HYDRAULIC TRANSIENT COMPUTER MODEL FOR SAN DIEGO WATER AUTHORITY

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Abstract

San Diego County Water Authority is a water wholesaler providing a safe and reliable water supply to its 24 member agencies in the San Diego region. The Water Authority supplies up to 90% of San Diego County's water, which serves more than 3 million residents. The water supply system includes approximately 300 miles of open channel and pressurized pipelines, ranging from 48 to 108 inches in diameter, 103 active meter connections, 7 pumping stations, 4 hydroelectric facilities, one water treatment plant, and one reservoir. These facilities were constructed over the last 60 years through a sequence of individual projects, resulting in a complex hydraulic distribution system.

DHI, Inc. and Franklin DeFazio, Inc. have been working together to develop a dynamic transient flow model that will be suitable for modeling the Water Authority's conveyance and distribution system. The dynamic transient simulation model will also be used to analyze and simulate relevant appurtenant facilities of other local agencies that have a significant hydraulic influence upon the Water Authority's system. The work includes modification to an existing Hydraulic Transient Engine known as FG3D (Flow Gradient Dynamics Inc.) which is incorporated into a MIKE URBAN (DHI, Inc.) hydraulic model to provide an integrated modeling system.

The project includes substantial programming of menus and tools, as well as additional functionality in the Transient Model code. The transient model will be verified on pilot reaches, including the Second Aqueduct untreated water pipelines from Twin Oaks Valley Flow Regulatory Structure (TOVFRS) to Otay Lake (135 miles) in conjunction with the Olivenhain Pipeline and Pump Station.

The outline of this ongoing project, as well as the experience from hydraulic transient computing and development is discussed in this paper.

Keywords
Transient flow, hydraulic analysis, water distribution, SCADA, GIS

INTRODUCTION

This paper describes the progress work on the ongoing project that consists of the software development and its application on a large scale water supply system. The work includes modification to an existing hydraulic transient engine known as FG3D (Flow Gradient Dynamics Inc.) which is incorporated into a MIKE URBAN (DHI, Inc.) hydraulic model to provide an integrated modeling system. The integrated modeling system will be capable of performing hydraulic, and hydraulic transient, computations for both steady state and time-varying conditions. These two fundamental numerical engines and the integrated modeling system are based on generally published and recognized solution techniques such as the finite difference method and the method of characteristics to solve one-dimensional version of continuity and momentum equations.

The project is executed in several phases including the following tasks: software design and implementation plans, mockup interface, integration of hydraulic engines into a modeling system, development of a pilot model, pilot model calibration and verification, and desktop verification. Specific time and effort is related to the continuous progress demonstration, workshops, training, and technology transfer.

HYDRAULIC ENGINE

The hydraulic transient numeric engine is based on Elastic Water Column Theory solved by the Method of Characteristics (John Parmakian, 1963).

Equilibrium equation:

$$\frac{\partial H}{\partial t} + V\frac{\partial H}{\partial x} = -\frac{a^2}{g}\frac{\partial V}{\partial x}$$

Continuity equation:

$$\frac{\partial H}{\partial t} + V\frac{\partial H}{\partial x} = -\frac{a^2}{g}\frac{\partial V}{\partial x}$$

Equilibrium and continuity equations are solved simultaneously. It is initially assumed that the term $V\delta V/\delta x$ is small when compared with $\delta V/\delta t$, and the term $V\delta H/\delta x$ is small when compared with $\delta H/\delta t$.

The general solutions of these equations are:

$$H - H_o = f\left(t - \frac{x}{a}\right) + F\left(t + \frac{x}{a}\right)$$

$$V - V_o = \frac{g}{a}\left[f\left(t - \frac{x}{a}\right) - F\left(t + \frac{x}{a}\right)\right]$$

Where: H = hydraulic grade line (ft or m), H_0 initial conditions for H

V = velocity (ft/s or m/s), V_0 initial conditions for V
a = celerity (ft/s or m/s),
g = gravity acceleration (ft/sec^2 or m/sec^2)
F = pressure wave travelling in direction of +x (ft or m)

The software provides the following analysis and methods: built-in steady-state engine, transient force computation engine, turbine modeling, pump modeling, various friction methods, rule-based control analysis, and variable-speed pumping analysis using four-quadrant pump curves.

It is possible to model various surge protection devices including open surge tank, spilling surge tank, one way surge tank, gas vessel (air chamber), surge tank with orifice, with bladder, variable area surge tank, differential surge tank, pressure relief valve, anti-slam valve for air release/vacuum valve, surge anticipation valves, rupture disk, valve, or pipe, inertial flywheel.

