Transient Pressure Monitoring Results – Nacimiento Water Project

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Abstract

The Nacimiento Water Project in San Luis Obispo County, California, was completed in late 2010, and is now capable of delivering 15,750 acre-feet of raw water annually from Lake Nacimiento through 45 miles of pipeline to its service area. The Project includes three pumping stations, three storage tanks, 45 miles of pipeline ranging from 36- to 12- inches in diameter, and a Supervisory Control and Data Acquisition (SCADA) system. The hydraulic aspects of the system dictated careful attention to hydraulic design, with due consideration of normal and transient pressures. The construction contract was modified to add a very intensive hydraulic transient monitoring system. This transient monitoring program was installed during construction, and includes nine TP-1 transient pressure monitoring systems installed at locations most prone to severe hydraulic transients. These systems provide detailed information regarding transient pressures and are integrated into the SCADA system to provide real-time alerts if threshold pressures are exceeded. This paper describes the Nacimiento Water Project, the hydraulic design considerations, the network of transient monitoring systems that is installed, construction considerations, lessons learned, and the results of transient pressure monitoring collected during initial startup and testing. Results will include analysis of actual pipe rupture data that occurred during construction, and validation of hydraulic models.

Project Description

The Nacimiento Water Project (Project), illustrated in Figure 1, will convey up to 15,750 acre-feet annually from Lake Nacimiento in San Luis Obispo County, California, through 45 miles of pipeline ranging from 36- to 12-inches in diameter. The Project includes three pump stations, three water storage tanks, and a supervisory and control and data acquisition (SCADA) system. Four turnouts are included to provide delivery to the Project participants: the City of Paso Robles, Templeton Community Services District, Atascadero Mutual Water Company, and the City of San Luis Obispo.

Design of the $176-million Project began in 2004 and construction was effectively complete with operational testing in December 2010.

The Project's hydraulic design [Hollenbeck 2009] played an important role in the engineering effort. It established key Project features that significantly affected the Project construction and operating costs. The design gave careful attention to phased water deliveries, hydraulic efficiency, optimum pipe diameters, pump station characteristics, transient pressure control measures and potential energy recovery.

