

Assessing Thickness of Pressurised Mains utilising Hydraulic Transients Modelling

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ABSTRACT: Hydraulic transients modelling of pressurised mains using industry standard software provides an aid for simulation of pressure surges thus giving a superior interpretation of the ramifications by such strong pressure waves. The simulation here has been applied to a Micro-Irrigation system using Bentley HAMMER CONNECT software. Hydraulic transients in pressurised mains caused by the pump stall due to power failure are analysed, and an approach for designing the thickness of pressurised pipelines is suggested by evaluating the extremity of the hydraulic transients.

KEYWORDS: Pressurised Mains, Power Failure, Pump Stall, Hydraulic Transients, Bentley HAMMER CONNECT, Steel Shell Thickness, Surge Protection, Air Valves and Air Vessels.

I. INTRODUCTION

Hydraulic transient analysis is important in the design of pressurised mains to substantiate their dependability for different operating conditions. Hydraulic transients occur in the system whenever flow conditions are modified, and they grow critical when swift and synchronised flow changes occur, for instance those associated with the power failure in a pumping station or sudden valve and hydrant operations. Hydraulic transients are normally distinguished by varying pressures and velocities in the system which can be detrimental to the pipeline and its appurtenances.

The projection of hydraulic transients is used to validate whether pipeline materials, their pressure classes, and wall thicknesses are adequate to withstand projected pressures and circumvent pipeline and appurtenance destruction. Detection of minimum allowable pressures is indispensable to avert release of air, cavitation, liquid column separation, thus impeding pipeline collapse. When acute hydraulic transients cannot be evaded, either the pipeline system or its attributes are changed, alternatively surge protection devices are specified so as to bring the intense pressures within allowable limits.

A computational model has been applied to simulate the transient behaviour in a Micro-Irrigation system. A thorough assessment of hydraulic transients for all pumps stall due to power failure in the pumping station has been performed to determine the pressure surges and for deciding the thickness of the pressurised mains in the system.

II. LITERATURE REVIEW

American Water Works Association, "Steel Pipe – A Guide for Design and Installation", Manual of Water Supply Practices (M11) Fifth Edition, for Hydraulics of pipelines, water hammer, pressure surge, determination of pipe wall thickness and calculation of external loads on buried pipelines [1].

Indian Standard Institution, "Code of Practice for Laying of Electrically Welded Steel Pipes for Water Supply", IS: 5822-1994 (Reaffirmed 2004), for general requirements of designing steel pipelines [2].

Bentley HAMMER CONNECT is an advanced numerical simulator to efficiently recognize, organize, and alleviate the risks associated with hydraulic transients. HAMMER made it easier to carry out this critical analysis using a computational model, which helped simulating hydraulic transients to understand pressure surges [3].

III. EXPERIMENTAL ASSESMENT

This assessment aims at hydraulic transient analysis of a Micro-Irrigation system to find out whether the thickness of pressurised mains adopted is adequate for the pressure or not. The simulation for ‘all pumps stall’ at pumping station has been done. (Single pump stall has not been analysed as it is required for deciding pressures only on the pipelines present within the pumping station.)

(A) System Description

A Micro-Irrigation system as shown in (Fig.1) is modelled for transient analysis by using Bentley HAMMER CONNECT software. The scheme is characterised by a total discharge of 18 m³/s, dynamic pump head of 125 m and 24 kilometres of mild steel pressurised pipeline. Some features of the Micro-Irrigation system are presented in Table 1.

Table 1. Details of Pipeline, Thickness, Pumps and Motors

Pumping Station to Distribution Chamber	Length	Internal Diameter	Max Thickness	Min Thickness	No. of Pumps			Pump Capacity (Each)	Total Line Discharge	Pump Head	Sump Depth	Sump Bottom	Water Level	Pump Level	Internal Head Loss	Bowl Efficiency	Motor Rating
	(m)	(mm)	(mm)	(mm)	Total	Working	Standby	(m ³ /hr)	(m ³ /hr)	(m)	(m)	(m)	(m)	(m)	(m)	(%)	(kW)
PS to DC	24077	3250	18	14	10	8	2	8100	64800	141	33.86	105.64	110.6	139.5	0.37	88.9	4200



(Fig.1). Schematic Diagram of Pressurised Mains

1. Hydraulic & Structural Design of Pressurised Mains

The Static head is the difference between the Maximum water level in Distribution Chamber and the Minimum Drawdown Level (MDDL) of the Pumping Station. In a pump discharge pipeline, the working pressure is based on the elevation difference between pipe centreline and the HGL created by the pumping operation (Its Shut-off head).

