Purandar
Lift Irrigation Scheme
(Maharashtra Krishna Valley Development Corporation)

Water Hammer Analysis Report

December 2009
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Appendix I: Advantages of proposed surge protection system
1.0 INTRODUCTION

Purandar Lift Irrigation Scheme (PLIS) is one of the flagship projects of Maharashtra Krishna Valley Development Corporation (MKVDC) aimed at irrigating about 25,000Ha of agricultural land in Haveli, Purandar, Daund and Baramati taluks of Pune District in Maharastra. The project comprises over 12.5km of 2000-2200mm diameter MS pipe lifting water by about 260m in four stages from Mula River. The project was commissioned about 2 years ago but the delays in arrival of motors at some of the booster stations has delayed the simultaneous operation of all pumps at all stations. In the meantime certain operational maintenance problems were noted with a few one way surge tanks that were designed to protect the pipeline from extreme low pressure surges. Though operational maintenance problems are characteristic of one way surge tanks they are difficult to foresee at the design stage and get aggravated if the raw water carries high quantities of sediments and other debris. The concerned authorities wanted a reassurance on the existing surge protection system and provide additional protection devices, if deemed necessary, before operating Purandar Lift Irrigation Scheme at its designed capacity. A field visit was undertaken by the consultant to examine the existing surge protection system and gain a first hand information on the operational maintenance problems of the pipeline system. An exhaustive transient modeling study was undertaken using the most powerful surge modeling software called Pipe2008:Surge to simulate the existing conditions and to propose changes to existing surge protection system, if warranted. Results from the modeling study, including the observations from field visit, are presented in this report.

2.0 OBJECTIVE AND SCOPE OF STUDY:

The primary objective of this study was to evaluate the adequacy of existing surge protection system for Purandar Lift Irrigation Scheme in order to operate the pipeline system at its design capacity in light of the operational maintenance problems noted with one way surge tanks. The secondary objective is to append the existing surge protection system with additional low maintenance surge protection devices if deemed necessary. This added protection is to ensure the safe operation of the pipeline system even when some of the one way surge tanks need to be temporarily isolated from the main pipeline for maintenance purposes.
The scope of the study includes building a transient analysis model of the pipeline system with existing protection using Pipe2008:Surge software, evaluating the adequacy of the existing surge protection system for critical operating conditions, strengthening of existing protection system with additional reliable and low maintenance surge protection devices if necessary and evaluating the adequacy of overall surge protection system by selectively removing existing one-way surge tanks from the transient model (keeping the additional protection devices in the model).

3.0 DESCRIPTION OF PIPELINE SYSTEM

The Purandar Lift Irrigation Scheme lifts 8m$^3$/s water by 266.5m from Mula River to the command area. Water is lifted to the command area in four stages. The pump station at Mula River intake comprises 4 vertical turbine (VT) pumps (3 working + 1 standby). There is an inline booster station comprising 4 horizontal split casing (HS) pumps (3 working + 1 standby) at about 6.3km chainage that discharges water into a delivery chamber DC-I. There are two more inline booster stations each comprising 4 number of HS pumps (3 working + 1 standby) that pump water from DC-I to another delivery chamber DC-II at the end of pipeline. Figure 3.1 shows the schematic representation of the pipeline system from intake to DC-II along with location of existing protection devices. The physical and hydraulic characteristics of the pipeline used for transient analysis are listed in the following.

### Rising mains:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Pipe line</th>
<th>Chainage from to</th>
<th>Length M</th>
<th>Discharge LPS</th>
<th>No. of Rows</th>
<th>Pipe Dia mm</th>
<th>Velocity m/sec</th>
<th>Wall thickness mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage I</td>
<td>RM-I</td>
<td>0 6430</td>
<td>6430</td>
<td>8000</td>
<td>1</td>
<td>2200</td>
<td>2.11</td>
<td>12</td>
</tr>
<tr>
<td>Stage II</td>
<td>RM-II</td>
<td>6430 10140</td>
<td>3710</td>
<td>8000</td>
<td>1</td>
<td>2200</td>
<td>2.11</td>
<td>12</td>
</tr>
<tr>
<td>-do- GM-I</td>
<td>10140 10785</td>
<td>645</td>
<td>6725</td>
<td>1</td>
<td>2000</td>
<td>2.14</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Stage III</td>
<td>RM III</td>
<td>10785 12270</td>
<td>1485</td>
<td>6725</td>
<td>1</td>
<td>2000</td>
<td>2.14</td>
<td>12</td>
</tr>
<tr>
<td>Stage IV</td>
<td>RM-IV</td>
<td>12270 12700</td>
<td>430</td>
<td>6725</td>
<td>1</td>
<td>2000</td>
<td>2.14</td>
<td>12</td>
</tr>
</tbody>
</table>
* RM IV releases water in Delivery Chamber II.

