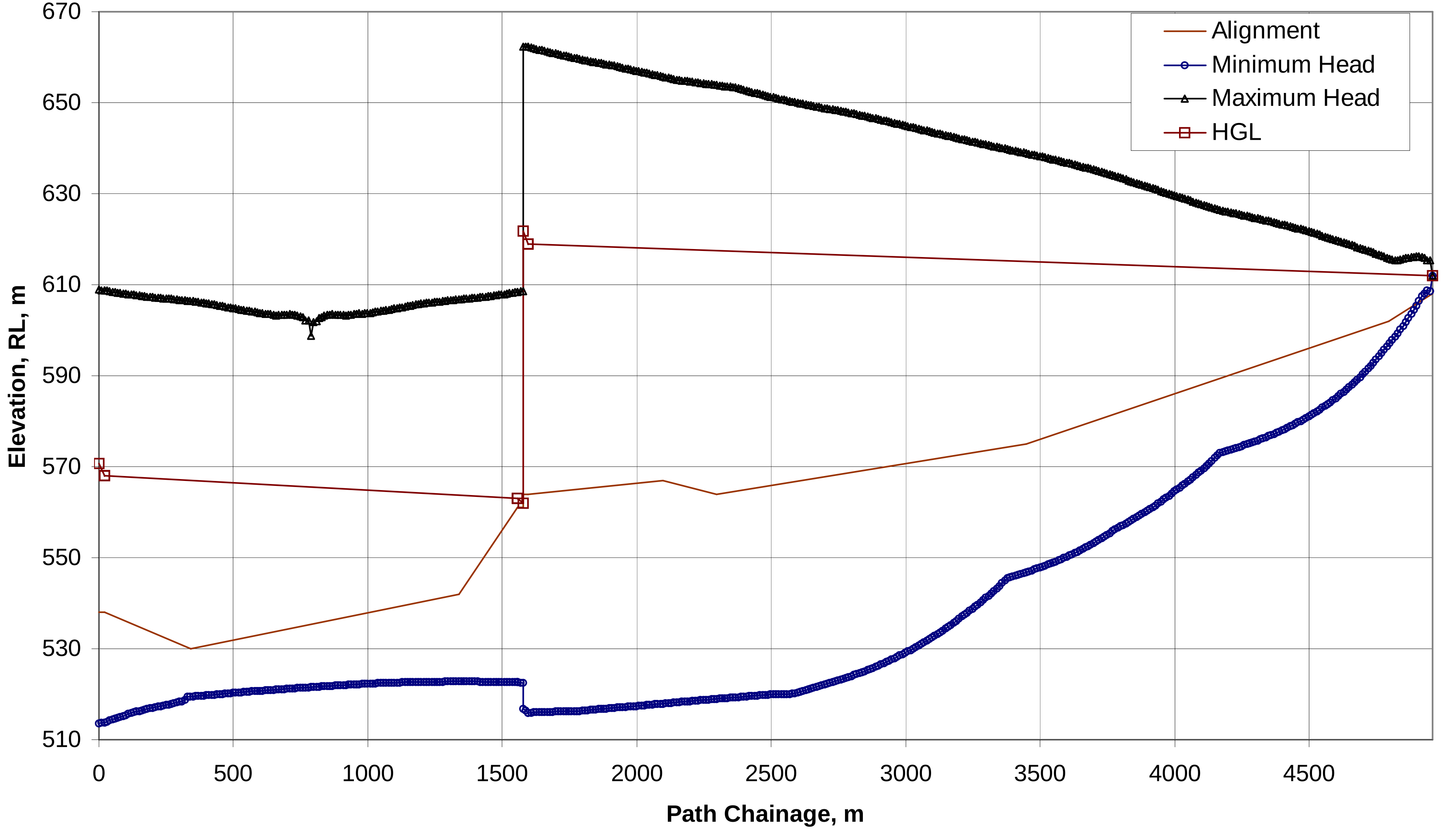


Fig.:Minimum and Maximum Piezometric Heads

Example 5
One Way Surge Tank

Reference File: ex5.sap

Alignment data file: example5.aln

```
1      0      316.5
1      10     316.5
2      0      316.5
2      10     316.5
3      0      312.495
3      25     312.529
3      50     312.564
3      75     312.598
3      100    312.632
3      125    312.667
3      150    312.701
3      175    312.735
3      200    312.769
3      225    312.804
3      250    312.838
3      275    312.872
3      300    312.907
3      325    312.941
3      350    312.637
3      375    312.332
3      400    312.028
3      425    311.724
3      450    311.419
3      475    311.115
3      500    310.811
3      525    310.506
3      550    310.202
3      575    309.898
3      600    309.594
3      625    309.289
3      650    308.985
3      675    308.681
3      700    308.376
3      725    308.072
3      750    307.768
3      775    307.463
3      800    307.159
3      825    306.393
3      850    305.628
3      875    304.862
3      900    304.097
3      925    303.331
3      950    302.566
3      975    301.800
3      1000   301.800
3      1025   301.800
3      1050   301.800
3      1075   301.800
3      1100   301.800
3      1125   301.800
3      1150   301.800
```

3	1175	301.800
3	1200	301.800
3	1225	302.464
3	1250	303.128
3	1275	303.792
3	1300	304.456
3	1325	305.120
3	1350	305.784
3	1375	306.447
3	1400	307.111
3	1425	307.775
3	1450	308.439
3	1475	309.103
3	1500	309.767
3	1525	310.012
3	1550	310.257
3	1575	310.501
3	1600	310.746
3	1625	310.991
3	1650	311.236
3	1675	311.481
3	1700	311.725
3	1725	311.970
3	1750	312.215
3	1775	312.047
3	1800	311.878
3	1825	311.710
3	1850	311.541
3	1875	311.373
3	1900	311.204
3	1925	311.036
3	1950	310.867
3	1975	310.699
3	2000	310.530
3	2025	310.362
3	2050	310.193
3	2075	310.235
3	2100	310.277
3	2125	310.320
3	2150	310.362
3	2175	310.404
3	2200	310.446
3	2225	310.488
3	2250	310.531
3	2275	310.573
3	2300	310.615
3	2325	310.657
3	2350	310.699
3	2375	310.741
3	2400	310.784
3	2425	310.826
3	2450	310.868
3	2475	311.205
3	2500	311.541
3	2525	311.878
3	2550	312.215
3	2575	312.551
3	2600	312.888
3	2625	313.224
3	2650	313.561
3	2675	313.898

