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Hydraulic Transient: Lift Irrigation Scheme

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ABSTRACT:

Water hammer or hydraulic transient occur in pumping mains of Lift Irrigation Scheme (LIS) due to rapid changes in flow. These changes may be due to valve operations (sudden opening or closing of valves) or due to sudden failure of pumps following power failure. The resulting maximum and minimum water hammer pressures govern the design of a pumping main. The present study focuses on analysis of hydraulic transient phenomenon that may occur in pumping main of LIS. Sensitivity of water hammer pressure may be investigated with variation of various input parameters like pipe type, diameter, thickness and water temperature, pump inertia etc. Here sensitivity of maximum and minimum water hammer pressure is investigated with variation of key input parameters like pipe diameter and thickness.

In this study, Shirala Lift Irrigation Scheme was modeled for transient analysis by using SAP2 software. The scheme is characterised by total discharge of 1.18 m^3/s, dynamic pump head of 58.86 m and 3.75 kilometers of mild steel pumping main. The sensitivity in hydraulic transient is investigated for variation of above mentioned key input parameters. It is observed that parameters to which water hammer is most sensitive are pipe diameter and thickness.

KEYWORDS: *Hydraulic transient, Pumping main, Pressure wave, SAP2, Sensitivity, Shirala LIS, Transient analysis, Water hammer*

I. INTRODUCTION

Pumping mains in lift irrigation scheme are required for safe, reliable and economic conveyance. Variation in fluid velocity causes pressure variations. Sudden failure of a pump or closing a valve cause propagation of transient pressure wave throughout the hydraulic system. This may cause significant pressure variations with reference to operating pressure, column separations, extensive cavitation, structural shakes and mass vibrations. Transient analysis is important aspect to be considered while designing pumping stations and pumping mains. Various codes and applications are developed to calculate or simulate water hammer, including but not limited to: Hammer, Surge, KYPipe, Hytran, Pipenet, Hypress, Flowmaster, LIQT, AFT Impulse, Transam, Relap5 andSAP2.

This study aims at hydraulic transient analysis of Shirala LIS for main governing conditions of upsurge & downsurge and also to investigate sensitivity of maximum & minimum transient pressures to change in parameters like pipe diameter and thickness. SAP2 software is used for transient analysis. Analyses are carried out with variations in input parameters.

The paper is divided into sub sections; section 2 presents recent literature on sensitivity analysis of water hammer problems in pipelines. Section 3 presents case study of Shirala LIS and input data. Section 4 deals with the methodology of the study. Section 5 presents analysis of results. The paper is concluded in section 6.

II. LITERATURE SURVEY

Kaliatka et al. (2009) studied water hammer model's sensitivity using a new approach called FAST (Fourier amplitude sensitivity test) and offered the results of their study. A water hammer induced by a fast valve closing was investigated using the RELAP5 / Mod3.3 code model.

Jalil Emadi and Abbas Solemani (2011) focused on determining significance of each input parameter of the application relative to the maximum water hammer estimated by the Hammer software. They found that moment of inertia of pump and electromotor, diameter, type and thickness of pipe and water temperature are the most effective parameters in reducing maximum water hammer.

Behnam Mansuri, Farzin Salmasi and Behrooz Oghati (2014) studied the sensitivity analysis for water hammer problem in pipelines by simulating the transient equations in MATLAB. They investigated sensitivity in negative and positive transient pressures by changing some variables such as pipe diameter, pipe length and wave velocity in pipe.

Sensitivity in transient analysis is less attended area in hydraulic transients. Limited literature is available.

III. CASE STUDY

This study examines hydraulic transients for main governing conditions of upsurge & downsurge and the sensitivity of transient pressures in the context of Shirala Lift Irrigation Scheme. It is on the left bank of Sina River, on upstream of Mahisgaon K.T.Weir near village Shirala in Paranda tahsil of Osmanabad district of Maharashtra state. The source of water is Sina river feed through Bhima-Sina link canal from Ujani reservoir. The scheme consists of lifting of water from Sina river on in single stage, providing irrigation benefits to 2850 Ha. of draught prone command area using 0.63 T.M.C. (17.84 Mm3) of water. The scheme is being implemented by the Water Resources Department, Maharashtra State. Figure 1 shows the geographical location of the scheme. It has two delivery mains, single pumping main and two pumps. Diameter, type and thickness of pipeline as well as discharge rate follow a uniform pattern throughout the pipeline system. Figure 2 shows layout of the scheme.

