Condition assessment of metallic water mains by internal pipe inspection

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Abstract
Breivoll Inspection Technologies (BIT) has successfully developed and implemented a new in-pipe inspection method for the condition assessment of metallic water mains, mainly cast iron. The method is based on Acoustic Resonance Technology (ART). The inspection data (acoustic signals) are stored on a hard drive prior to undertaking the detailed analysis back at the office. The assessment results are subsequently reported to the water company. It should be relatively easy to incorporate the results into the standard water company corporate data bases. This service enables water companies to achieve large cost savings by running a more optimally planned and co-ordinated water mains rehabilitation program.

Water distribution challenges
Corrosion in water mains is worldwide an increasing and costly problem. This is complicated by the fact that the state may vary significantly from one pipe segment to the next. Until now, visual assessment of a pipeline’s condition has been difficult to perform and has revealed limited information. Without proper information this may lead to non-optimal rehabilitation projects with respect to costs, timing and also rehabilitation method.

BIT’s solution
BIT performs detailed in-pipe condition assessments. The condition assessment is performed using high-tech inspection equipment and advanced computer software. The inspection device, the so called Pipescanner, is put into the main through an entrance pipe which must be mounted in the pipeline on forehand. From this point of entrance up till approximately 900 m can be inspected. With this technology we can, along the inspected pipe line’s length and from 0 to 360°:

- calculate the remaining wall thickness in the range of 1.5 to 25 mm
- distinguish between inside and outside corrosion and wall thickness reduction
- show the position and extent of rust, rust tubercles and sedimentation
- show the positions of manholes, joints, bends, narrowings, connections, valves and service pipes
- show the positions and character of longitudinally displaced joints and repairs

All these results are reported to the water company. So far condition assessments of Ø 250 to 325 mm cast iron pipes have been performed successfully in Norway and Sweden. Other sizes will be supported in the future.
Customer benefits
Savings may be realised on four levels:

- Just-in-time rehabilitation decreases direct and indirect costs associated with pipe failures, while optimally using a pipeline’s life cycle
- Rehabilitation costs are reduced by choosing the optimal rehabilitation method
- Improved planning and co-ordination with other infrastructural projects may improve the overall efficiency and thus reduce the overall costs
- The public’s negative perception of rehabilitation projects may be reduced

Additionally the assessment reports contribute to the quality of risk analyses of water supply networks.

1. Water distribution challenges
In many countries cast iron water mains make out a large part of the water distribution networks. Grey cast iron was a widely used material from the 19th century until 1960/1970 and still many water mains of this material are in use. Quite a large part of these cast iron water mains are more than 60 years old, even up to 100 and more. Ductile cast iron mains came in use after 1960/1970. All cast iron mains are affected to any degree by corrosion, also the younger ductile cast iron mains, particularly the first generation, which had no inner or outer protection. Corrosion affects a pipe’s wall thickness and structural pipe strength and is subsequently an important risk factor with respect to pipe failure.
In many countries water asset managers are confronted with too high leakage and breakage rates, leading to delivery problems, energy loss, damages and an increased risk for contamination of drinking water. Costs due to failures can be considerable.

At some point in time mains need to be rehabilitated, structural, semi-structural, non-structural or point wise, preferably before the damage is done. However, rehabilitation rates are often low, typically below one percent, where the needed annual investment is estimated to be between two and four percent. But despite this presumably too low rate, costs related to infrastructure operations and maintenance
are already up to approximately 75% of a water utilities operating costs. Therefore, both from an operational and cost-point of view it is important to optimally use a main's lifetime and then apply, when necessary, a cost-effective rehabilitation method.

In order to choose the appropriate and most cost-effective rehabilitation methods an asset manager needs information on the actual condition of the assets. Information on the actual real condition of several mains will strongly improve the quality of life-cycle cost analyses and risk assessments and will support the asset manager to make better decisions regarding what to do with the assets. However, so far there are no good real pipe condition assessment methods. Leakage detection is an important inspection method but reveals no information on a main's structural condition. Camera inspection doesn't reveal information on the structural condition and taking samples by digging up some pipes and analysing them is expensive and not conclusive for the whole pipeline as the state of a pipeline may vary significantly from one pipe to the next. So, how to choose the most cost-effective rehabilitation method and how to take the worst mains first?

2. BIT’s solution
To tackle this problem Breivoll Inspection Technologies (BIT) developed a so called Pipescanner. This is an in-pipe inspection device based on Acoustic Resonance Technology (ART).

Figure 2. The Pipescanner with the transducers arranged in the centre part.

ART as used by BIT is developed and patented by Det Norske Veritas (DNV). BIT is an exclusive licence holder of this technology applied on water pipelines. BIT performs detailed in-pipe condition assessments using this high-tech inspection equipment and advanced computer software.