The Friction loss in pipeline is calculated using the Modified Hazen William’s formula. Bend Losses have been calculated based on actual bends as per plan and profile. The other line losses like Station losses, and Valve losses could be significant and needs to be considered for an accurate pump head.

Pipe structural design is done with pressures on centreline of pipe. In large diameter pipelines this has to be done taking Positive maximum head over the invert of pipeline, and Negative minimum head below the crown.

Soil cover depth is maintained to ensure that the pipeline does not float during or after execution due to uplift on monsoons or from leaked water saturating the trench. The choice of pipeline embedment soil, its type and the backfill compaction level are the most important factors affecting the performance of the steel shell & soil association.

(B) Software Overview and Simulation Assessment

Bentley HAMMER CONNECT uses the most widely used and tested method known as the Method of Characteristics to solve full continuity and momentum equations for a Newtonian fluid, and accounts for the fact that liquids are compressible and that pipeline walls can expand under high pressures. Transient modelling essentially consists of solving these equations for every solution point and time step, for a wide variety of boundary conditions and system topologies.

Stall of all pumps due to power failure is the most critical condition with regard to pressure surges for a pressurised main in Lift-Irrigation Systems. Single pump stall, when multiple pumps are running in parallel operation is critical in respect of pressure surges in the pumping station.

In this assessment, all pumps were individually modelled in the software with full range of characteristic curves and GD^2 values. This accurately models the operation of pumps in the initial state as well as after failure due to effect of reversal of flow on each pump, and the time of shut-off for each pump's non-return valve.

For analysis of hydraulic transients, in 24 km long pressurised main, the total duration of simulation was decided as minimum 6 cycles. One cycle of surge is the time required for the pressure wave to travel from the pumping station's end to the discharge end and back. For pressurised mains up to 25 km long, it is usually observed that the extreme pressure surges usually tend to occur in the 3rd or beginning of the 4th cycle. Also, when the Air Vessel is not provided, prolonged oscillations may result in maximum pressure surges in the 4th or 5th cycle.

Accurate results of a transient analysis depend on knowing the various hydraulic and physical characteristics of the system. The velocity of the pressure wave is a fundamental feature in hydraulic transient assessment, as the pressure surges are directly proportional to its value. This velocity depends on the pipeline diameter, its wall thickness, the material of the pipeline walls, and the density and compressibility of the fluid in the pipeline.