Figure 1. Index map of Maharashtra showing location of Shirala LIS

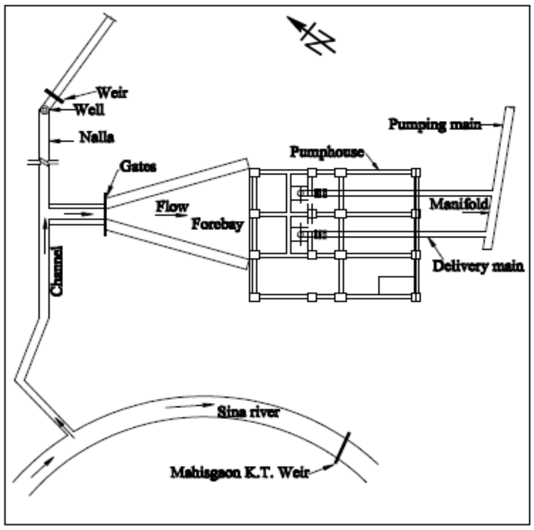

Figure 2. Typical layout of Shirala LIS

Input data

Physical and hydraulic characteristics of the pumping main used for transient and sensitivity analysis includes pumping main alignment data and pump data. The input data was obtained from Lift Irrigation Circle, Central Designs Organisation, Nashik. Figure 3 shows the longitudinal alignment of the pumping main. Figure 4 shows the schematic layout of the water transmission system of the project. It consists of two delivery mains and single pumping main. Delivery mains are 24 m long mild steel pipes of 600 mm internal diameter with 12 mm wall thickness. Centerline elevation of horizontal delivery mains is 482.50 m.Their chainage ranges from 0 to 24 m. Pumping main is 3750 m long mild steel pipe of 850 mm internal diameter with 6 mm wall thickness. Centerline elevation of pumping main at start is 482.50 m and at end at delivery chamber is 515.155 m. Its chainage ranges from 24 to 3774 m.

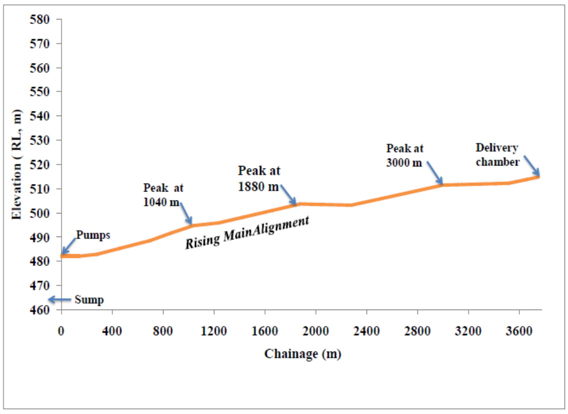

Figure 3. Longitudinal alignment of pumping main

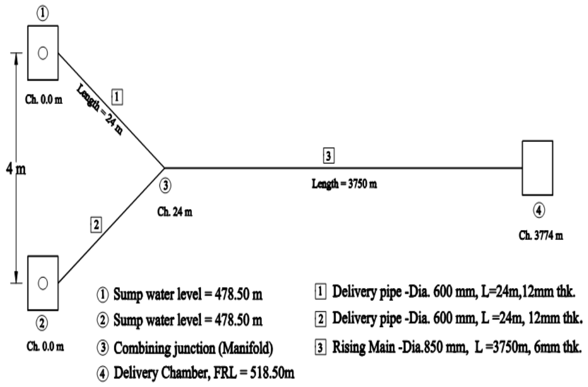

Figure 4. Schematic layout of Shirala LIS

Table 1 shows input data required for transient analysis.

Table 1. Input data for transient analysis

1	Design discharge	1.18 m^3/s
2	Sump bottom level	466.00 m
3	MDDL in pump sump	471.00 m
4	FRL in sump	475.50 m
5	POL in sump	478.50 m
6	Centerline level of delivery pipe	482.50 m
7	FSL in delivery chamber	518.50 m
8	Pumping main Material Diameter Pipe wall thickness Number Length Discharge	 Mild steel (MS) 850 mm 6 mm 1 No 3750 m Discharge 1.18 m^3/s
9	Delivery main Material Diameter Pipe wall thickness Number Length Discharge	 Mild steel (MS) 600 mm 12 mm 2 Nos 24 m Discharge 0.59 m^3/s
10	Pump details Type H.P. Nos Rated discharge / pump Rated Head for pump Rated speed of pump Pump efficiency GD^2 of pump GD^2 of motor	 Vertical turbine pumps 525 H.P 2 Nos 0.59 m^3/s 58.86 m 988 rpm 87.42 % 37 kg-m^2 68 kg-m^2