2.1. Acoustic Resonance Technology
Acoustic Resonance Technology refers to the use of wide-band acoustic pulses to excite resonant modes in materials, in this case in water pipes. These modes will be reflected from the pipe walls, received and then further analysed. The area which is put in resonance and from which the acoustic signal is reflected is called a ‘foot print’. The acoustic reflected signal contains information such as wall thickness and corrosion in this foot print. ART has clear advantages over traditional (ultrasonic)
thickness measurements, such as the possibility to process thickness over an adjustable area and to do so even when the pipe is covered with for example corrosion products or sediments.

Figure 3. Traditional ultrasound method and ART method compared.

With this technology we can:
- calculate the remaining wall thickness in the range of 1.5 to 25 mm
- distinguish between inside and outside corrosion and wall thickness reduction
- show the position and extent of rust, rust tubercles and sedimentation
- show the positions of manholes, joints, bends, narrowings, connections, valves and service pipes
- show the positions and character of longitudinally displaced joints and repairs

2.2. The Pipescanner
The operating system is developed in close cooperation with our technology providers Piezo Composite Transducers (PCT), DataRespons, Jupiter System Partners and Beck Engineering and the Oslo Water and Sewerage Department (Oslo VAV). Verification of the method has been carried out by SINTEF, DNV and Oslo VAV. The inspection equipment exists of an in-pipe inspection device, the so called Pipescanner, and the top-side inspection equipment, i.e. an inspection van with all necessary equipment for operating the Pipescanner and acquisition and storing of data.

The inspection part of the Pipescanner consists of a number of ultrasound transducers placed such that the acoustic signals cover the entire pipe wall over 360°. These signals put the foot print areas in the pipe wall in resonance and the reflections are again received by the transducers.
All data are transferred by cable to the top side inspection data equipment, processed and stored on a hard drive and then further processed and analysed at BIT’s headquarters. Subsequently the analysed data are reported to the customer.

Figure 4. The ultrasound transducers are placed such that the acoustic signals cover the entire pipe wall over 360°.

2.3. The inspection operation

The *Pipescanner* is put into the main through an entrance pipe which must be mounted in the pipeline on forehand. The *Pipescanner* is moved through the pipeline to the inspection starting point and kept in the centre of the water filled pipeline by centring wheels while pulling it back and acquiring the data. After scanning the entrance pipe will normally be removed.

Depending on diameter, accessibility and internal condition of the pipeline we can scan up to approximately 900 meters per day (8 hrs). Sharp bends and corrosion products may hinder or even prohibit access to the projected starting point in the main, particularly in smaller diameter mains. Today’s *Pipescanner* is conditioned for pipe diameters DN250 – 400, but scans have so far been performed on DN250 – 325 pipelines.

Figure 5. Inspection operation: the *Pipescanner* is put in the main.
2.4. The condition report

The processed data are visualised in different coloured 2D condition plots, along the scanned length and 0 - 360°:

- a thickness plot, showing thickness distribution
- a distance plot, showing interior topography
- a pitting plot, showing corrosion on the inside and outside

Additionally the positions of joints, branch and service pipes, repairs, valves, narrowings and bends are shown in these plots.

Figure 6. Plots of two sections in the same grey cast iron main from 1953, illustrating the different conditions of the pipes along the length of the main and a repair (at 18 – 19m) with cement mortar lined ductile pipe.

These plots are generated after processing of the inspection data and give a good impression of the pipeline’s condition at a glance. It is possible to reveal what type of cast iron pipes are used with respect to length and thickness, repairs with other pipe types, homogeneity regarding thickness, larger thin areas, pipe production variances, much corroded or not, inside/outside corrosion and the pipeline’s actual position in the ground.

However, these plots are only a part of the condition report. The report is specifically in positioning and quantifying:

- remaining solid wall thickness in millimetres; this relates to remaining lifetime, possible rehabilitation areas and rehabilitation method
- inside and outside corrosion as a percentage of a pipe’s area; this relates to the rehabilitation method
- main’s topography: position of rust tubercles, sedimentation, valves, service pipes etc
- condition classification (under development)
Figure 7. Large production variance per pipe, considerable internal corrosion and large tubercles are the main characteristics of this grey cast iron pipeline from 1943.

The pipe condition data in the report must be of such quality that they inform clearly on the condition of the main and support asset managers in their decisions what to do with the main: to rehabilitate or not to rehabilitate, where, when and how? Therefore, in addition to providing basic data like solid wall thickness and thickness distribution, position of corrosion areas and tubercles and internal and external pitting, we recognise the need for a condition classification or coding system, describing pipe defects and severity with respect to the pipeline’s remaining life or failure risk. Today, as far as we know, a standard for classification, like for example the European Standard 13508 for sewerage pipes doesn’t exist for water pipes.

