P-CAT™ – PIPELINE CONDITION ASSESSMENT TECHNIQUE FOR WATER AND SEWER MAINS

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ABSTRACT

Recent advances for assessing the remaining life of ageing water and sewer pipelines are a key consideration when developing a maintenance plan for those systems. One common method currently employed is to replace pipelines after a certain number of ruptures have occurred. This method can result in the unnecessary replacement of up to 90% of a pipeline that is still within its economic service because only 10% is badly deteriorated.

P-CAT™ is a cost-effective technique for the condition assessment of pipelines over long distances with a spatial accuracy of up to 10 – 20 m. It is a non-invasive screening tool that can applied to a wide range of pipe materials and sizes. Testing can quickly be done with no excavation work and minimal disruption to services.

This pipeline condition assessment technique can provide a pipeline's sub-sectional condition (remaining wall thickness) and perform localised fault detection, including the identification of gas pockets, blockages, unknown off-takes and the sealing status of valves. This is done using a controlled hydraulic pressure event which is introduced to the system using an existing pipeline asset such as an air valve or scour valve. Using p-CAT™ within the early stages of a project can locate the key deteriorated sections to implement pin-point methods for subsequent investigation. With adequate pressure, transient condition assessment and analysis can be applied to sewer, raw and potable water, providing detailed results on difficult pipelines where other technologies cannot.

The following technical paper shows the procedure of applying the p-CAT™ transient analysis technique to both water and sewer rising mains. It details the testing, analysis and results of the conducted pipeline wall condition assessment and the accompanying localised pipeline fault detection. A summary of any suggested rehabilitation and maintenance based on the case studies' condition assessment results is also included.

KEYWORDS

Pipeline Condition Assessment Transient Analysis Water Sewer Mains

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1 INTRODUCTION

Recent advances for assessing the remaining life of ageing water and sewer pipelines are a key consideration when developing a future maintenance plan for those systems. One common method that is currently employed is to replace pipelines after a certain number of ruptures have occurred. This method can result in the unnecessary replacement of up to 90% of a pipeline that is still in good condition because only 10% has deteriorated beyond its economic service life.

A reliable and cost-effective method for pipeline condition assessment in the market today is p-CAT™. This transient analysis technology was developed by the University of Adelaide and Detection Services Pty Ltd to enable the non-invasive diagnosis of a pipeline's condition over a long distance. This technology uses existing pipeline assets, requires no excavation and causes minimal disruption to current services, allowing calculated decisions to be made regarding pipelines that require rehabilitation.

Transient analysis can provide a pipeline's sub-sectional condition (remaining wall thickness) and perform localised fault detection, including the identification of gas pockets, blockages, unknown off-takes and the sealing status of valves. This is done using a controlled hydraulic pressure event introduced to the system using an existing pipeline asset such as an air or scour valve. With adequate pressure, this condition assessment technique can be applied to sewer, raw and potable water, providing detailed analysis on difficult pipelines where other technologies cannot.

The following paper details the process of p-CAT™ testing and analysis on both water and sewer rising mains and the results of the analysis undertaken for each case study. The identified localised faults and condition of the pipeline are also summarised with the recommended course of rehabilitation.

2 TRANSIENT ANALYSIS (P-CAT™) METHODOLOGY

A controlled transient event (or small magnitude controlled water hammer event) is a pressure wave that occurs in a pipeline when the flow is changed rapidly. Circumstances resulting in this change include an abrupt valve opening or closure or sudden pump start or stop. The presence of pipe wall damage due to metallic corrosion, cement mortar lining loss or the leaching of the pipeline wall material has a visible impact on the resultant transient pressure wave trace as the wavefront passes the location of damage. This variation in the pressure wave reflects off the fault to travel along the pipeline and be measured at locations along the pipe with pressure transducers.

The pressure to flow relationship is the basis of the advanced mathematical techniques in the pipeline condition assessment technology, p-CAT™, which uses fluid transient pressure waves for detecting the size and location of these defects. Changes in the thickness of the pipe wall and lining give rise to reflections which can be theoretically interpreted to obtain an understanding of the damage along the pipeline.

Each test involves a controlled transient pressure wave signal being introduced into the pipe of interest using a hydraulic transient generator (see Figure 1). This change in pressure along the pipeline is recorded at two or more measurement points (see Figure 2), as the transient pressure wave passes down the pipe. The transient signal can travel long distances along a pipeline without major deterioration, typically 2 – 5 km, which is a major advantage of this technology.

Figure 1: Transient generation stations.

Figure 2: Transient measurement stations.

Data acquisition systems at the generation and measurement points collect the injected transient pressure wave signal and any reflections caused by pipeline characteristics, such as a pipeline fault or configuration change (see Figure 3).

Figure 3: Transient data acquisition system set up.

The collected data is then analysed and interpreted to provide insight into the pipe condition. Transient analysis uses two main techniques for interpreting the results from the transient pressure wave tests:

- Sub-Section Partitioned Wave Speed Analysis™ for assessment of the level of deterioration of the pipe wall in a sub-section, and
- Signal Analysis for localised fault detection and identification of significant anomalies such as faults, air pockets and blockages.

This process can identify the condition of sub-sections of the pipeline, changes in material properties over lengths of the pipeline, severe blockages, air pockets, unknown off-takes, major leaks and the sealing status of valves over relatively long distances of pipeline with up to a 10 – 20 m spatial accuracy.

3 APPLICATION TO WATER RISING MAINS

3.1 CASE STUDY 1

3.1.1 PIPELINE OF INTEREST

The section of pipeline in case study 1 was chosen for p-CAT™ application as part of a trial to compare and contrast multiple different condition assessment technologies. It was located rurally with adequate access to the pipeline due to it being almost entirely above ground.

This section of the pipeline was constructed in 1943 and 1944 from 30-inch MSCL with a wall thickness of 3/16-inch. The original scope of work was a 1.5 km stretch of pipeline south of a stop valve, however Detection Services was able to collect sufficient data for the analysis of 2.8 km of pipeline within the allocated time frame, covering the original scope of work plus an additional 1.3 km of pipeline extending north from the stop valve of interest. Air valves were used as connection points for the testing equipment.