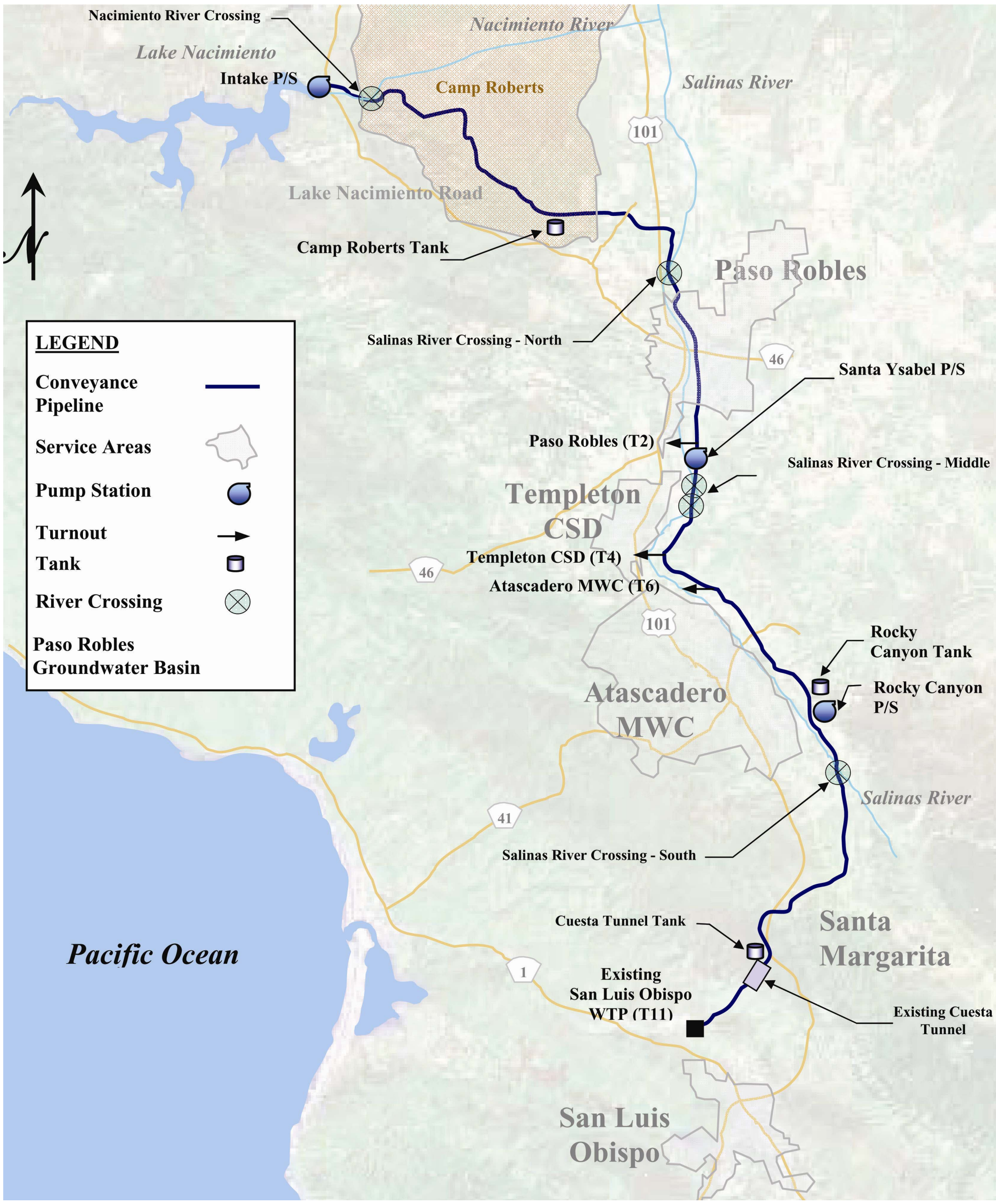

Figure 1. Nacimiento Water Project Map

The Project will operate as a pumped system under normal operation and as a result the most significant hydraulic event will likely be generated by emergency operation including sudden power loss at one or more of the pump stations or malfunction at one of the turnouts. Extensive surge modeling of the pipeline allowed the design of surge control facilities conforming to two criteria:

- Minimum pressure due to downsurge would always be above atmospheric pressure, and
- Minimum pressure during upsurge would not exceed initial hydraulic grade line by more than 100 feet.

The hydraulic modeling guided the selection of the following facilities to control surge due to pump station power failure:

- Air chambers on the discharge of the Intake, Santa Ysabel, and Rocky Canyon Pump Stations
- Slow closing air/vacuum valves at high points along pipeline
- Surge relief valves on the suction side of Santa Ysabel Pump Station

Characteristics and Capabilities - TP-1 Transient Pressure Monitoring System

The Project engineers recognized the importance of measuring transient pressures at critical points in the Project; and included standard digital data loggers which have become widely used within the water and petroleum pipeline industry. On this Project, however, there is a need to monitor for indefinite periods with the capability to detect and measure an unexpected transient that may last a fraction of a second. Not only are these events difficult to detect, they may be the most damaging of all and may go unnoticed for long periods of time. One of the most important aspects of digital sampling of pressure data is selection of an appropriate data sampling rate. An intensive sampling program might sample once per second generating 86,400 data points per day at each test station. Still this would be insufficient to accurately record an event lasting a fraction of a second. As is noted in Figure 2, an insufficient sample rate will lead to inaccurate and misleading portrayal of pressure.

