REDUCING SEVERITY OF PRESSURE TRANSIENTS IN WATER SUPPLY NETWORKS-A CASE STUDY

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ABSTRACT

Pipelines in water supply networks around the world including Australia that were constructed a long time ago have been subjected to various levels of deterioration. To prevent catastrophic pipe failures, internal and external loading on the pipes need to be maintained below accepted limits. Internal water pressure, including pressure transients, is identified as a major contributing factor for many pipe failures. Controlling the magnitude of pressure transients in water supply networks is essential to reduce the risk of pipe failures. The results of pressure monitoring and pressure transients modelling program conducted to identify and to reduce the potential pressure transients in one of the pressure zone of South East Water, Melbourne is reported in this paper. A scenario analysis is conducted to identify the best system operational configuration that can reduce the severity of measured pressure transients.

INTRODUCTION

Pressure transients in drinking water supply system could occur when existing steady-state conditions of the pipe network are altered by system operational change such as a pump-start-up or shutdowns. It is identified that pressure transients are one of the main factors that contribute to many pipe failures (Rathnayaka et al., 2015b). Pressure transients could also pose health risks when the pressure inside the pipe goes below the atmospheric pressure potentially allowing potentially contaminated external water to ingress into the potable water pipe through corrosion defects (Fleming et al., 2006, Friedman et al., 2004). Hence, investigating magnitudes and locations of pressure transients in pipe networks is important to minimise pipe failures and to reduce potential health risks.

However, obtaining accurate information about the magnitude of pressure transients in a water supply network is complex since the nature of the propagation of pressure transient waves in pipe network is very complex in comparison to the steady-state pressure variation. A number of methods are available within water utilities to obtain reasonbly accurate information about the steady-state pressure (e.g., SCADA system, steady-state hydraulic models). Because of the complexity associated with calculating the magnitude of pressure transients in pipe networks, the effect of pressure transients is not included in pipe failure prediction models and, some cases, an assumed transient pressure magnitude is assigned for the entire pipe network (Rajani and Abdel-Akher, 2012).

A number of previous studies looked into the effect of pressure transients in water supply networks. These studies included field monitoring and numerical modelling of pressure transients to obtain the magnitude of transients for a variety of purposes, such as pipe asset management (Rathnayaka et al., 2015a, Wang et al., 2013), failure analysis (Schmitt et al., 2006, Rathnayaka et al., 2015b), and back flow prevention (Ebacher et al., 2010, Svindland, 2005, Fleming et al., 2006, Friedman et al., 2004).

In the studies conducted by Fleming et al. (2006), Friedman et al. (2004), and Rathnayaka et al. (2015b) high speed pressure monitoring equipment was used for pressure monitoring. Conventional pressure monitoring equipment is not capable of capturing pressure transients waves as the speed of a transient pressure wave propagation in rigid pipes is too rapid (i.e., ~1000 m/s in rigid pipes). Therefore, high frequency pressure monitoring equipment was used to measure the pressure transients in water supply networks. A commonly used data logging system in cited studies is the Radcom pressure transient data logger, which is capable of login data up to 25 Hz.

Pressure transient numerical models were used to calculate the magnitude of pressure transients in an entire water supply network that cannot be obtained solely by pressure monitoring (Rathnayaka et al., 2015a). Field measured pressure data was used for the purpose of model validation. Two main numerical methods (wave characteristic method and method of characteristics) were found in literatures that are used for analysis of pressure transients in most of the commercially available computer programs. Both methods could provide

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similar results for a given network. However, the wave characteristic method is considered as computationally more efficient than the method of characteristics, thus is more suitable for analysis of large water supply networks (Ramalingam et al., 2009).