3.1.2 TESTING AND ANALYSIS UNDERTAKEN

The tests were conducted on the 16th February 2017. The field tests were undertaken on the pipeline for the purpose of assessing the pipeline condition and identifying known features and anomalies such as blockages, air pockets and wall thickness deterioration.

As a result, the analysis undertaken to determine the pipeline wall condition was based on the following assumptions in accordance with the as-constructed drawings and AS 1281-1993, as well as the relevant tolerance specified in ISO559-1991:

- Outside diameter of 762 mm.
- Metallic wall thickness of 4.8 mm (with 20% manufacturing tolerance).
- Cement mortar lining of 12 mm.

3.1.3 RESULTS

The following pipeline wall condition was identified during the p-CAT™ analysis:

- 2% of the pipeline was found to be in the most deteriorated condition with a remaining wall thickness of between 50% and 64%.
- 68% of the pipeline showed to have some deterioration with a remaining wall thickness of between 70% and 84%.
- The rest of the pipeline (29% of the total length) has remaining wall thicknesses of between 85% and 90%.

See Figure 4 for a visual summary of the pipeline wall condition transient analysis results.

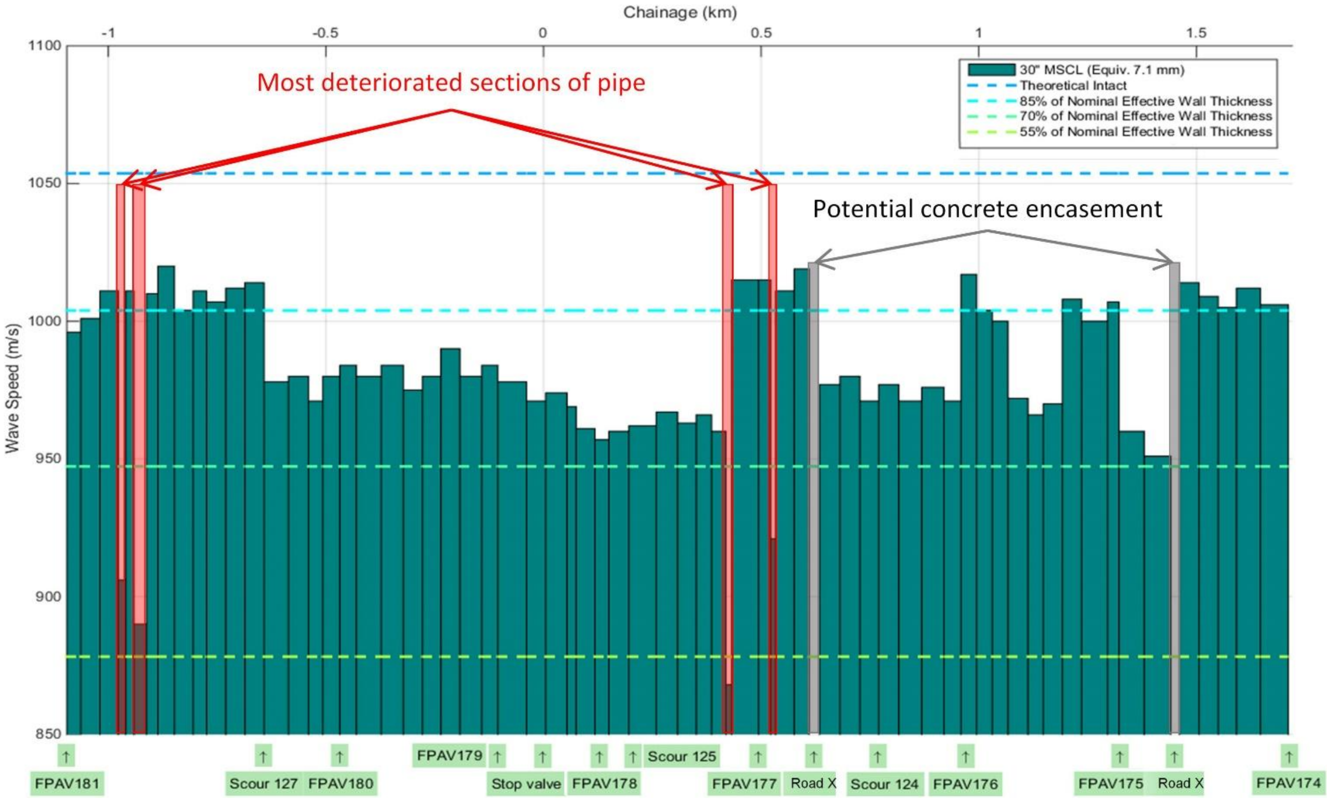

Figure 4: Internal pipeline wall deterioration for Case Study.

The following known features and anomalies were also identified during the signal analysis:

- Five medium priority anomalies representing:
  - Three sections of potential deterioration,
  - One location with a potential air pocket, or deterioration,
  - One location with a potential presence of blockage.
- Four low priority anomalies representing known pipe features including:
  - Two sections of replacement pipeline,
  - Two sections with a potential presence of concrete encasement under road crossings.

3.1.4 RECCOMENDATIONS

With regards to the tested section of the pipeline, it was recommended for Client 1 to conduct further investigations into the potential sections of deterioration as well as the possible presence of an air pocket and blockage.

Despite the standing pressure being lower than advised by the client prior to testing, the transient analysis provided the remaining wall thicknesses for 66 sub-sections of different deterioration conditions over the 2.8 km of pipeline. However, results of higher precision in terms of anomaly locations and details could have been achieved, if the pipeline pressure was increased. Detection Services welcomes the opportunity to conduct additional testing upon this pipeline with a greater standing pressure in order to obtain improved results.

3.2 CASE STUDY 2

3.2.1 PIPELINE OF INTEREST

The tests undertaken on this pipeline were conducted as part of a condition assessment project for a system in a busy CBD area. This particular section was one of two parallel pipelines following a busy main road into the city.

The 450 CI(CL) water main was constructed from 450 CI in 1886 and later concrete lined in-situ in 1982. The pipe section of interest was 2.8 km and contains two replacement sections of 450 MSCL. The pipeline section has seven off-takes which were required to be isolated for particular test set ups. Two in-line valves, one with two by-passes, were used to isolate the pipe section. Fire plugs and fire hydrants were used as connection points for testing equipment.