**Pumping Machinery** -

<table>
<thead>
<tr>
<th>Stage</th>
<th>Type of pumps</th>
<th>Total Head Meter</th>
<th>Discharge Lps per pump</th>
<th>No. of Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Vertical Turbine</td>
<td>65.0</td>
<td>2667</td>
<td>3 working +1 standby</td>
</tr>
<tr>
<td>II</td>
<td>Horizontal Splitcase</td>
<td>62.5</td>
<td>2667</td>
<td>3 working +1 standby</td>
</tr>
<tr>
<td>III</td>
<td>Horizontal Splitcase</td>
<td>69.5</td>
<td>2242</td>
<td>3 working +1 standby</td>
</tr>
<tr>
<td>IV</td>
<td>Horizontal splitcase</td>
<td>69.5</td>
<td>2242</td>
<td>3 working +1 standby</td>
</tr>
</tbody>
</table>

**Pump Details - Stage I**

a) No. of Working Pumps : 3  
b) Stand-by pumps : 1  
c) Combined discharge of all pumps (cumecs) : 8  
d) Discharge of each pump : 2.67 cumecs  
e) Design head Stage I : 65 m  
f) Wall Thickness : 12 mm  
g) Pump and Motor Inertial (Calculated) : 7272 Nm^2  
h) Pipe roughness(Hazen William) : 140  
i) Wave speed (m/sec) : 862  
j) Pump rated speed (rpm) : 600  
k) Pump Efficiency (%) : 95  
l) Check Valve (Non return valve) : Fast acting swing check

**Pump Details - Stage II**

a) No. of Working Pumps : 3  
b) Stand-by pumps : 1  
c) Combined discharge of all pump (cumec) : 8  
d) Discharge of each pump : 2.67 cumecs  
e) Design head Stage II : 62.5 m  

iii) Wall Thickness : 12 mm
f) Wall Thickness : 12 mm  
g) Pump and Motor Inertial (Calculated) : 6000 Nm^2  
h) Pipe roughness (Hazen-William) : 140  
i) Wave speed (m/sec) : 862  
j) Pump rated speed (rpm) : 750  
k) Pump Efficiency (%) : 95  
l) Check Valve (Non return valve) : Fast acting swing check valve

- **Pump Details - Stage III**
  
a) No. of Working Pumps : 3  
b) Stand-by pumps : 1  
c) Combined discharge of all pump (cumec) : 6.725 cumecs  
d) Discharge of each pump : 2.242 cumecs  
e) Design head Stage III : 69.5m  
f) Wall Thickness : 12 mm  
g) Pump and Motor Inertial (Calculated) : 5500  
h) Pipe roughness : 140  
i) Wave speed (m/sec) : 890  
j) Pump rated speed (rpm) : 750  
k) Pump Efficiency (%) : 95  
l) Check Valve (Non return valve) : Fast acting swing check valve

- **Pump Details - Stage IV**
  
a) No. of Working Pumps : 3  
b) Stand-by pumps : 1  
c) Combined discharge of all pump (cumec) : 6.725 cumecs  
d) Discharge of each pump : 2.242 cumecs  
e) Design head Stage IV : 69.5m  
f) Wall Thickness : 12 mm  
g) Pump and Motor Inertial (Calculated) : 5500  
h) Pipe roughness : 140  
i) Wave speed (m/sec) : 890  
j) Pump rated speed (rpm) : 750  
k) Pump Efficiency (%) : 95  
l) Check Valve (Non return valve) : Fast acting swing check valve
4.0 MODELING SOFTWARE

The study was conducted using the popular Pipe2008:Surge software developed at University of Kentucky, USA. Pipe2008:Surge is a versatile program capable of modeling any type of surge protection device and its powerful graphical results presentation and interpretation capability has helped thousands of engineers worldwide design large complex transmission mains, small branching networks as well as large distribution networks for over 30 years and therefore is well suited for this study.

5.0 STEADY STATE ANALYSIS

Figure 5.1 shows the schematic of entire pipeline for purandar lift irrigation scheme. Figure 5.2 shows steady state hydraulic analysis for this pipeline system when all pumps are operating at their rated speed and water level at the intake is at its lowest elevation. Total flowrate in the pipeline from intake to DC-I is 8m$^3$/s and the flowrate from DC-I to DC-II is 6.725m$^3$/s. The maximum steady state pressure on the pipeline system is slightly below 70m.

6.0 TRANSIENT MODEL RUNS WITH EXISTING PROTECTION SYSTEM

The existing PLIS pipeline system was protected by 7 number of one-way surge tanks, 2 number of stand pipes and one surge anticipation valve. Table 6.1 summarizes the location and sizes of existing surge protection devices. A transient analysis model was built for the PLIS pipeline with existing protection system using the Pipe2008:Surge program. Pump trip condition resulting from a power failure event was considered as the most critical transient event.