IV. METHODOLOGY

4.1 Transient Phenomenon

A phenomenon called water hammer / surge /hydraulic transients occurs in the pumping main of LIS when there are rapid changes in discharge. Change in flow rate due to rapid closure of control valves or tripping of pump following power failure causes to and fro transmission of transient pressure waves till steady state of flow is achieved. If the magnitude of resulting maximum and minimum pressure exceeds the limiting values and if the surge protection measures are not in place, a transient can cause pipe burst or pipe collapse. Therefore transient analysis is important during design stage for deciding protection measures and for ensuring proper functioning during operation stage.

4.2 Governing Equations

Transient / Unsteady flow through closed conduits can be described by the continuity and momentum equations given below. These equations are derived using equation of continuity of flow and Newton's second law [4].

Continuity Equation

$$\frac{\partial H}{\partial t} + V\frac{dH}{\partial x} + \frac{a^2}{g}\frac{\partial V}{\partial x} = 0 \qquad (1)$$

Momentum equation

$$\frac{\partial v}{\partial t} + V\frac{\partial v}{\partial x} + g\frac{\partial H}{\partial x} + \frac{fV|V|}{2D} = 0 \qquad (2)$$

In above equations, parameter D is inside diameter of pipe, a is pressure wave velocity, H is the piezometric head at the centerline of conduit above the specified datum, V is the average velocity of flow, f is friction coefficient, x is location dimension, t is time dimension and gravitational acceleration constant. The equations (1) and (2) describing the transient state flow in closed conduits are hyperbolic, partial differential equations. Most widely used Method of Characteristics is used to solve these equations. Transient analysis essentially consists of solving these equations, for every solution point and time step, for a wide variety of boundary conditions and system configurations.

4.3 Analysis Conditions

Various conditions considered in transient analysis are as below:

Steady state analysis: For steady flow there is no water hammer. Therefore, profiles for steady HGL, minimum & maximum pressure head must coincide. This option of analysis with all pumps running is a useful to check the validity of data and to detect possible errors.

Transient analysis: Power failure and single pump failure are the most critical surge condition for a pumping main in LIS. Failure of all the pumps due to power failure is critical with regard to surge pressures in the pumping main. Single pump failure, when multiple pumps are in parallel operation is critical with regard to surge pressures in the pump house. All transient analysis for a pumping main are carried out for critical surge condition of tripping of all pumps following power failure. Following conditions are considered.

i. Analysis without surge protection & without column separation: May or may not show extensive occurrence of negative pressures all along the alignment of pumping main.

ii. Analysis with column separation: If the above analysis shows extensive occurrence of negative pressures, transient analysis is carried out with column separation to find severity of upsurge due to rejoining of separated water columns.

iii. Analysis with / without column separation for upsurge protection: Is carried to find out effect upsurge protection devices on maximum pressure. These devices primarily control the upsurge.

iv. Analysis for downsurge protection: Is carried to find out effect of downsurge protection devices on minimum pressure. These devices primarily control the downsurge.

Limiting values of downsurge and upsurge

Permissible value of negative pressure is one third of atmospheric pressure i.e. -3.33 m plus allowance for overburden, if any, on lower side and value up to vacuum pressure i.e. -10.3 m on higher side. Generally, in conventional design, sub atmospheric pressures are not allowed.

Maximum pressure may be restricted to 1.25 to 1.5 times the pump head or working pressure [7].

V. RESULTS AND DISCUSSIONS

5.1 Results of Transient analysis in the context with Shirala LIS:

Hydraulic transient analysis is carried out for main governing conditions of upsurge & downsurge. These are described below.

i. Governing condition for downsurge or negative pressure: Analysis without surge protection & without column separation gives maximum values of downsurge. Results of analysis are tabulated as below in Table 2.

