RISK BASED INSPECTION (RBI) OF AGING PUMP-STATION PIPEWORK

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ABSTRACT

Long-distance, large diameter pipelines provide essential water supply to large populations throughout South Australia. The assessment of pipework integrity is of vital importance to the reliable operation of these pipelines. This paper describes the application of Risk Based Inspection (RBI) to pipework integrity, within pumping stations on the Morgan to Whyalla Pipeline (MWPL). It describes the case history and discusses the benefits and limitations of RBI.

INTRODUCTION

The SA Water major pipelines system is comprised of six major pipelines across the state. The major pipeline systems typically comprise large diameter, high pressure, above ground, mild steel cement mortar lined (MSCL) pipes, incorporating high and low voltage pump stations and water storages. Their purpose is to transfer bulk water across long distances and deliver it to local distribution systems. This provides security of water supply to customers in regional and metropolitan locations. The total length of the Major Pipelines Systems is 2,208 km, with maximum system diameters ranging from 750mm to 1450mm. These pipes have long anticipated design asset lives, which range from 80 years to 150 years. The current average age of the pipes (by system) within this program is 48 years, but some systems have pipe which was constructed in the early 1940’s, resulting in an asset age exceeding 70 years. An estimated 1.3 million South Australians, as well as associated commerce and industry are reliant on these assets performing reliably.

In 2012 and 2013 a number of weeps were identified in high pressure discharge pipe inside a number of pump stations. (Figure 4 is a view of a typical pump station.) Upon closer inspection of these weeps, it was found that significant pipe thinning had occurred and the integrity of the pipe wall was compromised, despite the cement lining protection and the high nominal residual life. Weeps had sometimes occurred in areas where there was no obvious reason or recognizable pattern of deterioration. SA Water operates 17 high voltage pump stations on the major pipeline systems and rupture failure has the potential to cause significant outages. Therefore, a more rigorous investigation was required. It was quickly identified that 100% ultrasonic thickness inspection was both expensive and time consuming. An alternative approach was required.

In a tender process, ALS recommended development of a RBI system, which would target the higher risk areas. It would provide recommended inspection techniques and develop an inspection schedule based on desktop analysis of the design, operating conditions and available history. SA Water supported this approach and a manual has been developed. There were a number of technical and asset management learnings arising from this approach.

OPERATING CONTEXT

At SA Water’s high voltage pump stations, pumps are usually started against a closed valve, and then the control valve (typically a gate valve) is slowly opened. Experience has shown that mechanical scouring of MSCL pipe occurred and thus velocities were very high. As a result of this experience, an ad hoc program of inspections was undertaken on some of the high voltage pump stations. Discharge pipe spools, immediately downstream of the control valve, were inspected. These inspections typically consisted of manual, random ultrasonic spot thickness tests, on the underside of the pipe, for about half a meter downstream of the flange.

As a result of the identification of the weeps in the high voltage pump stations, more comprehensive ultrasonic thickness scanning was undertaken, which identified significant internal corrosion. This had the potential to result in rupture failures causing damage to the pipe as well as other assets in the pump stations, rendering the pump station non-operational. The high voltage pump stations supply water to both metropolitan and regional customers, with populations up to 400,000 and 100,000 people respectively (on each individual system). Failures in the discharge pipework in these pump stations has the potential to damage the sensitive high voltage motors and switchboards (long replacement lead times) and cause extended customer supply outages.
Initially, 100% inspection was scoped for the pump stations. However, given the number of pump stations and surface area of pipework, it was soon realised that a more efficient method was required for long term asset management of the discharge pipe spools.

**RBI METHODOLOGY**

Risk Based Inspection of pipelines has its origins in the petrochemical industry and the American Petroleum Institute (API). The Scope of API Codes includes water pipelines. The API Codes are well established and proven, in practice. They provide a sound engineering basis for inspection, assessment, repair and re-rating of pipelines. To the writers’ knowledge there are no equivalent, suitable, Codes from other Institutions.