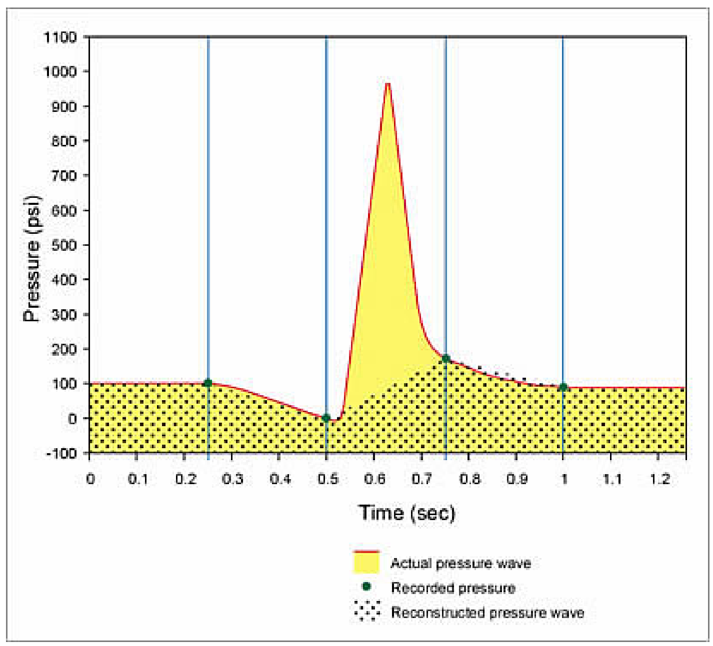

Figure 2 - Digital data collection with insufficient sample rate

Within the past several years, a system has been devised that overcomes several of the limitations of previous digital systems. It is capable of monitoring over extended period of time in a "snoozing" mode, recording background pressure at a user-set interval between once per second and once per day. Although the system appears to be snoozing, in reality it is very busy. It continuously samples the pressure 1000 times per second and computes a running average. Effectively the system algorithm has a built-in alarm clock that goes off when a pressure is detected that differs significantly from the average – in other words when a transient is detected. When this occurs, the system "wakes up" and records all data at another user-set rate up to 100 Hz. This continues until the transient has passed, at which time the system goes back to the "snoozing" mode. The scheme is shown graphically in Figure 3.

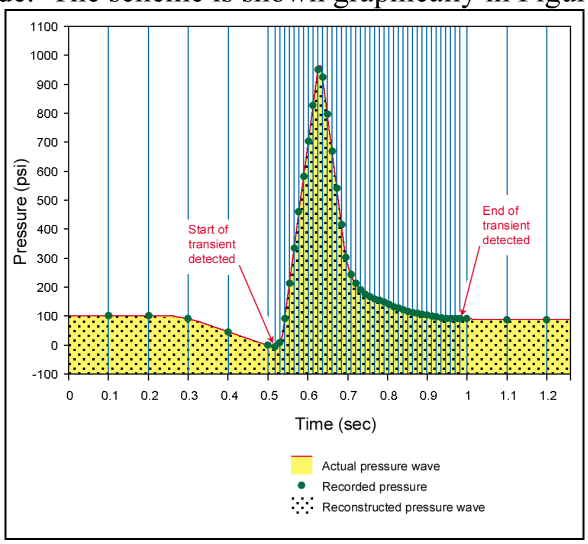

Figure 3 – TP-1 Data Recording Scheme

An additional feature of the TP-1 system is its inclusion of precision timing of pressure data using the GPS satellite constellation, thus providing the time that each data point was recorded in addition to the pressure data itself taken at 100 Hz. This capability provides an additional dimension to troubleshooting of pipeline problems and the analysis of transient data, allowing the localization of the source of a transient event where multiple TP-1 monitors are used and the instant of detection of a transient event is available to millisecond accuracy.

The TP-1 system allows users to set parameters that govern data analysis and recording, including the steady-flow background record rate, the transient event record rate, and criteria for transitioning from background to transient record modes. The system incorporates a transducer with a frequency response range to one KHz to capitalize on the high-speed data recording capability of the TP-1. It is connected hydraulically to the pipeline through standard ¼" NPT fittings, and is connected electrically to the TP-1 controller through a shielded cable. Cable lengths up to 300 feet have been successfully used. Pressure data recorded by the TP-1 system is stored on an internal 2-GB memory flash drive, providing storage for months of data under normal conditions. Data is uploaded from the TP-1 via wireless, LAN, or Ethernet connections for analysis by the user. Data is placed in a standard Microsoft Data Base for ease of analysis, and the analysis process is further facilitated by software that is part of the TP-1 system.