3.2.2 TESTING AND ANALYSIS UNDERTAKEN

Tests on the water main were conducted in the field on the 30th and 31st of May 2015 by Detection Services. The field tests were conducted on the water main with the purpose of assessing the pipeline condition and identifying anomalies such as blockages, air pockets and wall thickness deterioration.

Due to the age of the pipeline, the cast iron was expected to be thicker walled than current standards. As the original dimensions were unknown, current standards were used as guidelines. Assumed pipeline dimensions were obtained from AS1723-1975, AS 1724-1975 and ISO559-1991 as no explicit information about the specification of 1886 CI pipe was found. The pipe was assumed to be of a higher class (Class C) to account for a worst case scenario.

As a result, the analysis undertaken to determine the pipeline wall condition was based on the following assumptions in accordance with the provided information:

- CICL outside diameter of 507 mm.
- CICL metallic wall thickness of equivalent to 16.3 mm.
- CICL cement mortar lining of 13 mm.
- MSCL outside diameter of 457 mm.
- MSCL metallic wall thickness of equivalent to 4.0 mm.
- MSCL cement mortar lining of 12 mm.

3.2.3 RESULTS

The following pipeline wall condition was identified during the p-CAT™ analysis:

- 40% of the length of the pipeline was found to have the highest deterioration with remaining wall thickness of between 74% and 80%.
- 41% of the pipeline showed to have remaining wall thickness of between 80% and 90%.
- The rest of the pipeline (19% of the total length) has remaining wall thicknesses of between 90% and 98%.

The following known features and anomalies were also identified during the signal analysis:

- Three medium priority anomalies;
    - A non-sealing valve and two locations of a moving air pocket (See Figure 5).
- Six low priority known system components;
    - Four off-takes and two sections of MSCL replacements.

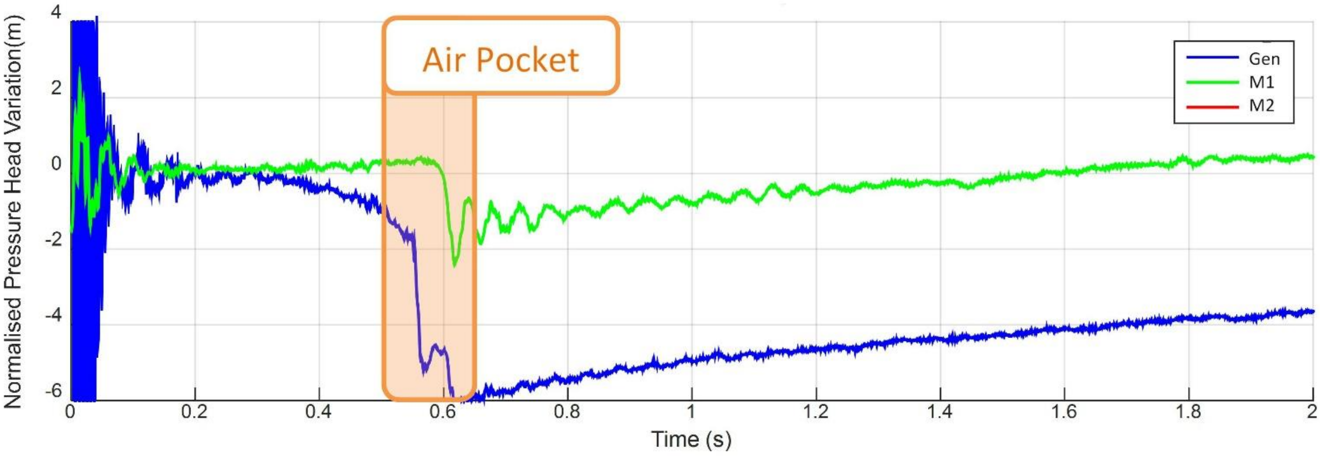

Figure 5: Air pocket at northern end of Case Study 2 pipeline.

In-line valves on the 450 CI(CL) water main and its associated off-takes were used to isolate sections during the testing of the pipeline. The sealing of the in-line valves and off-take valves associated with the off-line measurement points (stations located on the off-takes) were assessed during the analysis. The sealing of the other off-takes was not assessed.

Results from the transient analysis indicated that either the valve at the southern boundary of the pipeline section of interest (IV1), the associated bypass valve or both were not sealed during the first day of testing, although all valves were operated to isolate the tested section of the pipeline. Corroborating this result, anomalies corresponding to outside of the testing area were recorded during testing. The wave speed and the locations of pipeline features in this section of pipeline were not measured during testing as it was outside of the section of interest, however approximate locations matching some known features have been distinguished by assuming a similar wave speed to the adjacent section of pipeline (see Figure 6).

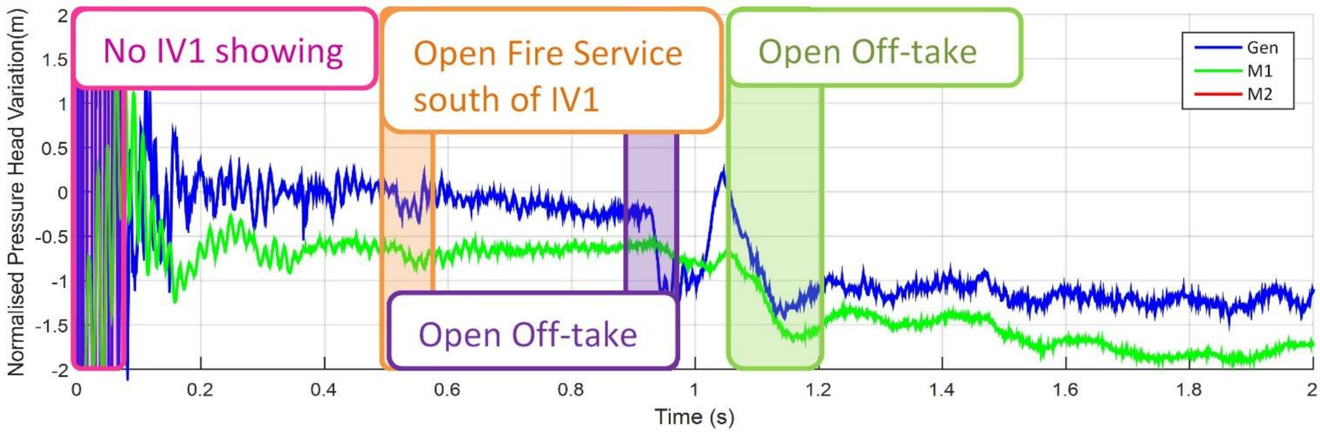

Figure 6: Example of anomaly identification for transient generated in Case Study 2.

