Practical evaluation of inline inspection methods for large pre-stressed concrete transport pipelines

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Abstract
Monitoring of Waternet's large diameter transport pipelines includes the main failure mechanisms: breakage of prestressing wires and joint leaks. New inline inspection tools have the potential to increase availability and safety, but validation in full-scale conditions is necessary. In this article, we present a practical validation of two inline free-swimming inspection tools for acoustic leak detection (SmartBall®), joint gap measurement with laser scan and electromagnetic wire breaks detection (PipeDiver®). SmartBall was able to pick up noise created by a simulated leak from a 0.9 mm pinhole, giving a lower detection limit under local conditions of about 40 l/h. Implementation allowed detection and repair of several small leaks. PipeDiver's laser scan technology measured joint gaps with accuracies comparable to the manual method, although differences on the individual joint level should be taken into account for decisions on repairs. PipeDiver's electromagnetic detection measured the number of wire breaks per pipe with accuracies comparable to the manual method, although differences in the sensitivity and accuracy occurred in the zones in which the wire breaks are present. Applicability for residual strength calculations will depend on precise comparison of consecutive inspection runs. To conclude, validation of these inspection tools provided confidence for future implementation.

Keywords
Pipeline inspection, pre-stressed concrete, wire breaks, joint leaks, leak detection

1. Introduction
The Water transport company Rijn-Kennemerland (WRK) maintains pipelines transporting pre-treated surface water to the dune area in the west of The Netherlands for infiltration as part of the drinking water production process. The WRK transport pipelines are critical due to their high maintenance costs and substantial consequence of failure, which can lead to large scale supply interruption and potentially severe damage to other critical infrastructures in the Amsterdam region. Leaks in the prestressed noncylinder concrete pipes (NCP) with diameters of 1500 mm (WRK-I) and 1200 mm (WRK-II) are mainly related to breakage of the spiral prestressing wires in the pipes (wire breaks) and opening of the joints between pipes (joint leaks). Due to the aging of the pipelines, built in the 1950's and 1960's respectively, increasing overground infrastructure in the dense metropolitan area and necessary renewal of permits and contracts, Waternet has developed a monitoring plan that includes various inspection activities. Measurements to determine the number of wire breaks and the gap width of the spigot and socket joints are performed on regular basis. The applied methods, however, require people to enter the pipeline and are time consuming, affecting the availability of the WRK transport system. Developments in new inline inspection tools have the potential to detect these types of anomalies in challenging operational conditions: unavailability of the pipes should be kept as short as possible and inspection tools should allow long (multiple kilometer) runs. Implementation of those new technologies in the current integrity assessment require validation of the measurement results in full-scale conditions. This research presents the results of a practical validation of two inline free-swimming inspection tools for leak detection, joint gap measurement and wire breaks detection.

2. Methods
The investigated tools, offered by Pure Technologies (a Xylem brand), were an inline free-swimming acoustic tool for leak and gas pocket detection (SmartBall®), an electromagnetic tool for determining the number and position of wire breaks in the prestressed concrete pipes (PureEM®), and a laser scan to measure the joint gaps between pipes. The latter two were both mounted on the inline free-swimming PipeDiver® platform.

2.1. Leak detection with SmartBall

SmartBall is an untethered, free-swimming tool equipped with a highly sensitive acoustic sensor that can locate 'pinhole' pipeline leakages. Leaks lower than 0.1 l/min have been detected and validated with location accuracies lower than +/- 2 m. To determine the lower detection limit of the SmartBall for the WRK-I pipeline, a device for simulating point leaks was developed (figure 1). A ball valve is not suitable for creating a simulated leak, due to pressure loss and variable flow in the ball valve itself and pressure losses in the line before and after the valve

(Laven, 2008). Therefore, a device was developed, consisting of a brass orifice plate placed as closely to the pipe wall as possible (0.3 m), providing a single diameter restriction, and a column containing sand and water to simulate counter pressure from the environment. The orifice plate could be exchanged, allowing different sizes of accurately drilled holes (0.3-1.0 mm) to be tested. The flow rate was measured with a graduated cylinder and stopwatch. In addition, another orifice could be placed containing a short (4 cm) piece of rubber sealing ring, allowing water to escape through a narrow slit simulating a joint leak. In the first test, the leak simulation device and the SmartBall were placed in adjacent valves 2.2 m apart. In the second test, a SmartBall run was carried out over 7.7 km, passing simulated leak with a velocity of 0.66 m/s (75% of the water velocity)

