Condition Assessment and Rehabilitation/ Renewal of Wastewater Rising Mains

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ABSTRACT

This paper discusses techniques for the condition assessment and rehabilitation/replacement of wastewater rising mains.

Rising mains are an essential component of the wastewater network. However, they often have no redundancy, with each pumping station being served by only one rising main. Problems with rising mains have the potential to cause pollution, damage property and adjacent services, resulting in significant costs.

Rising mains are very difficult to inspect, as they are under pressure and frequently cannot be taken out of service. Faults that cause problems may be very small and are often not identified from the inspections that are carried out.

Techniques for rehabilitation of pressure pipes are available, but are not as well established and not as proven as those used for the rehabilitation of gravity pipes.

This paper contains a review of available condition assessment and rehabilitation/replacement techniques. A risk based approach to the management of rising mains is recommended, where the likelihood and consequence of failure is determined. Inspections and rehabilitation/replacement is concentrated on those areas that result in the greatest reduction in risk. Contingency planning for rising main failure is also considered.

The paper considers the findings from the WERF reports "Inspection Guidelines for Ferrous Force Mains" and "Inspection Guidelines for Wastewater Force Mains", which were based on surveys of practices and techniques used in the United States of America. The paper uses rising mains on the North Shore City Council's wastewater network as a case study to compare the relevance of WERF's findings to the New Zealand context. The paper also makes comparison between practices used for the management of wastewater rising mains with those used for gravity wastewater pipes and potable watermains.

KEYWORDS

Wastewater Rising Mains, Condition Assessment, Rehabilitation

1 INTRODUCTION

This paper uses the rising mains on North Shore City Council's wastewater network as a case study to compare the relevance of WERF's findings to the New Zealand context.

1.1 OVERVIEW OF NORTH SHORE CITY COUNCIL'S WASTEWATER NETWORK

North Shore City is located in Auckland, New Zealand. The city has a population of 225,000 and covers an area of 130 sq km. The wastewater system includes 17 trunk rising mains, as well as other small local reticulation mains. This paper considers only the trunk rising mains.

A review of all of the trunk rising mains was undertaken in 2009/2010. A more detailed assessment was also completed during this period, as to the condition and rehabilitation/renewal options for the Pump Station 5 eastern rising main.

The location of the trunk rising mains are shown in Figure 1

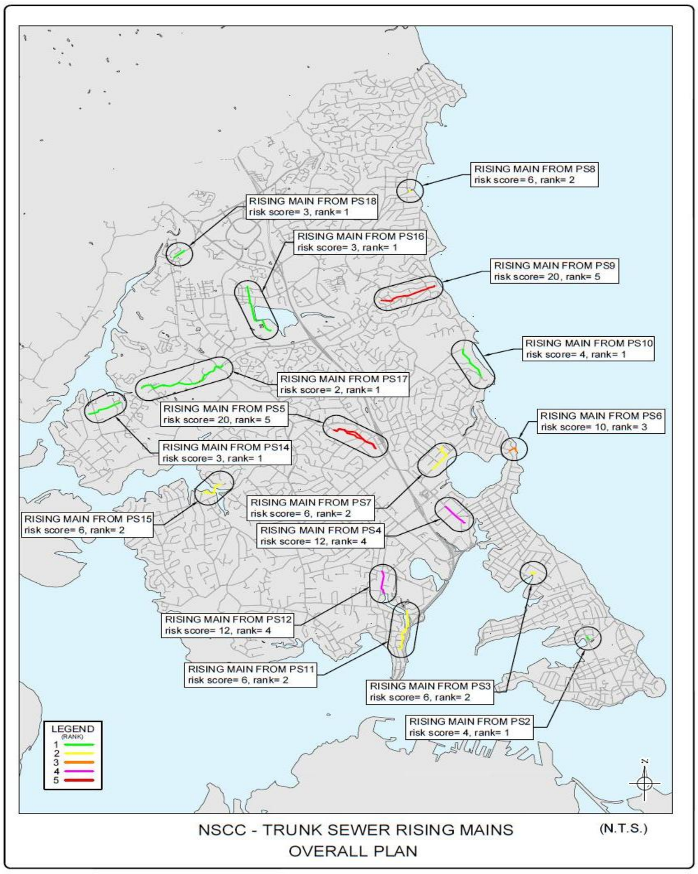

Figure 1 – North Shore City Council's Rising Mains

2 CHARACTERISTICS OF RISING MAINS

Traditional wastewater networks are mostly gravity systems. Pressure rising mains typically only make up a small proportion of the overall network, with rising mains being used to transport sewage over hills and other areas where there is inadequate fall for sewage to flow via gravity.