Table 2. Results of transient analysis for no protection condition

Pipe No	Node Ch. (m)	Max. Pr. (m)	Min. Pr. (m)
1	0	128.125	-54.695
2	0	128.125	-54.695
3	24	128.025	-54.665
3	280	120.53	-48.93
3	460	105.11	-38.55
3	860	81.04	-29.96
3	1240	77.15	-34.89
3	1660	72.385	-40.775
3	2040	70.19	-43.75
3	2520	67.9	-46.45
3	3000	62.03	-51
3	3420	61.19	-48.88
3	3750	37.6	-28.06

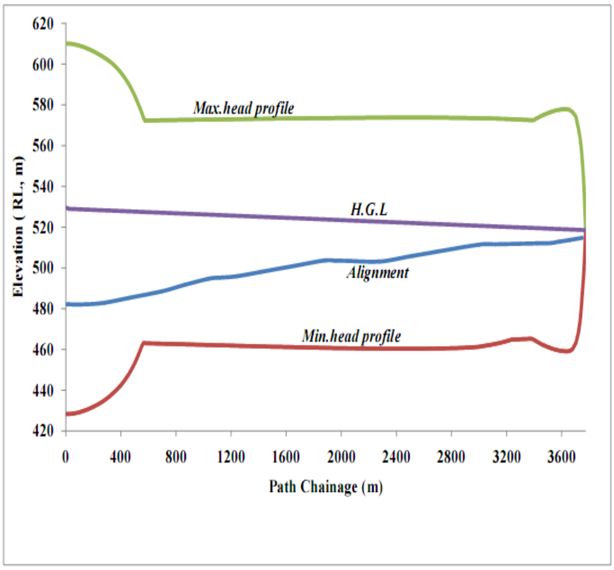

Figure 5. Minimum and maximum pressure for power failure with no protection

Figure 5 shows results of analysis with extensive occurrence of vacuum pressure all along the alignment of pumping main for no surge protection condition. Maximum value of minimum pressure is -55 m which is in excess of acceptable limit of -10m. Maximum value of upsurge is greater than two times the working head (58.86 m). Therefore values of both upsurge and down surge are exceeding limiting values.

ii. Governing condition for upsurge or positive pressure: Analysis without surge protection & with column separation gives maximum values of upsurge. Minimum pressure values in this analysis have no significance, hence skipped. Results of analysis are tabulated as below in Table 3.

Table 3. Results of transient analysis for column separation

Pipe No	Node Ch. (m)	Max. Pr. (m)
1	0	233.905
2	0	233.905
3	24	217.985
3	280	178.64
3	460	174.73
3	860	176.68
3	1240	163.43
3	1660	160.585
3	2040	151.18
3	2520	152.81
3	3000	152.4
3	3420	121.07
3	3750	116.31

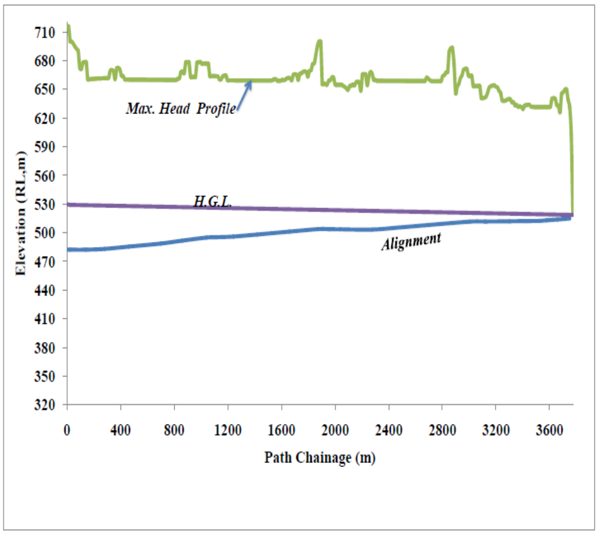

Figure 6. Minimum and maximum pressure for power failure with column separation

Figure 6 shows results of analysis without surge protection and with column separation. The maximum pressure for pumping main is 217.985 m. The hoop stress ($f = pD/2t$) at this pressure is 1544 kg/cm^2, which is moderately large compared to allowable value of 1200 kg/cm^2 as per IS 5822 -1994. As the maximum pressure is about four times the working pressure (58.86 m), pressure needs to be controlled with upsurge protection devices. For deciding intermediate locations and sizing of these devices, transient analysis with upsurge protection is carried out.

5.2 Sensitivity in transient analysis

Various input parameters like wave speed, friction factor, surge tank throttling coefficient, Machine inertia, water temperature, pipe type, thickness and diameter, electromotor rpm and power may have significant effects on the results of transient analysis. A thorough transient analysis will investigate the effect of different values for parameters. It is shown that maximum water hammer is most sensitive to pipe diameter and negative pressure is most sensitive to pipe thickness. Sensitivity study helps designers in well understanding of water hammer phenomenon.

