DNV·GL

WHITEPAPER

HYDRAULIC SURGE ANALYSIS USING LIQT

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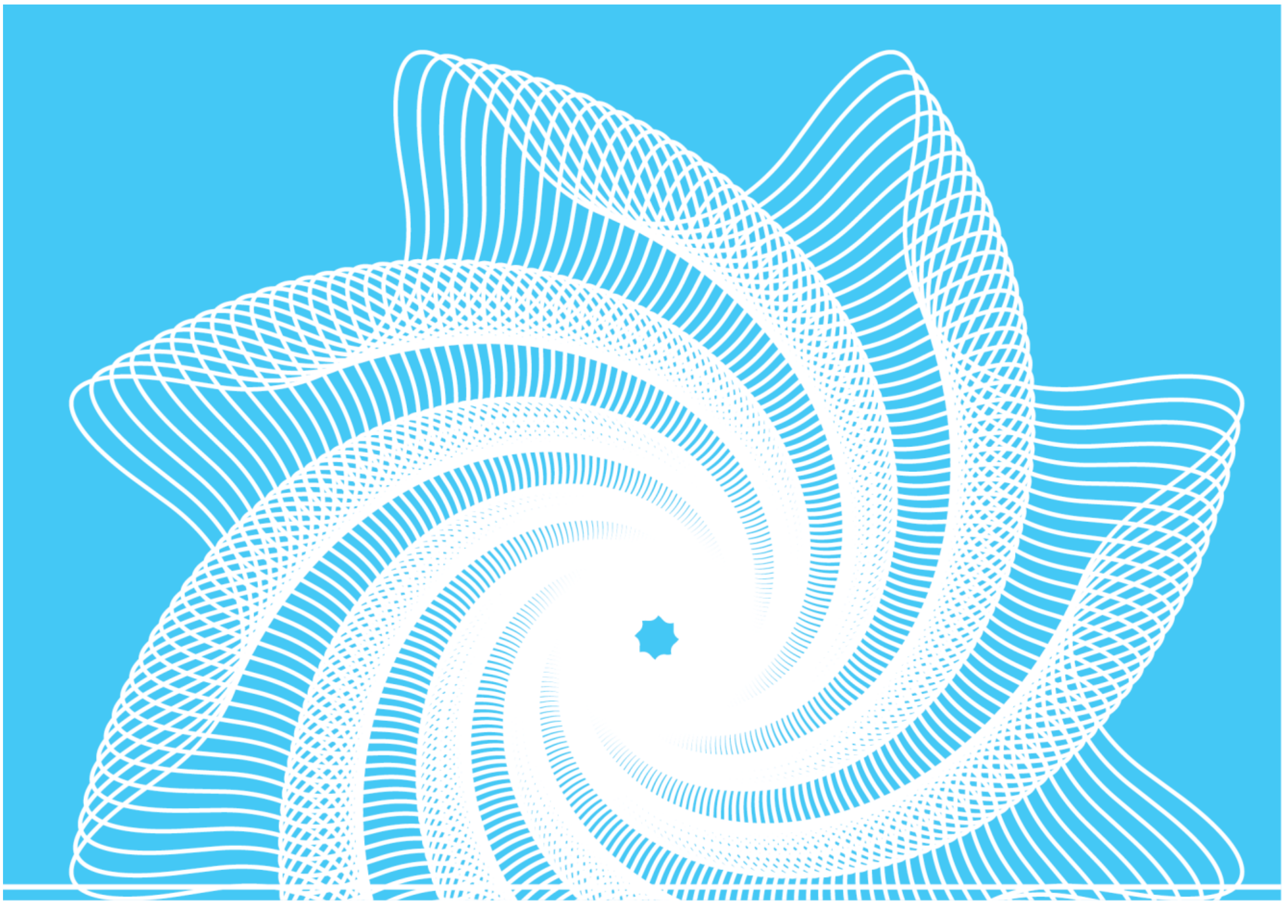

SAFER, SMARTER, GREENER

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2	2016-06	Rebranding	DNV GL		

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1 INTRODUCTION

Liquid piping systems seldom operate under true steady-state conditions. Varying operating conditions produce unsteady pressure-flow conditions, or "transients". These transients have been referred to as waterhammer, surging, shocks, or hydraulic transients. These transients can result in possible damage to the system or in operational inefficiencies and therefore should be prevented. However, by over-designing to mitigate transients, a project can incur excessive design and construction costs.

Computer solutions to address liquid transients have been available for many years. DNV GL's LIQT® (LIQuid Transients) product is a computer simulation tool used to perform transient analysis of closed conduit liquid networks. LIQT is a Microsoft® Windows® based computer program that was first developed in the 1970s by V.L. Streeter and E.B. Wylie of the University of Michigan, and Stoner Associates, Inc. (now DNV GL). Over the years LIQT has been extensively upgraded and maintained.