WERF estimate that rising mains comprise, on average, only 7.5% of wastewater networks in the USA. As a comparison, rising mains comprise 12% of the North Shore City system, roughly in line with the situation in the USA.

2.1 MATERIALS

Rising mains can be constructed from a variety of materials. Older mains tend to be ferrous pipe, e.g. concrete lined steel or cast iron pipes. Newer pipes are often PVC or PE, with some asbestos cement pipes being used. Each of these pipe materials have their own characteristics and issues that need to be considered when developing a condition assessment programme.

The majority of the rising mains in North Shore City are constructed from concrete lined steel, with 2 rising mains being concrete and one each being PE & PVC.

2.2 DIAMETERS

Rising mains are typically non man-entry size, requiring inspection by remote means. WERF estimate that 57% of rising mains are in the 100mm to 300mm range. North Shore City Council's rising mains range between 225mm to 840mm. The rising mains are a larger than the average in the USA with 59% being below 500mm diameter.

2.3 AGE

WERF estimate that 68% of rising mains are less than 25 years and 30% between 25 to 50 years old. In North Shore City the rising mains are typically older than this, with the majority of the mains being installed in the 1960's.

2.4 LOCATION

Rising mains are often installed under roads or road verges. This is the case in North Shore City, but six mains are installed, at least for part of their length, under developed land or under buildings. This can make inspection and maintenance difficult and can increase the consequence should problems occur.

Rising mains are typically installed shallow, with less than 2m cover.

2.5 REDUNDANCY

There is, typically, very little redundancy with rising mains. Normally, pump stations are served by only one rising main. Thus, if there is a problem with a rising main, the pump station will need to be shutdown and an overflow may occur. It may also be difficult to take the rising main out of service for inspection and testing.

This lack of redundancy contrasts with potable water systems, where most parts of the system are fed from two sources.

In the North Shore City system only one pump station is served by two rising mains.

3 COMMON CAUSES OF RISING MAIN FAILURE

Causes of rising failure fall into three broad categories, being:

- External corrosion
- Internal corrosion
- Mechanical failure and joint leakage.

The environmental and physical factors that can influence the likelihood of these failure mechanism occurring are summarized in Table 1.

Corrosion Type	Environmental Factors	Physical Factors
External Corrosion	• Soil Resistivity • Soil moisture content • Ground Water • pH • Chlorides • Sulphides • Redox potential	• Pipe material • Pipe thickness • Manufacturing/installation defects • External protection • Pipe age
Internal Corrosion	• Sewage chemical composition • H_2S concentrations • Temperature	• Pipe material • Pipe thickness • Manufacturing defects

Corrosion Type	Environmental Factors	Physical Factors
		• Forms of protective linings • Pipe age
Mechanical failure & joint leakage		• Pipe material • Pipe thickness • Manufacturing defects • Pipe age • Diameter of the pipe • Type of joints • Pipe installation/bedding • The location of the pipe • The depth of cover • Live loadings • Pressure changes • Third party damage • Ground movement

Table 1 – Common Causes of Rising Main Failure (Adapted from "Inspection Guidelines for Ferrous Force Mains")

The various factors affecting a rising main need to be considered to totality when attempting to predict the remaining useful life of a rising main. This can be challenging.

A rising main may often be subjected to different types of corrosion, to varying degrees, over its length, as a result of the various environmental and physical factors, as demonstrated in the following example of North Shore City Council's Pump Station 5 eastern rising main.

3.1 FAULTS OBSERVED IN NORTH SHORE CITY COUNCIL'S PUMP STATION 5 EASTERN RISING MAIN.

The Pump Station 5 eastern rising main is 1,100m long. It is 840mm diameter. The majority of the rising main was installed in 1962, constructed from concrete lined steel. A shorter section at the downstream end of the rising main is concrete.

A leak occurred in the 1990's. This is believed to be due to the external coating being damaged, either during construction or by a third party. (Mechanical failure, installation or third party damage).

Investigations on the rising main undertaken in 2009/2010 identified the following areas of concern. (The type of corrosion and influencing factors from Table 1 are shown on brackets):

- Areas where the internal mortar had eroded, typically in steep sections of the main. Grit in the sewage was possibly influencing the extent of erosion. (Internal corrosion influenced by internal protective lining, sewage composition).

