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Table Charts for Sizing Surge Anticipating Valve in Rising Mains

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Abstract: ***Transient analysis for large rising mains is performed to protect them from worst effects of water hammer. It requires costly surge analysis software for analysing system for surge & sizing surge protection devices. If software is not available, engineers requires, selection tables or formulae pertaining to quick sizing of surge protection device for given pumping main. If size of surge protection device is known suitable cost shall be considered in budgetary estimates. Surge anticipating valve is a cost effective, compact & reliable surge protection device used in pumping mains. It is installed on delivery manifold of the pump. There are no design guidelines or selection tables available by valve manufacturers for selection of surge anticipating valves. Hence in this paper, table charts are prepared to estimate amount of surge & size of surge anticipating valve using KYPIPE TranSurge software after numerous analysis of pumping mains for various combinations of flows, diameters, elevations and lengths. In the end, software results are validated by comparing it with results obtained by experiment.***

Keywords: ***Water hammer, Surge Anticipating Valve, Pumping main, KYPIPE TranSurge***

I. NOMENCLATURE

C	Pressure wave velocity, m/s
L	Length, m
Q	Discharge, m^3/hr
H	Static head, m
H_{max}	Pressure head above steady state pressure, m
H_{min}	Pressure head below steady state pressure, m
V_0	Normal velocity, m/s
d	Diameter, mm
k	Bulk modulus of water, kg/m^2
E	Modulus of elasticity of pipe material, kg/m^2
g	Gravitational acceleration, m/s^2
C_t	Pipe wall thickness, m
P	Pump head, m

II. INTRODUCTION

Hydraulic analysis of rising mains is generally based on steady state flow conditions. These systems are safe until the flow conditions are steady. But flow fluctuations in the system intentionally or unintentionally is an integral part of the operation. When these operations are occurred very quickly, they can cause hydraulic transient phenomena.

In this case transient means momentary variations in pressures called pressure surges. An efficient rising mains would help in preventing accidental damages due to surge and thus achieving longer lasting pipelines, valves and accessories. One such option for achieving this is analyzing the system for surge and if it is prone to large surge pressures, then protecting the system by providing appropriate surge protection devices at right locations. Rising mains includes construction of pump house or generators, electrical Substation, supply and laying of pipes etc. The cost of these projects are in multiple of hundreds of crore. The major cost component of the projects is supply & installation of pumps, pipes and valves. The length and diameter of the pipe network is huge. Hence if proper design of these systems is required to protect the system from unwanted pressure surges. Column separation phenomenon occurred after pump trip [1] and a comprehensive survey of laboratory tests and field measurements are already performed in earlier studies.

From An effective numerical model [2] it is understood the influence of using the protection devices to control the adverse effects due to excessive and low pressure occurs in the transient. The webinar from American Water Works Association (AWWA) [3], presents basic characteristics of transients, recognize the risks of transients & learn about the transient calculation methods. From a case study [4] of J. C. R. Devadula Lift scheme in Telangana State, India it is observed that extreme pressure heads (both maximum and minimum) immediately after power failure to pumps, water column separation has occurred on downstream of pump delivery and hence transient control device like air vessels and one-way surge tanks are planned for this pipeline system.

Transients can produce large pressure forces and rapid fluid acceleration into a water pipeline system. These disturbances may result in device failures, system fatigue or pipe ruptures, and even the backflow/intrusion of dirty water. Many transient events can lead to water column separation, which can result in catastrophic pipeline failures. Thus, transient events can lead to increased leakage or decreased reliability.

Objective of this paper is to prepare table charts to estimate water hammer & size of surge anticipating valve & later to validate the results of software using experiment.

III. METHODOLOGY

A. Water Hammer

Pipeline pressure surges are occurred by a sudden increase in pressure which is produced by a change in velocity of the moving fluid in a pipeline.

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Usually, during pipeline design, the movement of fluid is based on steady state calculations of the static head and frictional head losses, using the maximum operating pressure plus a small safety factor. However, in any system, the flow must be started and stopped by pump or valve operations and these can generate transient pressures well in excess of the steady state pressures.

Consider a pipe leading from a reservoir to downstream Fig. 1. A is pumping water from reservoir to a valve placed at a distance 'L' from the reservoir. IF pump trips suddenly, the water in the pipeline will move further downstream until its velocity reduces to zero. As water column moves downstream, low pressure developed upstream of this water column and then flow reverses. The entire mass of water return back towards pump and hammers on to non-return valve which is already closed after pump trip. Consequently low pressure developed upstream of outlet valves. The pressure wave moves back towards valve. This cycle continues until pipe wall friction stabilizes energy of the moving water.