3	2700	314.234
3	2725	314.571
3	2750	314.908
3	2775	315.244
3	2800	315.581
3	2825	315.917
3	2850	316.254
3	2875	316.372
3	2900	316.491
3	2925	316.609
3	2950	316.728
3	2975	316.846
3	3000	316.965
3	3025	317.083
3	3050	317.202
3	3075	317.320
3	3100	317.438
3	3125	317.557
3	3150	317.675
3	3175	317.794
3	3200	317.912
3	3225	318.031
3	3250	318.149
3	3275	318.268
3	3300	318.386
3	3325	318.250
3	3350	318.114
3	3375	317.978
3	3400	317.842
3	3425	317.706
3	3450	317.570
3	3475	317.433
3	3500	317.297
3	3525	317.161
3	3550	317.025
3	3575	316.889
3	3600	316.753
3	3625	316.923
3	3650	317.093
3	3675	317.263
3	3700	317.433
3	3725	317.603
3	3750	317.773
3	3775	317.943
3	3800	318.114
3	3825	318.284
3	3850	318.454
3	3875	318.624
3	3900	318.794
3	3925	318.964
3	3950	319.134
3	3975	319.304
3	4000	319.474
3	4025	319.828
3	4050	320.183
3	4075	320.537
3	4100	320.891
3	4125	321.246
3	4150	321.600
3	4175	321.955
3	4200	322.309

3	4225	322.663
3	4250	323.018
3	4275	323.372
3	4300	323.726
3	4325	324.081
3	4350	324.435
3	4375	324.790
3	4400	325.144
3	4425	325.498
3	4450	325.853
3	4475	326.207
3	4500	326.119
3	4525	326.030
3	4550	325.942
3	4575	325.854
3	4600	325.765
3	4625	325.677
3	4650	325.589
3	4675	325.501
3	4700	325.412
3	4725	325.324
3	4750	325.236
3	4775	325.147
3	4800	325.059
3	4825	325.354
3	4850	325.650
3	4875	325.945
3	4900	326.240
3	4925	326.536
3	4950	326.831
3	4975	327.127
3	5000	327.422
3	5025	327.717
3	5050	328.013
3	5075	328.308
3	5100	328.603
3	5125	328.899
3	5150	329.194
3	5175	328.790
3	5200	328.386
3	5225	327.982
3	5250	327.578
3	5275	327.175
3	5300	326.771
3	5325	326.367
3	5350	325.963
3	5375	325.559
3	5400	325.155
3	5425	325.438
3	5450	325.721
3	5475	326.004
3	5500	326.287
3	5525	326.570
3	5550	326.853
3	5575	327.136
3	5600	327.419
3	5625	327.703
3	5650	327.986
3	5675	328.269
3	5700	328.552
3	5725	328.835

3	5750	329.118
3	5775	329.401
3	5800	329.684
3	5825	329.967
3	5850	329.693
3	5875	329.419
3	5900	329.145
3	5925	328.871
3	5950	328.597
3	5975	328.323
3	6000	328.049
3	6025	327.775
3	6050	327.501
3	6075	327.227
3	6100	326.953
3	6125	326.679
3	6150	326.405
3	6175	326.131
3	6200	325.857
3	6225	325.583
3	6250	325.644
3	6275	325.705
3	6300	325.766
3	6325	325.827
3	6350	325.888
3	6375	325.949
3	6400	326.010
3	6425	326.071
3	6450	326.132
3	6475	326.193
3	6500	326.254
3	6525	326.315
3	6550	326.376
3	6575	326.816
3	6600	327.255
3	6625	327.695
3	6650	328.135
3	6675	328.574
3	6700	329.014
3	6725	329.454
3	6750	329.893
3	6775	330.333
3	6800	330.773
3	6825	331.213
3	6850	331.652
3	6875	332.092
3	6900	332.532
3	6925	332.971
3	6950	333.411
3	6975	333.851
3	7000	334.290
3	7025	334.730
3	7050	334.730
3	7075	334.730
3	7100	334.730
3	7125	334.730
3	7150	334.730
3	7175	334.730
3	7200	334.730
3	7225	334.822
3	7250	334.913

3	7275	335.005
3	7300	335.096
3	7325	335.188
3	7350	335.280
3	7375	335.371
3	7400	335.463
3	7425	335.555
3	7450	335.646
3	7475	335.738
3	7500	335.829
3	7525	335.921
3	7550	336.013
3	7575	336.104
3	7600	336.196
3	7625	336.288
3	7650	336.379
3	7675	336.471
3	7700	336.562
3	7725	336.654
3	7750	336.333
3	7775	336.013
3	7800	335.692
3	7825	335.371
3	7850	335.051
3	7875	334.730
3	7900	334.409
3	7925	334.088
3	7950	333.768
3	7975	333.447
3	8000	333.126
3	8025	332.806
3	8050	332.485
3	8075	332.164
3	8100	331.844
3	8125	331.523
3	8150	331.202
3	8175	330.881
3	8200	330.561
3	8225	330.240
3	8250	330.342
3	8275	330.445
3	8300	330.547
3	8325	330.650
3	8350	330.752
3	8375	330.854
3	8400	330.957
3	8425	331.059
3	8450	331.161
3	8475	331.264
3	8500	331.366
3	8525	331.469
3	8550	331.571
3	8575	331.673
3	8600	331.776
3	8625	331.878
3	8650	331.980
3	8675	332.083
3	8700	332.185
3	8725	332.288
3	8750	332.390
3	8775	332.690

3	8800	332.990
3	8825	333.290
3	8850	333.590
3	8875	333.890
3	8900	334.190
3	8925	334.490
3	8950	334.790
3	8975	335.090
3	9000	334.746
3	9025	334.401
3	9050	334.057
3	9075	333.712
3	9100	333.368
3	9125	333.023
3	9150	332.679
3	9175	332.334
3	9200	331.990
3	9225	331.645
3	9250	331.301
3	9275	330.956
3	9300	330.612
3	9325	330.267
3	9350	329.923
3	9375	329.578
3	9400	329.234
3	9425	328.889
3	9450	328.545
3	9475	328.200
3	9500	328.569
3	9525	328.937
3	9550	329.306
3	9575	329.674
3	9600	330.043
3	9625	330.411
3	9650	330.780
3	9675	331.149
3	9700	331.517
3	9725	331.886
3	9750	332.254
3	9775	332.623
3	9800	332.991
3	9825	333.360
3	9850	333.049
3	9875	332.738
3	9900	332.426
3	9925	332.115
3	9950	331.804
3	9975	331.493
3	10000	331.182
3	10025	330.870
3	10050	330.559
3	10075	330.248
3	10100	329.937
3	10125	329.625
3	10150	329.314
3	10175	329.003
3	10200	329.325
3	10225	329.648
3	10250	329.970
3	10275	330.292
3	10300	330.614