The sensitivity in negative and positive pressures is investigated by changing key parameters such as pipe diameter and wall thickness.

i. Effect of pipe diameter

Pipe diameter is one of the parameter affecting velocity and pressure caused by water hammer event. Pipe diameter affects flow velocity. It also affects direct velocity during down surge and reflection pressure wave velocity during upsurge. Pressure wave velocity reduces with increase in diameter causing considerable reduction in maximum water hammer pressure. But downsurge capacity of pipe decreases with increase in diameter.

ii. Effect of Pipe Thickness

Water hammer pressure wave velocity increases with pipe thickness causing considerable improvement in downsurge capacity of pipe. But maximum water hammer pressure increases slightly with increase in pipe thickness.

5.2.1 Sensitivity of maximum water pressures to increase in pipe diameter

Determination of maximum water hammer pressure in pumping main is the most important from technical and economical point of view. To investigate effect of variation of pipe diameter on maximum water hammer, pipe diameter is varied from 850 mm to 1250 mm in the increment of 100 mm, within permissible velocity range (1.0- 2.1 m/s).

Table 4. Sensitivity of maximum water hammer to variation in pipe diameter

Pipe Dia. 'D' (mm)	Pr. Wave vel. 'a' (m/s)	Pr. Rise ΔH=av/g (m)	Max +WHP (m)	Change in +WHP (m)
850	923.67	195.84	231.46	
950	893.26	151.15	186.77	44.69
1050	865.67	120.01	155.63	31.14
1150	840.49	97.67	133.29	22.34
1250	817.38	79.99	115.61	17.68

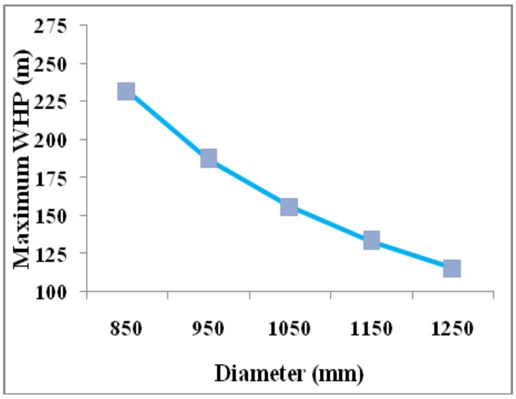

Figure 7. Variation of maximum water hammer with pipe diameter

With all other parameters remaining constant, results are shown in table 4 and figure7. It is observed that the maximum water hammer decreases linearly with increasing diameter. In the context of the Shirala project, 100 mm increase in diameter causes an average decrease of about 29 meters of water column in maximum water hammer for the diameter range considered. Therefore, maximum water hammer can be reduced by increasing pipe diameter (within permissible velocity range). This may increase initial costs of the project (by about 10% per kilometer length of pumping main) but it may eliminate the need for water hammer protection devices and future maintenance risks and costs.

5.2.2 Sensitivity of down surge to variation in pipe thickness

To investigate the effect of pipe thickness on down surge capacity of pipe, thickness range of 6 to 10 mm is considered.

Sensitivity of downsurge to variation in pipe thickness

Dia. (mm)	Pipe Thk. (mm)	Down surge capacity of pipes (m)	Down surge capacity /1 mm thk.	% Change
850	6	17.4		
	7	27	9.6	55%
	8	39.7	12.7	47%
	9	56	16.3	41%
	10	76.4	20.4	36%
		Ave	14.75	45%

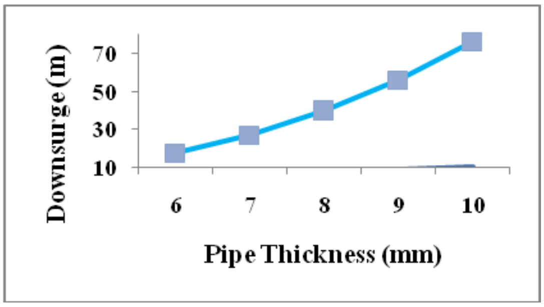

Figure 8. Effect of pipe thickness on downsurge capacity of pipe

With all other parameters remaining constant, results are shown in table 5 and figure 8. It is observed that the down surge improves by about 15 m in average for 1 mm increase in pipe thickness. On an average down surge improves by about 45% for 1 mm increases in pipe thickness with increase 13% in pipe cost per kilometer length.

VI. CONCLUSION

According to present study which was aimed at investigating the effect of key parameters; such as pipe diameter, thickness on hydraulic transient in the context of Shirala Lift Irrigation Scheme, shows that:

- With each 100 mm increase in pipe diameter, maximum water hammer pressure is reduced by 29 meters of water column.
- With each 1 mm increase in pipe thickness, minimum water hammer pressure / down surge carrying capacity is increased by 15 meters of water column

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