- External corrosion due to the external bitumen coating having debonded away from the pipe and, in other cases, where the coating had been damaged by coarse backfill material. The extent of external corrosion may have been affected by stray electrical currents and ground water/moisture and soil resistivity (External corrosion influenced by external coating, installation defects, age, electrical currents, ground moisture and soil resistivity)

- Problems with sections of welding at pipe joints. Some of these problems were due to poor manufacture. Others appeared to have resulted from deterioration over the life of the pipe, possibly contributed to by ground movement. (Joint leakage influenced by installation defects, age, ground movement)

These defects may be influenced by factors such as:

- Stray currents from electrical installations
- Backfill type and placement methods
- Ground movement
- Adjacent works/services
- Grit and debris in the wastewater

Most of the defects likely to exist in the rising main will not extend through the full thickness of the pipe wall and are not currently causing leaks. However, it is possible that some small leaks may exist, that have not yet come to the surface and become apparent.

Over time more faults will extend the full way through the pipe wall and cause leaks. The frequency of the leaking will increase. It is difficult however to locate faults prior to them leaking.

4 CONSEQUENCE OF RISING MAIN FAILURE

As rising mains, by their very nature, are under pressure, the consequence of failure can be much greater than with a gravity pipe.

Leaks often occur in gravity sewers, either at joints or at defects, which are undetected. The sewage leaks out of the pipe into the surrounding ground and never reaches the surface. Typically, infiltration, due to ground water entering into a gravity sewer, is more of a concern than sewage leaking out of the pipe, because of wet weather overflows that may occur as a consequence.

By contrast, the sewage from a small leak in a rising main, will often be forced to the surface due to the pressure in the main. It then becomes very apparent to the public. The jetting action, as the sewage escapes out of a small hole in the rising main, can damage the main further. A small hole can quickly develop into a major break in the main. The jetting action of the pressurized sewage can erode the surrounding soil, causing damage, settlement and undermining of the ground and surrounding utilities and infrastructure.

As an indication of how severe the consequences of a rising main failure can be, "Inspection Guidelines for Ferrous Force Mains" quotes an example of a rising main failure in March 2006 where 48 million gallons of sewage was discharged over a 4 day period into the Ala Wai canal. The sewage flowed along the canal into the ocean and polluted Waikiki's beaches and many of these had to be closed. A man who fell, or was pushed, into the Ala Wai harbour subsequently died and there are indications that bacteria found in samples could be implicated.

Cases of rising main failure to this extreme are not known to have occurred in New Zealand, but there is still the potential for them to happen.

4.1 EXAMPLES OF THE CONSEQUENCE OF RISING MAIN FAILURE

The consequence of a rising main failure may result in:

- Direct costs:
  - Repair of the rising main
  - Repair of damage due to sewage contamination, undermining of structures, utilities and infrastructure and damage from flooding from the leak.
- Health & Environmental costs:
  - Clean up of the sewage overflow at rising main failure site and/or at the pump station
  - Restoration of watercourses affected by sewage overflows
  - Affects to the health of persons who come into contact with the sewage overflow
  - Safety issues as a result of undermining and damage to structures, utilities and infrastructure and also during repair of the rising main and subsequent clean up.
- Socio-economic costs
  - Disruption to public and traffic
  - Fines from Regulatory Authorities
  - Negative publicity

The negative publicity from a rising main failure may often have the most long lasting, and greatest, negative impact on the utility company responsible for the rising main, outweighing the direct costs of the repair and clean up from the rising main break.

The extent of the consequences of a rising main failure will depend on the location of the rising main, the surrounding area and location of the overflow point at the pump station. The contingency measures developed by the utility company for responding to rising main failure, play a large part in mitigating these consequences.

5 CONDITION ASSESSMENT OF RISING MAINS

In a rising main, condition assessment should ideally identify and quantify defects in the pipe wall, before they extend through the wall and cause a leak. As outlined in Section 3, these defects can be caused by a variety of factors and may occur at isolated sections along the pipe. The condition of the pipe can vary significantly from one location to the next.

5.1 COMPARISON BETWEEN CONDITION ASSESSMENT OF GRAVITY MAINS AND RISING MAINS

Gravity mains will often contain significant defects without problems occurring. It is not uncommon to see CCTV inspections of gravity sewers containing large breaks with sections of pipe missing, but sewage still flowing. Contrast this with a rising main, where a very small hole can cause significant problems.

In a gravity sewer the inside wall of the pipe can be seen by CCTV inspection. In a raising main, the pipe wall may be covered by an internal coating.

In a gravity sewer, in most cases, with the exception of asbestos cement pipes, pipes will deteriorate from the inside out, e.g. deterioration due to hydrogen sulphide attack. Deterioration from the outside of the pipe wall is less of a concern. This contrasts with rising mains, which can be subjected to both internal and external corrosion.

In a gravity system there is generally good access into the pipe at manholes and pipes are typically straight. In contrast, in a rising main, there may be very limited or even no access into the pipe. Rising mains often contain bends that may be difficult for testing and inspection equipment to navigate through.