Using the time-tested Method of Characteristics (MOC), LIQT models the hydraulic response of various types of pipeline networks, which can include devices such as pumps and turbines, surge management equipment, regulators, valves, and dynamic controllers. LIQT can also model complex pump stations.

Typical applications for LIQT include modeling transients associated with:

- Normal or emergency pump startup and shutdown
- Turbine operations such as system startup or load rejection
- Valve operation
- Surge management devices
- Dynamic controllers
- Vapor cavity formation and collapse

LIQT can be used to assist engineers with assessing:

- Pump and pump station operations, including starting, stopping, and sequencing
- Valve movements
- Flow or pressure variations due to the effects of supply or demand on the system pressure response, or the effect of pressure variation on the system pressure and flow response
- Surge device selection and design for proper protection of pipeline system
- Interaction of the pipeline system with dynamic controllers
- Probable causes for system failure during upset conditions
- Transient pipe forces

The range of systems analyzed by the LIQT program spans a variety of industries. The following is a partial list of application areas LIQT has been utilized in:

- Chemical and petrochemical process piping systems
- Cryogenic fluids handling
- Hydroelectric generation schemes
- Loading and unloading pipeline systems (ship or shore based)

- Petroleum and liquid chemical transportation and distribution
- Plant utility piping
- Power generation piping systems
- Slurry pipeline systems
- Water and wastewater transmission and distribution
- Specialized systems

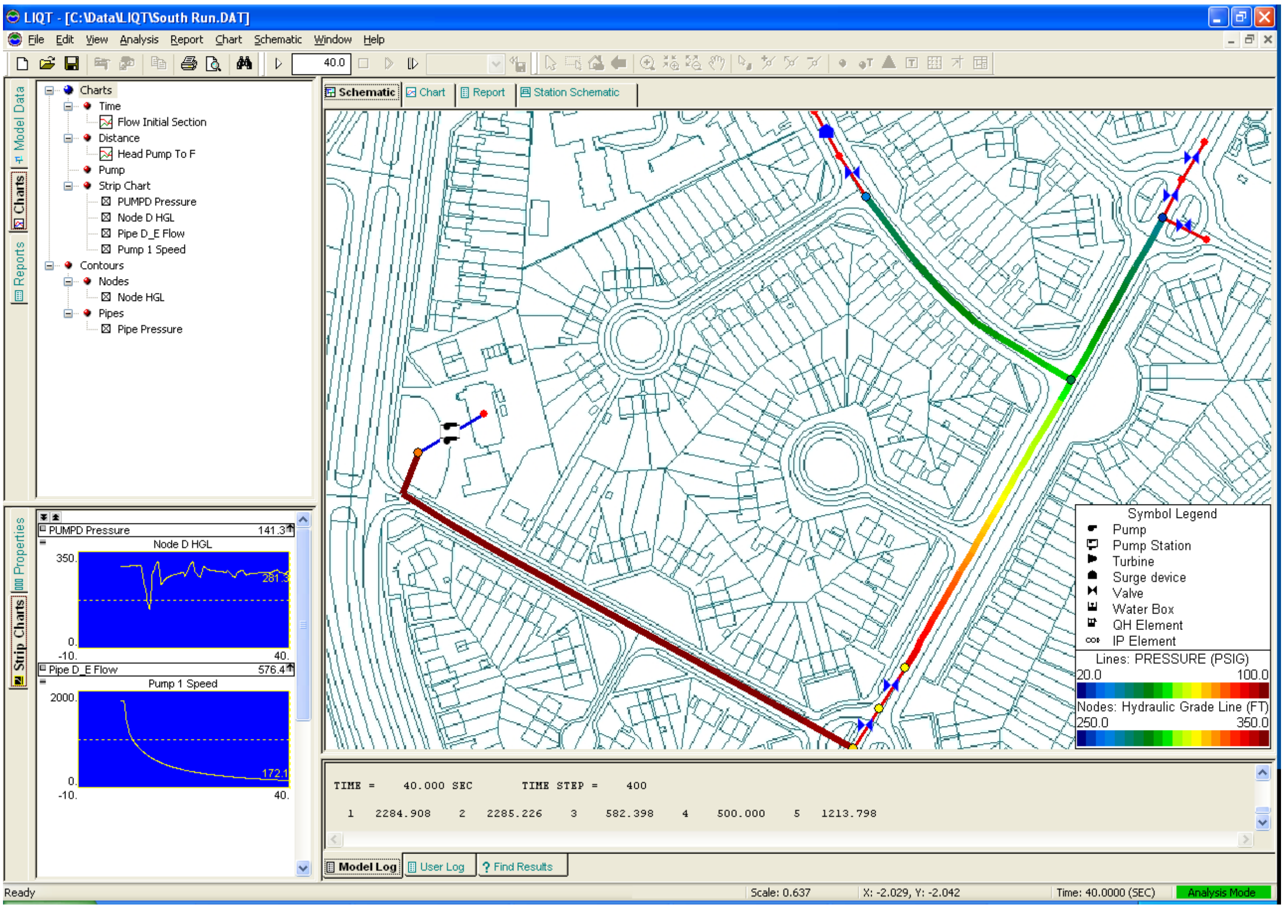
Engineers frequently find new applications for LIQT in piping system design and analysis.