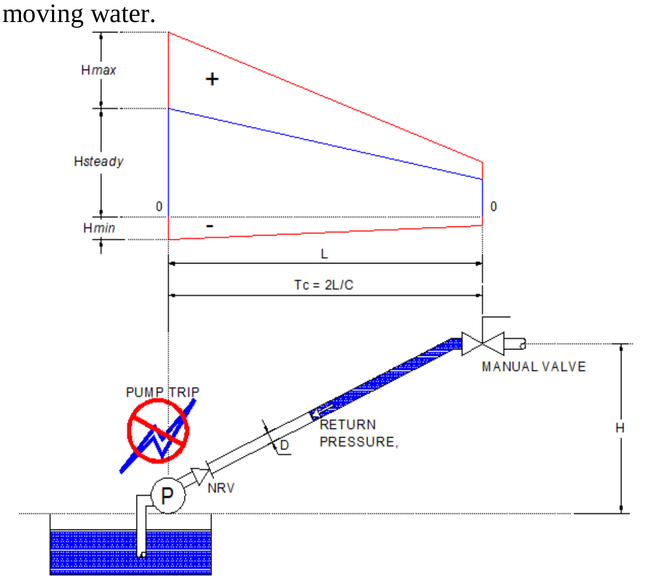

Fig. 1.Pressure variation due to water column separation

B. Critical Time, Tc

Every system has a critical time, Tc = 2L/C. Where, L is the longest possible path through the system (e.g. from pump to reservoir) and C is the pressure wave speed varies from 200 to 1400 m/s.

2L/C is the time required for a pulse to travel to the far end, then return. This critical time is fractions of a second for a short suction line, tens of seconds for a force main & minutes for long-distance transmission lines.

C. Computation of Hydraulic Transient

Joukowsky (1898) explained maximum water hammer pressure (which occur at critical time of closure Tc or any time less than Tc) is given by the expression,

$$H_{max} = \frac{C\,V_0}{g} \qquad (1)$$

Where,

H_{max} = maximum pressure rise in the closed conduit above the normal pressure in m

V_0 = normal velocity in the pipe line, before sudden closure in m/s

g = acceleration due to gravity in m/s^2

C = velocity of pressure wave travel in m/s, Table II, can also be calculated from equation,

$$C = \frac{1425}{\sqrt{1+\frac{kd}{EC_t}}} \qquad (1)$$

Where,

k = bulk modulus of water (2.0 x 108 kg/m^2)

d = diameter of pipe in m

C_t = wall thickness of pipe in m

E = modulus of elasticity of pipe material in kg/m^2, Table I

Table I: Values of E (modulus of elasticity) for common pipe materials

Material	E, kg/m^2
Polyethylene	1.2 x 10^7
PVC	3.0 x 10^8
Concrete	2.8 x 10^9
Ductile Iron	1.7 x 10^{10}
Steel	2.1 x 10^{10}

Table II: Approximate values of C (velocity of pressure wave) for common pipe materials

Material	C, m/s
PSC or BWSC pipes	1000 - 1200
Steel pipes	900 - 1200
PVC pipes	220 - 400
PE pipes	150 - 250

D. Water Hammer Governing Equations

The water-hammer equations [1] are applied when the pressure is above vapor pressure. They comprise the continuity equation and the equation of motion:

$$\frac{\partial h}{\partial x} = \frac{1}{g}\frac{\partial V}{\partial t} \qquad (1)$$

$$\frac{\partial h}{\partial t} = \frac{C^2}{g}\frac{\partial V}{\partial x} \qquad (2)$$

Where, h is the piezometric head (HGL), t the time, V the flow velocity, x the distance along the pipeline, y the pipe slope, C the pressure wave speed, g the gravitational acceleration.

E. Surge Anticipating Valve

Surge Anticipating Valve (SAV) Fig. 2 [6] is an automatic controlled valve, activated by the pressure of the pipeline. The valve protects the pumping system from water hammer, caused by sudden pump shut-off (case of power failure, for example). The valve is assembled as shown in Fig. 3 on a T-junction of the main pipeline, instantly opens when the pump stops, relieving the returning high pressure wave. The valve slowly closes once the pressure returns to the static level. The valve also functions as a pressure relief valve.

