San Francisco Water System Analysis Ensures Valve Quality & Performance

Faced with an aging water system, San Francisco Public Utilities Commission (SFPUC) and SRT consultants are committed to replacing two gate valves, recently having conducted an analysis on previous water system conditions to see how much pressure could reach the valves. Both valves are proposed for installation upstream of the Baden Pump Station and Valve Lot: one on the existing 60-inch diameter Crystal Springs No. 2 (CS-2) pipeline, and one on the existing 44-inch-diameter San Andreas Pipeline.

The firm provided an in-depth examination to determine the maximum possible surge pressures that could reach these valves, in order to aid in their design. Simultaneously, the report explores adjustments needed to maintain safe pressure levels along the recently installed sections of slip-lined pipes on the SFPUC's San Andreas Pipeline No. 2 (SAPL2). In a meeting between SRT consultants and SFPUC Operations, it was found that potential catastrophic transients would likely be caused by an instantaneous power failure when utilizing the Baden Pump Station (BPS) or the Lake Merced Pump Station (LMPS). There are no worries over transient threats on the system due to a sudden valve closure, or any other known source. After careful review and reflection through the software company Flowscience, it was further determined that the worst-case transients would likely occur in a case of a simultaneous failure of both the BPS and LMPS while running at high flow rates.

The intent of the "High Zone" analysis is documented in the SFPUC Regional Water System Transient Analysis Report. The report is an inside look on the inspection of transient surge pressures that are adequately low to prevent damage of the newly slip-lined section. Existing upper zone surge protection devices that are already sufficient to protect the system have also been inspected, due to the newly rehabilitated pipeline sections with minutely smaller inner diameters.

The report consists of a collection of modeling objectives, assumptions, methodology, and results for investigating the effects of transient surge pressures on two new valves located upstream of the Baden Pump Station, and the effects of transient surge on SFPUC's "High Zone" due to three lengths of pipeline recently slip-lined under the San Andreas Pipeline No. 2 Rehabilitation Project. Per the SFPUC's request, maximum surge pressures were also monitored at requested valve locations along SFPUC's Crystal Springs No. 2 Pipeline (CS-2 Pipeline).

The purpose of the valve analysis was to assess the newly installed valves and ensure that they do not undergo high surge pressures under various operating schemes. The analysis also reviewed existing "Low Zone" surge protections to check that they are sufficient enough to protect the valves and system infrastructure.

Modeling Scenarios

During a meeting, several scenarios were discussed between SFPUC and SRT Consultants. Per the original scope, four scenarios were to be analyzed; however, a fifth scenario was also added to better clarify SFPUC's questions. One aim was to conduct the analysis believed to be the worst-case pressure surge condition for each new valve at Baden. Another aim was to test existing surge protection systems against changes made under the SAPL2 Rehabilitation Project (namely slip-lining along SAPL2).

Scenarios 1 and 2 were designed to assess maximum surge pressure in the system before and after the completion of slip-lining projects, with a focus on the "High Zone" results. To see how tasks would carry out, a baseline analysis was first performed with existing pipeline sizes and roughness coefficients along SAPL2. Scenario 2 repeated this same analysis, but with updated slip-lined pipe sizes and roughness coefficients. This was used to determine whether or not the projects worsen with overall surge pressures due to smaller effective diameters. Additionally, existing "High Zone" surge protection devices were checked to see if they were satisfactory when dampening surge pressures in the High Zone system.

Scenarios 3, 4, and 5 assessed maximum surge pressures experienced by the proposed Baden valves following simultaneous LMPS and BPS failures. Scenario 3 specifically looked at pressures when the new CS-2 valve would be closed, while Scenario 4 focused on pressures when the SAPL1 valve would be closed. Finally, Scenario 5 focused on when both valves are closed. Scenario 2 also came into use, serving as a baseline analysis for BPS suction when both valves were fully open.

Software Setup

SFPUC utilizes Synergi Water Modeling Software, created by DNV GL, and its water hammer tool, LIQT, to analyze system transients. All scenarios and associated boundary conditions were first built in the Synergi Water environment, and then exported to LIQT for analysis. Once in LIQT, SRT proceeded to change the initial pump conditions to reflect the instantaneous failure of all Lake Merced and Baden pumps.

Some other modeling adjustments and changes were required for the analysis as well, such as rebuilding Baden Pump Station and Lake Merced Pump stations; adding surge tanks on the suction and discharge lines at both pump stations; and adding fixed head nodes at Sunset Reservoir, Merced Manor Reservoir and University Mound Reservoir. It was also necessary to break down large clusters of gate valves and other node-connecting elements (NCEs). A cluster is composed of any NCEs that are connected directly to each other, and each cluster cannot have more than 5 NCEs. Adjustments to settings on pipe force, time step, wave speed standard deviation in the model, setting up plot variables, and time-series charts were also made.