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Chainage</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Pump House I</td>
</tr>
<tr>
<td>2</td>
<td>135</td>
<td>One way surge tank</td>
</tr>
<tr>
<td>3</td>
<td>135</td>
<td>100mm ⚫ Kinetic air valve</td>
</tr>
<tr>
<td>4</td>
<td>273</td>
<td>200mm ⚫ Kinetic air valve</td>
</tr>
<tr>
<td>No.</td>
<td>Length (mm)</td>
<td>Description</td>
</tr>
<tr>
<td>-----</td>
<td>-------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>5</td>
<td>390</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>6</td>
<td>880</td>
<td>200mm Kinetic air valve</td>
</tr>
<tr>
<td>7</td>
<td>1580</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>8</td>
<td>1870</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>9</td>
<td>1900</td>
<td>One way surge tank</td>
</tr>
<tr>
<td>10</td>
<td>2010</td>
<td>150mm Combination air valve</td>
</tr>
<tr>
<td>11</td>
<td>2360</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>12</td>
<td>2410</td>
<td>50mm Kinetic air valve</td>
</tr>
<tr>
<td>13</td>
<td>3953</td>
<td>150mm Combination air valve</td>
</tr>
<tr>
<td>14</td>
<td>4500</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>15</td>
<td>4770</td>
<td>One way surge tank</td>
</tr>
<tr>
<td>16</td>
<td>4770</td>
<td>200mm Kinetic air valve</td>
</tr>
<tr>
<td>17</td>
<td>5150</td>
<td>200mm Kinetic air valve</td>
</tr>
<tr>
<td>18</td>
<td>6410</td>
<td>150mm Combination air valve</td>
</tr>
<tr>
<td>19</td>
<td>6415</td>
<td>One way surge tank</td>
</tr>
<tr>
<td>20</td>
<td>6430</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>21</td>
<td>6780</td>
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<td>22</td>
<td>8800</td>
<td>2 No of 200mm Kinetic air valve</td>
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<td>23</td>
<td>8850</td>
<td>2 No of 150mm Combination air valve</td>
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<td>24</td>
<td>9330</td>
<td>2 No of 200mm Kinetic air valve</td>
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<td>25</td>
<td>9360</td>
<td>One way surge tank</td>
</tr>
<tr>
<td>26</td>
<td>9360</td>
<td>50mm Kinetic air valve</td>
</tr>
<tr>
<td>27</td>
<td>9750</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>28</td>
<td>10140</td>
<td>Delivery Chamber I</td>
</tr>
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<td>29</td>
<td>10160</td>
<td>200mm Kinetic air valve</td>
</tr>
<tr>
<td>30</td>
<td>10440</td>
<td>150mm Combination air valve</td>
</tr>
<tr>
<td>31</td>
<td>10560</td>
<td>Stand Pipe 500mm</td>
</tr>
<tr>
<td>32</td>
<td>10785</td>
<td>Pump House III</td>
</tr>
<tr>
<td>33</td>
<td>10800</td>
<td>Surge Anticipatory valve 200mm</td>
</tr>
<tr>
<td>34</td>
<td>10920</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>35</td>
<td>11855</td>
<td>200mm Kinetic air valve</td>
</tr>
<tr>
<td>36</td>
<td>12130</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>37</td>
<td>12185</td>
<td>One way surge tank</td>
</tr>
<tr>
<td>38</td>
<td>12185</td>
<td>100mm Kinetic air valve</td>
</tr>
<tr>
<td>39</td>
<td>12270</td>
<td>Pump House IV</td>
</tr>
<tr>
<td>40</td>
<td>12300</td>
<td>200mm Kinetic air valve</td>
</tr>
<tr>
<td>41</td>
<td>12400</td>
<td>2 No of 200mm Kinetic air valve</td>
</tr>
<tr>
<td>42</td>
<td>12420</td>
<td>One way surge tank</td>
</tr>
<tr>
<td>43</td>
<td>12420</td>
<td>50mm Kinetic air valve</td>
</tr>
<tr>
<td>44</td>
<td>12750</td>
<td>Stand Pipe 500mm</td>
</tr>
<tr>
<td>45</td>
<td>12770</td>
<td>Delivery Chamber II</td>
</tr>
</tbody>
</table>

Transient analysis of this pipeline was carried out without any protection to assess the potential for high/low transient pressures following a pump trip event. Figure 6.1 shows the envelope of maximum and minimum pressure heads over the entire pipeline system (intake to DC-II) following the pump trip event (simultaneous failure of all of the operating pumps) during a 200 second transient.
simulation. Figure 6.2 shows the close up view of max-min pressure envelope for pipeline from intake to DC-I and Figure 6.3 show the close up view of the max-min pressure envelope from DC-I to DC-II. The green dotted line indicates the maximum hydraulic grade line and the red line indicates the minimum hydraulic grade line during the 200 second simulation. Purple line below the pipeline profile indicates the lowest allowable pressure (vapor pressure or cavitation pressure). The light blue line indicates areas of the pipeline that cavitated during the transient simulation. As evident from Figures 6.1-6.3, severe high pressures (as high as 200m or 20bars) occur over much of the pipeline while the highest steady state pressure was only about 70m. Simultaneously, low pressures in the system reach cavitation pressures and many parts of the system experience cavitation (water column separation) conditions. Therefore, a pump trip event is expected to generate both high pressure and low pressure problems that call for a suitable and effective protection.