3	10325	330.937
3	10350	331.259
3	10375	331.581
3	10400	331.904
3	10425	332.226
3	10450	332.548
3	10475	332.870
3	10500	333.193
3	10525	333.515
3	10550	333.837
3	10575	334.160
3	10600	334.482
3	10625	334.804
3	10650	334.876
3	10675	334.947
3	10700	335.018
3	10725	335.090
3	10750	335.161
3	10775	335.233
3	10800	335.304
3	10825	335.376
3	10850	335.447
3	10875	335.518
3	10900	335.590
3	10925	335.661
3	10950	335.733
3	10975	335.804
3	11000	335.876
3	11025	335.947
3	11050	336.019
3	11075	336.090
3	11100	336.161
3	11125	336.233
3	11150	336.304
3	11175	336.376
3	11200	336.447
3	11225	336.519
3	11250	336.590
3	11275	336.817
3	11300	337.045
3	11325	337.272
3	11350	337.500
3	11375	337.727
3	11400	337.954
3	11425	338.182
3	11450	338.409
3	11475	338.636
3	11500	338.864
3	11525	339.091
3	11550	339.319
3	11575	339.546
3	11600	339.773
3	11625	340.001
3	11650	340.228
3	11675	340.455
3	11700	340.683
3	11725	340.910
3	11750	341.138
3	11775	341.365
3	11800	341.592
3	11825	341.820

```
3     11850 342.047
3     11875 342.404
3     11900 342.760
3     11925 343.117
3     11950 343.473
3     11975 343.830
3     12000 344.186
3     12025 344.543
3     12050 344.899
3     12075 345.256
3     12100 345.612
3     12125 345.969
3     12150 346.325
3     12175 346.682
3     12200 347.038
3     12225 347.395
3     12250 347.751
3     12275 348.108
3     12300 348.464
3     12325 348.821
3     12350 349.177
3     12375 349.534
3     12400 349.890
3     12425 352.845
3     12450 355.800
3     12475 355.800
$
```

Pump characteristics data file: example5.pmp

```
0.1389      83    35
0.2778      81    55
0.4167      78    65
0.5556      75    75.5
0.6944      70.5  82.5
0.8333      66    86
0.9722      60    87
1.005       58    87
1.1111      54    85.5
1.25        45.5  80.5
1.3889      38    75
$
```

Results for Example 5: sap2.res

```
PROJECT          : Example 5

ANALYSIS CASE    : Two one way surge tanks

  TRANSMISSION MAIN DETAILS:

  PIPE NUMBER                               =  1
  UPSTREAM NODE NUMBER                      =  1
  DOWNSTREAM NODE NUMBER                    =  3
  NUMBER OF SUCCESSOR PIPES                 =  1
  SUCCESSOR PIPE NUMBER/S                   =  3
  DISCHARGE (cum/sec)                       = 1.005
  INTERNAL DIAMETER (mm)                    =  750.
  LENGTH (m)                                =    10.
```

```
PRESSURE WAVE VELOCITY (m/sec)          = 1032.

PIPE NUMBER                             =  2
UPSTREAM NODE NUMBER                    =  2
DOWNSTREAM NODE NUMBER                  =  3
NUMBER OF SUCCESSOR PIPES               =  1
SUCCESSOR PIPE NUMBER/S                 =  3
DISCHARGE (cum/sec)                     = 1.005
INTERNAL DIAMETER (mm)                  =  750.
LENGTH (m)                              =    10.
PRESSURE WAVE VELOCITY (m/sec)          = 1032.

PIPE NUMBER                             =  3
UPSTREAM NODE NUMBER                    =  3
DOWNSTREAM NODE NUMBER                  =  4
NUMBER OF PREDECESSOR PIPES             =  2
PREDECESSOR PIPE NUMBER/S               =  1  2
DISCHARGE (cum/sec)                     = 2.010
INTERNAL DIAMETER (mm)                  = 1400.
LENGTH (m)                              = 12475.
PRESSURE WAVE VELOCITY (m/sec)          =  926.

PUMP DETAILS:

PUMP CLUSTER NUMBER                     =  1
NODE NUMBER                             =  1

NUMBER OF WORKING PUMPS                 =  1
OPERATING DISCHARGE PER PUMP (cum/sec)  = 1.005
RATED DISCHARGE OF PUMP (cum/sec)       = 1.005
OPERATING PUMP HEAD (m)                 =  58.0
RATED PUMP HEAD (m)                     =  58.0
RATED PUMP EFFICIENCY (%)               = 87.0
RATED SPEED OF PUMP (rpm)               =  960
GD-SQUARE OF THE PUMP (kgf-sqm)         =  62.00
GD-SQUARE OF THE MOTOR (kgf-sqm)        = 138.40
WATER LEVEL IN THE SUMP (RL,m)          = 314.10
NON-REVERSE ROTATION RATCHET PROVIDED?  = NO
CODE FOR TYPE OF NON-RETURN VALVE       = 6
PUMP TRIP CODE                          = 1
[Running Pump:0; Tripping Pump:1]

PUMP CLUSTER NUMBER                     =  2
NODE NUMBER                             =  2

NUMBER OF WORKING PUMPS                 =  1
OPERATING DISCHARGE PER PUMP (cum/sec)  = 1.005
RATED DISCHARGE OF PUMP (cum/sec)       = 1.005
OPERATING PUMP HEAD (m)                 =  58.0
RATED PUMP HEAD (m)                     =  58.0
RATED PUMP EFFICIENCY (%)               = 87.0
RATED SPEED OF PUMP (rpm)               =  960
GD-SQUARE OF THE PUMP (kgf-sqm)         =  62.00
GD-SQUARE OF THE MOTOR (kgf-sqm)        = 138.40
WATER LEVEL IN THE SUMP (RL,m)          = 314.10
NON-REVERSE ROTATION RATCHET PROVIDED?  = NO
CODE FOR TYPE OF NON-RETURN VALVE       = 6
PUMP TRIP CODE                          = 1
[Running Pump:0; Tripping Pump:1]

DELIVERY RESERVOIR DETAILS:
```

NODE NUMBER = 4
DISCHARGE INTO THE RESERVOIR (cum/sec) = 2.010
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) = 355.80

NUMBER OF ONE WAY SURGE TANKS = 2

DETAILS OF ONE WAY SURGE TANKS:

SL NO	PIPE NO	LOCATION Ch.,m	GL RL,m	STAGING HEIGHT,m	DIAMETER m	STORAGE DEPTH,m	CONNECTING PIPE SIZE,mm
1	3	0.	315.40	20.00	5.000	3.00	700.
2	3	7400.	336.70	8.30	3.000	2.00	400.

RESULTS OF ANALYSIS

NOTES:
1.Where moderate to extensive occurrence of vapour pressure is indicated by analysis, the results are to be treated as of qualitative value only.
2.Where air valves/air cusion valves are used as vacuum breaker the results are to be treated as approximate.
3.The User Manual may be referred for more details regarding limitations of analysis and for preparing results in graphical form.