2 FEATURES

LIQT features a completely interactive user interface for both building complex hydraulic models and running them as a hydraulic simulation. Models can be built graphically using components previously set up in what is called a "Warehouse". This means that commonly used facilities must only be set up one time and can then added to different models as needed. Custom graphical charts, strip charts, and reports can also be set up once and used with different models.

Once a model has been built, it can be run to simulate various hydraulic transients. The hydraulic trends can be observed interactively using dynamically updating strip charts, pipe color contours, and dynamically changing data labels. When an analysis is complete, other graphical charts and reports can be generated, and the time-based results can be exported to a standard data file that can then be input into other programs, such as Microsoft Excel®, for further analysis and presentation.

LIQT provides a schematic window (shown below) to view the geographic connectivity of the system, and a pump station schematic window to graphically view the geographic details of complex pump stations. Background images can be added to the system schematic to provide a helpful visual context for the model. Facilities can be edited by double-clicking them in the schematic.



LIQT also provides sophisticated tools for searching through the results and scoping reports to those results. Hydraulic conditionals can be set up that will stop the simulation when a particular hydraulic condition has been met. Also, LIQT can be initialized automatically by generating a steady-state solution or by allowing the user to specify the initial conditions. Vapor cavity formation and collapse can be modeled with LIQT.

LIQT features a variety of pipes, pump setups, and surge devices for modeling. Five types of pipes can be modeled: four for Newtonian fluids and one for non-Newtonian fluids. Three different pump station setups can also be modeled. Reciprocating pumps and variable geometry turbines can be modeled. In addition, several types of relief valves, an accumulator, a vacuum breaker, two types of surge tanks, and a sophisticated combination air inlet/relief and vacuum breaker valve can be modeled. And, variable density and specific weights of fluids can be modeled.