The Risk Based Inspection process is thoroughly explained in API 580, “Risk-based Inspection”. In addition, API 571 “Damage Mechanisms Affecting Fixed Equipment in the Refinery Industry” is a useful reference. It provides succinct, practical advice on all of the damage mechanisms affecting pipelines, including those applicable to water pipelines.

The steps in performing RBI are:

- Owner operator commitment to a long term, engineering approach
- Review history and proposed future activity
- Identify damage mechanisms and failure modes
- Determine likelihood of failure
- Determine failure consequences
- Determine risk
- Scope inspections targeted to current condition and the damage mechanisms
- Owner/operator sign-off to steps, above
- Conduct inspections
- Design and approve restrictions, repairs, modifications (if applicable)
- Inspect after repair (if applicable)
- Engineer’s sign-off on suitability for continued service
- Review RBI (update damage mechanisms, schedules). Known as “evergreening”.
- Major review, usually after 10 years of operation.

**RBI APPLIED**

The first six steps in the RBI process developed an RBI manual, which provided specific assessment for the relevant asset types. In this case, it was MSCL pipe, carrying water (both raw river water and potable water). The manual details the history, design specification, damage mechanisms, severity ratings and the risk assessment process.

Development of the manual was led by ALS Industrial, with input from SA Water on design, drawings, water quality, operating parameters, pressure analysis and other key data. Not all of the required data was available and some data required analysis before feeding into the Manual.

Once the manual was developed, each individual spool was assessed for overall risk and then an inspection regime was developed. The individual assessment was made by entering the operating parameters into an Excel spreadsheet, derived from the Manual.

The assessment considered the historical inspection coverage. There were minimal recent, relevant inspections. Consequently, all of the pipework was ascribed an increased risk ranking. An inspection technique which would give a high likelihood of detection (LOD) of the predicted damage mechanisms was warranted. E.g. detection of detachment of cement lining and consequential internal corrosion.

The results of the analysis for higher risk spools in Pump Station 1A are shown in Table 1.

**Table 1: Pump Station 1A. RBI predictions.**

<table>
<thead>
<tr>
<th>Damage Mechanism</th>
<th>Cause</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of internal lining</td>
<td>Cavitation/turbulence</td>
<td>Almost certain</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Loss of internal lining</td>
<td>High pressure, especially pulses</td>
<td>Almost certain</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>General internal corrosion by mains water</td>
<td>Loss of internal lining plus velocity &gt;4.5m/sec</td>
<td>Almost certain</td>
<td>Moderate</td>
<td>High</td>
</tr>
</tbody>
</table>

**RESULTS**

The RBI methodology was applied to all pump stations on the MWPL System. I.e. Pumps Stations 1, 1A, 2, 2A, 3, 3A, 4 & 4A.

Detached cement lining was identified as the precursor to failure. Areas of cavitation, turbulence, pressure pulses, or increased velocity, had a higher likelihood of detachment of the cement lining.

As verification of the RBI methodology, 100% ultrasonic inspection was performed on all accessible discharge pipework at Pump Station 1A. RBI predicted that straight lengths of pipe, remote from bends, reducers or valves had a lesser likelihood of failure. This was confirmed by the inspection of Pump Station 1A and therefore only higher risk locations were inspected on the other pump stations i.e. omission of straight lengths, remote from bends, reducers or valves. Inspection, at Pump Station 1A, also confirmed that suction pipework was of a lower likelihood of deterioration. Inspections on other pump stations omitted suction pipework.
Initially, thermography was trialled to determine its capability in identifying detached cement lining. However, this had mixed results (possibly due to corrosion occurring under the cement lining, or lack of sufficient temperature differential between the water and external ambient temperature). Further thermography work was postponed.

100% UT scanning of all high risk spools was subsequently selected and completed on the pump stations. Several areas of significant corrosion were identified, including one area which required immediate repair, due to critically low wall thickness.

When the first round of inspection work was completed, the results were fed back into the RBI Manual and Spreadsheet to determine the next scheduled inspection for each spool. This involved estimation of corrosion rate and a calculation of the minimum allowable wall thickness (MAWT). Internal corrosion only commences when the cement lining fails, therefore an estimate was made of the date of cement lining failure, in order to calculate corrosion rate.