1. Detailed Hydraulic Transients Results - HGL and Pressure (Without Surge Protection)

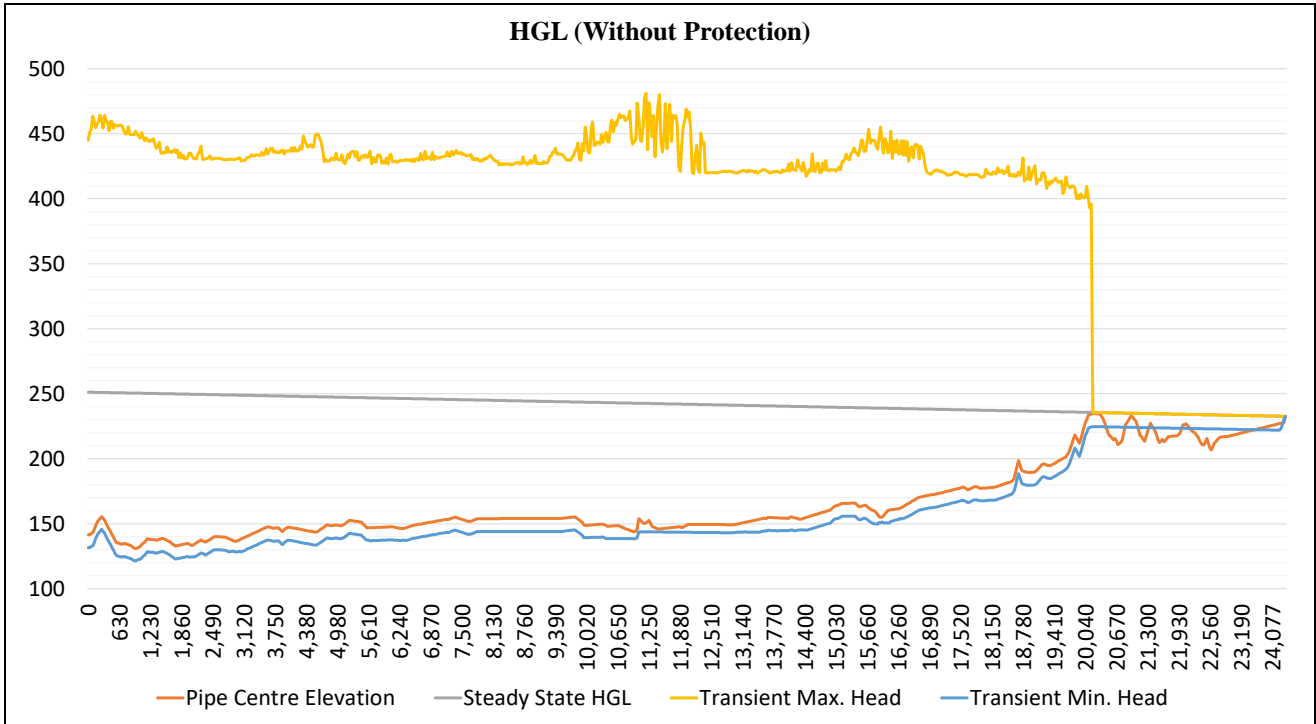
The eight-pumps stall simulation at total discharge of 18 m³/s for time step of 0.025 to 0.05 seconds (This analyses pipeline in sections of 30m to 60m giving accurate results) was conducted for the described Micro-Irrigation system without surge protection as shown in (Fig.2a). The system was not protected against excessive pressure.

Upon pumps stall the water flow gradually reduces until it gets fully stopped, and then the water starts to flow in the opposite direction. Water backflow towards the pumps is prevented by non-return valves. At the moment of pump stall, the negative pressure wave starts to spread along the system. Where the pressure head is predominantly influenced by friction, as in long pipelines, the water vapour pressure may be generated at pump stall, and hence the water column gets separated. The separation most often occurs when pump stalls at the highest point on the pipeline. The decrease in pressure may produce foaming and release air bubbles that may concentrate at the highest points in the pipeline. These air bubbles then travel along the pipeline and cause pressure surges.