Transient analysis of this pipeline was repeated with all the existing surge protection devices to assess the adequacy of existing surge protection system in containing high and low surge pressures. Figure 6.4 shows the envelope of maximum and minimum pressure heads over the entire pipeline system (intake to DC-II) following the pump trip event during a 200 second transient simulation. Figure 6.5 shows the close up view of max-min pressure envelope for pipeline from intake to DC-I and Figure 6.6 shows the close up view of max-min pressure envelope from DC-I to DC-II. Figures 6.7 and 6.8 show the close up views of pipeline system from intake to DC-I and DC-I to DC-II, respectively. Figure 6.9-6.12 show the variation in pressure heads at pump discharge manifolds of all pump stations (intake and three booster stations).

Before judging the adequacy of existing surge protection system, it is important to know the allowable maximum and minimum pressures for the pipelines based on their diameter, thickness, and material. Assuming a Modulus of Elasticity of 240 MPa and a Poisson’s ratio of 0.3 for MS pipes (Grade B), the allowable maximum negative pressure for a 12mm thick 2200 mm diameter MS pipe is \(-8.60\) m (AWWA M11). It should be noted that concrete lining adds to the strength of MS pipes against buckling pressures but such contributions were NOT included in computing the allowable maximum negative pressures. The Yield Point stress for fabricated MS pipes of grade B steel is roughly 240 MPa. Using 60% of this as
the design stress, the 12mm thick 2200 mm diameter MS pipe can withstand up to 197m of positive pressure (AWWA M11). The minimum thickness for handling the 2200 mm MS pipes is 7.64 mm. Table 6.2 summarizes the allowable pressures for different diameters and thickness values of the pipeline and the high and low pressures during different transient conditions should stay within the allowable limits. Table 6.2 also lists maximum allowable pressures computed based on IS 5822-1980. Since AWWA suggested values offer more conservative estimates for the allowable pressures, they are used as the limiting pressures in this study.

Table 6.2. Allowable pressures for different pipe thickness values

<table>
<thead>
<tr>
<th>THICKNESS (MM)</th>
<th>PIPE DIAMETER (MM)</th>
<th>MAXIMUM ALLOWABLE NEGATIVE PRESSURE (M)</th>
<th>MAXIMUM ALLOWABLE POSITIVE PRESSURE (M)</th>
<th>MAXIMUM ALLOWABLE PRESSURE BASED ON IS5822-1980 (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2000</td>
<td>-6.62</td>
<td>148</td>
<td>180</td>
</tr>
<tr>
<td>10</td>
<td>2200</td>
<td>-4.97</td>
<td>135</td>
<td>164</td>
</tr>
<tr>
<td>12</td>
<td>2000</td>
<td>-11.44</td>
<td>178</td>
<td>217</td>
</tr>
<tr>
<td>12</td>
<td>2200</td>
<td>-8.60</td>
<td>161</td>
<td>197</td>
</tr>
</tbody>
</table>

As noted from Figures 6.4-6.6 and 6.9-6.12, the highest surge pressure is 125 m on the entire pipeline system and the low pressures are well above the cavitation limit. Figure 6.13 compares the variation in pressure head at pump discharge manifold of intake pump station with and without protection. Similarly, Figures 6.14-6.16 compare the variation in pressure heads at pump discharge manifold of all three booster stations with and without protection. In view of these observations, it may be concluded that the existing surge protection system comprising one-way surge tanks, stand pipes and surge anticipation valve is adequate to protect the pipeline from unwanted high and low surge pressures.

7.0 FIELD VISIT

A field visit was arranged by MKVDC authorities to review the existing surge protection system of PLIS and have a first hand assessment of the current and
future operational maintenance problems noted by the MKVDC authorities. Prior to this visit, the consultant was provided with all the characteristics of pipeline system and locations and sizes of existing surge protection devices. The consultant has verified the adequacy of existing surge protection system through a complete surge modeling study (section 6). Results from this study have indicated that the existing surge protection system is theoretically adequate to prevent extreme high and low surge pressure in the event of simultaneous failure of all of the operating pumps. The current operation of PLIS is limited to operation of only one pump at each station due to the late arrival of motors at some pump stations.

7.1 OST Drawdown Levels

The MKVDC authorities had recorded the maximum drawdown levels in each of the 6 one-way surge tanks on the pipeline system during a pump shutdown event. Surge analysis was repeated to simulate this single pump operating condition and generated a pump trip event and noted the maximum draw-down values in each of the OSTs. Figures 7.1-7.7 show the water level drawdown curves for each of these OSTs. Table 7.1 compares the maximum measured drawdown values with computed drawdown values. As evident from this table, the observed drawdown values are in reasonable agreement the computed values.
## IVRCL INFRASTRUCTURES & PROJECTS LTD
### PURANDAR LIFT IRRIGATION SCHEME
#### SURGE TANK READING AFTER EMERGENCY TRIPPING OF MOTOR