Figure 8. Part of the assessment report: most important findings and classification.

<table>
<thead>
<tr>
<th>Length (m)</th>
<th>Classification</th>
<th>Findings</th>
<th>Comment</th>
<th>Failure code</th>
</tr>
</thead>
<tbody>
<tr>
<td>48-50</td>
<td>3</td>
<td>Reduced solid wall thickness</td>
<td>Larger area, thickness down to 7mm. Large and many tubercles</td>
<td>IT</td>
</tr>
<tr>
<td>76-77</td>
<td>3</td>
<td>Reduced solid wall thickness</td>
<td>Larger area, thickness down to 7mm. External corrosion.</td>
<td>E</td>
</tr>
</tbody>
</table>

Failure code: I= Internal corrosion/damage  F= Internal fouling  E= External corrosion/damage  T=Thickness reduction  P=Production variance  J=Joint failure

Classification - 0: no failure - 1: almost no failure - 2: Some failure - 3: Much failure - 4: Very much/very serious failure

Additionally, the data should be accessible and ideally easily to process at the customer’s side. We deliver the condition reports electronically, enabling our customers to link them up to their GIS systems. This gives our customers the possibility to easily identify which mains have been inspected by the BIT Pipescanner and what has been concluded with respect to their condition.
Figure 9. Part of the assessment report: description of properties per pipeline segment.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Length, m</th>
<th>Distance from point of entrance</th>
<th>Information</th>
<th>Lowest thickness (mm)</th>
<th>Internal corrosion</th>
<th>External corrosion</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4,2</td>
<td>13,1-17,3</td>
<td></td>
<td>11,63</td>
<td>0,13</td>
<td>0,18</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3,3</td>
<td>17,3-20,6</td>
<td></td>
<td>5,29</td>
<td>3,23</td>
<td>0,25</td>
<td>Repair with cement mortar lined pipe</td>
</tr>
<tr>
<td>3</td>
<td>0,8</td>
<td>20,6-21,4</td>
<td></td>
<td>6,08</td>
<td>0,00</td>
<td>0,09</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5,5</td>
<td>21,4-26,9</td>
<td></td>
<td>5,37</td>
<td>0,03</td>
<td>3,02</td>
<td>Repair with cement mortar lined pipe</td>
</tr>
<tr>
<td>10</td>
<td>4,5</td>
<td>49,1-53,6</td>
<td>10,97</td>
<td>0,17</td>
<td>0,75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>6,5</td>
<td>53,6-60,1</td>
<td>5,39</td>
<td>8,51</td>
<td>0,52</td>
<td></td>
<td>Different pipe type: 6,5 m. Thin wall</td>
</tr>
<tr>
<td>12</td>
<td>2,1</td>
<td>60,1-62,2</td>
<td>Manhole 763</td>
<td>6,12</td>
<td>48,35</td>
<td>0,97</td>
<td>Fire valve; branch; 2 valves</td>
</tr>
<tr>
<td>13</td>
<td>4,4</td>
<td>62,2-66,6</td>
<td>Inclination 8.2°</td>
<td>8,46</td>
<td>0,27</td>
<td>2,21</td>
<td>Indication of hole at 62,4 m and 230°</td>
</tr>
</tbody>
</table>

| 16      | 6,5       | 75,7-82,2                       | 5,42        | 4,52                  | 0,64             |        | Thin goods, some corrosion |
| 17      | 6,5       | 82,2-88,7                       | Inclination 4,7° | 5,30                  | 6,16              | 0,23             | Thin goods, some corrosion |
| 18      | 1,9       | 88,7-90,6                       |             | 8,38                  | 4,79              | 0,04             |        |
| 19      | 6,5       | 90,6-97,1                       | 5,41        | 3,96                  | 0,21             |        | Thin goods |
| 20      | 2,0       | 97,1-99,1                       | 5,34        | 4,30                  | 0,45             |        | Repair area |
| 21      | 4,2       | 99,1-103,3                      | 8,19        | 10,12                 | 0,04             |        | Repair area |
| 22      | 2,0       | 103,3-105,3                     |             | 5,48                  | 6,30              | 1,17             | Joint 14 cm |
| 23      | 4,8       | 105,3-110,1                     |             | 5,03                  | 1,27              | 2,84             | Repair with cement mortar coated |

Explanation:
*Lowest thickness: [60%] >60%, [55-50%] 55-50%, [50%] <50%.
**In-external corrosion: [0-8]% 0-8%, [8-15]% 8-15%, [15-40]% 15-40%.