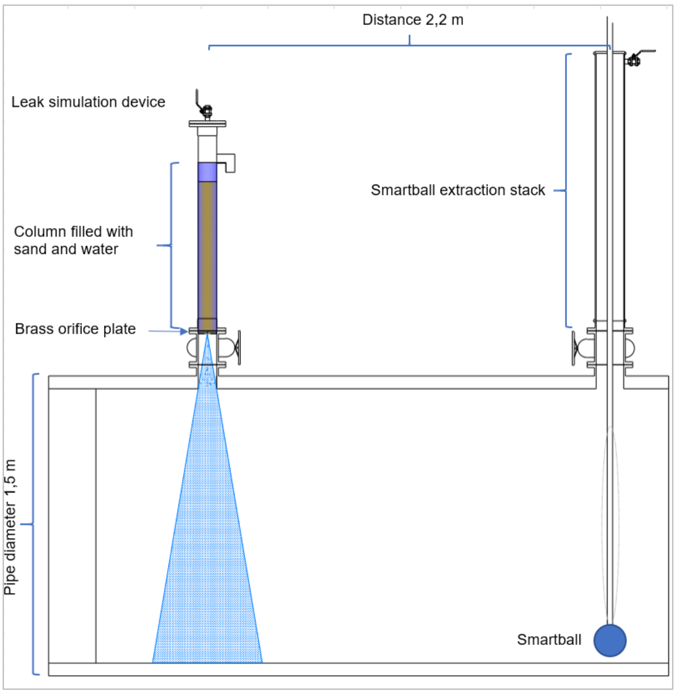

Figure 1: SmartBall validation setup with leak simulation device.

2.2. *Wire break detection and joint gap measurement with PipeDiver*

PipeDiver is a free-swimming inspection platform that can be used to inspect pressurized pipelines using electromagnetics (EM). EM is applied in prestressed concrete pipelines to locate and estimate the number of wire breaks. The technology produces a magnetic signature for each pipe section, which makes it possible to identify anomalies that are produced by zones of wire break damage. Various characteristics associated with an anomaly, such as length, magnitude and phase shift, are evaluated to provide an estimate of the number of wire breaks. For joint gap measurements, lasers and cameras were installed at three of PipeDiver's back petals. The lasers make the joint gap visible on the camera footage for automatic determination of the gap width at 3 clock positions.

Measurements were done in an 3.36 km long part of the WRK-II pipeline with an average inspection speed of 0.7 m/s. It was chosen to compare the results against manually performed measurements that were obtained one year earlier in the same section of the WRK-II pipeline. The number of wire breaks in each pipe was determined by applying the Remote Field Coil Modulation Technology (Eddy Current) from Tallow and Pure Technologies. Joint gap measurements were done manually at 4 clock positions using a caliper gauge.

Figure 2: Field team during Pipediver's insertion procedure.

3. Results

3.1. Leak detection

The leakage flow rate of the point leaks showed good correlation with the cross-section of the orifice opening (figure 3). The flow rate measurements were accurate and reproducible. The smallest pinhole that gave a stable signal in the SmartBall was 0.9 mm in diameter. The detection limit at 2 bar, under local conditions of the WRK-I pipeline, was about 40 L/h. The signal from a point leak was more clear than the signal from a joint leak simulation of similar flow rate.

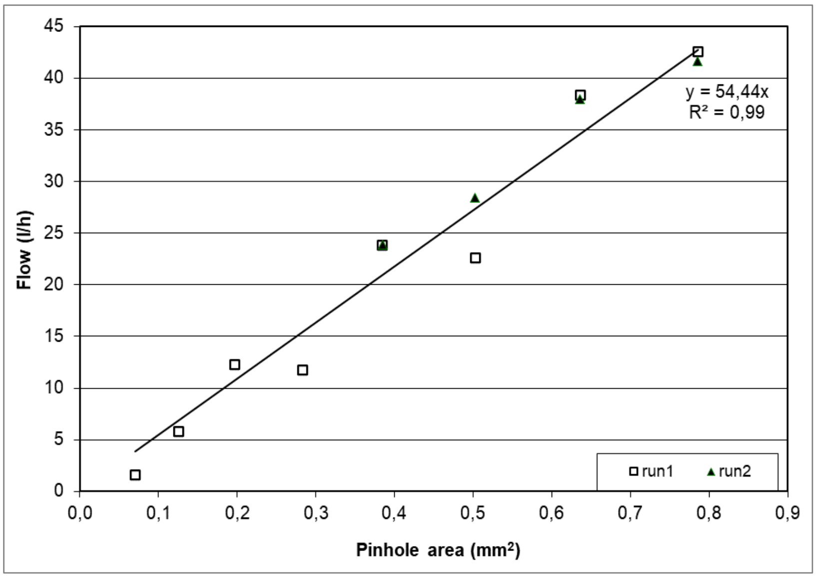

Figure 3: Results leak simulation

3.2. Wire breaks detection

A total number of 58 pipes displayed electromagnetic anomalies consistent with wire breaks. The number of wire breaks per pipe ranged from 5 to 105 broken wire wraps. Figure 4 shows the direct comparison between the total number of wire breaks per pipe as determined with the manual method (Remote Field Coil Modulation Technology) on the horizontal axis and with the PipeDiver (PureEM) on the vertical axis. Linear regression gives a coefficient of determination (R^2) equal to 0.95. The intersection at 0.4 and a slope below 1 indicate an overestimation of the lower number of wire breaks and an underestimation of higher number of wire breaks. However, only two pipes with more than 100 wire breaks were present in the dataset.