2. Detailed Hydraulic Transients Results - HGL and Pressure (With Surge Protection)

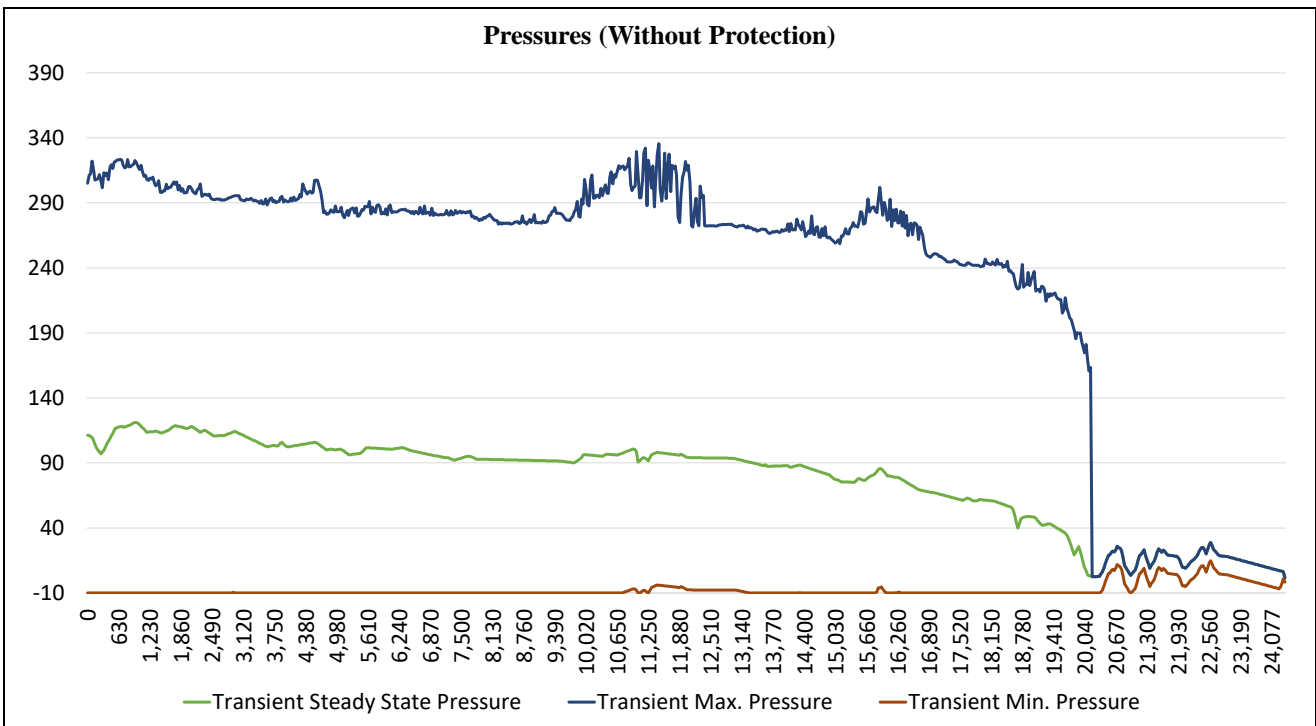
The same simulation was repeated with surge protection devices as shown in (Fig.2b). This time the system was protected against excessive pressure.

The transmission of negative pressure wave takes place along the entire pipeline, which causes negative pressure at some locations. Installation of air valves is an efficient defence against this unacceptable phenomenon. These valves regulate the quantity of air in the system so as to reduce or prevent potentially catastrophic consequences of the moving and entrapped air. In the Micro-Irrigation system under study, air valves are positioned along the route and their purpose is to deaerate the system during everyday operations, introduce the air in cases when the pressure in the pipeline is lower than the atmospheric pressure, and release the air from the pipeline when the system is refilled with water. With air valves there is no negative pressure near the pumping station. After various iterations it was found that an effective surge control can be achieved with only air valves, and without requiring air vessels.