DETAILS REGARDING PUMPS

FAILING PUMP

PUMP NUMBER = 1
TIME OF FLOW REVERSAL (sec) = 1.82
MINIMUM FLOW OF PUMP (%) = -1.3
MINIMUM HEAD OF PUMP (%) = 14.0
MAXIMUM HEAD OF PUMP (%) = 100.0
MINIMUM SPEED OF PUMP (%) = 31.1

FAILING PUMP

PUMP NUMBER = 2
TIME OF FLOW REVERSAL (sec) = 1.82
MINIMUM FLOW OF PUMP (%) = -1.3
MINIMUM HEAD OF PUMP (%) = 14.0
MAXIMUM HEAD OF PUMP (%) = 100.0
MINIMUM SPEED OF PUMP (%) = 31.1

DETAILS REGARDING ONE WAY SURGE TANKS

TANK NO.	STORAGE DEPTH(m)	EXTENT OF DRAINING(m)	TIME OF COMPLETE DRAINING (Sec)	MAX VELOCITY IN CONN. PIPE(m/sec)
1	3.00	2.75	NO FULL DRG	4.17
2	2.00	1.17	NO FULL DRG	3.94

MINIMUM & MAXIMUM PIEZOMETRIC HEADS AT SPECIFIED CHAINAGES

PIPE SPECIFIED NEAREST NODAL MIN HEAD MAX HEAD

NUMBER	CHAINAGE(m)	CHAINAGE(m)	(RL,m)	(RL,m)
1	.0	.0	322.25	376.17
3	.0	.0	328.38	375.82
3	2000.0	1996.0	332.90	375.66
3	4000.0	3992.0	331.37	374.61
3	6000.0	5988.0	329.62	373.37
3	8000.0	7984.0	342.92	365.81
3	9000.0	8982.0	342.03	365.81
3	10000.0	9980.0	341.11	364.80
3	11000.0	10978.0	340.13	364.97
3	12475.0	12475.0	355.80	355.80

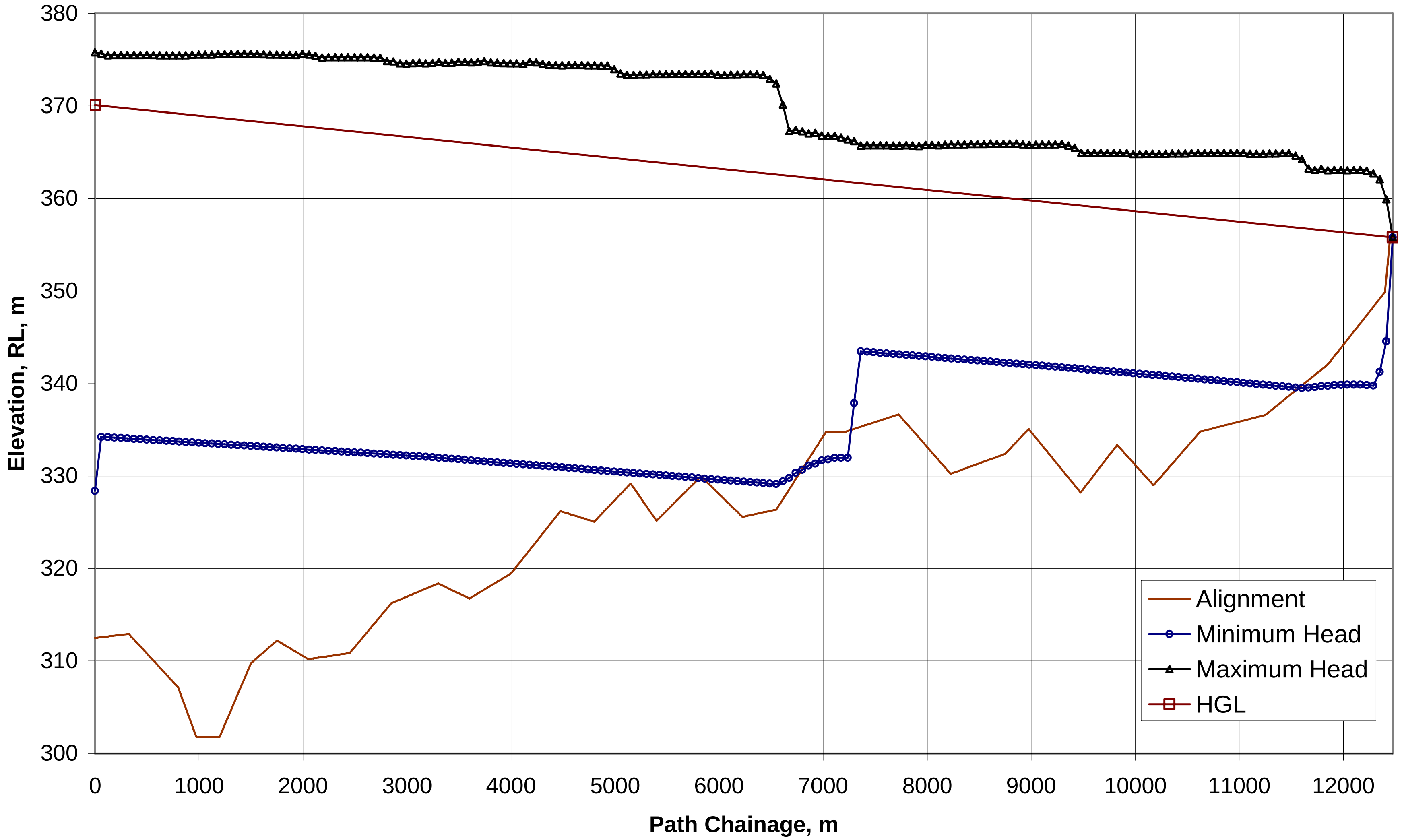


Fig.:Minimum and Maximum Piezometric Heads

Example 6
Air Vessel and Intermediate Non-return Valve

Reference file: ex6.sap

Alignment data file: example6.aln

```
1     0     471
1     10    471
5     0     471
5     300   473.6
5     960   477.68
5     1500  483.92
5     1920  486.72
5     1980  486.67
5     2280  484.24
5     2340  484
5     2640  484
5     2820  485.77
5     3300  490.4
5     3840  494.4
5     3900  494.26
5     4260  489.9
5     4320  488.86
5     4380  488.3
5     4440  488.74
5     4500  489.61
5     4620  491.69
5     4800  496.38
5     4860  497.12
5     5220  499.88
5     5280  500.77
5     5640  513.8
5     6660  548.12
5     7020  550.27
5     7260  555.47
5     7320  556.28
5     7380  556.28
5     7440  555.25
5     7500  553.87
5     7560  552.49
5     7620  551.12
5     7680  555.06
5     7740  559
5     7770  559.5
$
```

Pump characteristics data:
Choose Machinery finalised : No
Type of pump characteristics : Mixed