Installation of Transient Pressure Monitoring System on the Nacimiento Water Project

Discussions among the Project manager and design engineers determined that the optimum locations of the TP-1 systems would be pumping station suction and discharge lines, high-volume turnouts, and points of highest elevation (and thus lowest pressure head). This resulted in a plan to install nine transient pressure monitoring devices on the Project, making it perhaps the most intensively monitored pipeline today, in terms of transient pressure recording. The locations selected:

- Intake pump station discharge header
- High point upstream of the Camp Roberts Tank
- Paso Robles, Atascadero, and San Luis Obispo turnouts
- Suction and discharge headers at Santa Ysabel and Rocky Canyon Pump Stations

Figure 4 – Rocky Canyon Pump Station

Figure 5 - Rocky Canyon Pumps

Figure 6 – TP-1 Installation at Pipeline Highpoint on Camp Roberts

The TP-1 requires 700 milliamps of 12 volt DC power, which is normally provided via 120 volt AC power through a converter. At the pipeline highpoint near the Camp Roberts Tank location, AC power is not available, so the installation there is powered by a solar panel and battery storage.

The popularity of the TP-1's has increased since the first installation in 2005, and several improvements have been added to the system. For the Nacimiento project, several first-time features were seen:

- All nine TP-1's included Ethernet connection over the Project's fiber optic communication with the Project SCADA system, providing the remote capability to access the TP-1 system to modify operational parameters and retrieve data.

Figure 7 – Santa Ysabel Pump Station Pumps

- The GPS time synchronization capability of the TP-1's would be used to synchronize time at the power monitor located in switch gear at each of the three pump stations.
- An alarm is transmitted to the SCADA control room each time a transient is detected.
- The installation was accomplished concurrent with construction of the pipeline so that all testing operations could be recorded in detail

Status of Project Construction and Transient Pressure Monitoring Results

Construction of the Project began in October 2007, and substantially completed November 2010, by the completion of the contractor's startup and testing activities. The District's operators then performed a 30-day startup "run-in" test whereby various modes of operations were tested, or in other words, the Project was ran through its paces! The 30-day testing concluded on January 7, 2011, and the participating agencies have begun to take the delivery of the raw water, making a milestone of a new water source for several communities in northern San Luis Obispo County.

The District had TP-1 units installed as a change order to the Facilities construction contract. The installation consisted of nine TP-1 installations, and included connection into the SCADA system via the Project's fiber optic communication network. Installation included mechanical plumbing for the pressure transducers, electrical power, and instrument and control wiring. SCADA programming was also part of the installation. Training and software support by the supplier was also included. The cost of the Project's TP-1 system was $418,904 executed by change order.

The District judges the TP-1 instruments as an indirect insurance against the potential of future failure on this new hydraulic system, and that is why the installation was approved by the District's Board of Supervisors. A properly operated hydraulic system should never experience a detrimental transient condition; however, if a regularly occurring transient event does happen and goes undetected by operators and a severe rupture occurs, then the consequential and direct damage costs likely would be significant. The District's manager judges damage costs to be in the order of several times more than the initial investment of the TP-1 system. The District's manager also places a great significance on being able to understand the performance of this new hydraulic pipeline/pumping system, and once the TP-1 product was discovered on the market, it was simply a matter of design and executing a change order to have it implemented into the construction of the Project. The District's operators are now trained to review each transient alarm and to analyze the data to try to understand its cause. Each month, the operations staff reviews the previous month's pressure recordings and prepares a simple report to be shared with the District's engineering staff. The goal is – know what the system is doing, understand it, and work to eliminate any potentially detrimental transient problems.

Monitoring During Construction. The TP-1 recordation of pressures during the startup and testing phase of construction show interesting results when pressures greater than design values were recorded. Investigation as to why determined that the startup team operated the system outside the boundaries presented on the Project's design hydraulic grade line drawing when the system was being flushed. No damage occurred, fortunately, and the result was a lesson learned by the contractor's startup team members.

Figure 8 – Pipe Joint Separation at Stenner Creek Bridge

Transient Event When Pipeline Joints Abruptly Separated. On October 22, 2010, an above-grade stream crossing experienced a sudden release of water from the pipeline when the joints of the ductile iron pipe separated. Figure 10 is a photograph of this event. The 12-inch pipe was encased in a steel casing pipe that bridged across Stenner Creek very near the end of the pipeline. The static head at this location is about 928 feet (402 psi). The cause of the pipe joint separation was later determined as the improper use of a restraining joint product. The contractor repaired the separation with the correct restraining joint and the crossing has functioned properly.

