PRESSURE MONITORING OF SEWER RISING MAINS

Matthew Tynkkynen 1, Sally Crook 1, Roger Brown 1, William Crosby 1
1. Yarra Valley Water, Melbourne, VIC

ABSTRACT

This paper describes the key findings from Yarra Valley Water’s recent investigations into methods of automatically detecting Sewer Rising Main leaks and bursts.

Yarra Valley Water investigated a number of methods to detect failures in these key assets. Pressure monitoring was determined to be the preferred method due to comparatively high sensitivity and low cost.

The paper presents a case study of a recent rising main failure and demonstrates how Pressure Monitoring can be used to detect such failures quickly.

Yarra Valley Water’s investigations into Pressure Monitoring have also yielded additional benefits, including the identification of sites experiencing significant pressure transients due to water hammer.

INTRODUCTION

Sewer Rising Mains

Sewer Rising Mains are pipes that convey sewage from a Sewage Pumping Station (SPS) or a Sewage Flow Control Facility (SFC). They are used to transfer sewage flows under pressure where topographic constraints prevent the use of gravity sewerage infrastructure.

Yarra Valley Water (YVW) has approximately 160km of Sewer Rising Mains in service within its network. These convey flows from 87 SPS sites, and 5 SFCs.

The age and material of YVW’s Sewer Rising Mains vary. While metallic materials were favoured prior to 1990, the vast majority of YVW Sewer Rising Mains have since been constructed using polymeric materials.

Failures of Sewer Rising Mains

YVW has historically relied on the public to report failures of Sewer Rising Mains. The consequences of such failures can be significant, as these assets typically convey higher flows than gravity sewers and may be located close to highly sensitive environments.

YVW and other water authorities have faced regulatory action for undetected failures of Sewer Rising Mains. Given that many kilometres of YVW’s Sewer Rising Mains traverse non-residential areas, it is possible that failure of these assets could go undetected for some time when relying on traditional notification methods.

As a result, YVW has recently initiated a program to implement a live monitoring program to detect failures on its Sewer Rising Mains. This is being progressively implemented based on the risk profile of each main, where monitoring will be installed at the highest risk sites first.

This monitoring program forms part of a wider asset management strategy for YVW Sewer Rising Mains.
METHODS OF DETECTING FAILURE OF SEWER RISING MAINS

YVW commenced a project to determine an appropriate monitoring strategy for its Sewer Rising Mains in 2013/14.

This investigation commenced with the YVW Project Team engaging with other water utilities to determine potential techniques to monitor for failure of Sewer Rising Mains (MWH 2010). The techniques were investigated and compared by the Project Team, with the aim of determining the most cost effective and efficient method that YVW could employ for its live monitoring program.

The following options were investigated:
1. Duty Point Monitoring
2. Pressure Monitoring
3. End Flow Measurement
4. Flow Totalisation

Duty Point Monitoring
Duty Point Monitoring involves monitoring the outgoing sewage flow rate from the SPS or SFC through the Sewer Rising Main. An unusually high or low flow will trigger an alarm, as this indicates a change in normal operation of the pumps at the site.

A failure of the Sewer Rising Main will result in reduced resistance in the system and an increased flow rate from the pump.

Duty Point Monitoring is only able to detect failures between the pump station and the rising main high point.

Pressure Monitoring
Pressure Monitoring involves monitoring the pressure in the Sewer Rising Main at nominated points along the main, typically at the SPS or SFC.

During normal operating conditions, the static head is constant between pump runs, following the cessation of transient pressure waves caused by water hammer.

Pressure Monitoring aims to detect a drop in the static head in the Sewer Rising Main during the pump off period. Such a pressure drop is typical of a rising main failure.

End Flow Measurement
End Flow Measurement involves monitoring the accumulated daily flow at the discharge end of the Sewer Rising Main.

Where a daily figure is significantly lower than the average for the Sewer Rising Main, an alarm will be triggered. End Flow Measurement is suitable for rising mains of all profiles.

Flow Totalisation
Flow Totalisation involves monitoring the flow at the entrance and exit of the Sewer Rising Main.