Results for Example 6: sap2.res

```
PROJECT           : Example 6

ANALYSIS CASE     : Air vessel and Intermediate NRV
```

```
TRANSMISSION MAIN DETAILS:

PIPE NUMBER                              =  1
UPSTREAM NODE NUMBER                     =  1
DOWNSTREAM NODE NUMBER                   =  5
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  5
DISCHARGE (cum/sec)                      =  .423
INTERNAL DIAMETER (mm)                   =  400.
LENGTH (m)                               =    10.
PRESSURE WAVE VELOCITY (m/sec)           = 1071.

PIPE NUMBER                              =  2
UPSTREAM NODE NUMBER                     =  2
DOWNSTREAM NODE NUMBER                   =  5
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  5
DISCHARGE (cum/sec)                      =  .423
INTERNAL DIAMETER (mm)                   =  400.
LENGTH (m)                               =    10.
PRESSURE WAVE VELOCITY (m/sec)           = 1071.

PIPE NUMBER                              =  3
UPSTREAM NODE NUMBER                     =  3
DOWNSTREAM NODE NUMBER                   =  5
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  5
DISCHARGE (cum/sec)                      =  .423
INTERNAL DIAMETER (mm)                   =  400.
LENGTH (m)                               =    10.
PRESSURE WAVE VELOCITY (m/sec)           = 1071.

PIPE NUMBER                              =  4
UPSTREAM NODE NUMBER                     =  4
DOWNSTREAM NODE NUMBER                   =  5
NUMBER OF SUCCESSOR PIPES                =  1
SUCCESSOR PIPE NUMBER/S                  =  5
DISCHARGE (cum/sec)                      =  .423
INTERNAL DIAMETER (mm)                   =  400.
LENGTH (m)                               =    10.
PRESSURE WAVE VELOCITY (m/sec)           = 1071.

PIPE NUMBER                              =  5
UPSTREAM NODE NUMBER                     =  5
DOWNSTREAM NODE NUMBER                   =  6
NUMBER OF PREDECESSOR PIPES              =  4
PREDECESSOR PIPE NUMBER/S                =  1  2  3  4
DISCHARGE (cum/sec)                      = 1.692
INTERNAL DIAMETER (mm)                   = 1100.
LENGTH (m)                               =  7770.
PRESSURE WAVE VELOCITY (m/sec)           = 1004.

PUMP DETAILS:

PUMP CLUSTER NUMBER                      =  1
NODE NUMBER                              =  1

NUMBER OF WORKING PUMPS                  =  1
DISCHARGE PER PUMP (cum/sec)             =  .423
PUMP HEAD (m)                            = 112.0
```

```
SPEED OF PUMP (rpm)                        = 1480
WATER LEVEL IN THE SUMP (RL,m)             = 471.00
CODE FOR TYPE OF NON-RETURN VALVE          =  6
PUMP TRIP CODE                             = 1
[Running Pump:0; Tripping Pump:1]

PUMP CLUSTER NUMBER                        =  2
NODE NUMBER                                =  2

NUMBER OF WORKING PUMPS                    =  1
DISCHARGE PER PUMP (cum/sec)               =  .423
PUMP HEAD (m)                              = 112.0
SPEED OF PUMP (rpm)                        = 1480
WATER LEVEL IN THE SUMP (RL,m)             = 471.00
CODE FOR TYPE OF NON-RETURN VALVE          =  6
PUMP TRIP CODE                             = 1
[Running Pump:0; Tripping Pump:1]

PUMP CLUSTER NUMBER                        =  3
NODE NUMBER                                =  3

NUMBER OF WORKING PUMPS                    =  1
DISCHARGE PER PUMP (cum/sec)               =  .423
PUMP HEAD (m)                              = 112.0
SPEED OF PUMP (rpm)                        = 1480
WATER LEVEL IN THE SUMP (RL,m)             = 471.00
CODE FOR TYPE OF NON-RETURN VALVE          =  6
PUMP TRIP CODE                             = 1
[Running Pump:0; Tripping Pump:1]

PUMP CLUSTER NUMBER                        =  4
NODE NUMBER                                =  4

NUMBER OF WORKING PUMPS                    =  1
DISCHARGE PER PUMP (cum/sec)               =  .423
PUMP HEAD (m)                              = 112.0
SPEED OF PUMP (rpm)                        = 1480
WATER LEVEL IN THE SUMP (RL,m)             = 471.00
CODE FOR TYPE OF NON-RETURN VALVE          =  6
PUMP TRIP CODE                             = 1
[Running Pump:0; Tripping Pump:1]

DELIVERY RESERVOIR DETAILS:

NODE NUMBER                                       =  6
DISCHARGE INTO THE RESERVOIR (cum/sec)            = 1.692
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) = 566.00


DETAILS OF AIR VESSEL

AIR VESSEL LOCATION PIPE NUMBER            =  5
GROUND LEVEL AT THE LOCATION (RL,m)        = 473.500
SIZE PARAMETER OF THE AIR VESSEL (KAV)     =  2.93
NRV PROVIDED ON THE TRANSMISSION MAIN?     - NO
CONNECTING PIPE SIZE (mm)                  = 700.
TYPE OF AIR VESSEL (1 or 2)                = 1
SIZE OF ORIFICE IN CONNECTING PIPE (mm) = 400.

NUMBER OF INTERMEDIATE NONRETURN VALVES =  1
```

DETAILS OF INTERMEDIATE NONRETURN VALVES

SL NO.	PIPE NO.	LOCATION Chainage,m	BYPASS SIZE(mm)	DELAY IN CLOSURE(sec)
1	5	5600.	300.	.00

RESULTS OF ANALYSIS

NOTES:
1.Where moderate to extensive occurrence of vapour pressure is indicated by analysis, the results are to be treated as of qualitative value only.
2.Where air valves/air cusion valves are used as vacuum breaker the results are to be treated as approximate.
3.The User Manual may be referred for more details regarding limitations of analysis and for preparing results in graphical form.

DETAILS REGARDING PUMPS

FAILING PUMP

PUMP NUMBER = 1
TIME OF FLOW REVERSAL (sec) = .85
MINIMUM FLOW OF PUMP (%) = -2.9
MINIMUM HEAD OF PUMP (%) = 61.1
MAXIMUM HEAD OF PUMP (%) = 100.0
MINIMUM SPEED OF PUMP (%) = 68.9

FAILING PUMP

PUMP NUMBER = 2
TIME OF FLOW REVERSAL (sec) = .85
MINIMUM FLOW OF PUMP (%) = -2.9
MINIMUM HEAD OF PUMP (%) = 61.1
MAXIMUM HEAD OF PUMP (%) = 100.0
MINIMUM SPEED OF PUMP (%) = 68.9

FAILING PUMP

PUMP NUMBER = 3
TIME OF FLOW REVERSAL (sec) = .85
MINIMUM FLOW OF PUMP (%) = -2.9
MINIMUM HEAD OF PUMP (%) = 61.1
MAXIMUM HEAD OF PUMP (%) = 100.0
MINIMUM SPEED OF PUMP (%) = 68.9

FAILING PUMP

PUMP NUMBER = 4
TIME OF FLOW REVERSAL (sec) = .85
MINIMUM FLOW OF PUMP (%) = -2.9
MINIMUM HEAD OF PUMP (%) = 61.1
MAXIMUM HEAD OF PUMP (%) = 100.0
MINIMUM SPEED OF PUMP (%) = 68.9

DETAILS REGARDING AIR VESSEL

```
AIR VOLUME UNDER WORKING CONDITION (cum)          = 19.20
MAXIMUM AIR VOLUME UNDER SURGE (cum)              = 44.26
TIME OF OCCURENCE OF MAXIMUM AIR VOLUME (sec)     =  31.3
MINIMUM AIR VOLUME UNDER SURGE (cum)              = 16.17
TIME OF OCCURRENCE OF MINIMUM AIR VOLUME (sec)    =  81.7
MAXIMUM VELOCITY THROUGH CONNECTING PIPE (m/sec)  = 4.68
MAXIMUM VELOCITY THROUGH ORIFICE (m/sec)          = 14.3
```