METHODOLOGY

Rosedale Grove pressure zone was identified as one of the network sections in South East Water that is susceptible for severe pressure transients during pump operations. As part of the Advanced Condition Assessment and Pipe Failure Prediction (ACAPFP) Project, a comprehensive study was undertaken to examine the likely pressure transients in this section and to investigate possible mitigation mechanisms. The pressure was monitored using five Radcom high speed pressure transient data loggers (type: RDL671L). These data loggers have a long-life battery, and 4 MB internal memory, which enables the data logger to log continuously for a long period in remote locations without empting the memory. The data loggers were equipped with one input for an external pressure transducer and one output to download data into a personal computer. In this particular field work, the loggers were often connected to fire hydrants using a hydrant cap and flexi hose with a snap connection. The frequency of the loggers was set to 25 readings per second with a tolerance setting of ±5 kPa. The tolerance setting was used to enable the logger to save its memory and record pressure for a long duration without clearing the memory of the instrument. Five Radcom data loggers were installed at selected locations for a period of 1 month simulating two different operational scenarios (see Figure 2 for pressure monitoring sites).

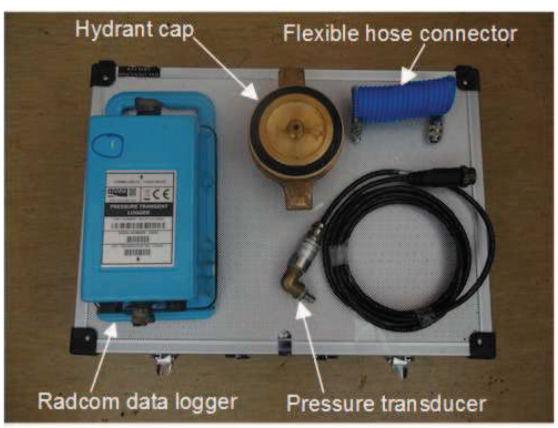

Figure 1. Radcom pressure transient monitoring data logger

Subsequently, a pressure transient model was developed for the full section (including the reticulation system) using wave characteristic based Surge2000 (KYPIPE) computer program (see Figure 3 for pressure transient model). The transient wave propagation speed was calculated using Equation 1. The model was calibrated and validated against measured pressure data. A sensitivity analysis was conducted to examine the sensitivity of the model for unknown parameters such as properties of a surge tank (air vessel type). Then, the model was run to simulate different operational scenarios that can reduce the severity of measured pressure transients.

$$c = \sqrt{\frac{E_f}{\rho(1 + K_R E_f D/E_c w\ )}} \qquad [1]$$

Where E_c is the elastic modulus of the conduit, E_f is the elastic modulus of the fluid, ρ is the liquid density in, K_R is the coefficient of restraint for the longitudinal pipe movement (unit less), D is the pipe diameter, and w is the pipe wall thickness.

RESULTS

The pressure monitoring program conducted on the Rosedale Grove section looked into two different operational scenarios shown in Figure 4. This pressure zone had two parallel trunk mains to convey water from the main pump station to the main reservoir located other end of the system. In the scenario 1, the valves that connected to the 450 mm main and the 600 mm main were kept closed; therefore, a pressure transient generated at the main pump station could not enter the reticulation until it propagate to the other end of the system. In the scenario 2, all the valves between two mains were kept open that allowed transients generated at main pump station to quickly enter into reticulation pipeline without much dissipation.

As shown in Figure 5 (a summary of pressure monitoring results of site 15), two different pressure regimes can be identified during the pressure monitoring program that correspond to two different operational scenarios stated previously (this trend was similar for all other monitoring sites except site 11). During the first five days of the pressure monitoring program, the system did not experience any significant pressure fluctuations including negative pressure (system operated under scenario 1). During this period only the 600 mm diameter main was used to transfer water from the pump station to the reservoir and 400 mm diameter main supplied water to the distribution zone (see Figure 4-scenario 1). No cross connections between two mains were kept open during this period as shown in Figure 4-scenario 1. Under this network configuration pressure transients could only enter into reticulation when the transient reached the far end of the network. The generated pressure transient was partly dissipated when the transient entered into reticulation. In addition, with this network configuration, the surge tank (air vessel.