Fig. 2.Typical Surge anticipating valve

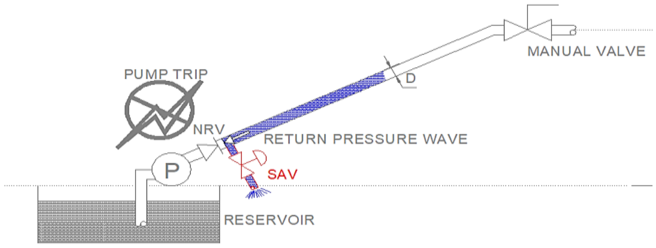

Fig. 3.Surge anticipating valve – Typical installation

To model surge anticipating valve in the software it is required to calculate resistance offered by the valve. Smaller the valve larger is the resistance.

$$Resistance = \frac{Headloss}{Flow^2} \quad (1)$$

Where,
Headloss in m, Flow in cubic meter per second
From Dorot valve vendor catalog [6] we get Kv value which represent flow required for 1 bar of headloss in the valve.
From Kv value, resistance of the valve can be calculated, which is tabulated in Table III.

Table III: Valve resistance chart

Diameter, mm	Q, m3/hr (Kv)	Valve Resistance
40	43	70092
50	43	70092
65	43	70092
80	115	9800
100	167	4647
150	407	782
200	676	284
250	1160	96
300	1600	51
350	1600	51
400	3000	14
450	3150	13
500	3300	12
600	6500	3
700	6500	3
800	6500	3

The term valve resistance used to indicate size of surge anticipating valve in the software.

F. Scenarios for Preparing Table Charts for Sizing surge anticipating valve

For preparing table charts for sizing of surge anticipating valve, combination of scenarios of pumping main characteristics are tabulated in table. The diameter of the pipe selected is as per average velocity of 1.4 to 1.5 m/s velocity which is common in pumping mains. For pipe diameter up to and equal to 500 mm HDPE pipe and above 500 mm Mild steel pipe is adopted. Accordingly wave speed for each pipe is considered. Roughness coefficient 140 considered for all pipes.

Table- IV: Scenarios for Analysis

Scenario Nos.	Lengths, m				H	Q	d	Pipe Type	Wave Speed
	L1	L2	L3	L4	m	m^3/hr	mm		m/s
1-4	100				10	100	150	HDPE	350
		500			10	100	150	HDPE	350
			1000		10	100	150	HDPE	350
				5000	10	100	150	HDPE	350
5-8	500	1000	3000	5000	50	100	150	HDPE	350
9-12	500	1000	3000	5000	100	100	150	HDPE	350
13-16	100	500	1000	5000	10	500	350	HDPE	350
17-20	500	1000	3000	5000	50	500	350	HDPE	350
21-24	500	1000	3000	5000	100	500	350	HDPE	350
25-28	100	500	1000	5000	10	1000	500	HDPE	350
29-32	500	1000	3000	5000	50	1000	500	HDPE	350
33-36	500	1000	3000	5000	100	1000	500	HDPE	350
37-40	100	500	1000	5000	10	2000	700	MS	930
41-44	500	1000	3000	5000	50	2000	700	MS	930
45-48	500	1000	3000	5000	100	2000	700	MS	930
49-52	100	500	1000	5000	10	4000	1000	MS	880
53-56	500	1000	3000	5000	50	4000	1000	MS	880
57-60	500	1000	3000	5000	100	4000	1000	MS	880
61-64	100	500	1000	5000	10	6000	1200	MS	900
65-68	500	1000	3000	5000	50	6000	1200	MS	900
69-72	500	1000	3000	5000	100	6000	1200	MS	900
73-76	100	500	1000	5000	10	8000	1400	MS	850
77-80	500	1000	3000	5000	50	8000	1400	MS	850
81-84	500	1000	3000	5000	100	8000	1400	MS	850
85-88	100	500	1000	5000	10	10000	1600	MS	950
99-92	500	1000	3000	5000	50	10000	1600	MS	950
93-96	500	1000	3000	5000	100	10000	1600	MS	950

Steps for analysis,

1. Each scenario is modelled in TranSurge software.
2. Using steady state analysis decided pump head to avail 10m residual head at outlet manual valve for all scenarios.
3. Placed air valves at every 500 m interval along pipeline.
4. Surge analysis is done for pump trip event.
5. Noted Maximum and minimum pressure along the pumping main.
6. If maximum pressure due to surge is more than pipe pressure rating, surge anticipating valve is introduced after pump & again model is analysed for surge.
7. If surge is still more than pipe rating, size of surge anticipating valve is increased by reducing resistance coefficient as per table.
8. With these iterations, required size of surge anticipating valve is selected and noted in table chart.
9. Likewise, 96 scenarios are analysed and prepared table chart for sizing of surge anticipating valve.