5.2 INSPECTION TECHNIQUES FOR RISING MAINS

There are a number of non-destructive testing methods available for directly measuring the structural integrity of rising mains. Refer Appendix A. Reviews of these techniques undertaken during the condition assessment of North Shore City Council's rising mains concluded that these techniques are of limited value, in that:

- Tests typically only provided a snapshot at a location in the rising main. There was no guarantee that the results can be accurately extrapolated to the rest of the main.
- Some of the tests required the pipe coatings to be removed. There is a risk that the removal of the coating may cause deterioration at that point.
- The testing is very expensive. The added value offered by the testing is doubtful.

These findings echo those from the WERF report "Inspection Guidelines for Ferrous Force Mains".

Of more benefit, are techniques that measure the integrity of the external and internal coatings or identify areas where corrosion is likely, e.g. through the measurement of soil resistivity or by locating air pockets within the pipe.

For ferrous pipes, cathodic protection can be installed to reduce external corrosion. This is often a cost effective measure to extend the life of rising mains. The testing required to design the cathodic protection will provide information on the integrity of the external coating, the extent of existing corrosion and the likelihood of further leaks occurring.

5.3 CONDITION ASSESSMENT RECOMMENDED FOR NORTH SHORE CITY COUNCIL'S PUMP STATION 5 EASTERN RISING MAIN.

For North Shore City Council's eastern Pump Station 5 Rising Main, the tests outlined in Table 2 were recommended to assess the condition of the pipe and design cathodic protection.

Investigation Actions	Comment
Inspect condition at areas identified from CCTV.	• Confirm if adjacent mortar is intact. • Repair areas where mortar has been removed.
Physically inspect by man-entry areas of scouring identified from CCTV.	• Confirm depth of scouring/remaining mortar. Confirm if adjacent mortar is intact
Leakage monitoring using hydrophones	• Identify the location of existing leaks.
Soil Resistivity Tests	• Identify areas where external corrosion may be likely • Identify preferable locations and depths for anode beds and also to assist the overall determination of cathodic protection requirements.
Fault Location/Current Mapping	• Identify the location of electrical shorts to the existing pipeline. To be completed prior to current testing as any earth shorts will distort

	the results.
Temporary Anode Bed	• Identify current requirements and pipe to soil voltage requirements
Direct Current Voltage Gradient	• Identify defects in coating. • Measurements through tarseal and reinforced concrete slabs may be problematic, but possible. To be investigated further.

Table 2 – Condition Assessment Recommended for North Shore City Council's Pump Station 5 Eastern Rising Main

5.4 BREAK HISTORY AS AN INDICATOR OF CONDITION

The above investigations, at best, provide only a snap shot at isolated locations or an indication of where there may be problems. As potential faults in rising mains are often very small and in discrete locations, it is possible that faults can be overlooked. Thus break history is considered to be the most accurate predictor of remaining operational life. The question is how to deal with rising mains where breaks and leaks cannot be tolerated.

A "fix it if it breaks" approach is in line with the approach often adopted for potable water reticulation pipes, where utility companies replace those mains that have failed, say three times previously.

6 RISK ASSESSMENT

Faults in rising mains can be very difficult and expensive to identify. Thus, it needs to be accepted that there will be cases where rising mains fail.

Therefore it is recommended that a risk based approach be adopted for the management of rising mains. This involves:

1. Assess the consequence of failure
    - Consider the direct, health & environmental and socio-economic costs outlined in Section 4.1
    - Contributing factors may include: size of main, flowrate, surrounding area & infrastructure, available storage, receiving environment at pumpstation overflow points.
2. Assess the likelihood of failure
    - In the first instance, this is likely to be a "best guess", undertaken considering factors such as age of pipe, pipe material, break history, possibility of ground movement, damage from installation of adjacent utilities.
3. Determine the risk of failure
    - Being the multiplication of the consequence and likelihood factors.
4. Identify possible mitigation measures, including:
    - Contingency measures should a failure occur, including: repair of main, storage/control of flows, clean up procedures and communication/notification processes.
    - Detailed condition assessment and monitoring
    - Repair/renewal of rising mains
    - Installation of cathodic protection.

5. Prioritise mitigation measures based on risk and cost, so as to develop a plan that reduces the risk by the greatest amount given the resources available.

6.1 DISCUSSION OF RISK ASSESSMENT UNDERTAKEN ON NORTH SHORE CITY COUNCIL'S RISING MAINS

The risk assessment process outlined above was undertaken on each of North Shore City Council's rising mains during 2009/2010.