TP-1 recorded the event, and the graphical representation is presented in Figure 11. The recording station is at the turnout to the City of San Luis Obispo (Unit T11), which is located about 3,000 feet downstream from this stream crossing. The sudden change in flow from this pipe failure resulted in a downsurge pressure change of about 400 psi that occurred in about 0.2-seconds. Pipe ruptures are infrequent events, yet with TP-1, the examination of the impact of the rupture (i.e., the impact of the sudden change in water velocity) is easily evaluated. Analysis of the recorded TP-1 data also confirmed that the pipe rupture was not the direct result of a transient event.

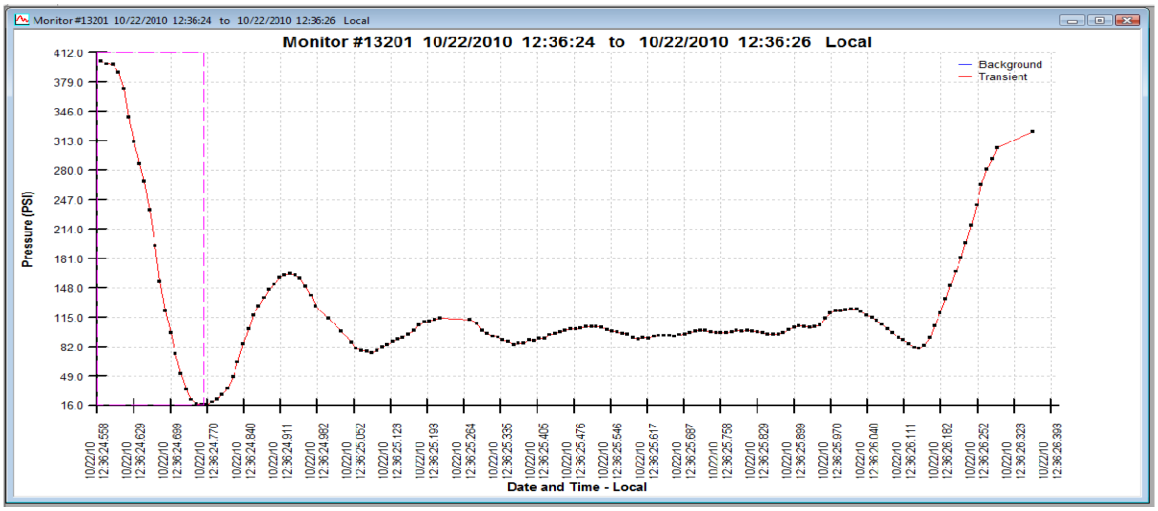

Figure 9 – TP-1 Graphical Results for Pipeline Rupture on 22 Oct 2010 at Stenner Creek

Comparison in Operating vs. Design Pressures. Table 1 presents a summary of the pressures measured and recorded with TP-1 compared to the design pressures predicted for these nine locations. The range of historical data is short since the project has recently completed construction.

Table 1 – Comparison of Pressures at the Nine TP-1 Locations

TP-1 Location	Date of Pressure Event	Measured Pressure (psi)	Design Limit (psi)	Comment
Intake Pump Station	27 Aug 2010 Jan 2011	164 126	128	Misoperation (flushing) Near Normal
Camp Roberts Pipe High Point	21 Oct 2010 Jan 2011	150 49	62	Misoperation of pumps
Paso Robles Turnout (T2)	4 Nov 2010 Jan 2011	435+ 158	165	Frozen pipe/transducer Near Normal
Santa Ysabel Pump Station (suction side)	30 Nov 2010 Jan 2011	192 160	160	Misoperation of pumps Near Normal
Santa Ysabel Pump Station (discharge side)	26 Oct 2010 10 Nov 2010 Jan 2011	394 275 240	241	Field Testing (test loop) Near Normal Near Normal
AMWC Turnout (T6)	25 Nov 2010 Jan 2011	435+ 175	146	Frozen pipe/transducer Under investigation
Rocky Canyon Pump Station (suction side)	29 Nov 2010 Jan 2011	45 17	17	Misoperation Near Normal
Rocky Canyon Pump Station (discharge side)	12 Oct 2010 Jan 2011	312 265	274	Field Testing (test loop) Near Normal
San Luis Obispo Turnout (T11)	20 Oct 2010 Jan 2011	461 426	430	Near Normal Near Normal

Conclusions

The District is very satisfied with the installation and operation of the TP-1 system, and judges the implementation as a good investment in this new Project.

References

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