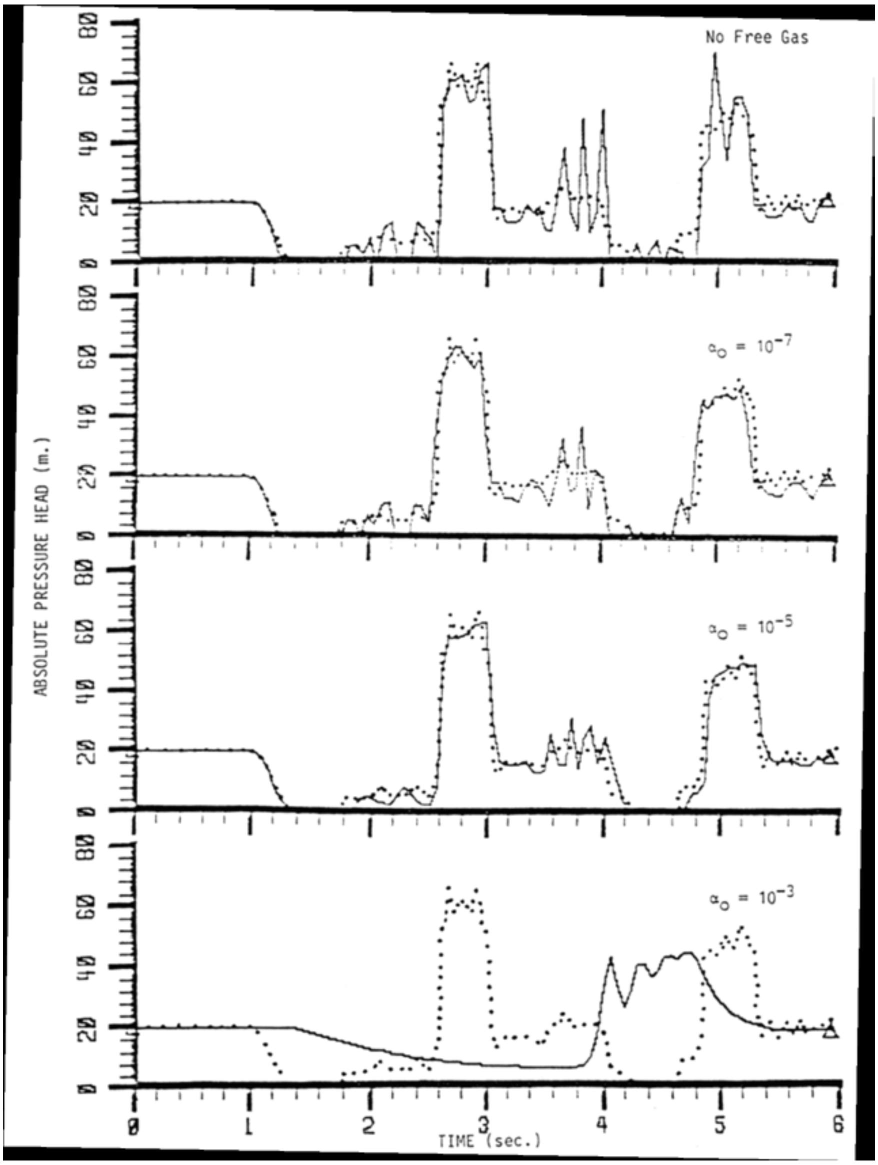
3 METHODOLOGY

LIQT uses the Method of Characteristics (MOC) to model transients through liquid pipelines. MOC is a time-tested technique for solving equations of transient flow. By estimating the speed of sound in a pipe, which takes into account the pipe's modulus of elasticity and thickness, MOC can be used to predict the variation of pressures and flows of a fluid in the interior of a pipe with time. As a result, LIQT can model variations in pressures and flows within a pipe, and not just at the ends of a pipe. This allows for greater detail in assessing the location of pressure peaks and troughs and of cavity formations within a pipe.

LIQT's pump model computes the performance over the entire four-quadrant range of pump operation using the method described in Fluid Transients1. This allows for capturing important transients associated with pump starting and stopping while combining interactions with the opening and closing of valves.

LIQT can be used to model vapor cavity formation and collapse using the MOC. It also includes an enhanced free gas method. Free gas computation simulates transient flow in a liquid system containing small amounts of gas. In systems affected by the presence of free gas, vapor column separation and subsequent collapse can be simulated more realistically.

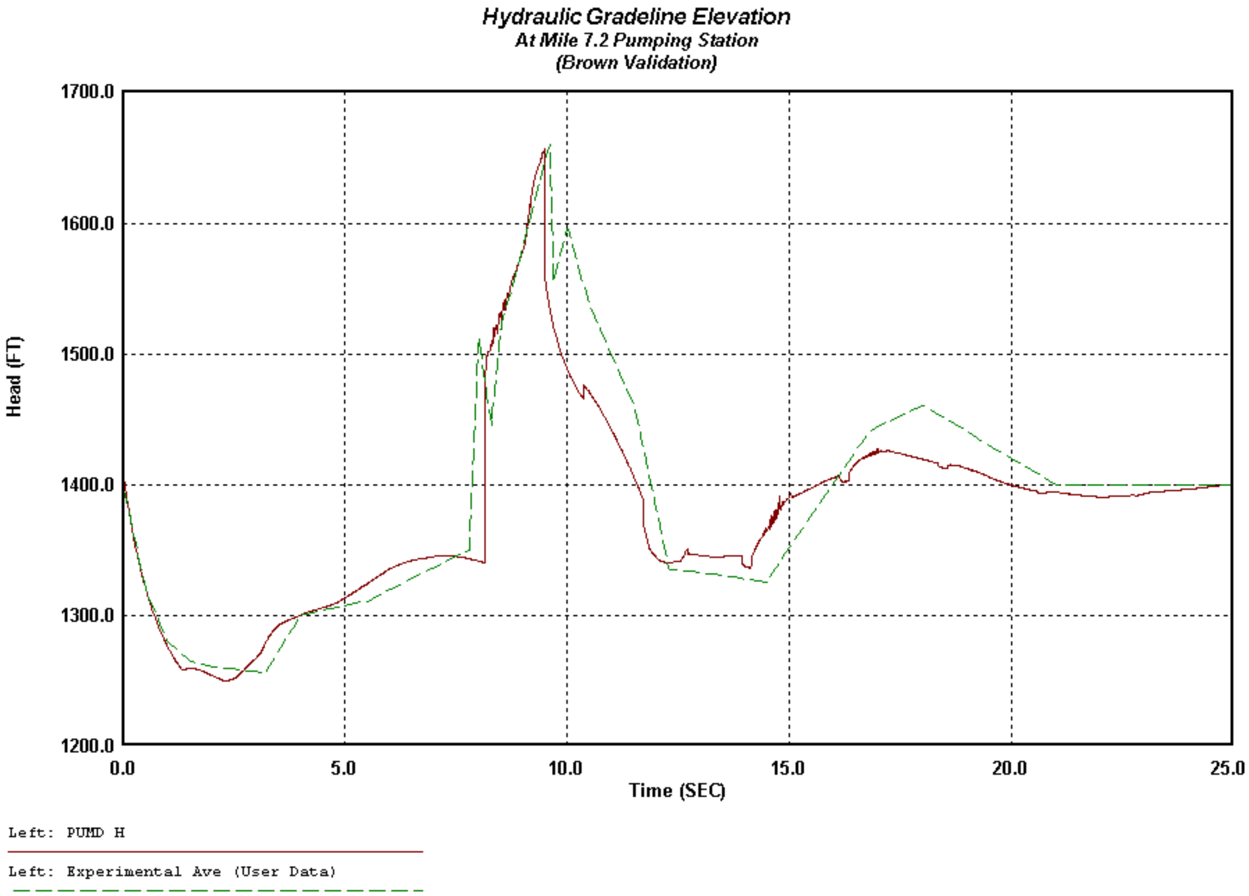
The following graph illustrates how using an appropriate free gas fraction (ao) can result in improved comparison with experimental results. Note that a free gas fraction of between 10-7 and 10-5 produces the best results, dampening numerical oscillations.