The rising assessment considered:

- Financial
- Public Health & Safety
- Adverse Publicity
- Operational
- Natural Environment

Likelihood was estimated very approximately, considering break history, pipe pressure, age and pipe material.

Adverse negative publicity had the largest effect on the risk scores. The highest risk scores were allocated where negative publicity could occur because of large sewage overflows or failures under buildings, particularly where repeat failures were possible.

Mitigation measures were identified using the process outlined in Figure 2.

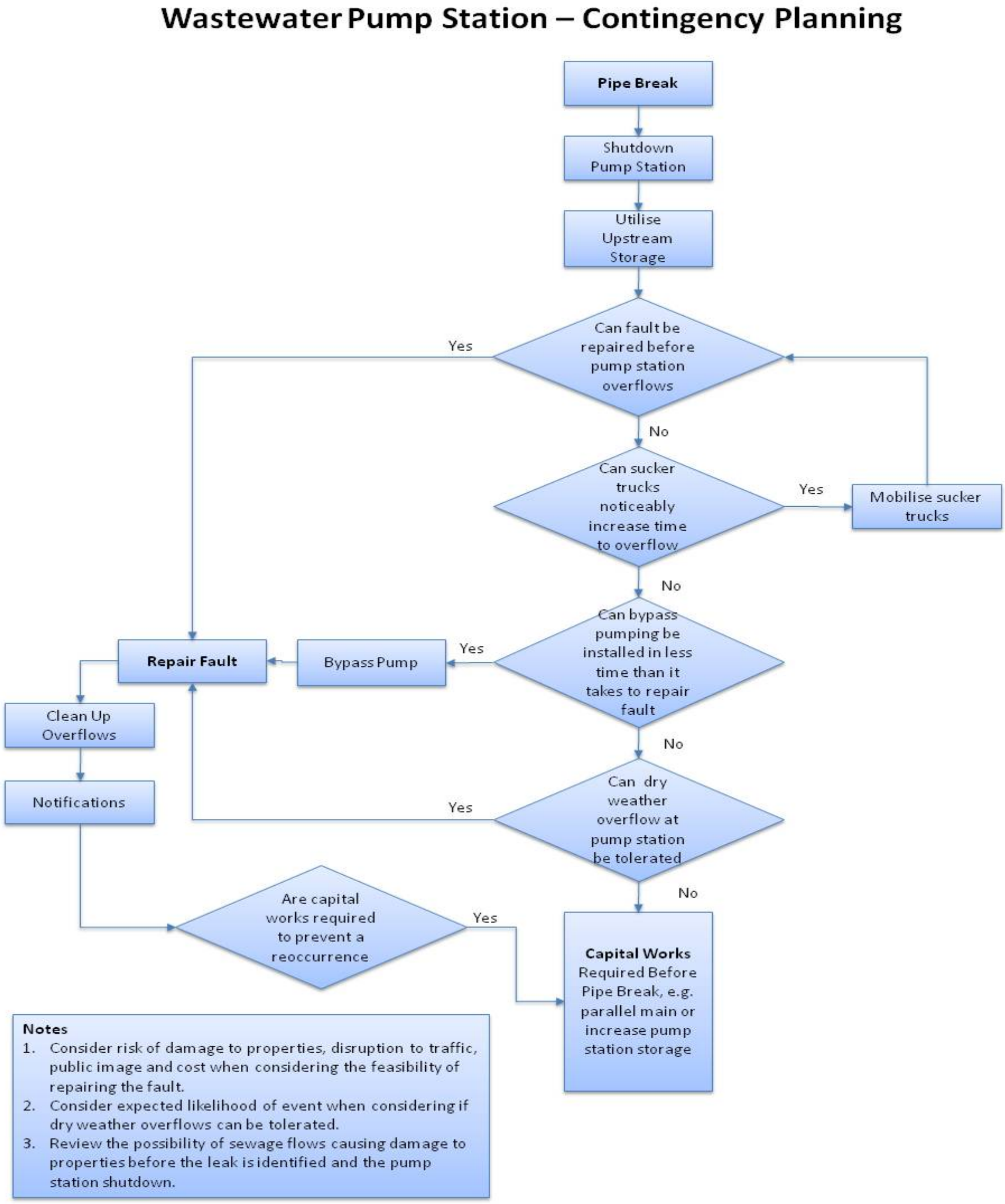

Figure 2 – Process for Developing Mitigation Measures

Generic mitigation measures are outlined in Table 3.