The RBI assessment determined that the water chemistry was relatively benign and of low corrosivity. Areas with no lining defects were therefore scheduled for reinspection at the maximum period, while other areas will be reinspected on a 2 or 5 year cycle. Table 2 shows the corrosion rate and residual life for reportable (i.e. corroded) spools in Pump Station 1A.

<table>
<thead>
<tr>
<th>Spool No.</th>
<th>Wall thickness (mm)</th>
<th>Apparent corr. rate (mm/yr)</th>
<th>Residual life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nom</td>
<td>Current</td>
<td>Loss</td>
</tr>
<tr>
<td>DP2f</td>
<td>6.3</td>
<td>3.9</td>
<td>2.4</td>
</tr>
<tr>
<td>DM1ah/D P1e LHS</td>
<td>6.0</td>
<td>2.0</td>
<td>4</td>
</tr>
<tr>
<td>DM1ah/D P1e RHS</td>
<td>6.0</td>
<td>2.0</td>
<td>4</td>
</tr>
<tr>
<td>DM1ah/D P2e LHS</td>
<td>6.0</td>
<td>3.7</td>
<td>2.3</td>
</tr>
<tr>
<td>DM1ah/D P2e RHS</td>
<td>6.0</td>
<td>3.7</td>
<td>2.3</td>
</tr>
<tr>
<td>DM1ah/D P3e LHS</td>
<td>6.0</td>
<td>4.5</td>
<td>1.5</td>
</tr>
<tr>
<td>DM1ah/D P3e RHS</td>
<td>10.0</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>DP4f</td>
<td>10.0</td>
<td>2.7</td>
<td>7.3</td>
</tr>
<tr>
<td>DP5f</td>
<td>10.0</td>
<td>3.0</td>
<td>7</td>
</tr>
</tbody>
</table>

When all RBI inspection was complete, results were reviewed to gain an overall appreciation of the condition of reportable spools. See Figures 1, 2 and 3 below.

Table 2: Pump Station 1A, Corrosion Rate and Residual Life

![Wall Loss Histogram](image)

**Figure 1: Wall Loss, Reportable Spools**

![Corrosion Rate Histogram](image)

**Figure 2: Corrosion Rate, Reportable Spools**

![Residual Life Histogram](image)

**Figure 3: Residual Life, Reportable Spools (without repairs)**

From Table 2 and Figures 1 to 3, it is apparent that:

- Targeted repair should be planned according to residual life. Some repairs are needed immediately.
- Future inspections should be conducted on a 2 year cycle, or a 5 year cycle, as appropriate.
The outliers, with very high corrosion rates (around 0.6mm/yr), may be an over-estimation, caused by premature failure of the cement lining.

With targeted repairs, the pipework has a residual life of at least 30 years.

Internal inspection was conducted on selected deteriorated spools. This confirmed the ultrasonic thickness results. It was found that corrosion was occurring beneath apparently intact cement lining. I.e. the cement lining had softened and deteriorated, rather than completely detaching from the bore. This damage mechanism was not adequately covered in the first draft of the manual and it was added, in a revision. This damage mechanism is called “depleted cement lining”. This experience illustrates the importance of the “RBI Review (“Evergreening”)” step. Unfortunately, external inspection techniques, capable of detecting detachment of cement lining, are unlikely to find depleted cement lining.

The cement linings on long, straight lengths were typically factory-applied, centrifugal lining, whereas shorter spools were hand-applied lining. Internal inspection found that the durability of the factory-applied lining was less variable, and superior to hand-applied lining. This is consistent with the omission of long, straight lengths from the RBI inspection.

RBI COMPARED TO TRADITIONAL METHODS

The traditional method would be full inspection on a regular basis, or, as per historical practice, ad hoc inspections, of limited pipe areas. These methods either under or over service the inspection needs, leading to either increased risk, or over investment in the asset. The RBI approach allows a tailored program to be established to suit the specific risk posed by each individual discharge pipe spool. This optimised asset management by providing information on which to base investment decisions. Action can be planned before the overall risk is unacceptably high.

The 100% inspection activities, at Pump Station 1A, and the follow-up internal inspections, verified the reliability of the RBI methodology.