The dynamic friction computation method was built into the numeric engine as a part of this project. The research to date on dynamic friction indicates that the most significant impact on pressure transient dampening occurs from dynamic friction effects during reverse flow conditions. Reverse flow is not a normal operation method in the Water Authority system. However, reverse flow will occur when a) flow in a pipeline is stopped, b) pump flows are terminated following pump tripout, and c) rapid flow reduction results in water-column separation and rejoining.

HYDRAULIC TRANSIENT MODEL

The model area includes Second Aqueduct untreated water pipelines from Twin Oaks Valley Flow Regulatory Structure (TOVFRS) to Otay Lake including Olivenhain Pipeline and Pump Station and inactive pipelines south of Miramar Vent, Figure 1.

There are two different hydraulic models that are developed as a part of this project:

a) Schematic hydraulic transient model
b) GIS based hydraulic transient model based on the actual GIS

Hydraulic models will be calibrated against historical data from SCADA database for selected operating modes including the typical operation of the Second Aqueduct between Twin Oaks and Otay Lake (ongoing activity).

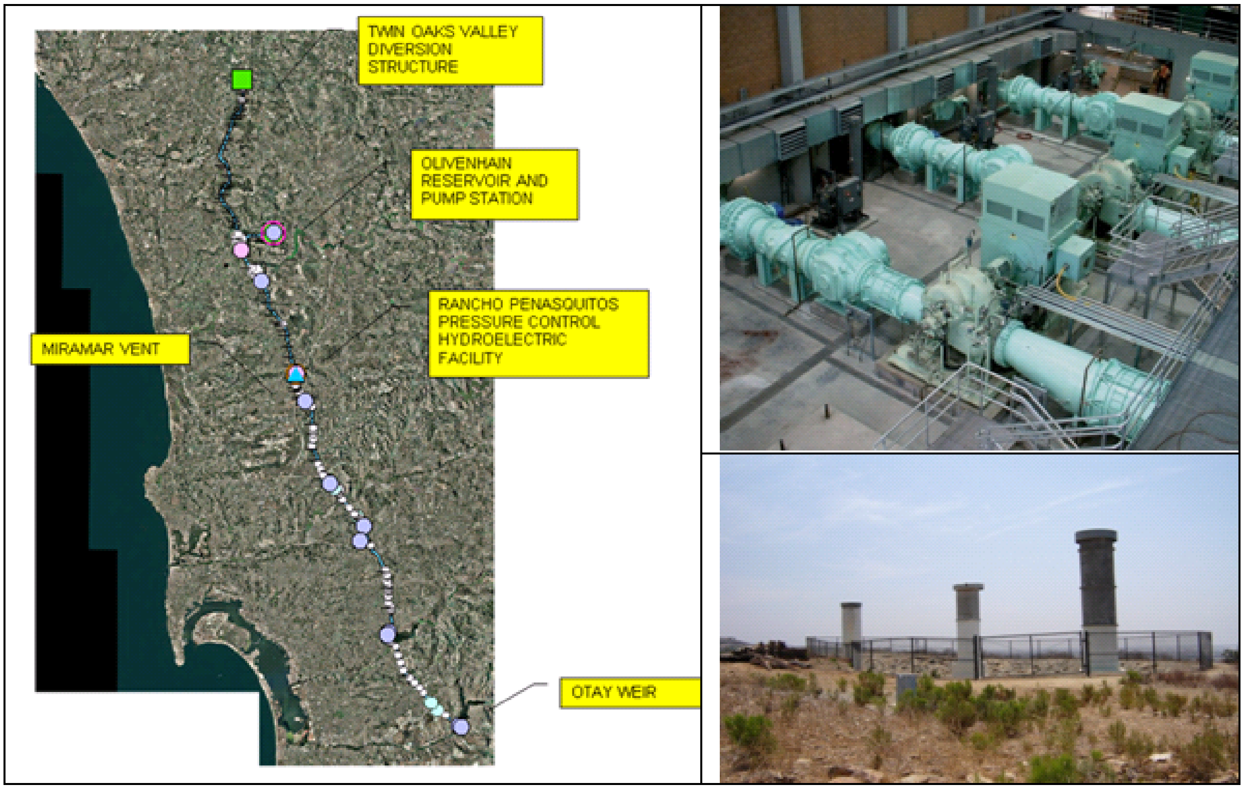

Figure 1: Hydraulic transit model area (left), Rancho Penasquitos Flow Control Facility (right top), Miramar vents (right bottom)