Date: 16/04/2009

<table>
<thead>
<tr>
<th>SR. NO.</th>
<th>SURGE TANK NO.</th>
<th>CHAINAGE</th>
<th>WATER LEVEL BEFORE TRIPPING (FROM TANK TOP) IN MM</th>
<th>WATER LEVEL AFTER TRIPPING (FROM TANK TOP) IN MM</th>
<th>DIFFERENCE IN WATER LEVEL IN MM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>135</td>
<td>390</td>
<td>475</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1900</td>
<td>100</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4770</td>
<td>FULL LEVEL</td>
<td>FULL LEVEL</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>6415</td>
<td>200</td>
<td>1420</td>
<td>1220</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>9360</td>
<td>FULL LEVEL</td>
<td>FULL LEVEL</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>12185</td>
<td>1220</td>
<td>1360</td>
<td>130</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>12420</td>
<td>FULL LEVEL</td>
<td>FULL LEVEL</td>
<td>0</td>
</tr>
</tbody>
</table>

Surge Anticipatory valve at ch. 10800 is operated successfully at low pressure = 3.5Kg/Cm² and at High Pressure = 8Kg/Cm²

The above readings are witnessed

For MKVDC

1. Mr. A C Kittad
2. Mr. R D Mandge

For IVRCL

Mr. V M Pawar

Note: The above readings are taken in two stages. In 1st Stage, started the PH1 & PH2 Motors and tripped at a time and noted the reading upto ch. 9360. In the 2nd stage, started the PH1, PH2, PH3 & PH4 Motors and tripped PH3 and PH4 Motors at a time and noted the reading.
### Table 7.1. Measured drawdowns compared to computed drawdowns

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Surge Tank No.</th>
<th>Chainage (m)</th>
<th>Measured Drawdown Values (m)</th>
<th>Computed Drawdown Values (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>135</td>
<td>0.085</td>
<td>0.180</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1900</td>
<td>0.800</td>
<td>0.140</td>
</tr>
<tr>
<td>3</td>
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<td>4770</td>
<td>0</td>
<td>0.070</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>6415</td>
<td>1.220</td>
<td>0.500</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>9360</td>
<td>0</td>
<td>0.003</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>12185</td>
<td>0.130</td>
<td>0.065</td>
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The difference in measured and computed drawdown values could be because of the following reasons.

1. Pump trip sequence, which could be slightly different from the way it was simulated in the model.
2. Slight inaccuracies in the way pipeline and pumping system were represented in the model.
3. Assumptions associated with OST modeling
4. Poor water quality which could affect the performance of a number of devices including the surge protection system

### 7.2 Other Observations

It was observed during the field study that OST at 1900m chainage appears to lose water even during normal pumping operation which might explain why there is a 0.66m difference in observed and computed drawdown values at this OST. Drawdown in OSTs during normal pumping operation is not possible unless there is a leak between NRV and OST; MKVDC authorities had agreed to look into this matter.
Field trip was helpful in gaining a meaningful insight into the actual operation of the pipeline system including the surge protection system. The field trip began at the intake of PLIS. Raw water from Mula River is drawn into the intake of PLIS through a Wm x Dm open channel L m long. There are 4 bays of w m X d m size that let water into the intake well of each pump from the open channel. End of April is a relatively dry flow period for this river and the water appeared to be close raw sewage emanating from Pune city. Water hyacinth was abundant in the river and has covered entire surface of the channel conveying water from the river to intake structure of PLIS. Though water hyacinth floating on water may not adversely affect the pumping operation and the efficiency of surge protection system, water hyacinth drawn into the pipeline system may have some serious effects on both pumping operation as well as the surge protection system. The strong and highly fibrous long roots of water hyacinth can interfere with normal pumping operation and surge protection system several different ways:

- Retard impeller rotation
- Partial blockage of pump suction and/or discharge sides
- Hinder hinge operation of NRVs at both pump station as well as one way surge tanks
- Block air valve and surge anticipation valve passages

Small polythene bags from river water appear to pass through the fixed screen at the intake structure as reported by the personnel in charge of PLIS operation. Bad quality of water coupled with water hyacinth and polythene bags can be a constant menace to trouble free operation of PLIS over a long run. While decreased pumping efficiency during normal pumping operations is one of the concerns, the more serious problem could be the decreased effectiveness of surge protection system.

The main protection for PLIS comes from several large one-way surge tanks. One-way surge tanks offer excellent protection to the pipeline system from extreme low pressure transients when designed and built properly and operated the way they were intended to function. Surge analysis of PLIS with all three pumps operation case as well as single pump operation case has indicated that the one-way surge tank based protection is theoretically adequate to protect the pipeline from extreme low and high pressure conditions in case of pump trip resulting from power failure. However, the long-term fail safe operation of the
surge protection system is questionable because of the quality of water is much worse than what was expected of raw water! This is because of the delicate nature of the OST based protection. OSTs are economical surge protection devices and offer a very good protection to pipeline systems as long as they are built, operated, and maintained in accordance with the assumptions involved in their usage in surge modeling. OSTs can very quickly and easily become a maintenance problem if there are any changes in physical or hydraulic characteristics of the system being protected. One important parameter that may have serious impact on long-term successful operation of OST is the quality of water.