The results & table charts are discussed in Results and discussion chapter.

IV. EXPERIMENTAL SETUP

The aim to perform experiment is to validate analysis done using KYPIPE TranSurge software. Experimental setup consist of bucket, pump, pipe & fittings, pressure gauge and pressure transducer & laptop.

Objective is to measure the instantaneous rise in pressure due following operations

1. Pump Start & off – pressure measurement at pump
2. Sudden closure of outlet valve – pressure measurement at valve

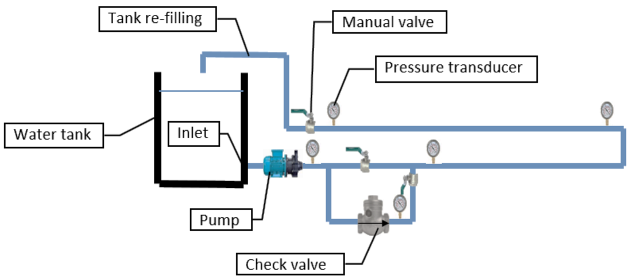

Fig. 4.Sketch for experimental setup

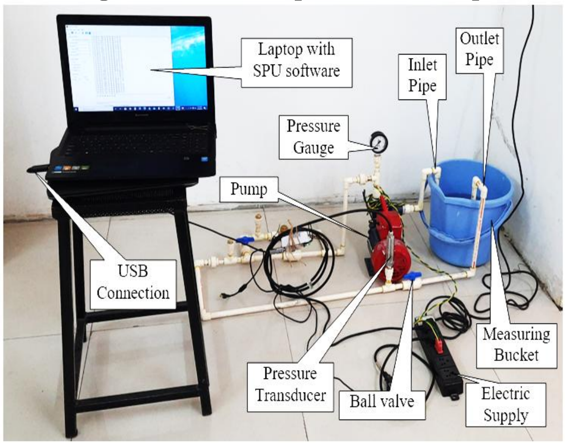

Fig. 5.Experimental setup

To experiment purpose cPVC pipe used because, this pipe is light weight, flexible & easy to handle and work with. If Galvanised Iron pipe is a rigid pipe, heavy in weight and difficult to work with for example threading.

The pressure transducer is connected to pipe where pressure is to be measured. Its USB output is connected to laptop where Serial Port utility (SPU) Software is installed. SPU software reads the pressure in the form of hexadecimal format (Fig. 6). Hence using excel formula "hex2dec" need to convert hexadecimal to decimal format. The output pressure is in KPa, can be converted to meter of water column by dividing KPa by ten.

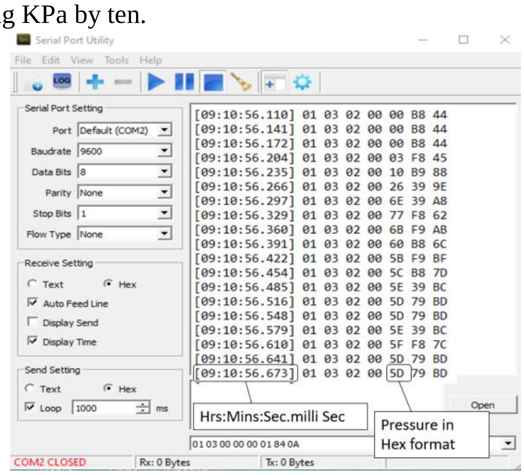

Fig. 6.Experiment results on SPU software in Hex format

To prepare experiment bench, pips & fittings are bought from hardware store. Cost of pipe & fittings including pump is around Rs. 6,000. Pressure transducer is bought from China through E-commerce website - Alibaba. The cost of pressure transducer is Rs 20,000 including excise duty. Installation of pipe fittings are in hardware store by a plumber.

Table V: List & specifications of components of experiment

Sr No	Material Description	Specification
1	1/2 inch Pipes & fittings	1/2 inch cPVC Pipe, 2.3 m long OD = 15.9 mm, ID = 12.0 mm, Thickness 1.95 mm. Hazen William's Friction Coefficient = 140, Wave speed = 600 m/s. Company: Prince
2	0.5 HP Pump	Head Range: 6 – 21 m, Discharge Range: 1950 – 450 LPH, Speed 2780 RPM, 0.37/0.5 kW/HP, Company: Crompton Mini Crest II
3	Pressure Transducer	Company: Holykell Product code: HPT903 Smart Digital Pressure Transmitter Measuring range: -1 to 20 Bar Accuracy: 0.25% Sampling Rate: 100 points/second to 1 point/99 second Resolution: 20 bits 10 ppm Water Proof: IP65 Response time: ≤1ms Output: USB to be connected to computer. Computer with software installed for recording. Cost: 195 USD + Duty Ordered from: Alibaba market place Made in: China
4	Pressure gauge	Drip Irrigation Pressure Gauge 0 to 7 kg/sq. cm, Dial Size: 2.5 inches Company: Automat
4	Computer	Laptop with Serial Port Utility software installed
5	Measuring tank	Bucket with measuring levels mentioned on inner surface.