Situation	Generic Mitigation Measure
There are known faults/issues that could lead to the pipe being damaged.	• Repair fault/issue
Should there be a leak or damage to the rising main, significant damage is likely to occur before the main can be shutdown.	• Undertake condition assessment • Capital works to reduce possible damage
The rising main can be shut down and likely problems with the rising mains can be repaired before the pump station overflows	• Develop contingency plan for repairing rising main.
The pump station will overflow before likely problems in the rising mains can be repaired	• Capital works to either reduce the likelihood of a problem occurring or to extend the time that the pump station can be shutdown. • Develop contingency plan for repairing main and cleaning up any overflow.

Table 3 – Generic Risk Mitigation Measures

The following preliminary works and further investigations were recommended, as a result of the risk assessment undertaken of each of the rising mains in the North Shore City Council network.

1. Works to be undertaken as soon as practical

    - Develop contingency plans for repairing and cleaning up, should leaks occur in rising mains – the majority of rising mains should be able to be repaired without overflows occurring at pumpstations, if sucker trucks are mobilized.
    - Address the known issues at three rising mains (e.g. remove obstructions, investigate possible leaks).
    - Consider renewal of three rising mains. Two of these rising mains had a history of problems and were located in developed areas, under buildings. The other rising main was located close to a large electrical substation. It was recommended that the section close to the substation be replaced in PE pipe, to isolate the rest of the main from stray electrical currents from the substation.

2. Second Priority Recommendations

    - Develop a condition assessment investigation programme, for other mains where leaks may cause damage to properties or the environment before the pumpstation can be shutdown. Consider installing cathodic protection on those mains that are concrete lined steel.
    - Investigate measures to improve storage at, or upstream of two pumpstations, as there is very limited existing storage at these pumpstation.

3. Third Priority Recommendations

    - Implement any improvement identified from the condition assessment investigations undertaken in Item 2.
    - Realign two sections of rising main that are currently located under buildings.

7 REHABILITATION/RENEWAL OPTIONS FOR RISING MAINS

There are a number of repair, rehabilitation and renewal options available for wastewater rising mains. These include:

- Corrosion reduction measures, such as internal coatings or installation of cathodic protection.
- Repair of sections of rising main.
- Rehabilitation to prevent leakage
- Fully structural rehabilitation to withstand all internal and external loadings
- Upsizing of the rising main, e.g. by pipe bursting
- Replacement of the rising main on the same or a different position.

7.1 COMPARISON BETWEEN REHABILITATION OF GRAVITY MAINS AND RISING MAINS

Rehabilitation of gravity wastewater mains, by trenchless techniques such as CIPP or spiral wound lining, is now an accepted practice. In most cases rehabilitation will be cheaper than replacement.

Rehabilitation of rising mains is not as common. However in some industries, such as the gas industry, rehabilitation for pressure pipes is more widespread.

There are a number of factors that favour rehabilitation of rising mains and others that make rehabilitation of rising mains more difficult than gravity mains. These issues are discussed below.

7.1.1 FACTORS FAVOURING REHABILITATION OF RISING MAINS

Reduction in cross-sectional area can be a concern, when rehabilitating gravity pipes. This is far less of an issue with rising mains, as the reduction of the cross-sectional area can be offset by increasing the operating pressure of the pipe. Hence sliplining of gravity pipes is rarely used these days, but is a common practice for rehabilitation of pressure pipes.

Dips in gravity pipes may be a reason for deciding to relay a gravity pipe, rather than to rehabilitate the pipe. Dips are not so much of an issue in rising mains.

7.1.2 ISSUES AGAINST REHABILITATION OF RISING MAINS

Gravity sewers normally have lateral pipes connecting onto them, e.g. from private connections. Relaying a gravity pipe on a different alignment can be difficult due to topography and the fact that all lateral connects also need to be realigned. Rising mains on the other hand are not affected by topography and connections and hence rising mains are often easier to relay than gravity pipes.

Rising mains are subjected to internal pressure, hence the liner must be able to withstand tension forces. Standard CIPP lining and spiral wound lining, used for gravity pipes, are not able to withstand significant tension forces. In the case of CIPP this can be overcome by using a reinforced liner, but this is more expensive.

In small diameter gravity pipes, it is normally assumed that the host pipe will not carry any of the loads and the liner is designed to be fully structural. There is very little cost saving in designing for a liner that utilizes some of the strength of the existing host pipe. This contrasts with rising mains where there can be significant differences in costs between a leak sealing liner, a liner that relies on the host pipe for a significant portion of its strength and a fully structural liner.

Taking the main out of service for rehabilitation can also be an issue in rising mains. In gravity mains, during dry weather, the flow will be significantly less than the total flow capacity of the pipe. Thus, only limited bypass pumping may be required. In rising mains, the full flow needs to be bypass pumped. In gravity mains there will normally be manholes at regular spacings that can be used for bypass pumping. On the other hand, rising mains are often several hundred metres long. If they are divided into smaller sections for rehabilitation, access points may need to be installed for bypass pumping.