Long term unhindered operation (as intended) is questionable for NRVs (non-return valves or check valves) used with OSTs of even potable water systems. NRVs are seldom designed for 100% backflow prevention even for potable water systems. NRVs are normally considered effective (and will not damage pump impellers) even if they allow a small percentage (1-5%) of normal flow in reverse direction. The efficiency of NRVs in preventing backflow could be much worse when dealing with non-potable water (raw water and sewage). Efficiency of NRVs may also deteriorate with time and the rate of deterioration may accelerate with bad quality of water. Artificial measures to prevent backflow through NRVs, such as use of higher strength springs on multi-door NRVs (either at the installation stage or some time after installation) will have an adverse effect on surge protection because of the added time delay in opening of the NRVs. A more detailed description on the delicate operation and maintenance requirements of OSTs are described in Appendix I.

While OSTs are excellent for protecting the pipelines from extreme low pressures, they cannot offer any protection against subsequent high pressure transients. In most pipeline systems, arresting initial extreme low pressures will prevent subsequent high pressure problems and therefore do not necessitate additional protection against high surge pressures. Pipeline systems that do not employ compressed air based protection (air vessels or bladder vessels) may be subjected to low intensity positive surge pressures capable of inflicting fatigue type damage to the pipeline system over a long run. In case of pipelines protected by OSTs and do not include any compressed air based protection devices may be subjected to check valve slam and consequent damages to
NRVs at OSTs. Significant backflow through NRVs forces the unsuspecting operators to close the line connecting the OST to the pipeline being protected. Some of these problems were quite evident during the field visit! Though the existing surge protection may work all right even with three pump operation of PLIS, any deviation from intended operation and maintenance procedures may result in serious damages to the pipeline system because of the inherent disadvantages of the OST based surge protection. The reliability of the current OST based surge protection becomes highly questionable during the dry periods where the quality of water is more close to sewage rather than raw water.

7.3 Recommendations Derived from Field Visit

In view of these observations, the following recommendations should be considered essential for efficient and safe long term operation of PLIS.

- Additional protection system for the intake structure to avoid major debris such as water hyacinth, plastic bags and other large objects should be provided. Use of moving trash rack is recommended at the intake. The size and type should be determined based on the characteristics of the trash rack, expected peak submergence at the intake etc. This is required because of bad quality of water which may not be envisaged during design stage.

- Increased vigilance on the surge protection equipment that comes in direct contact with water during dry periods.

- Addition of compressed air based surge protection devices to arrest low intensity and high frequency positive pressure transient pressures in an effort to minimize the check valve slam (NRVs on OSTs) thereby increasing the longevity of the NRVs and OSTs operation. Bladder type vessels should be considered over the conventional compressed air vessels to minimize the associated maintenance problems.

- Replacing some of the air valves along the pipeline with surge suppressing air valves in case of an emergency situation where an OST might fail to operate as intended. Use of surge suppressing air valves will prevent air slam pressures during the expulsion phase in case air gets in to the
pipeline following OST failure. A more detailed description on the advantages of bladder vessels is presented in Appendix I

- It was observed during the field visit that although there was adequate telephone communication between different pump stations during the pump startup and shutdown operations there was no direct data communication (pressure and flow data) between different pump stations which might help reduce human errors and aid in smoother operation of PLIS. Data communication between pump stations is generally considered essential for inline booster pump stations with no storage.

8.0 ADDITIONAL PROTECTION

After several trial runs, an optimal surge protection system based on bladder type air vessels and surge suppression air valves was obtained as an added protection to the existing surge protection system of PLIS. The main criteria used for arriving at this protection system was that the additional protection alone should be able to protect the pipeline from undue surge pressures in case the existing one way surge tanks or other existing surge protection devices need to be isolated for servicing. Care was taken to ensure that the added protection system will also work with the existing protection devices in working conditions and help containing the surge pressures in a more efficient manner. The use of bladder vessels adds “shock absorption” capability to the overall surge protection system (which was not available earlier with the OST based protection) which in turn significantly enhances life of the pipeline system. Appendix II presents the advantages of bladder vessels over conventional compressor based air vessels.

Figure 8.1 shows schematic of the pipeline system with additional protection devices. Steady state as reported in section 5 will also apply to the transient modeling scenarios with additional surge protection devices. Figure 8.2 shows the envelope of maximum and minimum pressure heads over the entire pipeline system (intake to DC-II) following the pump trip event during a 200 second transient simulation. Figure 8.3 shows the close up view of max-min pressure envelope for pipeline from intake to DC-I and Figure 8.4 show the close up view of the max-min pressure envelope from DC-I to DC-II. Figures 8.5 and 8.6 show the close up views of the pipeline system from intake and DC-I and DC-I to DC-II,
respectively. Figure 8.7-8.10 show the variation in pressure heads at pump discharge manifolds of all pump stations (intake and three booster stations). As noted from 8.2-8.4 and 8.7-8.10, the highest surge pressure is 110 m on the entire pipeline system and the low pressures are well above the cavitation limit.