3.2.4 RECCOMENDATIONS

With regards to the tested section of the pipeline, it was recommended for Client 2 to further investigate the presence of an air pocket and the sealing status of the southern inline valve.

3.3 CASE STUDY 3

3.3.1 PIPELINE OF INTEREST

The tests undertaken on this pipeline were conducted as part of condition assessment project for a rising main spanning from a dam pump station to a balancing storage.

The pipeline of interest is the first 10 km of the 23.5 km long rising main beginning at a dam pump station. The water rising main was constructed of MSCL, with a 1085 mm outside diameter. According to the as-constructed drawings, the section of interest was primarily composed of 8 mm wall thickness mild steel pipe, with 10 mm wall thickness near the pump station and for the above ground pipe crossings.

3.3.2 TESTING AND ANALYSIS UNDERTAKEN

The tests were conducted on the 31st January and 1st February 2017 by Detection Services. The field tests were conducted on the pipeline with the purpose of assessing the pipeline condition and identifying known features and anomalies such as blockages, air pockets and wall thickness deterioration.

The analysis undertaken to determine the pipeline wall condition using p-CAT™ was based on the following assumptions in accordance with the as-constructed drawings as well as the relevant tolerances specified in AS 1281-1993 and ISO559-1991:

- Outside diameter of 1085 mm.
- 10 mm mild steel wall with 20% tolerance near the dam pump station and over the above ground pipe crossings.
- 8 mm mild steel wall with 20% tolerance for the remaining section of interest.
- 16 mm cement mortar lining with additional 4 mm tolerance.

3.3.3 RESULTS

The following pipeline wall condition was identified during the p-CAT™ analysis:

- For the sections with an original wall thickness of 8 mm:
  - 1.7% of the length of the pipeline was found to have the highest deterioration with remaining wall thickness of between 67% and 80%.
  - 9% of the pipeline showed to have remaining wall thickness of between 80% and 90%.
  - The rest of the pipeline (83% of the total length) has remaining wall thicknesses of between 90% and 98%.
- Sections with an original wall thickness of 10 mm (5.3% of the pipeline length) had a remaining wall thickness of between 87% and 93%

The following known features and anomalies, and their resulting recommended actions were also identified during the signal analysis:

- Fourteen medium priority anomalies representing:
  - The presence of a blockage or partially closed isolation valve at an isolating valve pit at 12.11 km.
  - Four short lengths of deterioration or replacement of lower wave speed pipe material.
  - Four short lengths of deterioration, replacement of lower wave speed pipe material, or branch of a known pipe feature
  - Five potential concrete encasement sections or the presence of a blockage.

- Ten low priority anomalies representing known or potential pipeline features:
  - Non-return valve at the pump station,
  - Change in pipe wall thickness,
  - Presence of a consumer off-take branch,
  - Fish screens,
  - Four sections of above ground pipe crossings, and
  - Two sections of known concrete encasement.

See Figure 7 for a visual representation of the pipeline wall condition and anomalies.

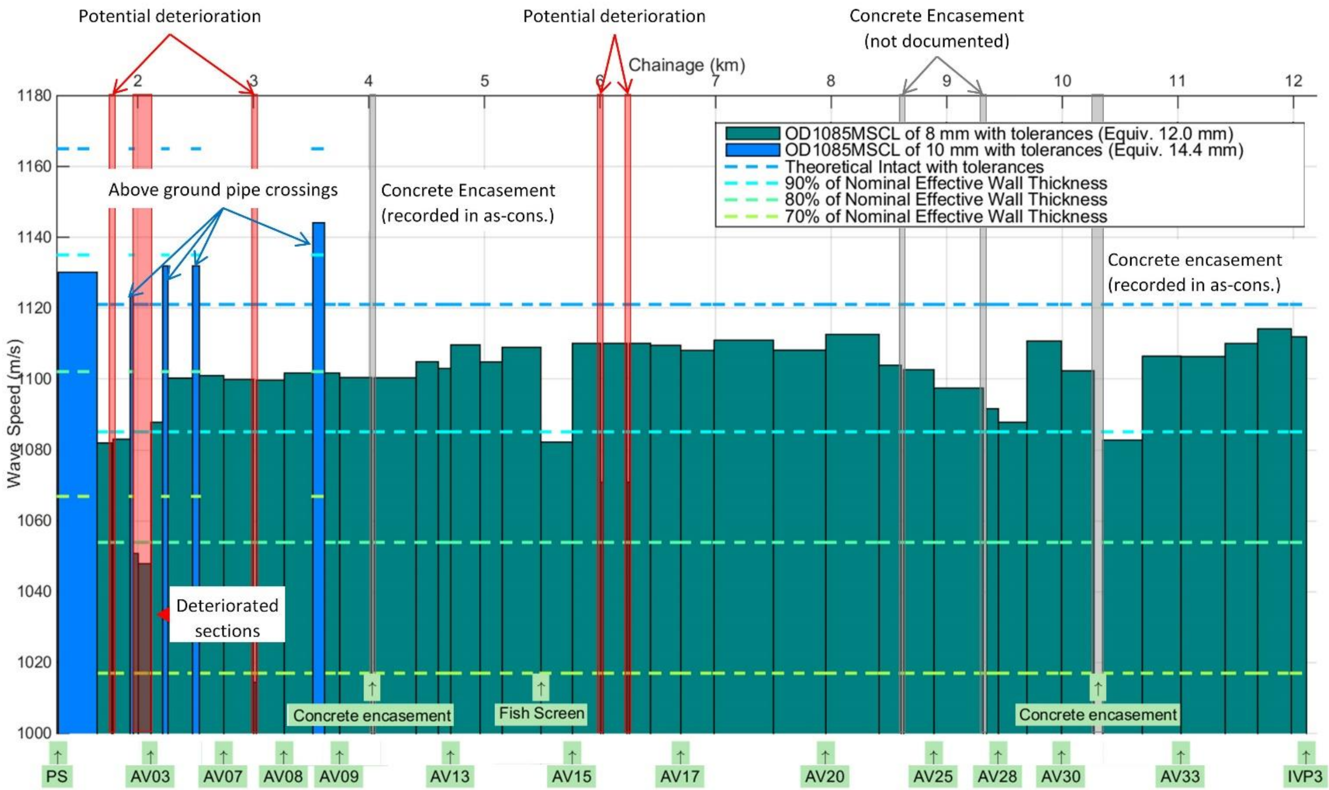

Figure 7: Internal pipeline wall deterioration for Case Study 3.