MINIMUM & MAXIMUM PIEZOMETRIC HEADS AT SPECIFIED CHAINAGES

PIPE NUMBER	SPECIFIED CHAINAGE(m)	NEAREST NODAL CHAINAGE(m)	MIN HEAD (RL,m)	MAX HEAD (RL,m)
1	.0	.0	508.06	608.63
5	.0	.0	508.13	608.58
5	2000.0	1981.3	513.94	603.18
5	4000.0	4001.6	522.19	591.42
5	5000.0	5011.6	525.89	585.35
5	6500.0	6488.0	543.54	576.14
5	7770.0	7770.0	566.00	566.00

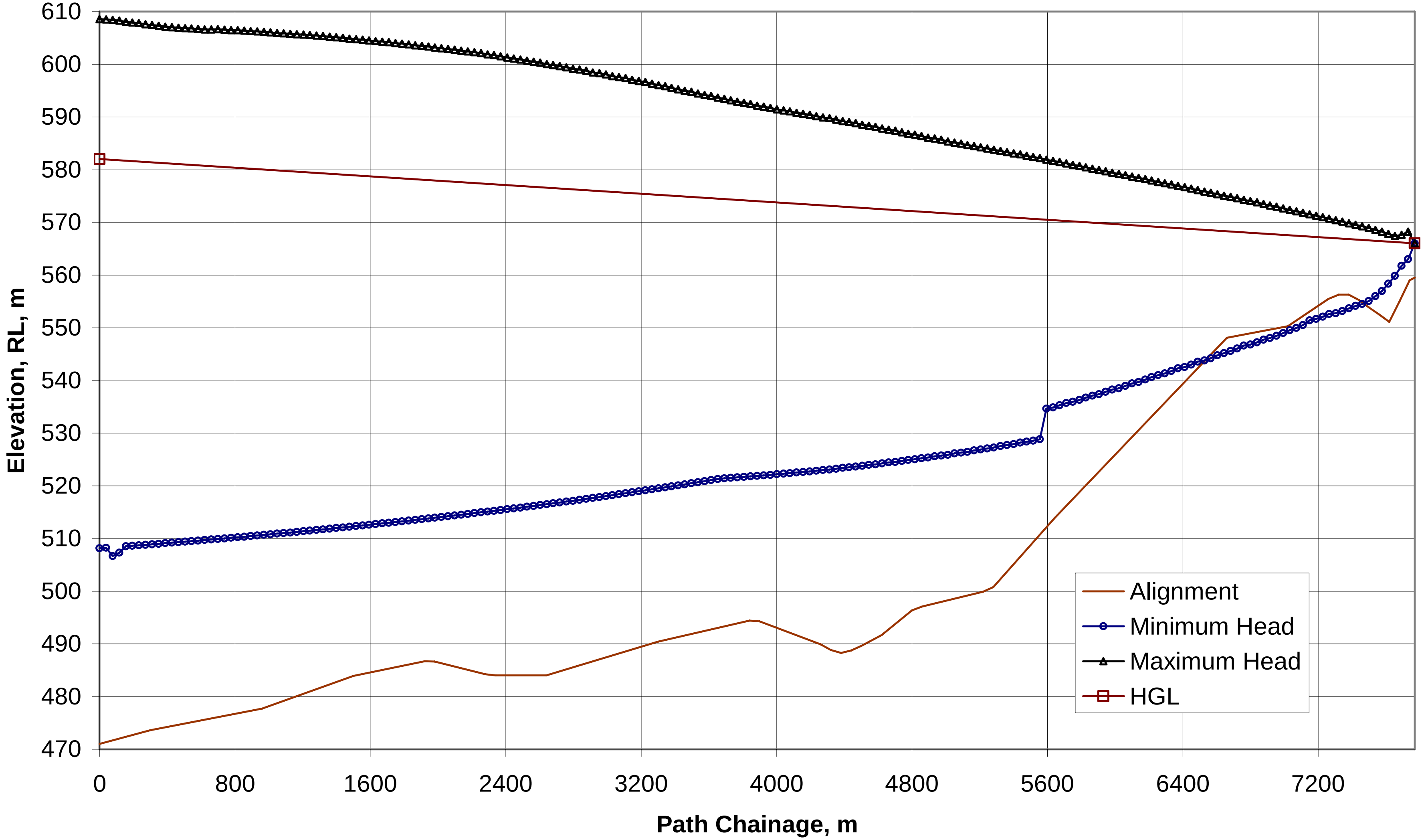


Fig.:Minimum and Maximum Piezometric Heads

EXAMPLE 7
GRAVITY MAIN

Reference File : ex7.sap

Alignment Data File Name : example7.aln

```
1 0     84
1 5000  76
1 10000 56
1 12000 22
1 15000 24
1 25000 32
1 30000 33.5
1 35000 40
1 40000 37.5
1 45000 40
1 50000 38
1 56000 51.5
1 65000 34.5
1 72000 54
1 81000 30.5
1 86000 21.5
1 93000 35.5
1 99000 50
1 107500 32
1 127500 28
1 132000 38
1 140000 11
1 145000 8
1 150000 18
1 155000 4
1 160000 4
1 165000 20
1 170000 29
1 177500 36
1 178500 36
2 178500 36
2 186000 18
2 188000 28
2 192000 17
2 200000 16
$
```

Results File for Example 7 : sap2.res

```
  PROJECT          : Example 7

  ANALYSIS CASE    : Gravity Main

  TRANSMISSION MAIN DETAILS:

  PIPE NUMBER                              =  1
  UPSTREAM NODE NUMBER                     =  1
  DOWNSTREAM NODE NUMBER                   =  2
  NUMBER OF SUCCESSOR PIPES                =  1
  SUCCESSOR PIPE NUMBER/S                  =  2
  DISCHARGE (cum/sec)                      = 2.080
```

INTERNAL DIAMETER (mm) = 1875.
LENGTH (m) = 178500
PRESSURE WAVE VELOCITY (m/sec) = 911.

PIPE NUMBER = 2
UPSTREAM NODE NUMBER = 2
DOWNSTREAM NODE NUMBER = 3
NUMBER OF PREDECESSOR PIPES = 1
PREDECESSOR PIPE NUMBER/S = 1
DISCHARGE (cum/sec) = 2.080
INTERNAL DIAMETER (mm) = 1500.
LENGTH (m) =21500.
PRESSURE WAVE VELOCITY (m/sec) = 925.