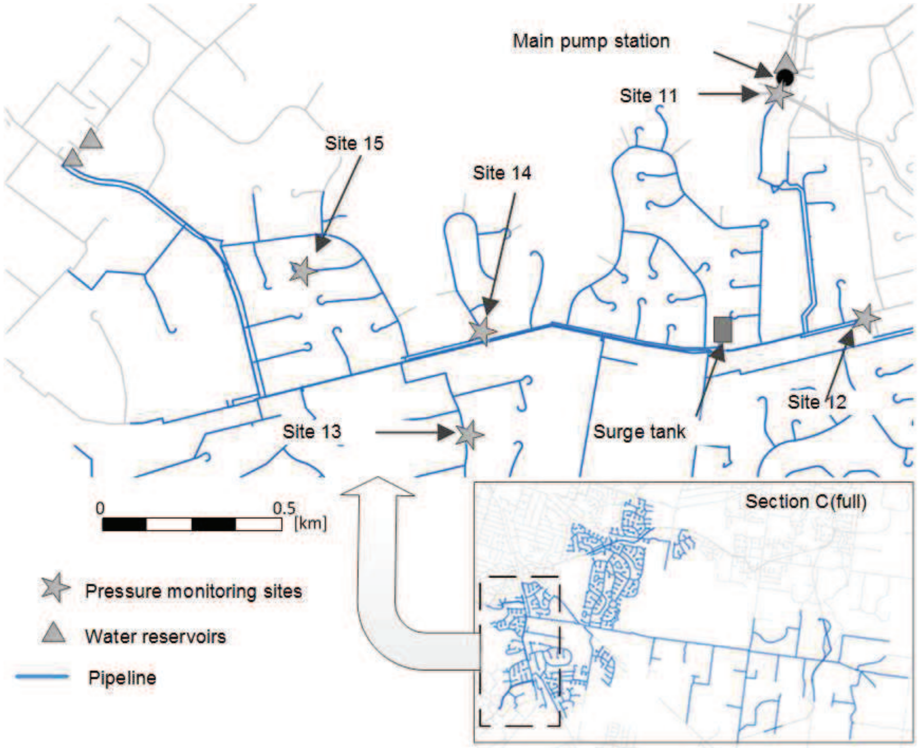

Figure 2. Pipe network and pressure monitoring sites

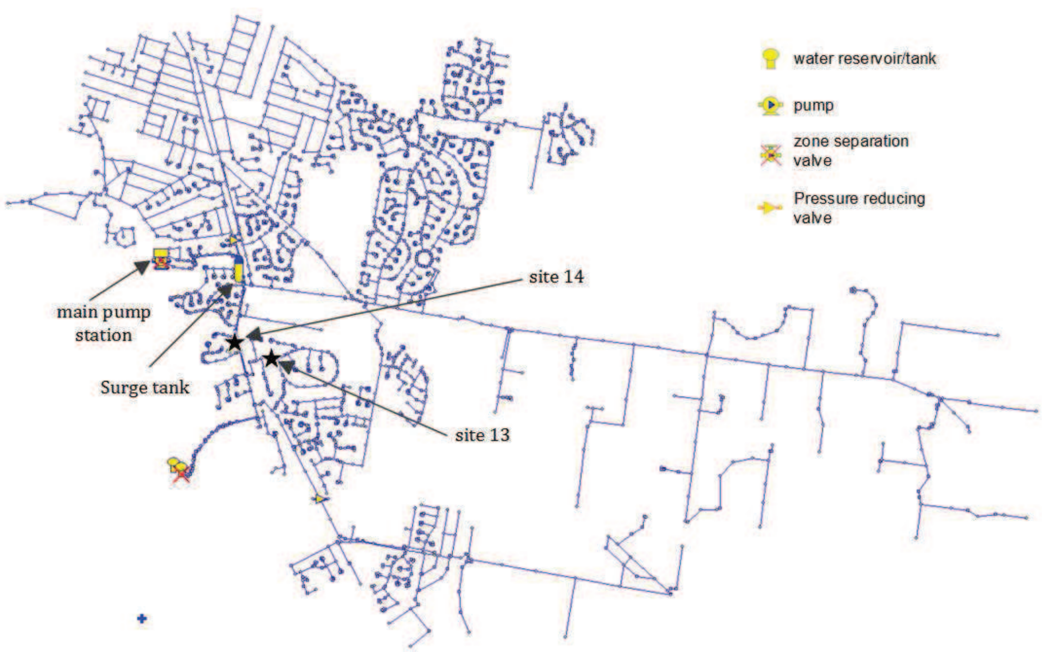

Figure 3. Pressure transient numerical model developed for Rosedale Grove section

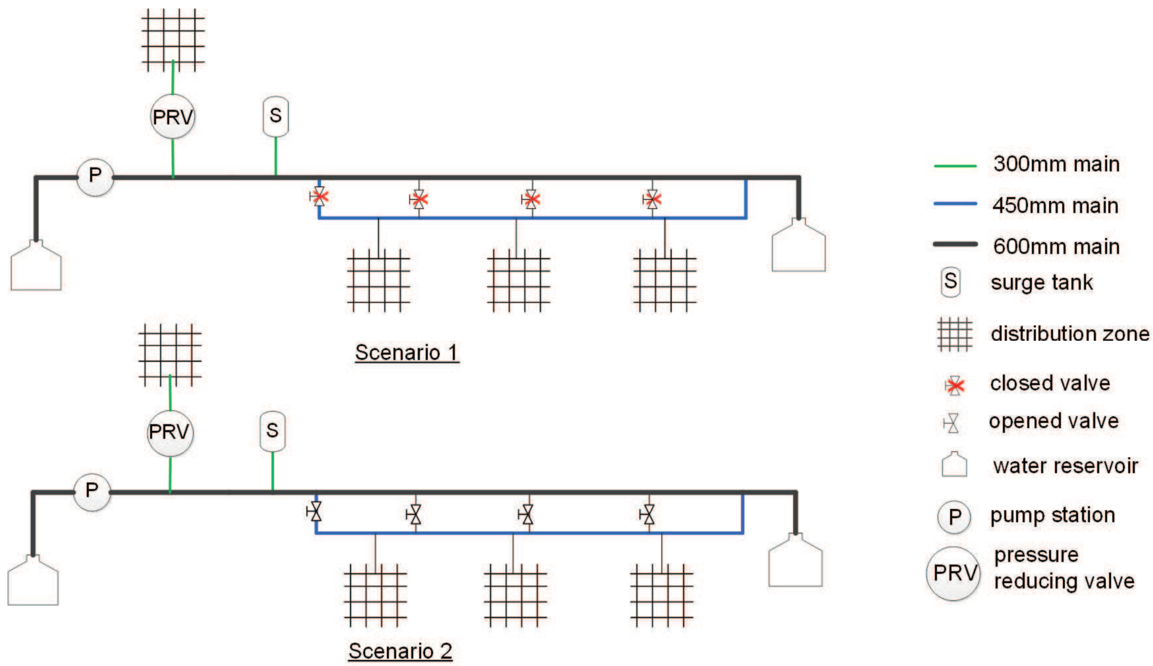

Figure 4. Two different scenarios monitored in Rosedale Grove pressure monitoring program

type) was very effective in dissipating pressure transients Because of above two reasons, the magnitude of pressure transient entered into 450 mm was very small (see Table 1).