Rising mains may contain bends, whilst gravity mains are normally straight. Common rehabilitation techniques for pressure pipes, such as sliplining, will require these bends to be exposed.

7.2 REHABILITATION OPTIONS CONSIDERED FOR NORTH SHORE CITY COUNCIL'S PUMP STATION 5 EASTERN RISING MAIN.

The following options were considered for the rehabilitation of North Shore City Council's Pump Station 5 eastern rising main. This is a 840mm diameter, 1.1km long rising main.

- Sliplining with PE
- Sliplining with GRP
- Slip Lining With Modified PE, i.e. drawn through a die or deformed so that its diameter is less than the existing pipe and expanded when in place.
- CIPP Lining

The advantages and disadvantages of these options are described in Appendix B.

Ultimately, it was recommended that this particular pipe be replaced on a different alignment by opencut excavation, rather than be rehabilitated. This was primarily because of the advantages of being able to move the rising main away from under buildings.

8 CONCLUSIONS

Rising mains are an essential component of the wastewater network. However, they often have no redundancy, with each pumping station being served by only one rising main. Problems with rising mains have the potential to cause pollution, damage property and adjacent services, resulting in significant costs.

Rising mains are very difficult to inspect, as they are under pressure and frequently cannot be taken out of service. Faults that cause problems may be very small and are often not identified from the inspections that are carried out.

Techniques for rehabilitation of pressure pipes are available, but are not as well established and not as proven as those used for the rehabilitation of gravity pipes.

A risk based approach to the management of rising mains is recommended, where the likelihood and consequence of failure is determined. Inspections and rehabilitation/replacement is concentrated on those areas that result in the greatest reduction in risk.

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Jason Consultants Ltd (2007) 'Inspection Guidelines for Ferrous Force Mains', commissioned by Water Environment Research Foundation

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APPENDICES

Appendix A - Non-destructive Testing Methods Available for Directly Measuring the Structural Integrity of Rising Mains

Appendix B - Rehabilitation Options Considered for North Shore City Council's Pump Station 5 Eastern Rising Main

Appendix A - Non-destructive Testing Methods Available for Directly Measuring the Structural Integrity of Rising Mains

Structural Integrity Investigation Techniques

technologies and tools used in investigating steel pipes so that we can ultimately prevent leakage.

Technique	Purpose	Description	Advantages	Disadvantages
Coating Defect Survey (DCVG)	Remaining efffective coating can be determined as a percentage of pipeline surface. Specific locations of coating loss can be found on pipe.	The method called Pipe current Mapping is used. It involves impressing current onto a pipe.	Pipe is impressed from the surface above the pipe.	finding actual fault locations may be restricting as they require unpaved surfaces above pipeline.
Linear Poralisation Resistance (LPR) soil testing	Determines overall condition of the pipe by estimating the pitting rate over the length of the pipe.	Analysis on sampled soil of close proximity to the pipe gives an estimated pitting rate of the pipe.	Cost effective and non-invasive because pipe exhumation is not necessary.	
PipeFail & Envirostat	Estimates the most likely time to failure of a pipeline.	With the use of these two algorithm tools, data is extrapolated over the entire length to get the outputs of failure in terms of annual probability	Proven to be very accurate. Wall thickness is not a limiting factor. Outputs can be applied directly to asset management models	
Ultrasonic - handheld instrument	Material thickness can be found by measuring time taken for a reflected wave to come back. Direct thickness reading can be compared to original wall thickness to see how much has corroded.	Instrument applied at an external point on pipe. Waves sent through pipe wall and time taken for reflected waved to come back can be correlated to material thickness	One of the best-established methods for simple external testing of points.	Needs bare metal surface, cant have coatings on it. Full surface contact is not always assured and may be difficult to verify in complex survey conditions. Large number of poiints required to produce a thorough corrosion evaluation
Ultrasonic- Teletest	Same methodology as above except ultrasound is sent along pipe rather than just at points of application.	Tranducer tool is mounted externally on 0.5m of pipe. Waves sent along pipe which detect echoes from corroded regions of the pipe. Corroded regions reduce the intensity of the ultrasound travelling beyond it	Provides 100% direct assessment for pipe lengths of typically 30m in either direction from the test position. In ideal conditions a total of 350m of pipeline can be inspected from a single test point. Hence costs are less.	Some limited success has been achieved in testing pipe passing through concrete walls and pipe encased in lightweight fireproofing cement. Need not remove/reinstate coating except for the area where the tool is mounted.
Ultrasonic- Pig	Material thickness can be found by measuring time taken for a reflected wave to come back. Direct thickness reading can be compared to original wall thickness to see how much has corroded.	Pig is sent along pipe and uses ultrasound to detect wall thickness. An echo is received from the internal and external pip surfaces.	Discriminates between internal and external defects. Detects cracking. No limitations of wall thicknses.	Ultrasonic is significant more expensive than MFL for in-line investigations.