An alarm will be triggered when there are discrepancies between the two meters. Flow Totalisation is suitable for rising mains of all profiles.
EVALUATION OF METHODS TO DETECT FAILURE OF SEWER RISING MAINS

Instrumentation Required
The instrumentation required to implement the four monitoring methods is compared in the following table.

<table>
<thead>
<tr>
<th>Method</th>
<th>Flow Meters</th>
<th>Pressure Meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duty Point Monitoring</td>
<td>1 at SPS/SFC(^1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Pressure Monitoring</td>
<td>N/A</td>
<td>1 at SPS/SFC(^2)</td>
</tr>
<tr>
<td>End Flow Measurement</td>
<td>1 at end of RM</td>
<td>N/A</td>
</tr>
<tr>
<td>Flow Totalisation</td>
<td>1 at SPS/SFC, 1 at end of RM</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Notes:
1. If a site is not equipped with a flow meter, the rate of drawdown as measured by a level monitor can be used to calculate the pumped flow rate.
2. Additional pressure meters may be required at intermediate low points of the Sewer Rising Main to be able to detect failure along the entire length of the pipe.

A number of YVW SPS and SFC sites were equipped with flow and/or pressure meters prior to the implementation of the monitoring program.

Analysis of data
Data from sites with existing instrumentation was available to compare methods for Sewer Rising Main failure detection. This data is collected and analysed by YVW’s SCADA (Supervisory Control And Data Acquisition) System.

Data captured from four rising main failures was available to compare and evaluate rising main monitoring techniques. This was used to assess which of the four methods would have been most effective in identifying the failure.

A comparison of the performance of the four methods with respect to one of these failures is demonstrated in the following case study.

CASE STUDY: SEWER RISING MAIN FAILURE ON 5/5/2013

On 5 May 2013, YVW was alerted to the failure of a Sewer Rising Main by a member of the public.

A large leak occurred at a 90° bend of a DN315 High Density Polyethylene (HDPE) main following the failure of an electrofusion joint.

The performance of the four monitoring methods to detect this failure is compared below.

Duty Point Monitoring
The flow rate output by a pump can be measured in two ways:
1. Using a flow meter located at the SPS or SFC site.
2. Calculating the flow rate based on the rate of drawdown within the wet well.

Both of these methods are compared below.

Data captured from four rising main failures was available to compare and evaluate rising main monitoring techniques. This was used to assess which of the four methods would have been most effective in identifying the failure.

A comparison of the performance of the four methods with respect to one of these failures is demonstrated in the following case study.

Drawdown time was shown to be a more effective method of monitoring duty point due to the increased variability associated with the data recorded by the flow meter.
Pressure Monitoring

Pressure Monitoring was also found to be successful in detecting the failure of the Sewer Rising Main. The figure below shows the reduction in static head between subsequent pump runs. In normal operation there is little loss of pressure between runs (demonstrated by a flat line between pump runs). Failure of the rising main is instantly detectable by pressure reduction between pump runs.

![Pressure Monitoring Figure]

End Flow Measurement / Flow Totalisation

As YVW did not have a flow meter in place at the end of the Sewer Rising Main, this failure could not be analysed with respect to End Flow Measurement or Flow Totalisation.

| Selection of Preferred Method |

In order to determine the preferred monitoring method, the Project Team assessed the four methods with respect to three key criteria:

1. Sensitivity – the size of the leak that could be detected by the method.
2. Responsiveness – how quickly the leak could be detected by the method.
3. Cost – the cost of implementing the monitoring method.

![End Flow Measurement Figure]

Table 2: Assessment of rising main monitoring methods

<table>
<thead>
<tr>
<th>Method</th>
<th>S³</th>
<th>R¹</th>
<th>C²</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duty Point Monitoring</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Pressure Monitoring</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>End Flow Measurement</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Flow Totalisation</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Notes:
³ For S (Sensitivity) and R (Responsiveness), a score of 1 is the highest and 4 is the lowest.
² For C (Cost), a score of 1 is the least expensive and 4 is the most expensive.

Based on the results of the assessment described above, Pressure Monitoring was selected as the preferred technique due to high sensitivity and comparatively low costs. In addition, YVW were able to utilise already installed pressure meters at a number of pump stations.

Alternative monitoring methodologies may be implemented where pressure monitoring is not practical due to the limitations outlined below.