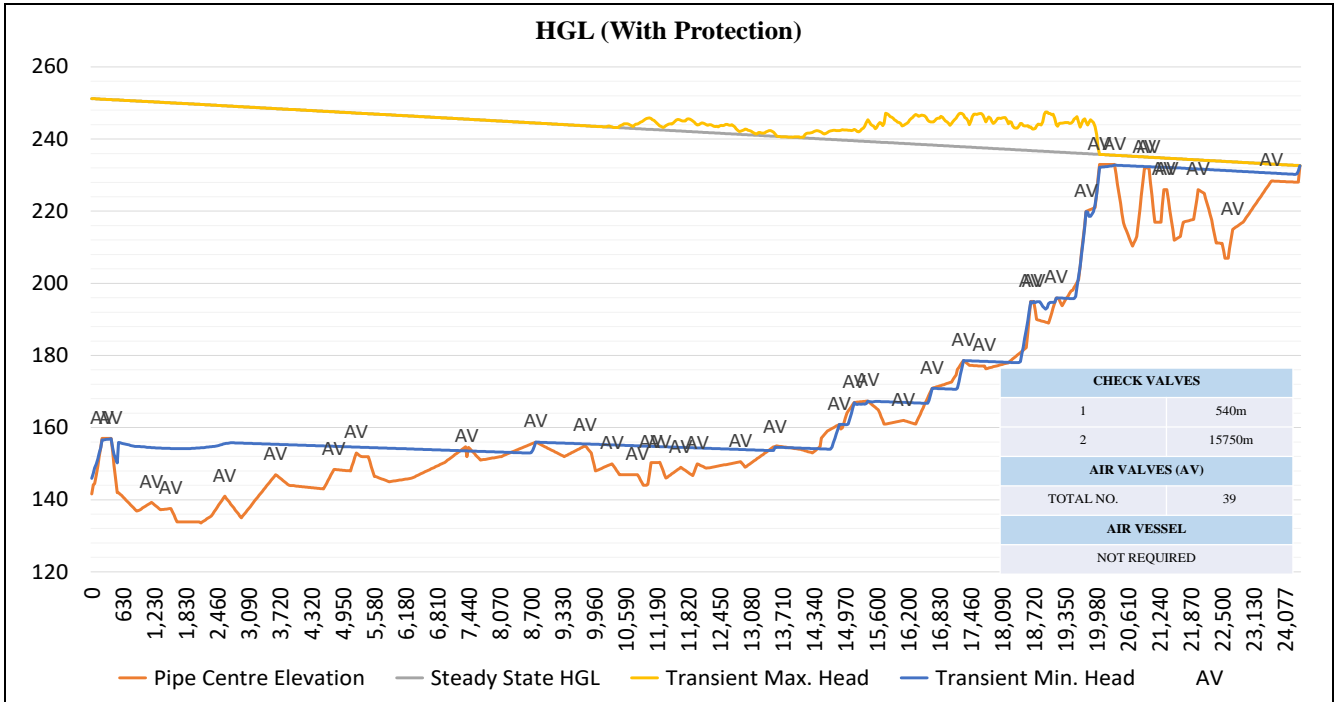


(Fig. 2a). Pumping Station to Distribution Chamber HGL (Without Surge Protection)

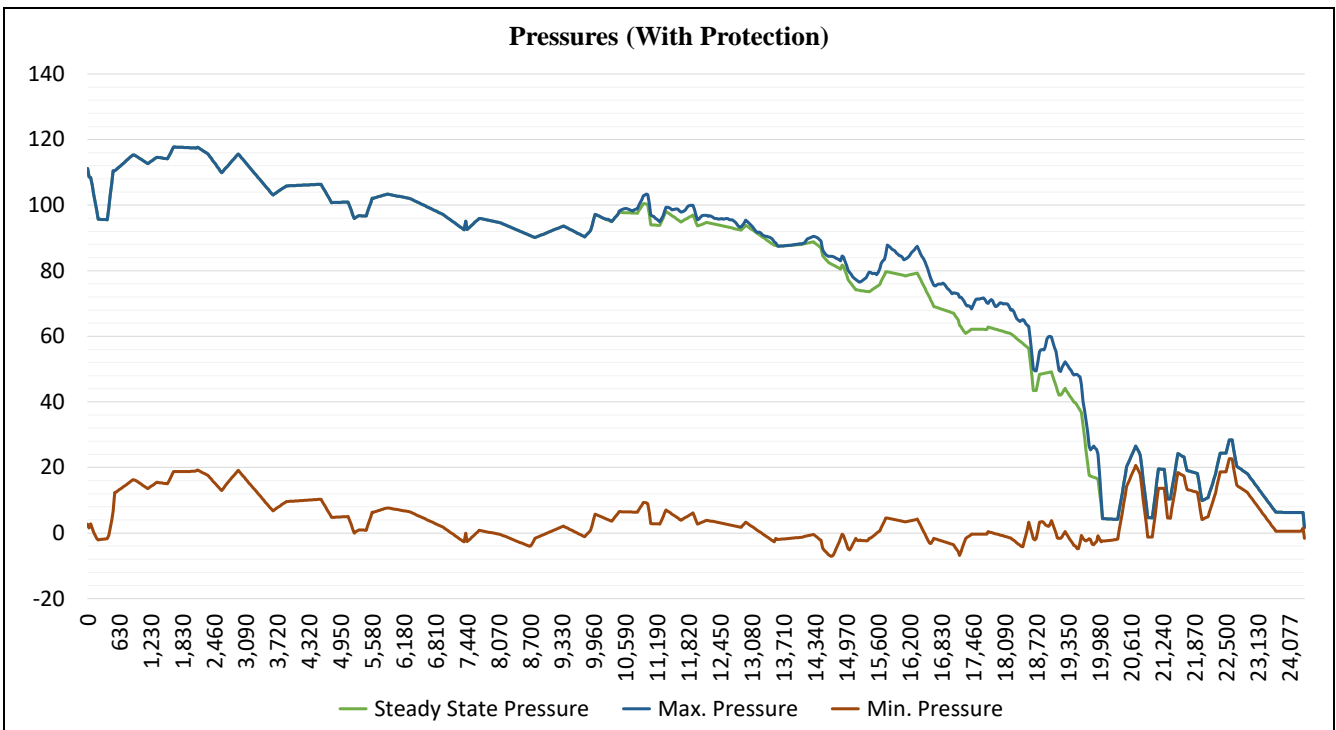
*Maximum pressures are 2 to 2.5 times steady state pressures.