Figure 8.11 compares the variation in pressure head at pump discharge manifold of intake pump station with existing protection and with additional bladder tanks. Similarly, Figures 8.12-8.14 compare the variation in pressure heads at pump discharge manifold of all three booster stations with existing protection and with additional bladder tanks. As evident from these figures, addition of bladder vessels helps reduce sharp increase/decrease in pressures during the transient simulation (because of the shock absorbing capability of the bladder vessel) and therefore enhances the life of pipeline system.

9.0 ADDITIONAL MODELING SCENARIOS

One of the main reasons for proposing the bladder vessel based added surge protection was to protect the pipeline system from undue surge pressures in case OSTs need to be isolated for periodic or unexpected maintenance. Therefore, it is essential to verify if the new protection system is adequate in case one or a few OSTs taken out of service.

This scenario models the condition where all OSTs are taken out of service – keeping all other surge protection devices in place (including the additional protection devices such as bladder vessels). Figure 9.1 shows the schematic of the pipeline system highlighting the isolated devices. Figure 9.2 shows the envelope of maximum and minimum pressure heads over the entire pipeline system (intake to DC-II) following the pump trip event during a 200 second transient simulation. Figure 9.3 shows the close up view of max-min pressure envelope for pipeline from intake to DC-I and Figure 9.4 show the close up view of the max-min pressure envelope from DC-I to DC-II. Figures 9.5 and 9.6 show the close up views of the pipeline system from intake and DC-I and DC-I to DC-II, respectively. Figure 9.7-9.10 show the variation in pressure heads at pump discharge manifolds of all pump stations (intake and three booster stations). As noted from 9.2-9.4 and 9.7-9.10, the highest surge pressure is 115 m on the entire pipeline system and the low pressures are well above the cavitation limit.
10.0 SUMMARY

In summary, the existing OST based surge protection system is sound and adequate for PLIS as per the original design conditions and prevailing surge protection design practices in India. However, OSTs have certain inherent characteristics that lead to operational maintenance problems especially when there are significant seasonal variations in quality of water being lifted. During the field visit to PLIS arranged by the MKVCD officials, certain operational maintenance issues were noted primarily with respect to the operation of OSTs. In order to safeguard the long term operation of the PLIS at its design capacity, it was proposed to augment the existing protection system with low maintenance bladder tank based surge protection system. This transient modeling study has arrived at the most efficient and optimal surge protection system based on bladder vessels and verified the adequacy of the new surge protection system even when all of the existing OSTs need to be isolated for periodic or unexpected maintenance purposes.

11.0 RECOMMENDATIONS

The following recommendations are arrived at for PLIS based on an extensive transient modeling study which when implemented allow for safe and efficient long term operation of PLIS at its design capacity.

- Additional screening system at intake structure to avoid major debris such as water hyacinth, plastic bags and other large objects should be provided.
- 5 number of bladder vessels manufactured by Fayat Group of Companies in France.

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- Reliable communication system between the pump station that eliminates human errors.

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APPENDIX - I

Advantages of proposed surge protection system

- Minimizes initial down surge by releasing water into the areas of the pipeline most susceptible for water column separation.
- Minimizes the effect of subsequent upsurge by providing a safe passage (admitting water back into the bladder vessel) to the high pressure wave.
- Bladder vessel requires little or no maintenance
  - Bladder separates water from air thereby eliminating the need for frequent recharge of compressed air.
  - No compressor and no backup generator.
  - No additional power requirement, which could be a significant factor.
  - No mechanical moving parts other than collapsible bladder inside the vessel - little or no down time.
  - Eliminates corrosion of vessel interior as the water is not in contact with air.
  - Pipeline may be started almost immediately in case of pump trip following power failure as the bladder gets charged by the line pressure and relatively smaller size vessel does not require much time for charging (gets charged by the time pumps are running at their rated speed).
  - Reduces the high transient pressures generated at the time of normal pump startup, thereby minimizing the startup times.
- 3-stage non-slam surge suppressing air valves could serve as dual purpose surge protection (during a transient event such as a power failure condition) devices as well as air venting devices (during initial filling of the pipeline).

Problems associated with conventional OST and Air Vessel based protection systems:

It has become a common practice to use one way surge tanks (OSTs) as primary surge protection devices in India. Though OSTs and air valves provide protection against low pressures only, lack of confidence on local air valves as surge protection devices has forced some designers to ignore the recent developments in air valve technology and recommend only OSTs as a cheaper and meaningful alternative. However, recognizing the uncertainty and the operational maintenance issues associated with the OSTs (as discussed in a later section), designers have been recommending use of air vessels near the pump station for large pipeline systems. Dr. Lingireddy, with his over 15 years of research and modeling experience (and technical support to large consulting companies around the world), sees potential problems with OSTs and Air vessels as main surge protection devices. The following sections summarize the problems associated with both OSTs and Air vessels in protecting large pipeline systems.
One- way Surge Tank (OSTs)