Limitation 1: Rising Main Profile (Vertical Alignment)

As outlined previously, Pressure Monitoring is only able to detect leaks between the pressure meter and the adjacent high point(s) of the Sewer Rising Main.

In the case of rising mains with intermediate high points, multiple pressure meters may be used to provide more extensive coverage of the main. An example is provided in Figure 7.

Note:
¹ The purple arrow indicates the extent of the Sewer Rising Main that will be able to be monitored for leaks by the pressure meter installation at the SPS or SFC.
² The green arrow shows the additional extent of the Rising Main that will be covered as a result of the installation of a secondary Pressure Meter, downstream of the rising main high point.
**Limitation 2: Time between pump runs**

Pressure Monitoring requires a reading to be taken of the static head within the Sewer Rising Main during the pump off condition. In order to accurately measure static head, there must be sufficient time for the effect of pressure transients to cease, as shown in the below figure.

Pressure Monitoring may not be effective at sites that pump frequently. In some cases it may be desirable to modify the operation of the SPS or SFC to periodically allow an extended pump off time to improve the suitability of pressure monitoring for leak detection.

**IMPLEMENTATION OF PRESSURE MONITORING**

Pressure Monitoring was implemented by YVW using a risk-based approach, where the highest risk sites were the first to have monitoring equipment installed and alarms set.

The Project Team assessed the risk of a failure for all rising mains currently in service. This risk was calculated based on a function of two key measures:

- Criticality – the consequence of the failure.
- Condition – the likelihood of the rising main failing as a result of its physical properties.

**SENSITIVITY OF PRESSURE MONITORING**

The sensitivity of Pressure Monitoring (i.e. the size of the leak that can be detected) is influenced by two key variables:

- The profile of the Sewer Rising Main (i.e. its vertical alignment).
- The time between pump runs (i.e. the duration where the pumps are off and static head can be measured).

**Rising Main Grade**

The reduction in static head associated with a leak will vary depending on the grade of the rising main.

A pressure meter on a rising main with a steep grade will be able to detect a smaller leak than a pressure meter on a rising main with a flat grade. This effect is illustrated in the figure below.

Pressure Monitoring may not be effective at sites that pump frequently. In some cases it may be desirable to modify the operation of the SPS or SFC to periodically allow an extended pump off time to improve the suitability of pressure monitoring for leak detection.

**Implementing Pressure Monitoring**

Pressure Monitoring was implemented by YVW using a risk-based approach, where the highest risk sites were the first to have monitoring equipment installed and alarms set.

The Project Team assessed the risk of a failure for all rising mains currently in service. This risk was calculated based on a function of two key measures:

- Criticality – the consequence of the failure.
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**Sensitivity of Pressure Monitoring**

The sensitivity of Pressure Monitoring (i.e. the size of the leak that can be detected) is influenced by two key variables:

- The profile of the Sewer Rising Main (i.e. its vertical alignment).
- The time between pump runs (i.e. the duration where the pumps are off and static head can be measured).

**Time between pump runs**

A longer time between pump runs provides a longer period over which the ‘trigger’ volume loss can be reached, leading to detection of smaller leaks.

**Improving Sensitivity of Pressure Monitoring**

In cases where the desired sensitivity is not achieved, it may be possible to modify the operational philosophy of the SPS or SFC, to allow for an extended pump off time.

These modifications could include an increase in the operating band of the site, or a modified pumping regime during low flow periods. The changes in operational philosophy that are possible at a site will vary, as a range of other operational considerations need to be taken into account (e.g. emergency storage available, the degree of surcharging in the upstream pipework, etc.).

In cases where sensitivity cannot be achieved through extended pump off times, or is limited by the grade of the rising main, an alternative method of leak detection may be more appropriate.

Sensitivities of less than 1% of pumped flow can generally be achieved by the use of Pressure Monitoring.
SETTING ALARMS FOR PRESSURE MONITORING

A number of options for analysing pressure meter data and setting alarm points were investigated, using historical SCADA data during both baseline conditions and failure states.

Differential pressure calculations (i.e. a comparison of pressure at the start and end of the pump off period) were compared to a single measurement of pressure prior to the commencement of the next pump run.