The hydraulic transient model was developed based on a combination of the earlier versions of the FG3D engine data sets and characteristics, and the latest ESRI based geodatabase of the aqueduct pipe data. The model consists of approx. 3,000 pipe sections of the total pipe length of 135 miles, 20 free surface tanks used to model storage tanks and vents, 70 A/V valves, 22 control valves, 8 valve turn outs, 3 pumps, and 1 turbine. Valve Tau characteristics curves are used to define the valve Tau coefficient versus the stroke. The input of the pump and turbine data is done using 4-quadrant curves of dimensionless head and torque values for up to 13 different pump speeds. The flow though the aqueduct reach between Twin Oaks Valley Diversion Structure to Olivenhain Reservoir as well as to Rancho Penasquitos Flow Control Facility and to southern agencies and Lake Otay is a gravity flow, pressurized in most cases but with occasional cascading flow sections south of Miramar vents. The most complex flow control facility within the Pilot reach is Rancho Penasquitos Flow Control and hydroelectric facility consisting of four large sleeve valves that are used, along with a turbine, to control the flow through the facility.

The interface of a hydraulic transient modeling software allows the user to setup the model, run the simulations, and analyze the simulation results from within MIKE URBAN (DHI Software) or ArcMap (ESRI) extension based interface, Figure 2.

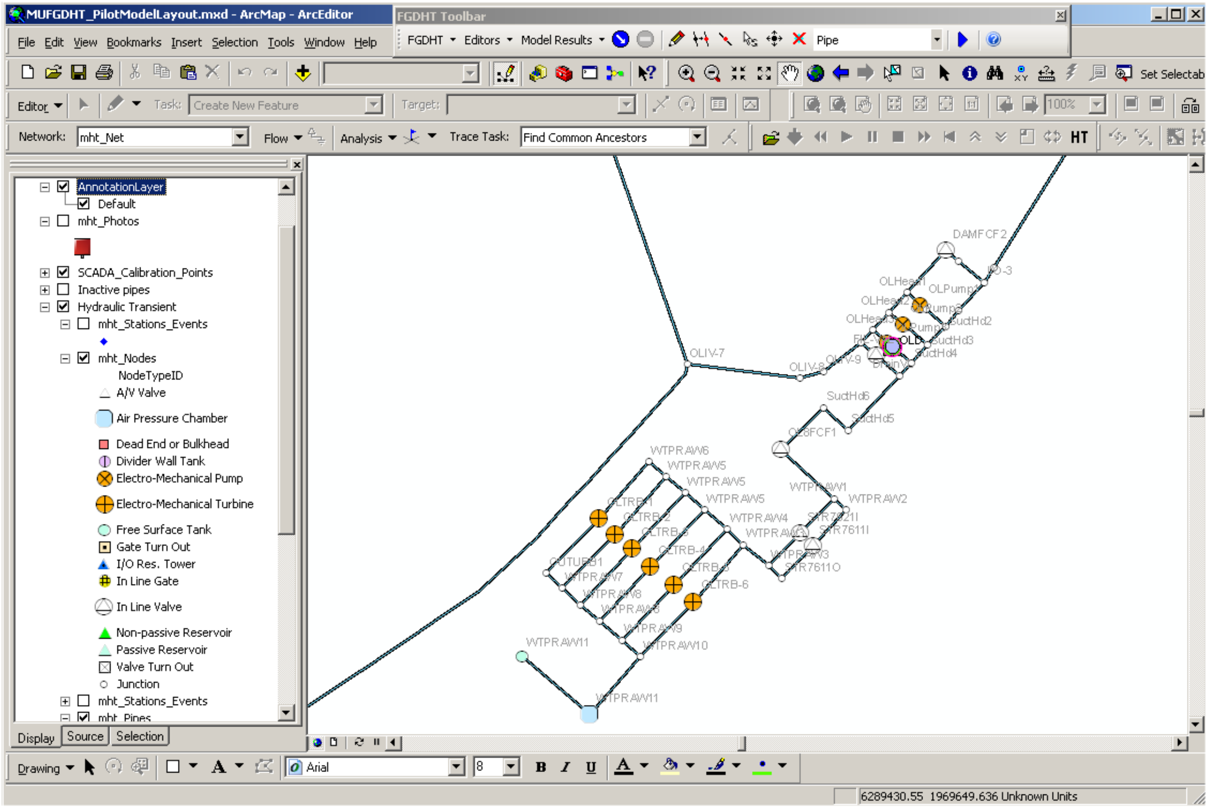

Figure 2: GIS based hydraulic transient model of the pilot area – example of a model representation of a pump station and hydropower facility

MODEL VERIFICATION

Different verification techniques are used to check the new modeling software results including a) desktop verification against alternative model results, b) comparison with the previous version of FG3D model, and c) comparison of the model results against SCADA data. Desktop verification against alternative model results is done by comparing FGDHT engine with HYPRESS (DHI) hydraulic transient engine. Despite different ways of representing valves and pumps in both models, the preliminary results showed reasonable matching values. The comparison based on the previous version of FG3D engine has been done on 5 different test cases and the initial differences helped us to debug the FGDHT model, reach the matches, and continue with more test cases. The comparison of the model against SCADA or other measured data is an ongoing task and has not been completed yet.