Pit Depth Measurements	Manual techniques in obtaining rate of corrosion by measuring pit depth and pipe age.	Many methods ranging from mechanical caliperse to depth gauges to ultrasonic and electromagnetic techniques. Section of pipe is exposed in excavation and a selection of whatever pits are observed and measured.	Widely available tools, portable and simple to use. An established technique in evaluating the remaining structural life.	Difficult to find true age of pipeline. Pit dept sampling is very random and variable, hence can be misleading and represent worst case sceneario. Internal pitting difficult to identify and measure.
Destructive Testing	Retain, inspect and test coupons on pipe wall in a laboratory. To examine metal structure, fracture surfaces and corrosion pits	Drilling techniques used to obtain coupons and then mechanical tests and metallurgical tests performed.	Gives a local indication of condition and in particular any graphitic corrosion. Good for building a data base of pipe failtures and their symptoms.	Very small sample of the pipe in relation to overall length. substantial costs in exposing the pipe and subsqeuent reinstatement of pipe and excavation.
Electromagnetic Methods -Magnetic Flux Leakage (MFL)	Finds changes in pipe thickness and detect characterize the flaws.	Pig with magnet is used to pass flux through pipe. Areas of lesser pipe thickness have high flux leakage hence can be detected and characterised easily.	Several types of anomaly due to corrosion can be detected. Recommended: 1-2 sites per km to be scanned.	MFL tools cannot detect all metal loss. Coatings thicker than 6mm prevent accurate data collection. Does not require removal of coating.
Electromagnetic Methods -Broadband Electromagnetic (BEM) - PIG	Identifies loss of metal, graphitization and fractures.	Involves the application of MFL and eddy current systems. The technique works by inducing eddy currents to flow in close proximity to a transmitter. The eddy currents migrate with time allowing a complete profile of the pipe to be obtained.	Adapted to both external and internal investigation. Can scan easily through coatings, linings and insulation. Frequency at which it operates can be easily modified to suit situation. Unaffected by background electromagnetic noise eg cables. Data can be processed in real time and displayed as a contour plot.	When scanning internally, the process is not continuous and so it is time consuming. Scanning can be done on small sections or on the bigger section. Scanning is very expensive, $80,000 for 10 locations.
Radioactive Technologies	Shows changes in thickness and density which are associated with		A non destructive test method	Has considerable health and safety issues. Expensive. Requires specialist

NOTE: visual inspection is a recognized technique but not applicable for this pipe as it is all underground. CCTV is also available for internal inspection of faults.

Appendix B - Rehabilitation Options Considered for North Shore City Council's Pump Station 5 Eastern Rising Main

OPTION	REHABILITATION			
	SLIP LINING WITH PE	**SLIP LINING WITH GRP**	**SLIP LINING WITH MODIFIED PE**	**CIPP LINING**
DESCRIPTION	Pull a new PE pipe inside existing pipe.	Push new GRP pipes inside existing pipe. Grout annulus.	PE pipe will modified (drawn through a die or deformed) so that its diameter is less than the existing pipe. It will be pulled into place and the pipe reverted back to its original size so it forms a tight fit against the existing pipe.	Line pipe with glass reinforced epoxy CIPP. Provides fully structural solution, no support from host pipe required
ADVANTAGES	• Quick to implement • Works could be staged, lining most critical now and less critical in future years. • No joints (all welded)	• Less reduction in cross-sectional area than sliplining with PE • Smaller launch pits.	• Quick to implement • Works could be staged, lining most critical now and less critical in future years. • Less reduction in cross-sectional area than sliplining with PE • No joints (all welded)	• Quick to implement • Works could be staged, lining most critical now and less critical in future years. • Minimal loss of internal diameter.
DISADVANTAGES	• More disruption than CIPP due to additional dig ups and pipe layout areas. • Excavations required at bends. • Loss of internal diameter.	• Joints between joint sections.	• More disruption than CIPP due to additional dig ups and pipe layout areas. • Excavations required at bends.	• New technology, not a lot of pressure pipe lining has been completed worldwide. • Large diameter pipe for this sort of lining. • 4-5 couplers required to be installed. • Small wrinkles at bends likely. • Wrinkles at other locations unlikely with this type of liner material, but if they do occur will need to be repaired.
COSTS	Cheapest	Medium Cost	Medium Cost	Most expensive