The readings are taken from experimental setup for Two Scenarios. Similar software model is built and analysis results are presented in result and discussion chapter.

V. RESULT AND DISCUSSION

A. Validation of Software Results

The readings taken from experimental setup for Two Scenarios. These results are presented in graphical format pressure Vs Time.

Experiment scenario 1: Pump start & off - pressure measurement at pump (Fig. 7)

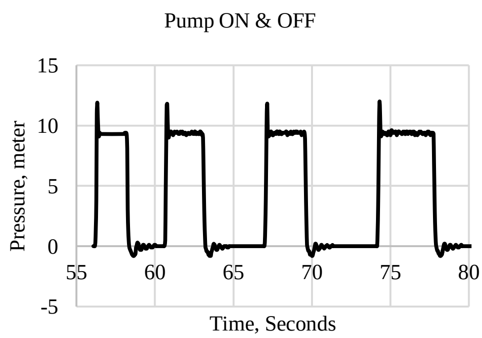

Fig. 7.Pressure rise & fall due to Pump start & off – Experiment result

In this case, when the pump starts, there is sudden rise in pressure up to 12 m and then the pressure tends to steady state pressure of 9 m. When pump is trip, there is negative pressure near pump.

Experiment scenario 2: Sudden closure of outlet valve – pressure measurement at valve (Fig. 8)

In this case, the steady state pressure is 3 m. When the outlet valve is closed suddenly, there is sudden rise in pressure up to 21m.

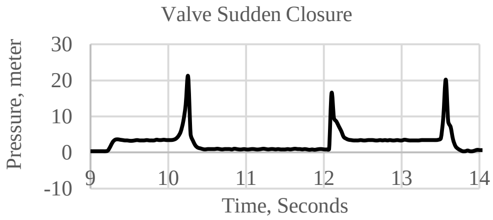

Fig. 8.Pressure rise due to sudeen valve closure – Experiment result

The software results can for both scenarios are shown in below figures. Before that the steady state pressure needs to be recorded as shown if Fig. 9 & 10. At pump steady state pressure is 0.9 bar (9 m) and at outlet valve it is 0.3 bar (3 m)

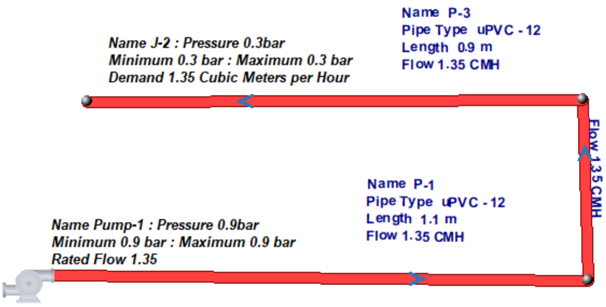

Fig. 9.Software model same as experimntal model

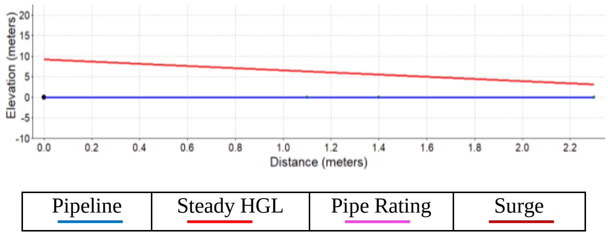

Fig. 10. Steady state pressure - Software result

Software scenario 1: Pump start & off - pressure measurement at pump (Fig. 11)

As its can be seen from results, the pump start and off the pressure is 1.1 bar (11 m) and -0.3 bar (-3 m) respectively, which matches with the results from experimental results.