However, during the rest of the period of pressure monitoring period significant pressure fluctuations were measured including negative pressure (system operated under scenario 2). For the remaining period of monitoring, all cross connections between the two mains were kept open and significant pressure transients were recorded at all sites including negative pressure (see Table 1). All monitoring sites experienced the effect of pressure transients that were generated at the main pump station (near site A) except site 1, where the logger was installed between the pump and the control valve that regulate the flow leaving the pump station. Therefore, the logger installed at site 11 measured the steady-state pressure head provided by the pump during its normal routine operation. The pressure monitoring program indicated that severe pressure transients developed during pump start-up and shut-down. Pressure rises after pump start-ups as high as 150 kPa were measured at site 12 located nearly 0.8 km downstream of the main pump station. Slightly less pressure transient magnitudes were measured at the other 3 monitoring sites located further downstream of site 11 and the main pump station. The pressure dropped from 646 kPa to 190 kPa at site 12 during a pump shut-down event. Similar pressure drops were measured at site 13 and site 14 during the pump shut-down events. One pump shutdown event caused the pressure to become negative (to a minimum of -100 kPa) at site 15. During the pressure recovery phase, pressure rise of around 440 kPa above the operational steady-state was measured. Although loss of pressure due to creation of vapour cavities is possible, no customer complaints were received perhaps due to running of the pump operations during night time

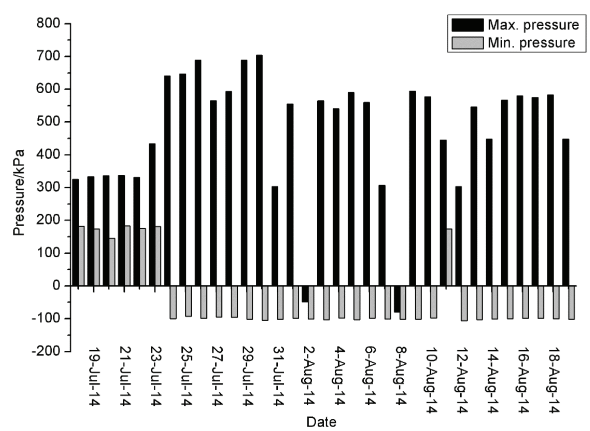

Figure5.A summary of pressure monitoring at site 15.

The pressure transient model created for this section was validated by using selected data from a pump start-up event, which occurred on 29/07/2014. Different combinations of valve opening times (5 s, 20 s, 60 s), initial pump control

***Table 1**. A summary of pressure monitoring program for different scenarios*

Site no.	Logger installation location	Scenario 1			Scenario 2		
		Typical operational pressure /kPa	Minimum pressure /kPa	Maximum pressure / kPa	Typical operational pressure /kPa	Minimum pressure /kPa	Maximum pressure / kPa
site 11[a]	Outlet tap on 600 mm pipe, main pump station	880	64	1186	880	-38	1139
site 12	Pressure regulator valve on 300 mm pipe, 0.8 km downstream of main pump station	484	426	538	495	190	646
site 13	Hydrant on 100 mm pipe, 1.8 km downstream of main pump station	450	385	495	455	134	578
site 14	Hydrant on 150 mm pipe, 2.2 km downstream of main pump station downstream of main pump station	366	312	409	371	54	503
site 15	Hydrant on 100 mm pipe, 2.5 km downstream of main pump station	260	145	337	267	-100	704

[a] No pressure transients occurred at site 11. This site only measured steady-state operational pressure