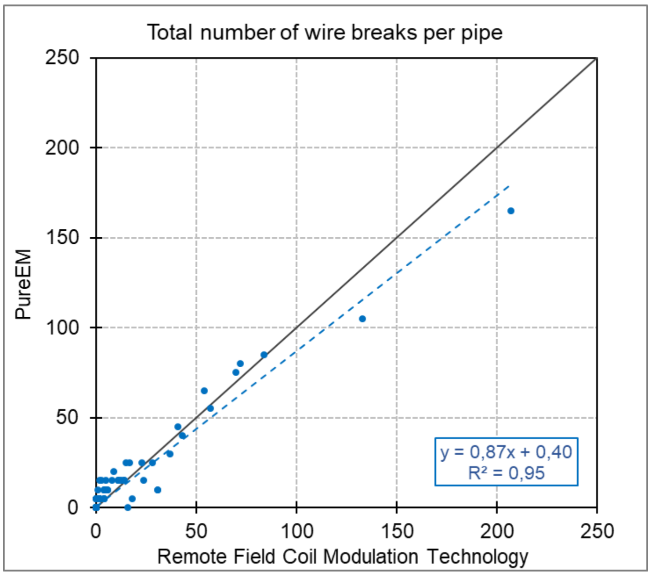

Figure 4: Direct comparison between total number of wire breaks per pipe as determined with the manual method using the Remote Field Coil Modulation Technology and the with the PipeDiver using PureEM.

3.3. Joint gap measurement

The joint gap measurements obtained by PipeDiver with laser triangulation (technique A) and done manually with a caliper gauge (technique B) are statistically analyzed using the Bland-Altman-method (Giavarina, 2005). Direct comparison in figure 5 shows a horizontal pattern that is caused by rounding of the laser triangulation results to 5 mm. Linear regression gives a coefficient of determination (R^2) equal to 0.73. The intersection at 5.8 mm and a slope below 1 indicate an overestimation of the smaller joint gaps.

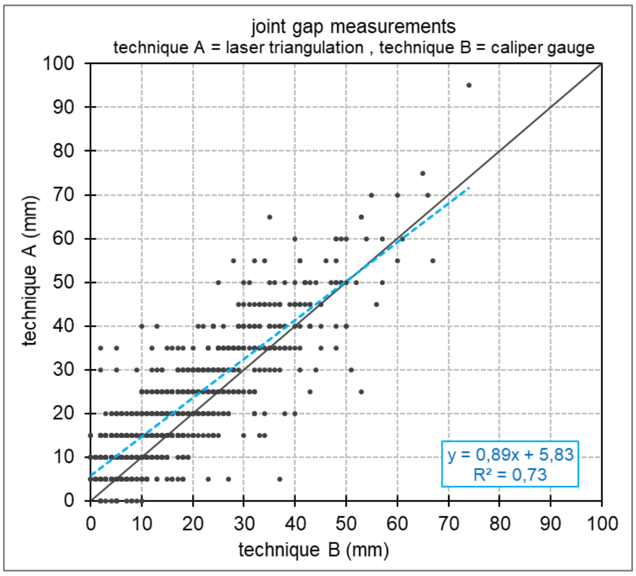

Figure 5: Direct comparison between joint gap measurements (n = 1180).

Figure 6 plots the differences between measurements of both technologies on the vertical axis, against the mean of both measurements on the horizontal axis (Bland-Altman plot). The mean of the two methods was chosen on the x-axis, because no method is preferred beforehand. The average difference between the measurement amounts to 4.1 mm with a 95% confidence interval of 12.8 mm. The difference are comparable over the range of joint gaps measured.