In both cases, the impact of transients was discounted by disregarding values within a specified time frame following the cessation of a pump run.

A single measurement prior to a pump run was found to be equal in sensitivity to a differential measurement and was adopted.

Figure 10: Comparison of differential pressure (top) and single point pressure readings (bottom)

Setting alarm limits
Baseline data (a minimum of 30 days) was collected and analysed in order to set appropriate alarm limits as illustrated in the following figures.

These show the alarm limits that have been adopted for two of YVW’s operational SPS sites.

Figure 11: Alarm limits for SPS667

ADDITIONAL BENEFITS OF PRESSURE MONITORING

Monitoring pressure in rising mains has benefits in addition to automated leak detection. One such benefit is the identification of water hammer effects. A summary of YVW’s investigations into this issue is discussed below.

Water Hammer Rectification
For newer SPS and SFC constructions, YVW has installed a pressure meter to collect pressure data from Sewer Rising Mains. This has shown that some sites have significant issues with water hammer in the rising main when the pumps stop.

YVW has applied normal standards for motor control at SPSs and SFCs. In most cases for pumps larger than a few kilowatts, this means a conventional Soft Starter is used. In some rare cases where control of pressure has been required, Variable Speed Drives (VSDs) are installed.

Whilst conventional Soft Starters manage the starting currents for the pump motor, they are not effective in managing the flow from the pump. When stopping a pump, the Soft Starter ramps down the motor voltage, however the pump will continue to run until the voltage is too low to sustain it, at which point the pump will come to a fairly sudden stop. No amount of tuning of the Soft Starter parameters is able to mitigate this.

The pressure surges caused by the sudden stopping of a pump can be quite severe, and will depend on two main factors:

- The size, length and vertical profile of the rising main.
- The velocity of the flow.

At some sites within YVW’s network, surge amplitudes of over 70 metres were found to occur on pump stop.

Figure 12: Alarm limits for SPS720
In an effort to try and manage this surge issue, YVW trialled both a VSD and a Soft Starter that used different technology at one site. The trial used:

- A Schneider Altivar ATV61 VSD on Pump 1.
- A Schneider Allistart ATS48 Soft Starter on Pump 2.

This type of Soft Starter has torque control and ramps the voltage down in a non-linear way to achieve a more linear change in the pump output.

**Trial Results**

The results of the trial of the new technology are presented in the below figure.

YVW observed similar improvements in Water Hammer surge with both the VSD and the Soft Starter, with the surge on pump stop reduced from over 71 metres to 10 metres.

As the Soft Starter has a similar performance but a significantly reduced cost (about 40% of the cost of the VSD) YVW decided to expand the trial to a number of other sites using the same Soft Starters.

Similar results were achieved at these other sites.

**Further trials**

YVW has also trialled an ABB PSTX Soft Starter with torque control and achieved almost identical results to the Schneider ATS48.

The conclusion made by YVW is that the important component is the torque ramping functionality of the starters; and that the performance is not related to a specific brand of Soft Starter.

**CONCLUSION**

This paper has described the investigations undertaken by YVW to develop a live monitoring program for its Sewer Rising Mains. This program aims to detect leaks on these key assets quickly, as a means to minimise the consequences of failure.

YVW has selected Pressure Monitoring as its preferred method of leak detection for a number of reasons including:

- Sensitivity for leak detection.
- Short response time to leaks.
- Comparatively low capital and operating costs.

The YVW Pressure Monitoring program will be progressively rolled out, with full coverage of Sewer Rising Mains expected by the end of 2015/16. The highest risk sites will be completed first, where Pressure Meters will be retrofitted to existing pump valve assemblies.

YVW has observed additional benefits throughout this program, including the identification of sites with significant water hammer.
Where sites are observed to have particularly high water hammer effects following the installation of a pressure meter, there are technologies available that can help to alleviate the surge.

NOMENCLATURE

RM      Rising Main
SCADA   Supervisory Control And Data Acquisition
SFC     Sewage Flow Control Facility
SPS     Sewage Pumping Station
VSD     Variable Speed Drive
YVW     Yarra Valley Water

REFERENCES

MWH. 2010. Sewer Rising Main Continuous Online Leak Monitoring System Review, MWH, Melbourne, VIC, Australia