(Fig. 2b). Pumping Station to Distribution Chamber Pressures (Without Surge Protection)



(Fig. 3a). Pumping Station to Distribution Chamber HGL (With Surge Protection)



(Fig. 3b). Pumping Station to Distribution Chamber Pressures (With Surge Protection)

IV. RESULTS AND DISCUSSIONS

(A) Steel Shell Thickness Design of Pressurised Mains with Guniting

The primary design consideration for the determination of pipeline wall thickness is in its ability to withstand various internal and external pressures. The remaining performance criteria are then validated for the adequacy of the overall steel shell design.

IS: 5822-1994 ‘Code of Practice for Laying of Electrically Welded Steel Pipes for Water Supply’, specifies that the pipeline has to be designed to sustain 33% negative pressure (vacuum). The steel shell thickness required for sustaining negative pressure surges is, in many cases, much larger than that required to sustain maximum positive pressure. Hence the attempt of the designer should be to ensure that the minimum pressure surge is higher (vacuum being negative pressure) than 33% vacuum and the stretches of negative pressures are short in length so that the large thicknesses are restricted to small length of the pipeline.

Only Steel shell is used for sustaining negative pressures, also Stiffening effect due to Concrete Guniting (3cm thickness) is considered.

The shell thickness of the pipeline is fixed using; Working pressure, Maximum of Test and Surge pressure in full filled pipeline (Static Pressure), and the thickness from Vacuum and Handling considerations.

1. Steel Shell Thickness Design from Static Pressure

(a) T1 [Shell Thickness as per IS 5822, Clause B – 9.2, for Working Pressure]

$$\text{Shell thickness (mm)} = \frac{\text{Internal working pressure (N/mm}^2\text{)}}{2 (\text{design factor}) \times \text{Minium yield stress (N/mm}^2\text{)} \times \text{Joint weld efficiency} + \text{internal working pressure}} \tag{Eq. 1}$$

*Design factor is 0.6 for working pressure.

(b) T2 [Shell Thickness as per IS 5822, Clause B – 9.2, for Maximum of Test Pressure and Surge Pressure]

$$\text{Shell thickness (mm)} = \frac{\text{Internal test/surge pressure (N/mm}^2\text{)}}{2 (\text{design factor}) \times \text{Minium yield stress (N/mm}^2\text{)} \times \text{Joint weld efficiency} + \text{internal test/surge pressure}} \tag{Eq. 2}$$

*Design factor is 0.9 for test pressure including surge pressure.

2. Steel Shell Thickness Design from Vacuum and Handling Considerations

With internal pressure other factors influencing the design of shell thickness, are handling, ability to withstand stresses imposed during construction, deformation when not under pressure and external loads.