Modeling Assumptions

System Operation

During the analysis, the upstream fixed hydraulic grade line (HGL) for the Low Zone was set to 305 feet with an inexhaustible supply, and set up in the model as a fixed head reservoir located at the Pulgas Weir. The downstream HGL of the Low Zone was the University Mound Reservoir, set at a constant elevation of 179 feet and providing dual-direction flow. The upstream HGL for the High Zone was variable based on the pump hydraulics of each scenario, and the downstream HGL was the Sunset Reservoir, set to a constant elevation of 382 feet with dual direction flow.

The Harry Tracy Water Treatment Plant (HTWTP) was assumed to be offline and isolated to mimic a plant shutdown. This conservative condition for surge analysis indicated there was a substantial surge pressure effect when the High Zone was left connected to the HTWTP Clearwell. It was assumed the High Zone would feed zero flow to the low zone via Cappuccino Pressure Reducing Valve (PRV) or any other PRV. Overall, both the Low Zone and High Zone pipelines were assumed to be hydraulically connected via open crossovers and bypass line.

Pump + Valve Conditions

To model the worst case scenario for surge pressure, only the BPS and LMPS were set up to supply water to High Zone, and the analysis was set up with the highest anticipated pumping rates: 50 million gallons per day (MGD) at Baden and 70 MGD at Lake Merced. The status of all valves in the transient analysis were equivalent to that of valves existing in the Synergi model prior to export. It assumed that all valves were correctly configured for the scenarios explored.

Surge Tank Configurations

The Baden Pump Station currently has surge tanks on both the suction and the discharge side of the pumps. Both were included in the analysis. Flowscience recommended an orifice plate, a device used for measuring flow rate, be installed upstream on both tanks, but SRT could not find any documentation that indicated that orifice plates were installed beforehand Therefore, it was left out of the analysis to remain conservative. The BPS surge tank settings and initial conditions were researched utilizing the current Operations Manual.

The Lake Merced Pump Station currently has surge tanks on both the suction side and discharge side of the pumps, which are both included in the analysis. Flowscience also recommended that orifice plates be installed upstream of both surge tanks but once again, it was determined that orifice plates were never installed.

Analysis

Scenarios 1 and 2 – High Zone Analysis

When comparing the results of Scenarios 1 and 2, SRT found that they were very similar. The lowest section of newly slip-lined SAPL2 pipeline had slightly higher pressures under Scenario 2 when compared to Scenario 1: 208 psi vs. 203 psi. The inverse relationship occurs with BPS discharge, with Scenario 1 maximum pressures being just slightly higher than Scenario 2 maximums. The cause of this is not understood, but when looking at the 99th percentile max, the pressures are near equivalent.

The maximum air volume is additionally slightly higher for Scenario 1 vs. Scenario 2 (75% vs. 67%). This indicates that more water vacates the tank under Scenario 2. The LMPS discharge surge tank behavior appears to be equivalent between Scenarios 1 and 2.

Altogether it appears that both scenarios have similar maximum and minimum pressures and surge tank behavior. The addition of slip-lining on the SAPL2 pipeline appears to cause a minor increase in pressure at the slip-lined sections themselves, likely due to the increased piping restriction (smaller inner diameter of slip-lined sections). Infrastructure in this area needs to be ensured that it can handle such extreme pressures, and that such infrastructure is rated to handle up to 300 psi as a factor of safety. The LMPS discharge pressures and SAPL2 slip-line pressures range between 203 and 208 psi, and therefore infrastructure in these areas should be rated at 250 psi to be safe.

Scenarios 2,3,4, and 5 -- Low Zone Analysis

Scenario 2 was used to determine the baseline Low Zone condition before valves were closed under the remaining scenarios. Since the minimum pressure at BPS indicated a pressure that was lower than 0 psi, it appears that this worst-case scenario has the potential to depressurize the area surrounding the BPS suction. The LMPS suction surge tank appears to have no issues, never reaching its maximum or minimum volumes. However, the gas volume always remained above 50 percent, indicating the tank is more susceptible to down-surge than it is to up-surge, but it appears to be appropriately sized.

Scenario 3, which had the CS-2 valve closed, indicated overall lower maximum and minimum pressures at both pump stations, with LMPS suction becoming very close to being depressurized. The BPS suction pressure again appears to depressurize during a down-surge. The CS-2 valve pressure increased from 100 psi to 128 psi between Scenarios 2 and 3.