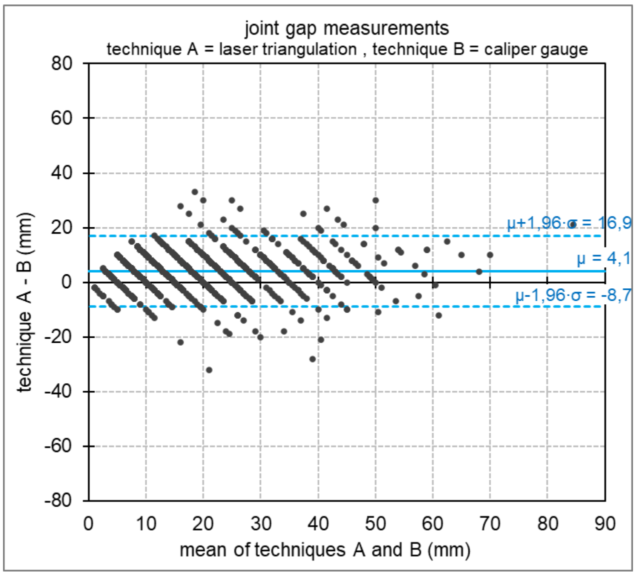

Figure 6: Bland-Altman plot showing the difference between the measurements against the mean (n = 1180).

4. Discussion

4.1. Leak detection with SmartBall

SmartBall was able to pick up noise created by a simulated leak from a very small pinhole (0.9 mm), giving a flow rate of about 40 l/h. This was measured in a static situation, with the SmartBall tied onto the extractor stack. At the distance between the valves (2.2 m), the SmartBall was not situated directly under the leak (the blue cone in figure 1). In an additional experiment, SmartBall was run in its regular way, passing under the simulated leak. This measurement confirmed that it was able to detect the leak in normal operating conditions for both a point leak and a joint leak of about 40 l/h.

4.2. Wire break detection with PipeDiver

Comparison of the total number of wire breaks per pipe as determined by PipeDiver and the manual method show a good correlation. This could be expected, because both use comparable electromagnetic techniques to detect broken wire wraps. This means that the faster underwater method doesn't result in large deviations from the time consuming manual method. PipeDiver is less sensitive than the manual method for low number of wire breaks. This could be partially explained by rounding of the measurement results to 5 wire breaks. To what extent this is acceptable will depend on the assessment criteria used by the asset manager to evaluate inspection results. For a first reconnaissance, the PipeDiver will provide valuable information on presence of wire breaks in a short time. For monitoring purposes on pipe level for example, comparison of consecutive measurements will require unrounded measurement results with equal accuracy. If one also is interested in detailed calculation of the residual strength of a pipe segment, additional information about the density of broken wire wraps is necessary. It is important to decide on these tolerance values before new inspections are executed, in order to take these into account by reporting the measurement results.

4.3. Joint gap measurement with PipeDiver

While the average difference between both methods (4.1 mm) seems relatively small, the confidence interval is quite large. The results show large differences for individual joint gaps. For the implementation of the technique in the decision making process this means that no simple correction to the data can be done and that a change in the trend of historical data can be expected. A number of possible explanations can be given for the differences. The joint gap between two concrete pipes is not always sharp and equal around the circumference of the pipe. For the manual method, the measurement results depend on the exact location of the measurement and on the person doing the measurement. Furthermore, the gap width can deviate between empty and pressurized situation. It's important to take these differences into account by implementing a new measurement technique.

5. Conclusions

The inline inspection tools provided valuable information on the main failure mechanisms of the WRK-pipelines: joint leaks and pre-stressed steel wire breaks. They improve the reliability, availability and safety of the pipelines and enable a condition-dependent maintenance strategy. Advantages of the inline method are reduced downtime (days versus weeks for the manual method), no need to empty the pipeline, and increased safety for the operators. Validation of new inspection techniques turned out the be critical for their implementation in the existing monitoring plan.

SmartBall was able to pick up noise created by a simulated leak from a very small pinhole (0.9 mm), giving a lower detection limit of about 40 l/h at 2 bar, under local conditions of the WRK-I pipeline. With this confirmation of the sensitivity of the Smartball leak detection, Waternet inspected both entire pipelines and was able to detect and repair several small leaks.

PipeDiver's laser triangulation technology was able to measure joint gaps with accuracies comparable to the manual method, although differences on the individual joint level should be taken into account for decisions on repairs. Waternet has negotiated with the licensing authority that the inline joint gap measurement can be used for future inspections.

PipeDiver was also able to measure the number of wire breaks per pipe with accuracies comparable to the manual method, although differences in the sensitivity and accuracy occurred in the zones in which the wire breaks are present. Although the inline method works very well for a first evaluation of the overall condition of the pipeline, Waternet still bases residual strength calculations and prioritizing of repairs on the manual method. Future use of the PipeDiver's PureEM for re-evaluation will depend on precise comparison of consecutive inspection runs.

6. References

Giavarina, D. (2005) Understanding Bland Altman analysis. Biochemia Medica 2015;25(2):141-51

Laven, K., G. Varga, M. Eisenbarth en J. Hegarty (2008) Application of inline acoustic leak detection for condition assessment of large diameter force mains. Proceedings of the 2008 No-Dig conference and exhibition (Dallas, USA); North American Soc. For Trenchless Technol. Paper D-2-03.