SOURCE RESERVOIR DETAILS:

NODE NUMBER = 1
DISCHARGE FROM THE RESERVOIR (cum/sec) = 2.080
WATER LEVEL IN THE RESERVOIR (RL,m) = 96.00

DELIVERY RESERVOIR DETAILS:

NODE NUMBER = 3
DISCHARGE INTO THE RESERVOIR (cum/sec) = 2.080
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) = 16.45

RESULTS OF ANALYSIS

NOTES:
1. Where moderate to extensive occurrence of vapour pressure is indicated by analysis, the results are to be treated as of qualitative value only.
2. Where air valves/air cusion valves are used as vacuum breaker the results are to be treated as approximate.
3. The User Manual may be referred for more details regarding limitations of analysis and for preparing results in graphical form.

TOTAL OUTFLOW AT RESERVOIR TILL VALVE CLOSURE(cum)= 1742.6

MINIMUM & MAXIMUM PIEZOMETRIC HEADS AT SPECIFIED CHAINAGES

PIPE NUMBER	SPECIFIED CHAINAGE(m)	NEAREST NODAL CHAINAGE(m)	MIN HEAD (RL,m)	MAX HEAD (RL,m)
1	.0	.0	96.00	96.00
1	40000.0	39888.3	69.08	135.55
1	80000.0	79776.5	67.78	135.36
1	120000.0	119664.8	53.66	140.60
1	160000.0	159553.1	39.55	145.62
1	178500.0	178500.0	32.85	147.30
2	178500.0	178500.0	32.85	147.30
2	190000.0	189761.9	24.30	147.74
2	200000.0	200000.0	16.45	16.45

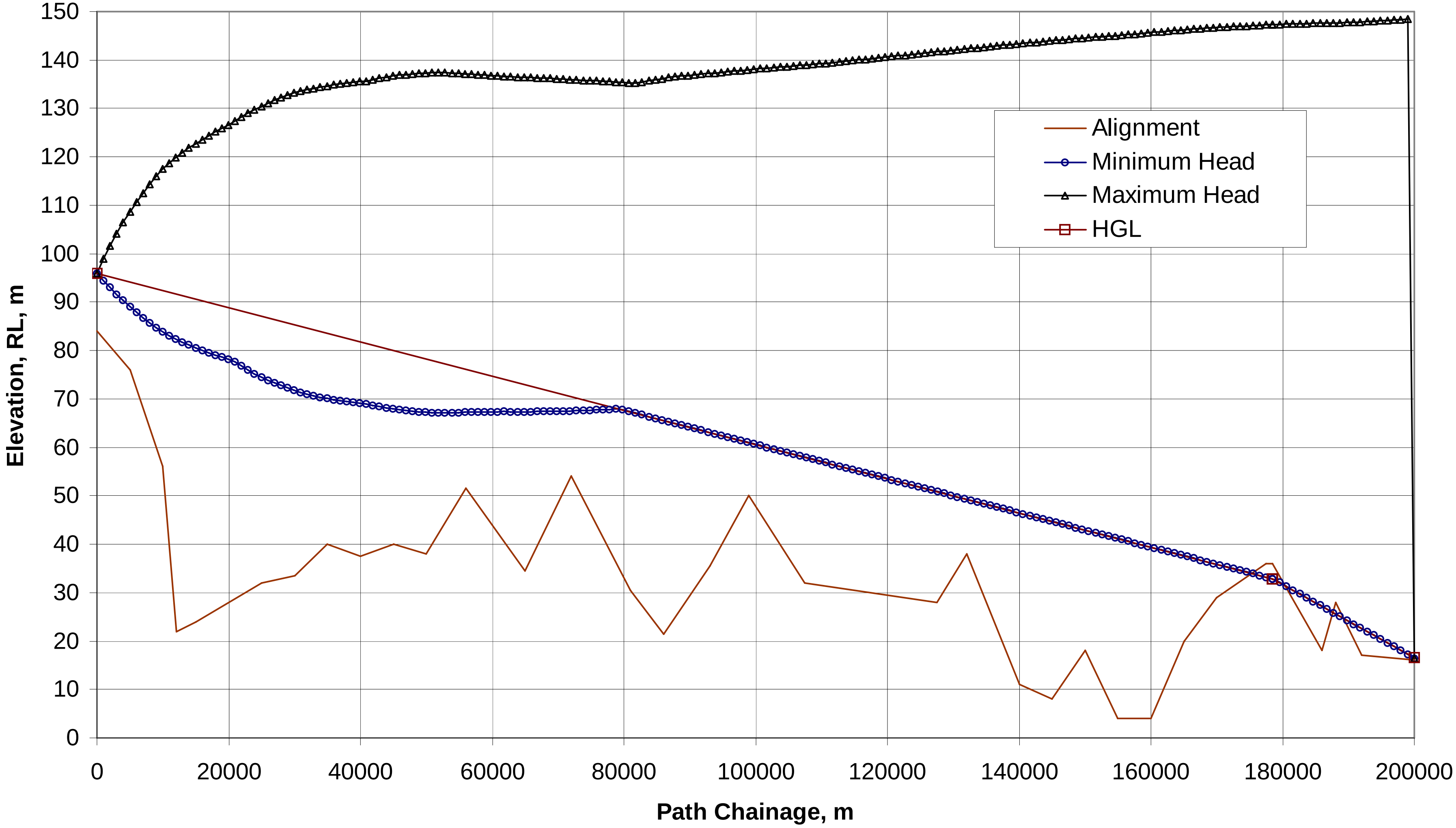


Fig.:Minimum and Maximum Piezometric Heads

EXAMPLE 8
GRAVITY MAIN WITH THROTTLING AT U/S END

Reference File : ex8.sap

Alignment Data File Name : example8.aln

```
1 0    84
1 2000 82
2 2000 82
2 5000 76
2 10000 56
2 12000 22
2 15000 24
2 25000 32
2 30000 33.5
2 35000 40
2 40000 37.5
2 45000 40
2 50000 38
2 56000 51.5
2 65000 34.5
2 72000 54
2 81000 30.5
2 86000 21.5
2 93000 35.5
2 99000 50
2 107500 32
2 127500 28
2 132000 38
2 140000 11
2 145000 8
2 150000 18
2 155000 4
2 160000 4
2 165000 20
2 170000 29
2 177500 36
2 178500 36
3 178500 36
3 186000 18
3 188000 28
3 192000 17
3 200000 16
$
```