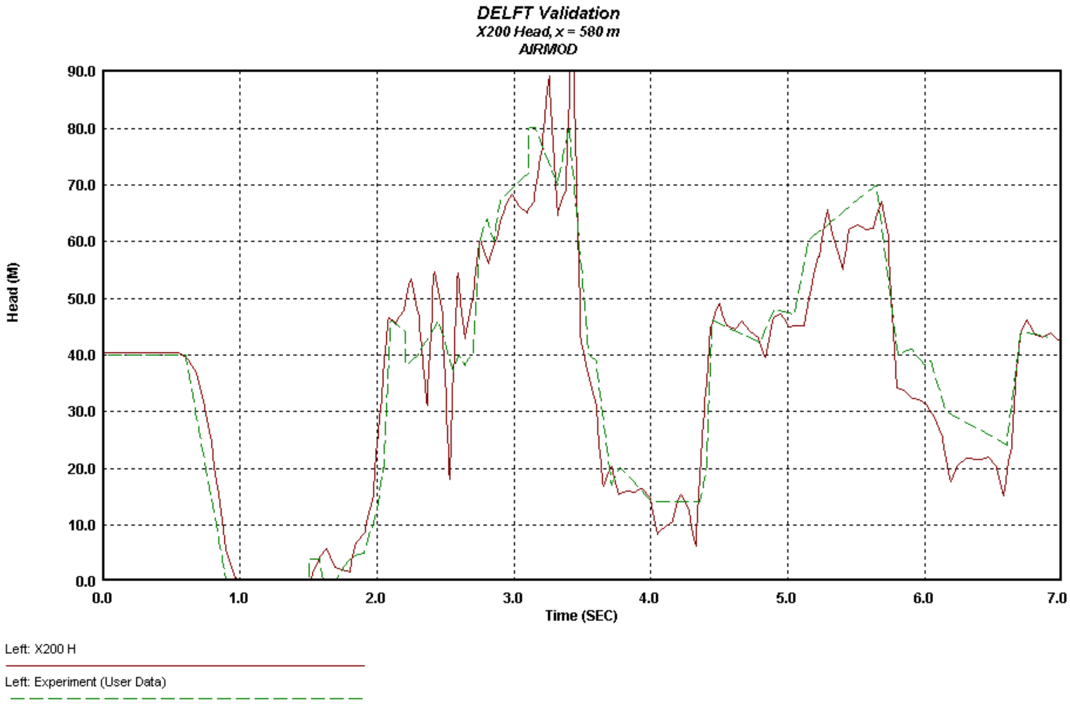
4 VALIDATION

LIQT has been validated against numerous benchmark test cases that have been published in the literature. The following paragraphs provide three benchmark cases that are based on experimental test results to demonstrate the accuracy of LIQT.