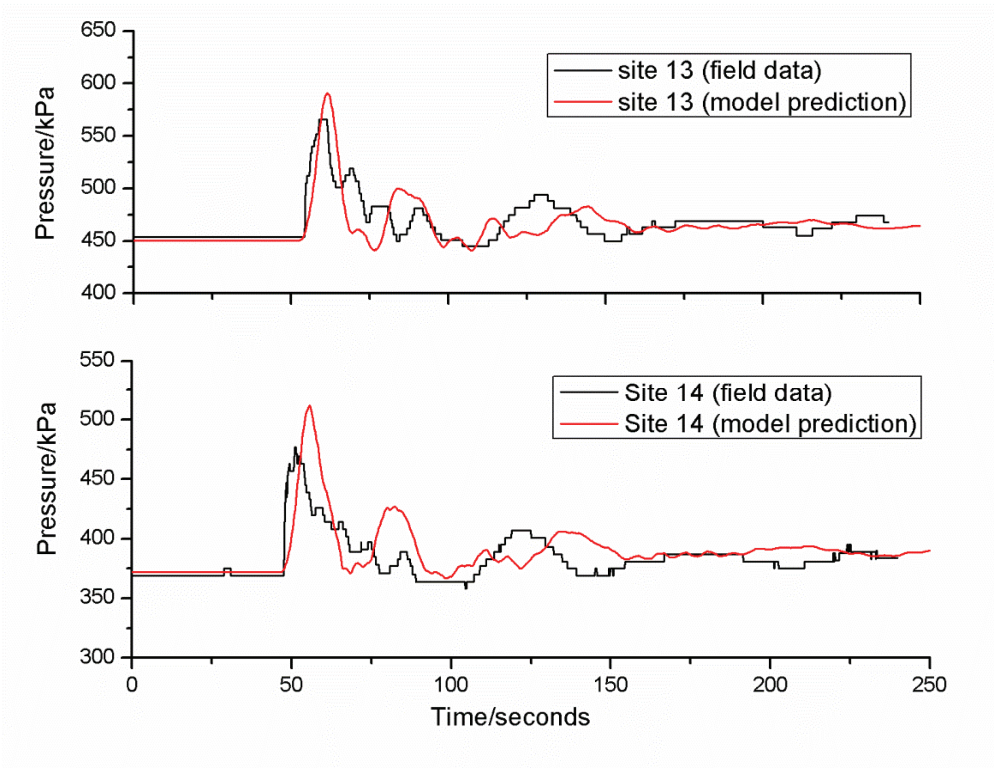

Figure 6. Model prediction of pressure transients

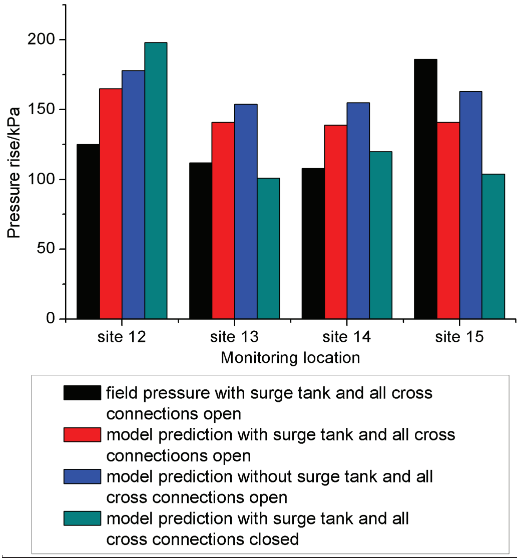

Figure 7.Comparison of pressure rise during different scenarios and monitoring location

valve opening ratios (25 %, 40 %) and initial gas volumes for surge tank (air vessel type) (2 m^3, 8 m^3,16 m^3) were used to run the models to obtain the best match with the field data (sensitivity analysis). The best prediction of the field measured pressure data was obtained for the valve opening times of 5 s, initial pump control valve opening ratio 40 %, and the assumption of 2 m^3 initial gas volume of the surge tank (See Figure 6 for the prediction for site 13 and site 14). It appears that a lower value of initial pump control valve opening ratio, a higher valve opening time, and a higher initial gas volume in surge tank (air vessel type) tends to provide lower pressure transient magnitudes. Although all five sites showed good agreement with the magnitudes of field measured pressure transients, the wave shape did not match sufficiently well in site 15. At site 13, pressure raised from 450 kPa to 566 kPa during field pressure monitoring. For the same site, the model's predicted maximum pressure was 591 kPa. At site 14, pressure rise of 108 kPa from initial steady-state pressure of 372 kPa was measured, and the calculated pressure rise using the pressure transient model was 139 kPa.

The validated model was used to examine the effectiveness of the surge tank (air vessel type) and cross connections to investigate the possible mitigation of the occurrence of pressure transients. Presence of surge tank (air vessel type), and two valve configurations mentioned in Figure 4 allowed to run three different scenarios in section C;

i. Surge tank active and all cross connections between 600 mm and 450 mm mains are open;
ii. Surge tank inactive and all cross connections between 600 mm and 450 mm mains are open; and
iii. Surge tank active and all cross connections between 600 mm and 450 mm mains are closed.