(a) T3 [Shell Thickness as per AWWA (Eq 4-3), for Vacuum]

Designed for pressures lower of 33% vacuum or Minimum Surge pressure.

$$\text{Shell thickness (mm)} = \frac{\text{Pipe Diameter (mm)}}{239} \tag{Eq. 3}$$

*Formula modified for Metric Units.

(b) T4 [Shell Thickness as per AWWA, for Handling]

$$\text{Shell thickness (mm)} = \frac{\text{Pipe Diameter (mm)} + 500}{400} \tag{Eq. 4}$$

*Formula modified for Metric Units.

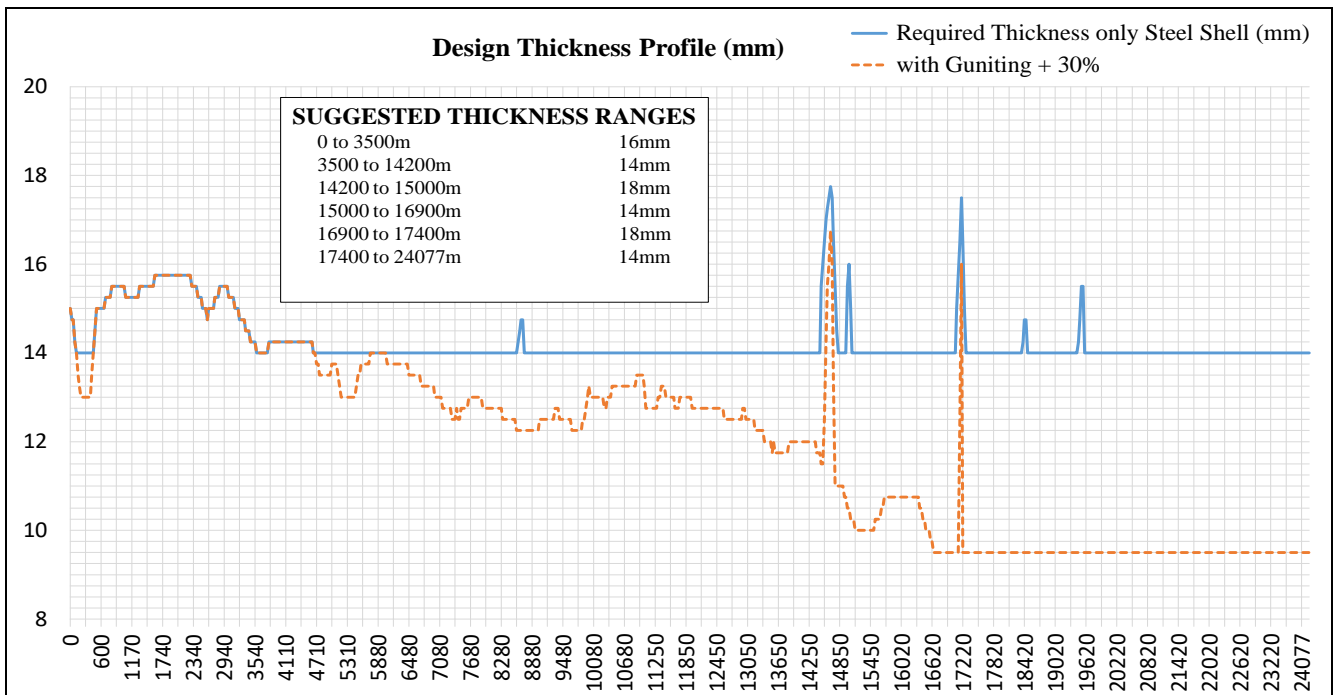


The thickness selected is the maximum of T1, T2, T3 and T4. This thickness can sustain surge up to 1.5 times the working pressure. Appurtenances just adequate to restrict the maximum surge pressures within 1.5 times the steady state pressures are adequate as good design, and additional appurtenances to reduce it below that are pointless.