3.3.4 RECCOMENDATIONS

The results provided from this analysis will assist in the assessment of the current condition of the pipeline. This information can assist Client 3 to make accurate decisions in planning and budgeting for future maintenance programs. It was recommended for the client to further investigate the presence of replacement material sections before concluding that sections are deteriorated and to further examine the sealing status of the isolation valve.

3.4 CASE STUDY 4

3.4.1 PIPELINE OF INTEREST

Pipeline condition assessment was undertaken on a trunk water main for Client 4. The field tests were conducted on the water main with the purpose of assessing the pipeline condition and identifying anomalies such as blockages, air pockets and wall thickness deterioration. The pipeline analysed spans approximately 3 km of a busy multilane highway with a sectional elevation difference of up to approximately 40 m. The section from the northern end to a railway line was of particular interest. This included a section spanning a creek which has been noted to be leaking.

The trunk water main consists of the following various pipe materials and sizes, including some sections with in-situ cement lining:

- 450 and 525 Wrought Iron (WI) constructed in 1893
- with in-situ cement lining added in 1953.
- 600, 700 and 825 Mild Steel Cement Lined (MSCL) constructed in 1979.
- 450 Cast Iron (CI), 600 WI and 600 Mild Steel Locking Bar (MSLB) constructed in 1916 with in-situ cement lining added in 1983.

3.4.2 TESTING AND ANALYSIS UNDERTAKEN

Testing was conducted overnight on the 29th and 30th of April 2015 by Detection Services.

Assumed pipeline dimensions were obtained from ISO559-1991, ANSI B36.10-1979 and AS/NZS 2280-1999. Due to the age of the WI and 600 MSCL/MSLB the original wall thickness was not known, a wall thickness based on the standards was used as a guideline for the theoretical wave speed. The in-situ lining thickness was also unknown.

Due to the complicated and uncertain pipeline configuration at the end cap boundary, and the number of material changes within the section (see Figure 8), the first 257 m of the pipeline was not able to be accurately assessed using Sub-Section Partitioned Wave Speed Analysis™. A short section of 750 MSCL was also not assessed due to the inability to isolate an off-take near that section.

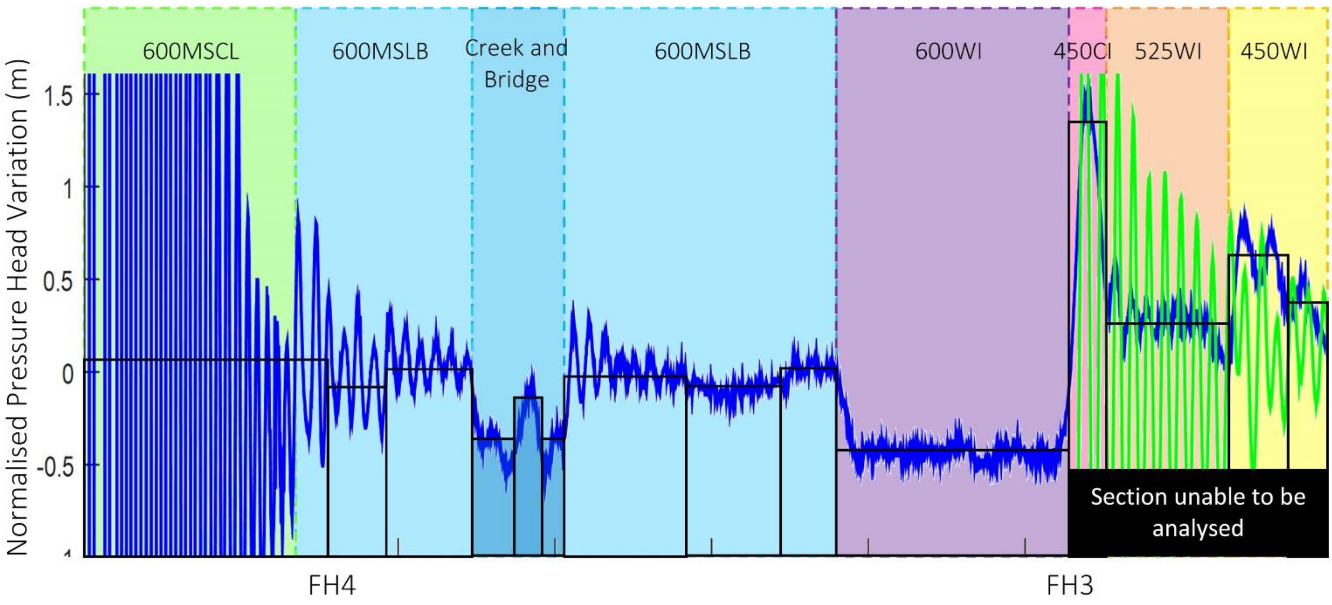

Figure 8: Pipeline configuration of the end cap boundary of Case Study 4.

3.4.3 RESULTS

The Sub-Section Partitioned Wave Speed Analysis™ results for the trunk water main are summarised below. These results are compared to the theoretical wave speed and the remaining effective wall thickness visually in Figure 9. The findings include:

- The 600 WI sub-section:
  - This pipeline section had a resulting effective remaining wall of 40.0%.
  - This deteriorated result may be due to there being a modulus of elasticity of the wrought iron which may be lower than that which was assumed.
- The 600 MSLB sub-section:
  - This pipeline section had an effective remaining wall thickness of between 36.5% (surrounding the creek) and 87.7%.
  - The 72 m section corresponding to the section spanning the creek and its surrounds represents the lowest remaining wall thickness (5.2 mm) and hence greatest potential deterioration.
  - A 92 m section of MSLB with effective wall thickness of 2 mm less than the surrounding pipeline was also found.
- The 600 MSCL has an average effective remaining wall thickness of 92.7%
  - This most likely represents a class change to Series E where the pipeline is of relatively good condition.
- The 825 MSCL was found to be in relatively good condition with the majority of the section indicative of an average effective wall thickness of 72.3%
  - This is equivalent to intact Class B (7.1 mm with intact 16 mm lining) or Class C/D with reduced lining cohesion.
  - A 260 m section of the 825 MSCL has reduced condition with effective remaining wall thickness of 63.4% which may be the result of an average of 1.2 mm of external corrosion or cement lining debonding.