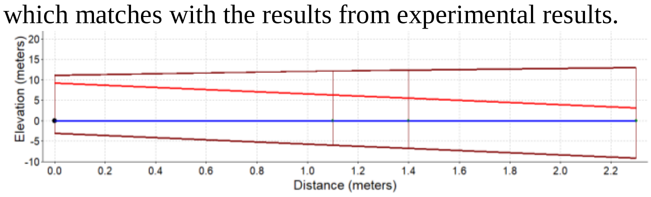

Fig. 11. Pressure rise & fall due to Pump start - off - Software result

Software scenario 2: Sudden closure of outlet valve – pressure measurement at valve (Fig. 12)

As its can be seen from results, the pressure at outlet valve is 2.1 bar (21 m) due to sudden valve closure which is exactly matches with experimental results.

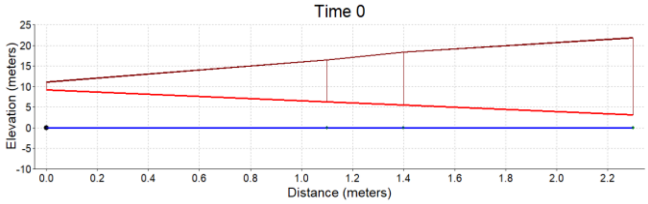

Fig. 12. Pressure rise due to sudden valve closure - Software result

Validation results are summarized in Table VI. Table shows comparison of results obtained by Experiment and software for steady state, pump start – off & sudden valve closure case.

Table VI: Experiment and software results comparison

Sr. No.	Scenario	Maximum pressure, m	
		Experiment	Software
1	Steady State pressure at outlet valve	3	3
2	Pump start & off, pressure at pump	12	11
3	Sudden valve closure, pressure at outlet valve	21	21

B. Table Charts for Sizing Surge Anticipating Valve

A sample model is shown in Fig. 13 for scenario number 96 that is flow of 10,000 m^3/hr, 1600 mm diameter MS pipe, elevation difference 100 m (Table VII). Surge results for pump trip event for pumping main only with air valves are shown is Fig. 14. It can be seen that, surge pressure is 193 m for pump head of 119 m.

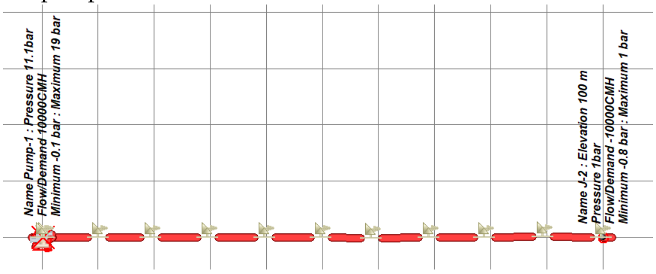

Fig. 13. Software model prepared for sizing of surge anticipating valve (Scenario 96)

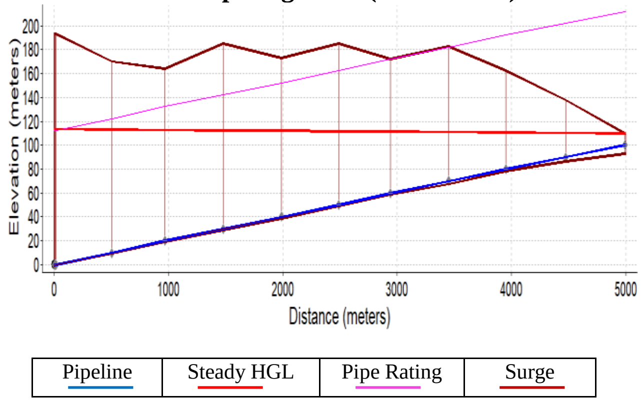

Fig. 14. Water hammer due to pump trip – without Surge anticipating valve (Scenario 96)

From summary of maximum and minimum pressures (Fig. 15) it is observed that, minimum pressure after pump trip is minus 7.7 m near outlet valve (J-2), 34.158 seconds after pump trip. Maximum surge pressure 193 m is near pump, 35.419 seconds after pump trip.

SUMMARY OF MAXIMUM AND MINIMUM HEADS:

Position no.	MaxHead m	MinHead m	Time Reverse Grad.	MaxPressure bar	MinPressure bar	MaxTime (sec)	MinTime (sec)
AIR-1	112.03	-1.47	9.354	10.986	-0.144	60.32347	17.79698
AIR-2	144.05	-1.05	4.033	14.126	-0.103	31.68435	14.00217
AIR-3	155.38	-1.08	5.300	15.238	-0.106	33.95757	14.45793
AIR-4	132.79	-1.09	6.551	13.022	-0.107	37.71959	14.69111
AIR-5	134.89	-1.09	7.600	13.228	-0.107	38.12758	15.13628
AIR-6	112.61	-2.59	13.281	11.044	-0.254	36.81352	48.46518
AIR-7	82.56	-1.67	17.431	8.096	-0.164	35.36700	51.88278
AIR-8	47.77	-3.31	34.376	4.685	-0.324	34.13772	29.46343
AIR-9	9.82	-7.02	83.694	0.963	-0.688	6.51904	34.18541
J-2	9.82	-7.79	83.211	0.963	-0.764	6.50844	34.15892
O-Pump-1	193.24	-0.98	1.866	18.950	-0.096	35.41999	78.61951
SDO-1	193.20	-1.22	1.002	18.946	-0.120	35.41999	78.65663
SDO-2	160.31	-0.91	2.804	15.721	-0.089	35.87037	13.62590
SDO-3	193.11	-0.34	1.065	18.938	-0.033	35.41999	78.66724
SDO-4	193.22	-0.65	1.468	18.948	-0.064	35.41999	78.65133
O-Pump-1	0.00	0.00	0.000	0.000	0.000	0.00530	0.00530

Fig. 15. Summary of maximum and munimum pressure before use of SAV (Scenario 96)

Hence, Surge anticipating valve is required to be introduced after pump. By using 800 mm surge anticipating valve, it can be observed that, surge pressure is completely eliminated (Fig. 16). Surge anticipating valve (SAV) is sized by means of valve resistance valve. For 800 mm SAV, valve resistance is 3. Valve resistance value can be referred from Table 3.

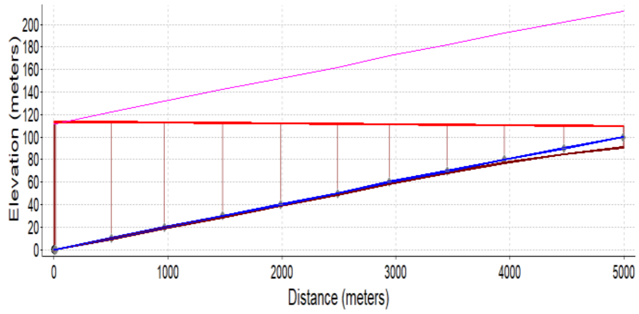

Fig. 16. Elimination of surge after pump trip – with Surge anticipating valve (Scenario 96)

From summary of maximum and minimum pressures (Fig. 17) it is observed that, minimum pressure after pump trip is minus 9.59 m near outlet valve (J-2), 68.539 seconds after pump trip. Maximum surge pressure 113 m is near pump, 11.002 seconds after pump trip.

SUMMARY OF MAXIMUM AND MINIMUM HEADS:

Position no.	MaxHead m	MinHead m	Time Reverse Grad.	MaxPressure bar	MinPressure bar	MaxTime (sec)	MinTime (sec)
AIR-1	51.39	-1.60	19.377	5.039	-0.157	14.08696	16.60437
AIR-2	92.89	-1.20	8.178	9.109	-0.118	10.01689	15.96831
AIR-3	82.50	-1.08	11.130	8.090	-0.106	9.48164	14.20355
AIR-4	72.11	-1.09	13.605	7.072	-0.107	11.54317	14.12406
AIR-5	61.73	-1.09	16.016	6.054	-0.107	8.42172	14.48443
AIR-6	41.00	-1.63	23.029	4.020	-0.160	14.61162	33.78271
AIR-7	30.62	-3.10	28.536	3.002	-0.304	7.61085	39.34096
AIR-8	20.22	-5.33	64.839	1.983	-0.523	7.06495	44.83562
AIR-9	9.82	-8.95	83.694	0.963	-0.878	6.51904	99.99891
J-2	9.82	-9.59	83.227	0.963	-0.941	6.50844	68.53960
O-Pump-1	113.63	-0.64	1.871	11.143	-0.063	11.00261	12.89456
SDO-1	113.62	0.00	0.000	11.142	0.000	10.65284	13.03765
SDO-2	103.24	-0.85	4.818	10.124	-0.083	0.53000	13.31322
SDO-3	113.61	0.00	0.000	11.141	0.000	0.02120	13.02705
SDO-4	113.62	-0.26	1.526	11.143	-0.026	10.49385	12.97405
O-Pump-1	0.00	0.00	0.000	0.000	0.000	0.00530	0.00530

Fig. 17. Summary of maximum and munimum pressure after use of SAV (Scenario 96)

After analysing 96 combinations of flows, lengths, elevations etc. a table chart is prepared indicating maximum surge and required size of surge anticipating valve to eliminate surge. The results are shown in below Table VII.