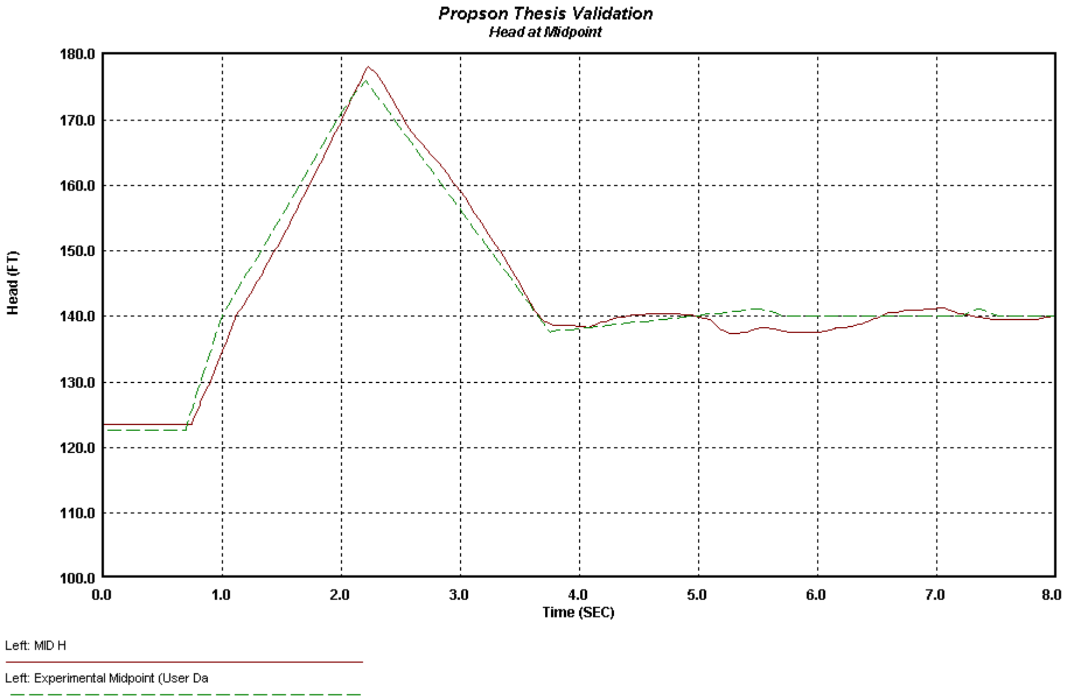
The first validation case is a pump failure comparison. The experimental results are reported in Water Column Separation At Two Pumping Plants2. As shown in the following chart, LIQT's results compare well against the Brown results.



The second validation case is a pressure variation case with vapor cavity formation and collapse. The experimental results are reported in Gas Release During Transient Cavitation in Pipes3. As shown in the following chart, LIQT's results compare well against those reported by Kranenburg.

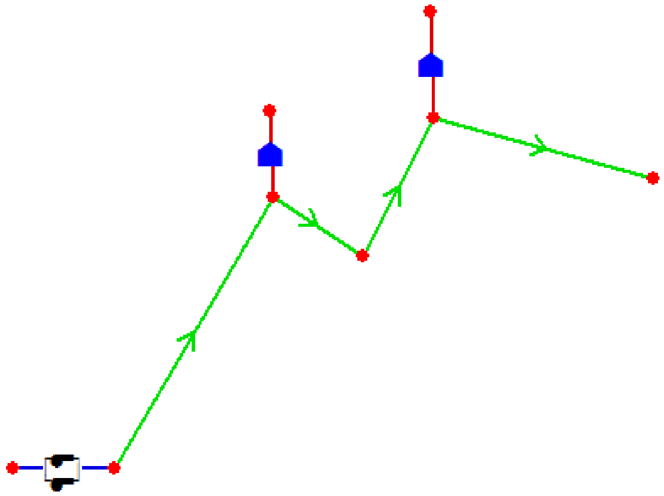


The third validation case is a valve stroking test case. The experimental results are reported in Valve Stroking To Control Transient Flows In Liquid Piping Systems4. Once again, LIQT's results compare well against the experimental results of Propson.