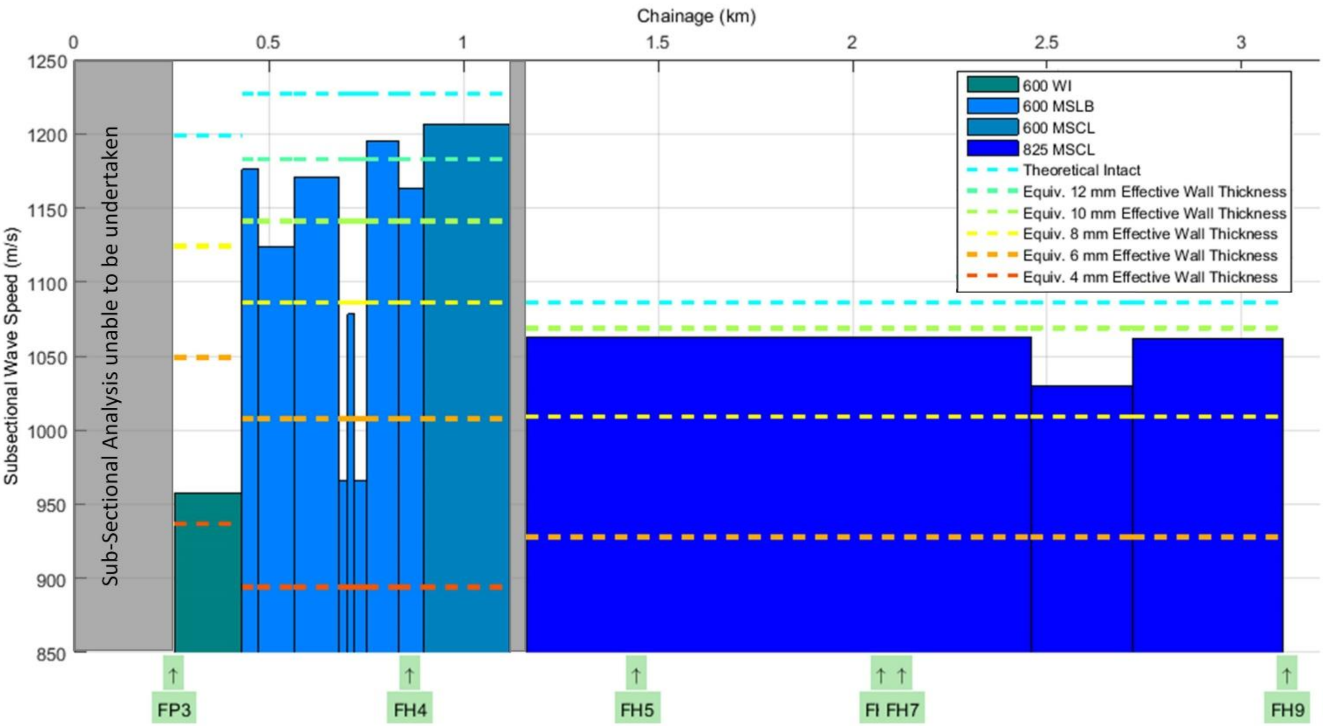

Figure 9: Internal pipeline wall deterioration for Case Study 4.

The following known features and anomalies, and their resulting recommended actions were also identified during the signal analysis:

- Five medium priority anomalies representing deteriorated sections of pipe or unrecorded material changes.
- Nine low priority anomalies representing known or potential pipeline features:
  - Three off-takes,
  - Five locations of material changes,
  - One in line valve.

3.4.4 RECCOMENDATIONS

With regards to the tested section of the pipeline, it was recommended for Client 4 to conduct further investigations into the potential sections of deterioration especially around the creek. Further information into the configuration of the pipeline would allow for the results to be expanded in the sections of pipe that were unable to be completely analysed.

4 APPLICATION TO SEWER RISING MAINS

4.1 SEWER MAIN CASE STUDY 5

4.1.1 PIPELINE OF INTEREST

The sewer rising main of interest was selected for condition assessment as it was one of the only two sewer mains within the area. Whilst the other sewer main was intended for replacement, significant costs could potentially be reduced if the condition of this pipeline could be determined.

The sewer rising main was approximately 1.2 km consisting of predominantly D.N.300 AC. The pipeline section of interest lies between a pump station and an inlet of a sewerage treatment plant.

4.1.2 TESTING AND ANALYSIS UNDERTAKEN

p-CAT™ testing was conducted by Detection Services for Client 5 for the condition assessment of the D.N.300 AC sewer rising main. The tests were conducted on the 22nd November 2016. The field tests were undertaken on the pipeline with the purpose of assessing the pipeline condition and identifying known features and anomalies such as blockages, air pockets and wall thickness deterioration.

The analysis undertaken to determine the pipeline wall condition was based on the following assumptions as per the standard AS 1711–1975:

- D.N.300 AC Class B pipeline.
- Outside diameter of 333.8 mm.
- Wall thickness of 17.3 mm.

4.1.3 RESULTS

Due to the numerous air pockets in the pipeline system only large subsections could be determined. The pipeline wall condition of the water rising main was identified using p-CAT™ analysis:

- Sub-section 1 (length 316 m) had 70% remaining wall thickness.
- Sub-section 2 (length 325 m) had 64% remaining wall thickness.
- Sub-section 3 (length 222 m) had 90% remaining wall thickness.
- Sub-section 4 (length 284 m) had 63% remaining wall thickness.

The calculated wave speeds were affected by the entrained air generated by the pump station and the presence of numerous permanent aeration zones, which absorb the energy of the generated transients as the signal propagates along the pipeline. Hence the determined wave speeds, and the thus wall thicknesses, represent the worst-case scenarios of the current pipe wall condition.