Table VII: Table charts for sizing of surge anticipating valve

Scenario No.	Q (m^3/hr)	d (mm)	Pipe Type	Wave Speed (m/s)	H (m)	L (m)	P (m)	H+ H_{max} (m)	SAV Size (mm)
CASE - 1, Q = 100 m^3/hr									
1	100	150	HDPE	350	10	100	21	50	-
2						500	27	54	-
3						1000	34	34	-
4						5000	90	90	-
5					50	500	66	97	65
6						1000	73	100	65
7						3000	101	101	-
8						5000	129	129	-
9					100	500	115	175	80
10						1000	122	153	80
11						3000	150	150	-
12						5000	178	178	-
CASE - 2, Q = 500 m^3/hr									
13	500	350	HDPE	350	10	100	20	39	-
14						500	23	51	-
15						1000	26	44	-
16						5000	48	48	-
17					50	500	62	111	150
18						1000	65	102	150
19						3000	76	88	-
20						5000	87	89	-
21					100	500	111	179	150
22						1000	114	152	200
23						3000	125	150	100
24						5000	136	149	-
CASE - 3, Q = 1000 m^3/hr									
25	1000	500	HDPE	350	10	100	20	35	-
26						500	22	39	-
27						1000	24	24	-
28						5000	40	40	-
29					50	500	61	97	150
30						1000	63	106	200
31						3000	71	81	-
32						5000	79	82	-
33					100	500	110	178	250
34						1000	112	149	250
35						3000	120	158	150
36						5000	128	140	150
CASE - 4, Q = 2000 m^3/hr									
37	2000	700	Mild Steel	930	10	100	22	22	-
38						500	23	23	-
39						1000	25	25	-
40						5000	31	31	-
41					50	500	60	192	200
42						1000	61	164	250
43						3000	66	137	250
44						5000	70	118	200
45					100	500	109	347	250
46						1000	110	268	400
47						3000	115	210	250
48						5000	119	207	250

Scenario No.	Q	d	Pipe Type	Wave Speed	H	L	P	$H+H_{max}$	SAV Size
	m^3/hr	mm		m/s	m	m	m	m	mm
CASE - 5, Q = 4000 m^3/hr									
49	4000	1000	Mild Steel	880	10	100	22	22	-
50						500	22	22	-
51						1000	22	22	-
52						5000	28	26	-
53					50	500	62	152	250
54						1000	63	145	400
55						3000	66	135	300
56						5000	67	116	300
57					100	500	110	301	400
58						1000	111	264	600
59						3000	113	193	400
60						5000	116	192	400
CASE - 6, Q = 6000 m^3/hr									
61	6000	1200	Mild Steel	900	10	100	23	20	-
62						500	23	20	-
63						1000	24	21	-
64						5000	28	25	-
65					50	500	62	198	300
66						1000	63	150	400
67						3000	65	113	300
68						5000	68	98	300
69					100	500	111	297	400
70						1000	112	264	600
71						3000	114	211	500
72						5000	117	189	500
CASE - 7, Q = 800 m^3/hr									
73	8000	1400	Mild Steel	850	10	100	25	20	-
74						500	25	20	-
75						1000	26	21	-
76						5000	29	24	-
77					50	500	64	137	300
78						1000	65	147	400
79						3000	66	107	400
80						5000	66	92	400
81					100	500	113	286	600
82						1000	114	255	2x600
83						3000	116	187	800
84						5000	118	182	800
CASE - 8, Q = 10000 m^3/hr									
85	10000	1600	Mild Steel	950	10	100	27	20	-
86						500	28	20	-
87						1000	28	20	-
88						5000	31	23	-
89					50	500	67	121	400
90						1000	67	122	600
91						3000	69	114	400
92						5000	70	96	350
93					100	500	116	233	800
94						1000	116	270	2x800
95						3000	118	189	2x800
96						5000	119	189	800

VI. CONCLUSION

Experimental results are compared with software results, for scenarios, Surge pressure for sudden valve closure and pump start and trip. It is concluded that software results are consistent with experiment results & hence KYPIPE TranSurge software is validated.

The table charts prepared for sizing of surge anticipating valves are prepared using numerous combination of flow, elevations, diameters etc. These table charts are useful if surge analysis software is not available. If given pumping main characteristics such as flow, length, elevations etc. are similar to mentioned in the table, then one can easily estimate amount of surge and size of surge anticipating valve.

The limitation of the study is, if the characteristics of pumping main are beyond the table charts, then one has to perform surge analysis using software and arrive at size of surge anticipating valve.

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