The aim of these model runs was to identify the optimum network configuration that can help to reduce the severity of pressure transients. A comparison of model predicted pressure changes during each scenario, and measured pressure data is shown in Figure 7.

The results of the model created without a surge tank and all cross connections between two trunk mains (450mm and 600mm) open showed the highest model pressures at sites 12, 13, and 15. However, the results of the model created with surge tank and all cross connections between two trunk mains open indicated a significant drop of pressure rise in reticulation pipeline (sites 13, 14, and 15). However, with this network configuration, site 12 that located near to the 600mm diameter trunk main, experienced relatively higher pressure rise because no dissipation of pressure wave can occur in the reticulation pipeline. A slight reduction in pressure rise was observed when the model was run with an active surge tank, and cross connections were kept open between two mains. When all cross connections between two mains were kept open, pressure transients enter into the reticulation pipeline without much damping occurring in the surge tank (i.e., the surge tank was ineffective). Closure of all cross connections between the two mains made the pressure transient wave propagate only through the 600 mm main that is directly connected to the surge tank. A pressure wave can enter into reticulation only after reaching the other end of the two parallel mains that are located near the downstream reservoirs (see Figure 4) when most of the pressure transient was dampened out.

DISCUSSION

The main pump station of this pressure zone pumps water from a reservoir near the pump station (75 m elevation) to another reservoir (150m elevation) located approximately 3.5km downstream of the main pump station though 600 mm mild steel cement-lined pipe and a recently constructed 450 mm PVC pipe. The pump station was built in 1970 and mild steel cement-lined main was constructed 1971. The 600mm diameter rising main was originally designed to convey water between the two water reservoirs. A surge tank (air vessel type) was built and connected to the same trunk main to reduce the severity of pressure transients generated during pump operation at the main pump station. With time, new residential developments took place in this area, and several cross connections were made to the mild steel cement-lined trunk main to supply water for new residential areas. In 2012, a new 450 mm diameter rising main was constructed and connected to the old mild steel main. At present, water is pumped though both 600 mm and 450 mm diameter trunk mains to fill the downstream reservoir.

Because of the direct connections between the trunk mains and the reticulation pipelines, a significant portion of the pressure transient generated at the main pump strain propagates into the reticulation system causing objectionable pressure variations as measured during scenario 2 in this study. Customer complaints were received by the water utility due to inadequate pressure in the system to supply water for customers during events of pressure transients (Sourghali, 2014). As a result, a new operational scenario presented is examined in this study. It can be seen in Figure 7 (green bars in figure shows the reduction of pressure variation all monitoring sites located in reticulations system) that a significant reduction in pressure variations were measured when scenario 1 is implemented in the field (i.e., 600 mm diameter mild steel main is used to convey water to the far end reservoir without any cross connections, 450 mm diameter PVC main is used to supply water for customers). When scenario 1 is implemented, the system operation was very similar to that the network was originally designed in 1970, and the surge tank was actively involved in mitigating pressure transients. Lower magnitude of pressure variations that identified during pressure monitoring in scenario 1 was confirmed by results of numerical model where the lowest magnitude of pressure transients are calculated in all sites located in the reticulation pipelines.

CONCLUSIONS

Severe pressure fluctuations were measured during pump start-ups and shutdowns in the selected pressure zone. Significant pressure fluctuations were measured due to the collapse of vapour cavities when pressure dropped and subsequently recovered during transient events. Two simulated scenarios in field highlighted that the way of pressure transients are dissipated can be significantly different for different network configurations. The pressure transient model predicted the field measured pressure fluctuations accurately, and showed that the surge thank was effective in reducing the severity of pressure fluctuations. Severity of pressure transients occurred in selected network was significantly reduced using the new proposed network configuration.

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