Results File for Example 8 : sap2.res

```
PROJECT          : Example 8

ANALYSIS CASE    : Gravity main - Throttling at u/s end

TRANSMISSION MAIN DETAILS:

PIPE NUMBER                             =  1
UPSTREAM NODE NUMBER                    =  1
DOWNSTREAM NODE NUMBER                  =  2
NUMBER OF SUCCESSOR PIPES               =  1
SUCCESSOR PIPE NUMBER/S                 =  2
DISCHARGE (cum/sec)                     = 2.080
INTERNAL DIAMETER (mm)                  = 1875.
LENGTH (m)                              = 2000.
PRESSURE WAVE VELOCITY (m/sec)          =  911.

PIPE NUMBER                             =  2
UPSTREAM NODE NUMBER                    =  2
DOWNSTREAM NODE NUMBER                  =  3
NUMBER OF PREDECESSOR PIPES             =  1
PREDECESSOR PIPE NUMBER/S               =  1
NUMBER OF SUCCESSOR PIPES               =  1
SUCCESSOR PIPE NUMBER/S                 =  3
DISCHARGE (cum/sec)                     = 2.080
INTERNAL DIAMETER (mm)                  = 1875.
LENGTH (m)                              = 176500
PRESSURE WAVE VELOCITY (m/sec)          =  911.

PIPE NUMBER                             =  3
UPSTREAM NODE NUMBER                    =  3
DOWNSTREAM NODE NUMBER                  =  4
NUMBER OF PREDECESSOR PIPES             =  1
PREDECESSOR PIPE NUMBER/S               =  2
DISCHARGE (cum/sec)                     = 2.080
INTERNAL DIAMETER (mm)                  = 1500.
LENGTH (m)                              =21500.
PRESSURE WAVE VELOCITY (m/sec)          =  925.

SOURCE RESERVOIR DETAILS:

NODE NUMBER                             =  1
DISCHARGE FROM THE RESERVOIR (cum/sec)  = 2.080
WATER LEVEL IN THE RESERVOIR (RL,m)     =  96.00


DELIVERY RESERVOIR DETAILS:

NODE NUMBER                                    =  4
DISCHARGE INTO THE RESERVOIR (cum/sec)         = 2.080
RESERVOIR WATER LEVEL OR DELIVERY LEVEL (RL,M) =  16.45


DETAILS OF CONCENTRATED LOCAL HEAD LOSS:

NODE NUMBER                             =  2
HGL ELEVATION ON UPSTREAM SIDE (RL,m)   =  95.95
HGL ELEVATION ON DOWNSTREAM SIDE (RL,m) =  79.50
```

RESULTS OF ANALYSIS

NOTES:
1.Where moderate to extensive occurrence of vapour pressure is indicated by analysis, the results are to be treated as of qualitative value only.
2.Where air valves/air cusion valves are used as vacuum breaker the results are to be treated as approximate.
3.The User Manual may be referred for more details regarding limitations of analysis and for preparing results in graphical form.

TOTAL OUTFLOW AT RESERVOIR TILL VALVE CLOSURE(cum)= 1741.4

MINIMUM & MAXIMUM PIEZOMETRIC HEADS AT SPECIFIED CHAINAGES

PIPE NUMBER	SPECIFIED CHAINAGE(m)	NEAREST NODAL CHAINAGE(m)	MIN HEAD (RL,m)	MAX HEAD (RL,m)
1	.0	.0	96.00	96.00
1	2000.0	2000.0	93.19	101.14
2	2000.0	2000.0	79.50	102.63
2	40000.0	39892.7	69.48	130.79
2	80000.0	79779.7	58.94	129.56
2	120000.0	119666.7	48.40	133.14
2	160000.0	159553.7	37.86	137.06
2	178500.0	178500.0	32.85	138.37
3	185000.0	184642.9	28.18	138.66
3	199000.0	198976.2	17.30	139.56
3	200000.0	200000.0	16.45	16.45

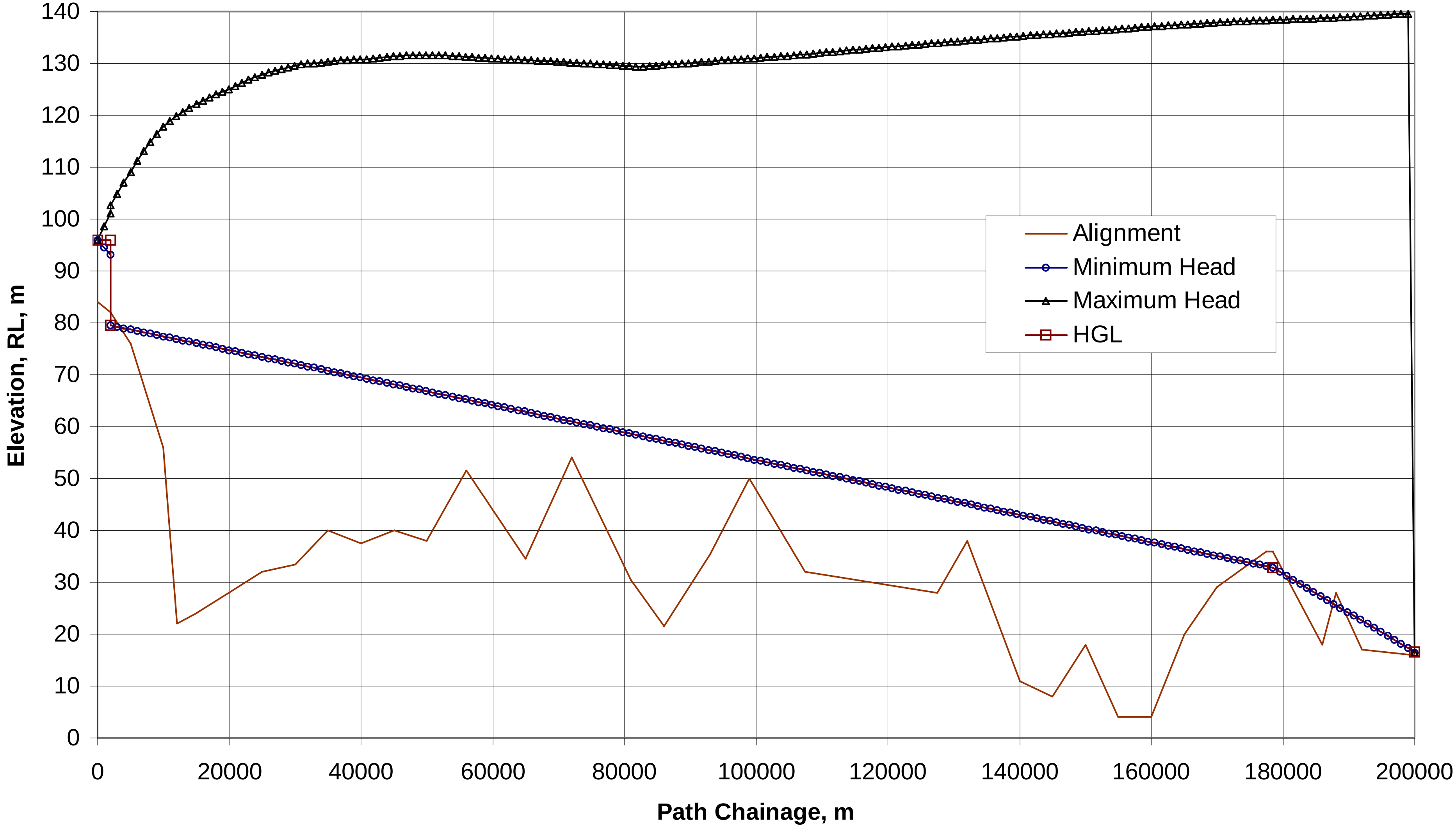


Fig.:Minimum and Maximum Piezometric Heads