The following known features and anomalies, and their resulting recommended actions were also identified during the signal analysis:

- Six high priority anomalies representing permanent aeration zones of various lengths.
- One low priority anomaly representing the pipe transition from D.N.200 CI to D.N.300 AC near the first pump station.

See Figure 10 for a visual representation of the pipeline wall condition and anomalies.

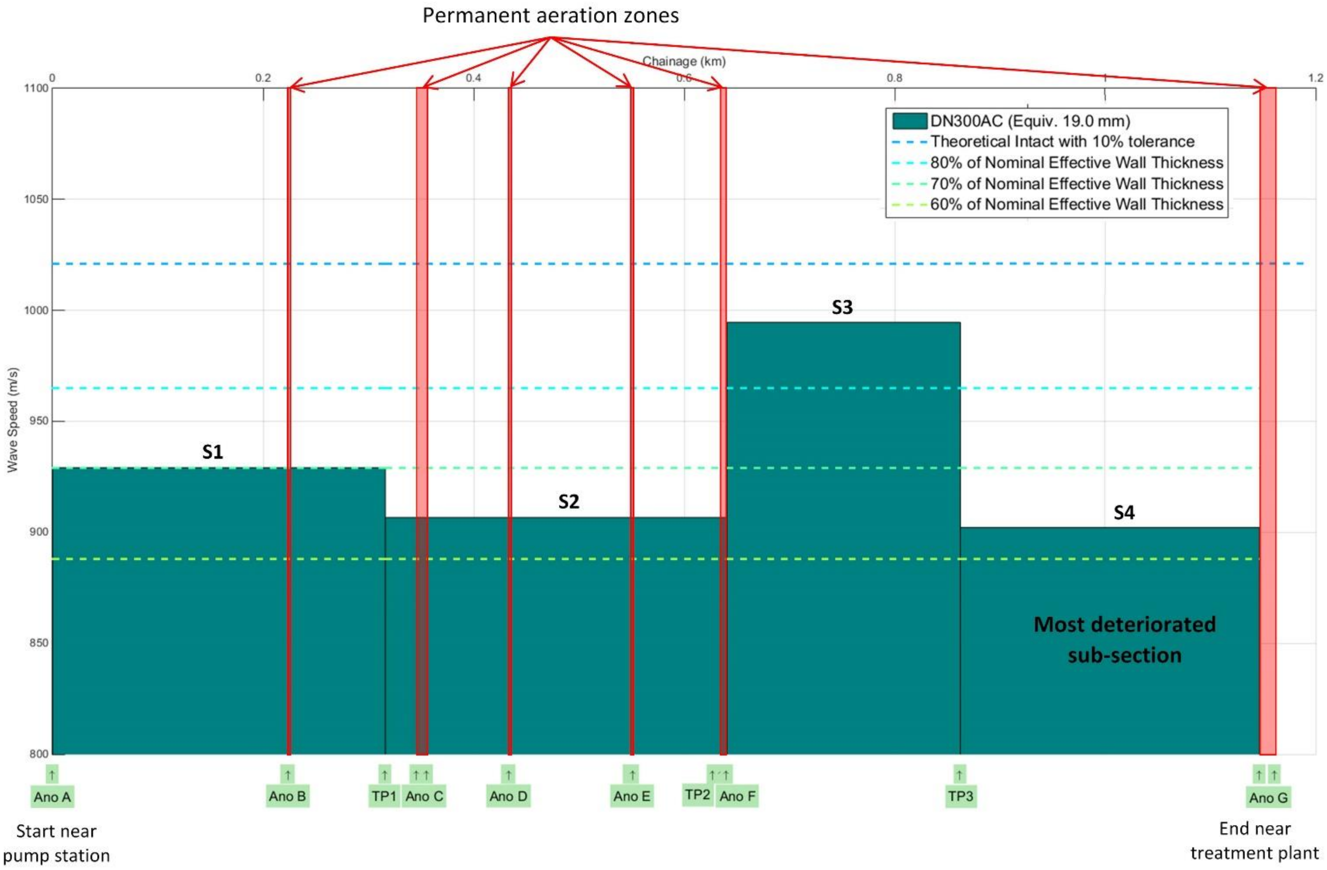

Figure 10: Pipeline wall deterioration for Case Study 5.

4.1.4 RECCOMENDATIONS

Due to the flat terrain where the pipeline was laid, air bubbles generated by the pump could easily accumulate into permanent aeration zones anywhere along the pipe length, particularly at the bends, and consequently accelerate internal corrosion. It was recommended for the client to change the pump size and/or speed such that the impacts of cavitation are minimised. Periodic vigorous flushing programs to remove potential gas pockets should also be considered.

4.2 CASE STUDY 6

4.2.1 PIPELINE OF INTEREST

This section of pipeline was selected as part of an ongoing project for the condition assessment of sewer and water assents for Client 6. The section of pipeline examined was constructed primarily of 410MSCL in 1976 and spans 1.25 km. The sewer pipeline starts at a pump station and ends at a scour valve which is located in a reserve.

4.2.2 TESTING AND ANALYSIS UNDERTAKEN

The tests were conducted on the 5th of November 2015 by Detection Services. The field tests were conducted on the pipeline with the purpose of assessing the pipeline condition and identifying known features and anomalies such as blockages, gas pockets and wall thickness deterioration.

As requested by Client 6, the analysis to determine the pipeline wall condition was undertaken for the following scenarios:

- O.D.419MSCL;
    - Outside diameter of 419 mm,
    - Metallic wall thickness of 6 mm,
    - Cement mortar lining of 12 mm (as per the As-built drawings provided).
- O.D.457MSCL;
    - Outside diameter of 457 mm,
    - Metallic wall thickness of 6 mm,
    - Cement mortar lining of 12 mm (as per per site measurement).

4.2.3 RESULTS

The following summarises the determined wall condition subjected to internal corrosion using the Sub-Section Partitioned Wave Speed Analysis™ as seen in Figure 8:

- Assuming O.D.419MSCL
    - Consistent condition, with the remaining equivalent wall thickness determined to be approximately from 92% to 97%.
- Assuming O.D.457MSCL Section:
    - Consistent condition, with the remaining equivalent wall thickness determined to be approximately from 99% to 106%, which is within the tolerance specified in ISO559:1991.