The model verification will be completed by comparing the model results against a detailed pressure monitoring of a high recording frequency during an intentionally introduced hydraulic transient event.

The first of the verification tests is analyzing the effect of closing all 4 sleeve valves at Rancho Penasquitos Flow Control Facility (RPFCF). The valve actuator time is defined as 20 and 28 minutes for either of 2 pair of valves. The total flow entering the 2nd Aqueduct at Twin Oak sis 330.25 cfs, a flow of 38.75 cfs is transferred from the main pipeline to Olivenhain water treatment plant, the flow of 255 cfs goes through RPFCF (from North) and a flow of 305 cfs goes from San Vicente Dam. The combined flow of 560 cfs goes south from RPFCF to Miramar Vent and south from there. Up to 505 cfs is distributed over various agencies leaving 55 cfs to Lake Otay (end of the 2nd Aqueduct).

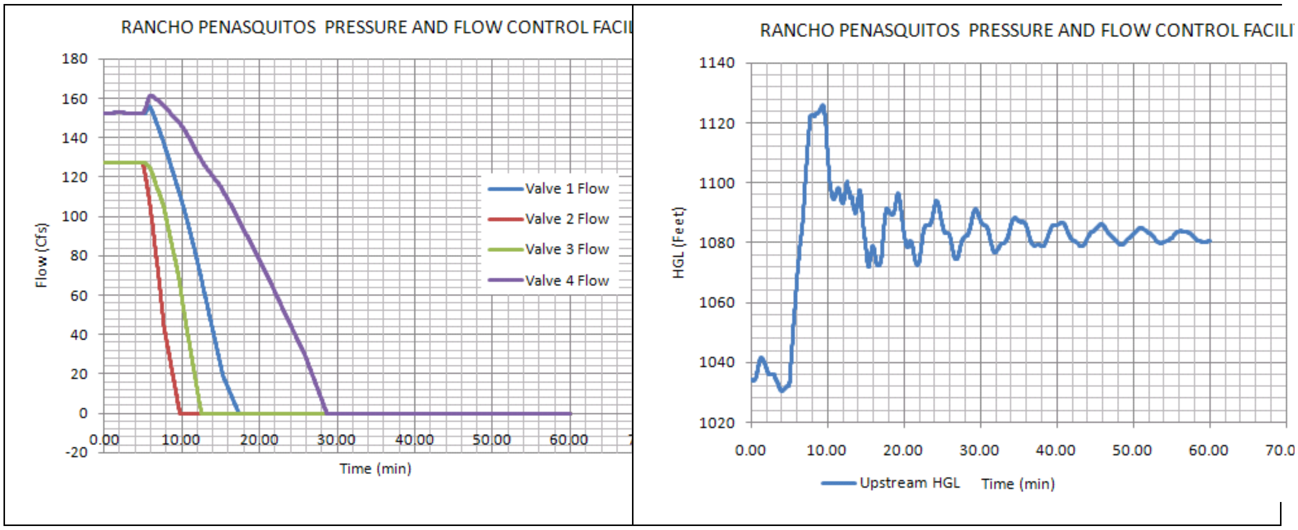

Figure 3: Valve closing (left) and Hydraulic grade line upstream (fight) of Rancho Penasquitos Flow Control Facility during the closure of all 4 sleeve valves

NEXT STEPS

Most of the project work including the software development and construction of GIS based hydraulic transient model is completed and the modeling software is undertaking numerous verification tests. Once the verification is completed and the accuracy or the confidence level of the model is known, it will be possible to start using the new model by SDCWA personnel in planning, operation and maintenance.

CONCLUSIONS

The new hydraulic transient flow model has been developed to model the Water Authority's conveyance and distribution system. The pilot model of the Second Aqueduct is compatible with the GIS system used by SDCWA and it is prepared for further expansions to the entire conveyance and distribution system. The hydraulic transient model is based upon the modification to an existing Hydraulic Transient Engine known as FG3D (Flow Gradient Dynamics Inc.) which is incorporated into a MIKE URBAN (DHI, Inc.) hydraulic model to provide an integrated modeling system. The hydraulic model is being verified based on previous model results and historical measurements available through a SCADA system including dedicated monitoring under transient flow conditions. Once completed, the model will be used by the Water Authority's personnel in planning, operation and maintenance.

Acknowledgement

Project work was conducted jointly by DHI Water & Environment Inc, Flow Gradient Dynamics Inc, and San Diego County Water Authority SDCWA, USA.