Prior to adopting the RBI approach, SA Water listed all the pipework, inside a pump station, as a single asset, regardless of whether it was suction (typically low pressure) or discharge pipe. Furthermore, past corrosion, or valve changes, had resulted in replacement of some spools. The replacements may have been of different wall thickness or pressure rating. The asset recoding structure was not suitable for RBI because the age, design and history of components was not recorded individually. As a result of the adoption of RBI, SA Water has initiated a process to identify all individual pipe spool segments, in each pump station, and list them separately in the asset management system.

Compared to the traditional inspection methods RBI has:

- Reduced overall inspection costs
- Focussed integrity assessment on high risk areas, due to review of failure modes and damage mechanisms.
- Reduced overall risk.
- Created repair and re-inspection schedules.
- Optimised whole of life asset management of the pipe spools.
- Provided an estimate of residual life of the asset.
- Facilitated mitigation strategies.
- Led to an improvement in pipe asset tracking and the management system.

DISCUSSION

RBI is well-proven system for the assessment of assets. It is a logical, well documented approach, which is easily learnt and understood by both technical staff and management.

A major supplementary benefit is the nurturing of structured teamwork, in a multi-disciplinary engineering team, including the client’s engineers and consultant engineers. Without this structured teamwork, RBI is likely to fail.

The early steps in the RBI process are critical. Damage mechanisms, likelihoods and consequences must be correctly identified and fully understood. The biggest concern is the omission of a major damage mechanism.

The application of RBI requires sound engineering and operational judgement.

RBI does not compensate for poor design, faulty installation, or excursions from nominated operating conditions.

Under RBI, the selection of appropriate inspection methodology occurs after the assessment of damage mechanisms, likelihoods, consequences and risk. The selected inspection methodology should be the most credible, economic, efficient and reliable, with an acceptably high likelihood of detection of the expected damage. I.e. targeted inspection. In most cases well-known basic methods of non-destructive testing (NDT) are chosen. However, sometimes there is a need to develop methods, or use advanced inspection technology. The thermography trials were an example of development.
New inspection technologies are continually reaching the market but they should not circumvent the steps in the RBI process. The inspection methodology must be appropriate for the application, once damage mechanisms, likelihoods, consequences and risks are known. In many cases, newly developed inspection techniques do not have sufficiently established credibility, reliability and likelihood of detection. New, advanced techniques often rely heavily on subjective interpretation of data, with no recognized Standards or Codes for guidance.

RBI is an iterative process. It becomes more accurate with the passage of time, and future inspections.

RBI integrates well with an ISO 55000 approach to asset management.

CONCLUSIONS

- RBI had its origins in the petrochemical industry but it is suited to any asset where there is a significant risk of failure.
- RBI is smart and efficient engineering. It avoids under-inspection or over-inspection.
- SA Water has been able to reduce re-inspection costs, optimise pipe spool replacement, reduce risks and improve asset management techniques.
- RBI relies on inspection technology. If reliability and likelihood of detection are low, then, the uncertainty in the RBI process is increased. Sound, conservative engineering judgement is essential, when uncertainty is high.
- RBI is intended to provide answers to the vitally important issues:
  - Is the asset fit for service?
  - What maintenance is required?
  - When is the next inspection?
  - How can deterioration be mitigated?
  - What is the residual life of the asset?
- RBI is not a precise process. It uses models and estimates. As time proceeds, it can be refined.
- RBI provides an auditable record of engineering due diligence.
- RBI facilitates communication and understanding of engineering activities to all stakeholders, both technical and non-technical.
- RBI is best applied as a long-term strategy, rather than a once-off activity.
- RBI can be integrated with maintenance management software and ISO 55000 systems.
- Once established, RBI can be easily and economically expanded to all areas of integrity management, within a corporation.

ACKNOWLEDGMENT

The writers wish to thank SA Water and ALS for permission to publish this paper.

REFERENCES

Figure 4: Typical Pumping Station

Figure 5: Thin Spot on Bend
Figure 6: Dark, Deteriorated Cement Lining with Corrosion Beneath