The following anomalies, and their resulting recommended actions were also identified during the signal analysis:

- Four low priority anomalies representing a check valve, two scour valves and a feature associated with the system.
- One high priority anomaly representing a significant gas pocket within the system located 134 m downstream from the scour valve located near the southern end (See Figure 11). It is recommended that the client take action to remove this gas pocket as it will be affecting system performance and there is an increased likelihood of localised internal deterioration at this point.

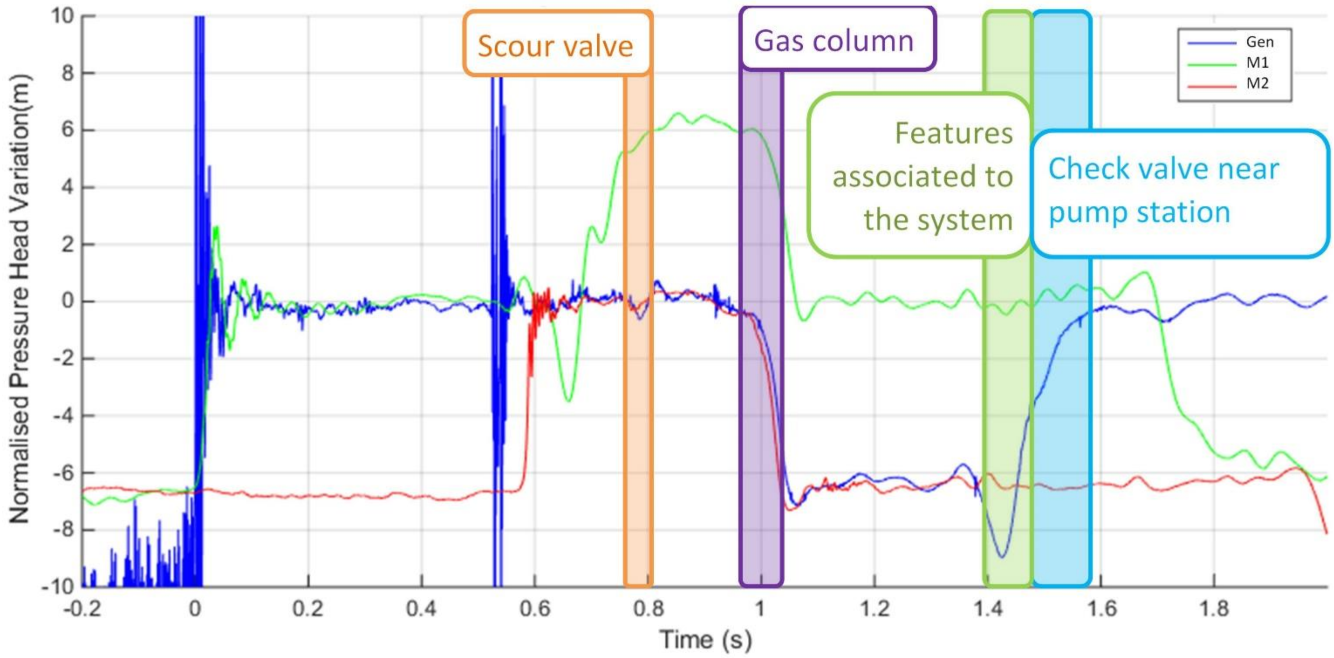

Figure 11: Pipeline wall deterioration for Case Study 6.

4.2.4 RECCOMENDATIONS

It was recommended for the client to take immediate action in regard to the existence of a significant gas column in the system. The gas pocket should be removed as it would be effecting system performance and represents a location at which localised deterioration is most likely to occur. Presence of an air valve shown on the as-built maps near this anomaly could not be confirmed in the field. Furthermore, it was also recommended for the client to update the GIS systems based on the features found during site inspections and in as-constructed drawings.

5 CONCLUSIONS

As the condition of sewer and water assets becomes increasingly more important to the management of ageing infrastructure a more effective and comprehensive method for damaged pipe identification and replacement will be required. A transient analysis technology such as p-CAT™ that can assess pipeline condition can assist in this future management without service interruption and in a non-invasive manner.

This transient analysis technology, consisting of sub-section partitioned wave speed analysis™ and signal analysis for localised fault detection, has been proven to provide the pipeline wall condition and localised faults within water and sewer rising mains, providing insight to the appropriate measures required for the management of the pipelines. In the case of pipelines such as the DN300 AC sewer rising main in Case Study 5, the transient analysis results provided can assist in the assessment of the current condition of the pipeline. The information obtained from condition assessment using transient analysis can assist asset managers for water and sewer systems in making accurate decisions in planning and budgeting for their future pipeline maintenance programs.

ACKNOWLEDGEMENTS

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REFERENCES

Standards Australia (1993), *'Cement mortar lining of steel pipes and fittings, AS 1281-1993'*, 3rd ed., Standards Association of Australia, Homebush, NSW, 7.

Standards Australia (1975), *'Asbestos cement pressure pipes, AS 1711–1975',* 2nd ed., Standards Association of Australia, North Sydney, NSW, 7.

Standards Australia (1975), *'Centrifugally Cast Grey Iron Pressure Pipes (Excluding pipes with bolted gland joints) AS 1723–1975',* 2nd ed., Standards Association of Australia, North Sydney, NSW, 13-22.

Standards Australia (1975), *'Cast Grey Iron Pressure Pipes and Fittings (with bolted gland joints) AS 1724–1975',* 1st ed., Standards Association of Australia, North Sydney, NSW, 13.

Standards Australia/Standards New Zealand (1999), *'Ductile Iron Pressure Pipes and Fittings, AS/NZS 2280–1999',* 5th ed., Standards Australia International Ltd, Sydney, NSW and Standards New Zealand, Wellington, 20-36.

American National Standards Institute (1979), *'Welded and Seamless Wrought Steel Pipe (ANSI B36.10-1979)',* American National Standards Institute, USA, 1073-1088.

International Organization for Standardization (1991), *'Steel tubes for water and sewage, ISO 559:1991',* 2nd ed., International Organization for Standardization, SUI, 5-11.