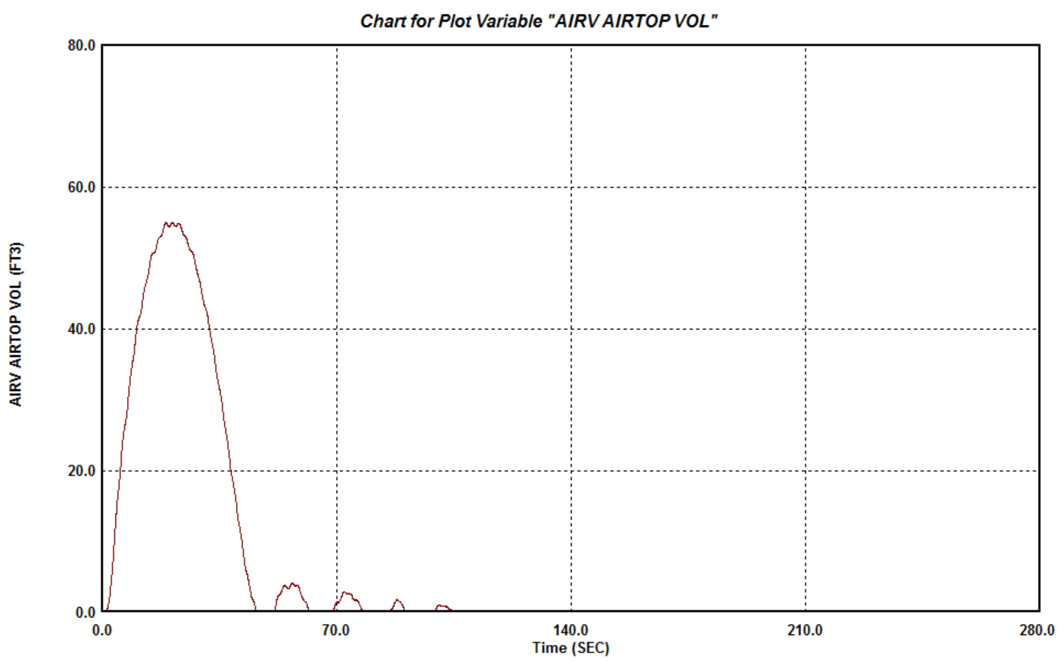
5 EXAMPLE

The following example demonstrates a pump station shutdown and restart on a 14,000-foot pipeline with two hills along it and a combination air inlet/relief and vacuum breaker valve at the top of each hill. After the first 0.1 seconds, the two pumps in the station lose power and begin to spin down. At 60 seconds the power is restored and the pumps begin to spin up.

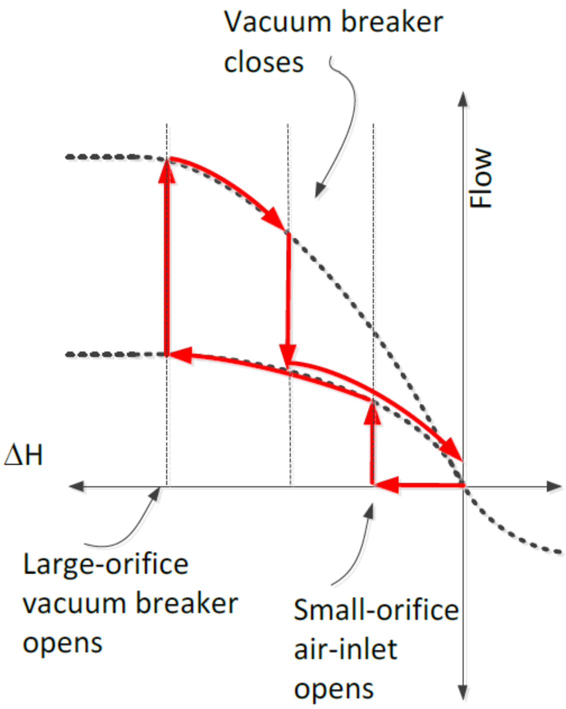


Pump spin down sends a pressure wave through the pipeline. When the pressure at the top of the hills becomes negative, air begins to flow into the air-valves to relieve the negative pressure. When the pressure at the top of the hills returns to positive, air begins to flow out of the air-valves. The amount of air in the air-valves also cushions the pipeline against pressure transients generated during pump spin up.

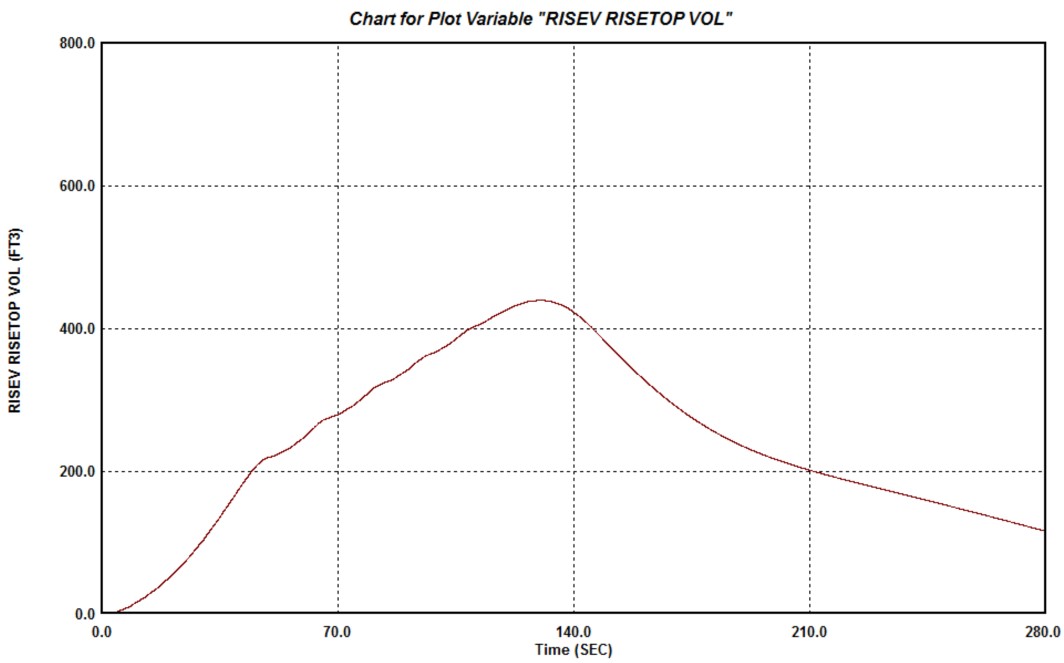
The following chart shows the air volume in the first air-valve. The cyclical variation in the air volume is a result of the cyclical variation in pressure at the top of the first hill.