Table 2. Illustrative details of Design for Steel Shell Thickness with Guniting

Chainage	Centreline of Pipe	Working Pressure from Static Head (m)		Surge Pressure (From Bentley HAMMER CONNECT Software)	Minimum Surge Pressure	Design Minimum Pressure = Lower of 33% Vacuum or Minimum Surge Pressure	THICKNESS CALCULATIONS					Required Thickness with Guniting
							T1 (Shell Thickness for Working Pressure)	T2 (Shell Thickness for Maximum of Test Pressure and Surge Pressure)	T3 (Shell Thickness for Vacuum) [Steel Shell Only]	T3 (Shell Thickness for vacuum) [Steel + 30mm Guniting with 30% Margin]	T4 (Shell Thickness for Handling)	
m	m	m H2O	kg/cm2	kg/cm2	kg/cm2	kg/cm2	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
0	141.63	114.26	11.43	11.43	-0.07	-0.34	15.28	10.20	13.82	9.49	9.49	15.50
30	141.63	111.07	11.11	11.11	0.07	-0.34	14.85	9.92	13.82	9.49	9.49	15.00
60	142.55	110.13	11.01	11.01	0.11	-0.34	14.73	9.83	13.82	9.49	9.49	14.75
90	143.00	109.66	10.97	10.97	0.13	-0.34	14.67	9.79	13.82	9.49	9.49	14.75
120	145.75	106.88	10.69	10.69	-0.09	-0.34	14.30	9.54	13.82	9.49	9.49	14.50
150	148.49	104.12	10.41	10.41	-0.29	-0.34	13.93	9.30	13.82	9.49	9.49	14.00
180	151.24	101.35	10.13	10.13	-0.44	-0.44	13.56	9.05	14.95	9.49	9.49	13.75
210	152.72	99.85	9.98	9.98	-0.41	-0.41	13.36	8.92	14.63	9.49	9.49	13.50
240	154.19	98.35	9.84	9.84	-0.32	-0.34	13.16	8.79	13.82	9.49	9.49	13.25
270	155.67	96.85	9.68	9.68	-0.21	-0.34	12.96	8.65	13.82	9.49	9.49	13.00

Based on these calculations a graph (Fig.4) has been prepared to help decide the final proposed thickness of steel shells in various range of chainages. The design thickness above is from internal pressure standpoint. The thickness checks for external pressure, buckling check, deflection check, compressive and stress check were also performed as per AWWA for the thicknesses calculated above.



(Fig. 4). Design Thickness Profile from Pumping Station to Distribution Chamber

V. CONCLUSIONS

1. Hydraulic transient analysis is a pivotal part of the pressurised mains design, and a thorough assessment contributes appreciably to the effective functioning of pipeline, appurtenances and pumping machinery.
2. The important contribution of this paper as compared to existing hydraulic transients design specifications, include an overview of steel shell design guidelines to be considered.
3. This assessment of the transient simulation will contribute to a greater understanding of the pipeline system behaviour and would also provide engineers with a design criterion.
4. Pump stall causes significant fall in pressure in the system, which may lead to negative pressures. Pressurised systems can be safeguarded against unwanted consequences of hydraulic transients by means of surge protection devices.
5. An empirical coefficient value for the standard formulas could be practically calibrated and checked against the actual field measured data from a similar pipeline.
6. A review for adequacy in resisting external loads, and minimum thickness for handling could also be performed.

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- [3] Bentley HAMMER CONNECT Software.

BIOGRAPHY



Abhilash Vishwakarma is a Project Engineer accomplished in managing a varied range of projects both within the public and private sectors in the Civil Engineering industry. He is actively involved in detailed engineering for Water Infrastructure works. As a professional he also blogs on his website *thecivilengineeringdaily.wordpress.com* about technical aspects of civil engineering works. He is a Rotaractor with active service, Past President of Rotaract Club of RCOEM, Past Zonal Rotaract Representative under District 3030 and an honorary member of The Rotary Club of Nagpur MIHAN Town. When he is not working you will find him spending time with his family and friends. His other personal interests include gardening and long walks.