Scenario 4, with SAPL1's valve closed, appeared to show a serious depressurization and surge tank emptying at BPS. It's unclear why the issue was so dramatic compared to Scenarios 3 and 5, which would in theory provide less hydraulic capacity and therefore lower pressures in the region than for Scenario 4. It appeared that there was a model setting or boundary condition error in the original Synergi model file that caused Scenario 4 to have an error.

Scenario 5 appears to show similar results compared to Scenario 3. In both scenarios, the BPS suction surge tank is again susceptible to down-surge, and the surrounding area going to vacuum. For Scenario 5, these vacuum conditions are slightly worse, as the Lowest Elevation Point goes to vacuum under Scenario 5 and not for Scenario 3. When comparing Scenarios 3 and 5 to Scenarios 1 and 2 (for the Low Zone only), it appears down-surge is more of an issue when there are no valves closed. When pipes are unobstructed, it appears the amplitude of the surge wave is greater, whereas the increased headloss associates with the closed valve conditions likely dampen that amplitude.

CS-2 Valves of Interest

The 3 valves along the CS-2 pipeline were monitored for Scenarios 3,4, and 5. Minimum pressure analysis showed very low pressures occurring at one of the valves, Valve K50, under Scenario 3 (~10 psi), and vacuum conditions occurring at K50 under Scenario 5. This appears to be due to the proximity of K50 to the Baden PS suction, and therefore is impacted by the down-surges occurring in this area. The other two valves had healthy minimum pressures with higher pressures always being associated with Scenario 3 and lower pressures associated with Scenario 5, when compared at the same node.

Conclusions and Recommendations

High Zone + SAPL2 Slip-Lining

Based on the analysis conducted and the original intent of the modeling exercise, there are several conclusions that SRT arrived at. The High Zone appeared to exhibit no marked difference between the original condition and post slip-lined condition. However, high pressures appear to occur under both conditions immediately downstream of the Baden PS. It is unclear why this occurs, however, since the static discharge head pressure is very high, around 200 psi, when the pumps fail, a few localized micro-surges may be the cause.

Localized pressure surges at newly slip-lined sections of SAPL2 were not substantial. Pressures are slightly higher and more variable at these locations, likely due to the inner diameter variations; however, pressures only slightly exceed a maximum of 200 psi at the lowest elevation slip-lined section of pipe. Pressures are therefore likely to be substantially lower than 200 psi at the other two higher elevation slip-lined sections of pipe.

The Baden discharge surge tank was found to react more to down-surge suppression than to up-surge suppression. It was later found that the initial setting of 50 percent was appropriate and likely does not require any adjustment. Emphasis was put on ensuring infrastructure directly surrounding the Baden PS discharge are pressure-rated to withstand 250+ psi; pipes and appurtenances should be rated for 300 to 350 psi. Exploring and considering further surge suppression measures would further help in reducing surge pressures that are possible at the Baden PS discharge.

Low Zone and CS-2 / SAPL1 Valve Closures

The existing “Low Zone” surge protection appears to protect the system from high pressure up-surges, but may be undersized for dealing with low pressure down-surges and preventing vacuum conditions from occurring. For all scenarios, regardless of whether valves were closed or not, the Baden PS suction surge tank evacuates its water fairly rapidly after pump failure, and pressure vacuums are indicated. Up-surges rarely exceed 100 psi at both pumps stations, but down-surges regularly cause pressures to drop below 0 psi around Baden PS. The Baden PS suction surge tanks ranged between 63% and 85% air, which indicates initial settings at Baden PS could be decreased from 70% air in anticipation of large down-surges.

The LMPS suction surge tank had no issues but still showed that the surge tank is suppressing down-surges more than up-surges, and therefore could have a lower initial setting than 50 percent in anticipation of this.

Valve closures appear to not produce any concerning pressure surges. The maximum pressure on the closed CS-2 valve was 130 psi, and the maximum pressure occurring on the SAPL1 valve was 175 psi, both of which occurred during Scenario 5, with both valves closed.

It was recommended for the Low Zone that SFPUC explores and considers lowering the initial surge tank air volume settings, in anticipation of extreme down-surges and vacuum conditions that can occur at Baden PS. It is also important to see to it that there are sufficient air-vacuum valves at Baden and at Valve K50, to allow atmospheric pressure into pipelines in case of vacuum conditions. It’s necessary to guarantee that piping, valves, and appurtenances are rated between 200 and 250 psi to protect against up-surge pressures.

As complex as this process was, public safety was the first priority when looking to update the new valves. The failures of water infrastructure systems are not to be taken lightly. Constantly checking for performance and quality issues on valves plays a critical role in the water distribution system as a whole. This strategic transient analysis allows for reliability, efficiency, and a safe approach.