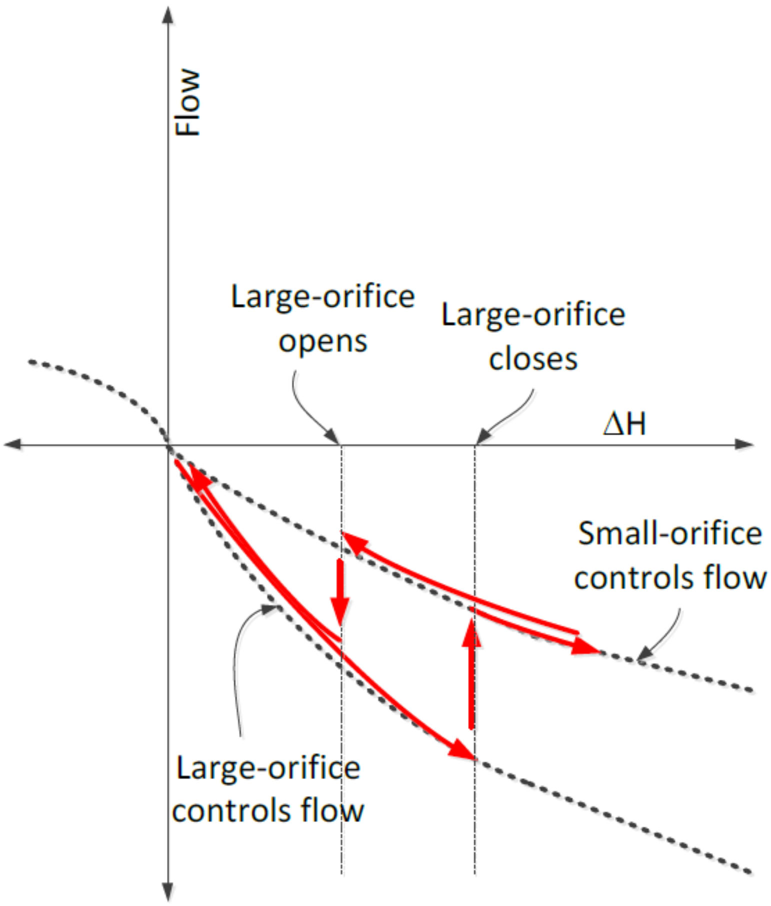
The inflow of air into this air-valve follows a pattern shown in the figure below. As the pressure at the top of the first hill begins to fall, the small-orifice air inlet opens and draws air into the pipeline. As the pressure continues to become more negative, the large-orifice vacuum breaker opens. As the pressure begins to increase, the vacuum breaker closes. However, the small-orifice air inlet/relief valve stays open and gradually expels the trapped air.



The following chart shows the air volume in the air-valve at the top of the second hill. The air volume in this air valve shows a more gradual change because the upstream pressure of the valve remains below atmospheric pressure until the pumps spin up and increase the pressure.



The outflow of air from this air-valve occurs at a slow rate and follows a pattern shown in the figure below.



The air-valve constricts the air flow if the head differential across it is large and allows flow through a larger orifice if the head differential across it is small. This causes the air to be released at a slow rate.

The combination air inlet/relief and vacuum breaker valve helps to reduce the transients generated by pump station shutdown and restart. Using this type of two-stage valve means that pressure waves can be mitigated with improved response for the overall system, namely smaller and more gradual pressure changes.

6 CONCLUSIONS

LIQT is a comprehensive software tool to manage underground infrastructure assets. Through GL Noble Denton's decades of experience in providing consulting services to water distribution utilities and liquid pipeline operators, LIQT is able to accurately model hydraulic transients. LIQT is industry recognized for its accuracy and versatility, and delivers a quick cost-effective solution to various hydraulic problems.

LIQT's advanced interactive simulation technique provides a user-friendly tool to analyze liquid transients in complex systems. It does so by modeling pipeline systems composed of pipes, pumps, valves, reservoirs, accumulators, surge devices, and other devices. Thus, LIQT is well poised to meet the needs of engineers analyzing transients in various kinds of pipeline systems.

7 REFERENCES

1. Wylie, E.B, Streeter, V.L., Fluid Transients, FEB Press, 1982, pp. 102-117.
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3. Kranenburg, C., Gas Release During Transient Cavitation in Pipes, Journal of the Hydraulic Division, ASCE, Vol. 100, No. HY10, Oct. 1974, pp. 1,383-1,398.
4. Propson, Thomas P., Valve Stroking To Control Transient Flows In Liquid Piping Systems, Dissertation, University of Michigan, Sept. 1970.

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