2.5. References
BIT started the implementation and testing of this new water pipe condition assessment method by the end of 2007 and continued during 2008. Scans have been performed at several water mains of municipal water companies in Norway and Sweden. Oslo VAV has approved the method after several inspections in DN250 and DN300 grey and ductile cast iron mains. Additionally, inspections were performed in Bergen, Stavanger, Trondheim, Bærum, Oppegård and Tromsø in Norway and Stockholm and Täby in Sweden.

3. Customer benefits
The condition reports based on the BIT’s inspection method can be used as basis for multi-year rehabilitation plans, in risk analysis projects and more directly in rehabilitation measures and maintenance schemes. Direct benefits are:
- improved infrastructure sustainability and cost savings: full use and extension of a pipeline’s service life through rehabilitation of the right pipeline at the right time with the right method
• better identification of risk sections, understanding of probability and consequences of a failure
In this way water utilities can take informed decisions on which pipelines should be rehabilitated first and what rehabilitation method should be used.

3.1. Improved sustainability and cost savings
Just-in-time rehabilitation decreases direct and indirect costs associated with pipe failure, while controlling (future) maintenance costs. BIT’s inspection method reveals detailed information on a main’s real condition with respect to remaining thickness, inside and outside corrosion and inside topography. Better knowledge on the real condition of a pipeline enables a better estimation of the pipeline’s remaining life and a better corresponding life-cycle cost analysis and optimizes choice, planning and timing of rehabilitation measures.

It prevents that ‘still good’ pipelines are exchanged or unnecessarily rehabilitated, thus making better use of a pipeline’s service life while saving costs. In other cases a pipeline’s service life can be extended by choosing the right and most cost-effective rehabilitation method at the right time within the multi-year period. Relining and other non-structural and semi-structural rehabilitation methods are, if appropriate, cost-effective rehabilitation methods. They will extent a pipeline’s life cycle with 25 or more years and reduce maintenance costs. They offer considerable savings compared to exchanging pipelines and even structural rehabilitation methods like cracking. As these methods are trenchless solutions they can be executed without affecting other underground infrastructure, preventing additional, actually untimely, infrastructural projects.

Alternatively, independent of the eventual choice of rehabilitation method, better knowledge on a pipeline’s condition enables improved planning and co-ordination with other infrastructural projects and thus improve the overall efficiency and reduce the overall costs.

Avoiding unnecessary rehabilitation projects, deciding for the right trenchless rehabilitation solutions if possible and coordination with other infrastructural projects lead to a more efficient use of personnel and money. Additionally, a better coordination of infrastructural projects and use of trenchless rehabilitation technologies will lead to fewer hindrances for the public and businesses, saving business for possible income losses and possibly reducing the negative perception of rehabilitation projects by the public.

The assessment results by BIT’s inspection method reveal adequate information on the structural condition of the pipeline and will support the asset managers in their decision whether rehabilitation is necessary, what rehabilitation method can be chosen and when rehabilitation can be executed. The assessment costs are small compared to the costs of exchanging a pipeline. The assessment rate per meter is
approximately 5% of pipeline exchange meter rate. This is dependent on the pipeline’s location (town centre or not) and the assessment length, as part of the inspection costs involved are fixed costs. In practice only a part of the total length of the pipeline will be assessed, which means that total assessment costs are much smaller than 5% of the exchange costs. The savings that can be attained by making an informed decision on rehabilitation yes or no, and then timing and most cost-efficient method are considerable and justify the assessment costs.

3.2. Contribution to risk management
Risk analysis has become increasingly important in the water industry. With respect to the water distribution network one evaluates possible failures of the network and the possible impact on water quality and security of delivery as well as possible consequences in terms of damage to the direct environment. Having identified the most critical pipelines an assessment of their conditions helps to better estimate the probability of a failure.

As shown in paragraph 2.4. a condition assessment of cast iron water mains reveals wall thickness distribution and thin areas, inside and outside corrosion areas, severity and distribution of tubercles at the inside and other variations in the pipeline’s material and construction. The position of joints, valves and service pipes can also be detected, as well as the lengths of the pipeline segments, positions and type of earlier repairs. The condition assessment by BIT also informs on how the pipeline lies in the ground. Ideally segments lie in a straight line, apart from planned bends. As even small angles between segments are detected and quantified the assessment reveals deviations from a straight line, indicating quality of the original laying operation or instability in the underground. Instabilities influence the pipeline’s position and possibly put more press on certain sections.

This information on the actual condition of a pipeline is valuable input in estimating the possibility of failure and contributes positively to the quality of risk analyses.

4. Conclusion
BIT’s Pipescanner method for condition assessment of cast iron water mains is a non-destructive in-pipe inspection method, revealing detailed information on a mains’ structural condition. With these assessment reports BIT offers administrators of water supply networks asset management support tools for better rehabilitation efficiency and failure risk reduction.