- OSTs offer protection to the pipeline system from only low pressure transients and offers NO protection against high pressure transients that may cause the pipe and valve bursts.
- One-way surge tanks and air valves essentially fall into the same category - can offer protection only against low pressure transients.
- Though OSTs offer cheaper protection to pipelines, they are rarely used in rest of the world and for several good reasons. Although conceptually simple and produce excellent computer modeling results, one-way surge tanks pose several operational maintenance problems initially as well as over a long run.
- OSTs store large quantities of water during normal pump operation and release this stored water during a power failure event to control the down surge.
  - Pumps cannot be started until OSTs are completely filled with water – capacity of a typical OST may be 2-5 lakh liters.
  - There must be water in the pipeline and at sufficient pressure to fill OSTs before starting the pumps.
  - Requires a reliable automatic shutoff mechanism to avoid manual filling operation.
  - Reliable auto shutoff mechanism requires the use of sophisticated level control valves which could turn out to be quite expensive forcing the contractors to resort to cheaper alternatives.
  - Use of cheap float control valves may serve the purpose in the short term but within a few years the floats stop functioning.
  - There have been incidents where the maintenance personnel have closed the isolating valves on the filling pipelines to prevent overflowing OSTs (malfunctioning floats). Such acts could lead to catastrophic failure of the pipeline if the OSTs stay empty during the subsequent transient events.
  - OSTs also pose the space constraints (requires large open spaces) and substantial periodic cleaning time.
  - Pipeline protected by OSTs require longer startup times in order to be able to fill all OSTs before the normal pumping operation.
  - No protection is offered by OSTs during the pump startup time and therefore requires longer startup times. These longer startup times are in addition to the time required for filling the OSTs.

Non-return Valves:

- The other important component of an OST is the non-return valve (NRV) on the pipeline that connects the OST with the pipeline to be protected.
- Hydraulic grade on the pipeline at OSTs are higher than the water surface elevation in OST, requiring an NRV to prevent water from entering the OST during normal operation.

- Non-return valves available in the market are designed to protect pumps from significant reverse flow and not necessarily prevent 100% backflow though the NRV. In other words, NRVs are generally not designed to be 100% leak proof.

- Large NRVs generally rely on swinging plates that can generate significant impact loads when activated. This prohibits 100% leak proof design for NRVs and a small amount of reverse flow as a leakage is not detrimental for pump stations. They are considered adequate even if they allow 5% of flow in the reverse as such low reverse flows will not damage pumps.

- NRVs on OST connection lines must be 100% leak proof as even a small leakage could lead to overflowing OSTs within a very short time.

- In addition, the traditional NRV design does not require quick opening of the swinging plates – NRV should close rapidly to prevent flow reversal but is seldom critical for it to open quickly when placed at pump discharge. However, NRVs on the OST lines must open quite rapidly to prevent the down surge effects. Unless the OST is very tall, there may not be enough head on the upstream side of NRV to help open the flaps rapidly.

- Most computer modeling studies assume instantaneous opening of the flaps following low pressure conditions at OST but it may be far from reality.

- Besides, low quality NRVs may develop more friction on the hinges over a period of time which could further increase the NRV opening time.

- Though one can find NRVs that seem to open quickly and provide 100% leak proof design initially, they are bound to not work the same way in a long run as they are not designed with that criteria (rapid opening and 100% leak proof) in mind.

In summary, OST is a good protection device against low pressure transients provided all components of OST are of highest quality and work in accordance with the assumptions used in the surge modeling which is very rare to achieve in reality.

**Air Vessels:**

Although air vessels are excellent surge protection devices and protect the pipelines from both high and low pressure transients, they do come with a big maintenance overhead. Improper selection and maintenance of air vessels may result in severe damage to the pipeline system. The following points highlight the problems associated with air vessels as surge protection devices.
- Dissolution of air: Air is in direct contact with water and gets dissolved in water even under normal operating conditions.
- Necessitates compressor: Constant loss of air (by dissolution in water) requires replenishment of air by means of external air compressors.
- Compressors need additional power source and power consumption which is generally not accounted for at the time of designing electrical systems.
- Reliable operation of compressors may call for backup generators.
- Compressors need periodic maintenance whether they are being used or not. In case of Sripadsagar project, the pipelines are likely to operate only for about 6 months in a year. However, the compressors must be maintained throughout the year irrespective of whether they are operational or not.
- Complicated System of Controls
  - Compressor
  - Air receiver
  - Measuring equipment
  - Alarm systems
  - Control panel
- More importantly, dissolved air will be released into the pipeline when the water reaches high altitude points because of prevailing low pressure conditions. If adequate air venting is not available at these points, the air can choke flow at these locations thereby reducing the overall delivery efficiency of the pipelines. It may be noted that cheap air valves, though capable of venting air during the pipeline filling operation, will remain closed under pressure flow conditions and will NOT open even if significant amount of air gets accumulated in the valve chamber.
- Air vessels are highly prone to corrosion due to air-water interface.
- Requirement for power and associated daily maintenance restricts the use of air vessels to places close to pump stations.
- Maintenance intensive Electro-mechanical solution