NO-DIG DOWN UNDER MELBOURNE 2019
Engaging beneath the surface

NUMERICAL STUDY ON THE EFFECT OF DEFECTS ON THE PERFORMANCE OF SPRAY LINED CAST IRON PIPES

Guoyang Fu[1], Benjamin Shannon[1], Suranji Rathnayaka[2], Ravin Deo[1], Chunshun Zhang[1], Jayantha Kodikara[1]

[1] Monash University, Clayton, VIC, Australia
[2] City West Water, Footscray, VIC, Australia

ABSTRACT: Due to aging and deterioration, water pipelines, especially cast iron pipelines, are gradually approaching the end of their design life. To more effectively reline these deteriorated pipelines, water utilities have been seeking new solutions for pipe rehabilitation. Various technologies have been developed, among which, spray lining techniques have attracted the attention of water utilities. A number of water utilities in Australia already started trialling polymeric spray liners in their water pipe networks. It has been known that deterioration, in particular corrosion, induces surface defects, which may be in the form of corrosion patches, through-wall holes or cracks on the external surface of the cast iron water pipes. In the application process of spray liners, imperfections may also form, e.g., uneven liner thickness. The defects in the host pipe and the imperfections in the liner may significantly affect the performance of the lined pipes. Literature review reveals that little research was conducted to investigate the effect of these defects/imperfections on the mechanical behaviours of the lined water pipes. This paper aims to numerically investigate and quantify the effect of the holes in the cast iron host pipe and the uneven thickness in the polyurethene spray liner on the performance of the lined pipes, using three-dimensional finite element analyses. Various sizes of circular holes, different levels of uneven thickness in the liner, different values of internal pressure and friction coefficients at the interface between the cast iron pipe and liner are considered. The outcome of this study can assist in quantifying the size and geometry of an unacceptable defect for a given host pipe and liner.

1. INTRODUCTION

In Australia, there are approximately 139,000 km of water pipes, a substantial portion of which are made by cast iron (Kodikara 2018). Long-term service, together with aggressive environment and increased demands have resulted in a very high rate of cast iron pipe failures. In order to rehabilitate these deteriorated cast iron pipes, various technologies have been developed, among which, spray lining techniques have attracted the attention of water utilities. Spray lining not only provides internal corrosion protection, but also improves pipeline hydraulics and water quality (Ellison et al. 2010). The advantages of using spray lining technology also include minimum disruptions to community, minimal effort to re-establish service connections and use of traditional maintenance/repair methods for spray lined pipelines (Marcino and Blate 2015). A number of water utilities already started trialling polymeric spray liners in their water pipe networks.

It has been known that due to deterioration, in particular corrosion, surface defects appear, in the form of corrosion patches, through-wall holes or cracks, on the external surface of the cast iron pipes. Imperfections may also form in the liner, e.g., uneven thickness for spray liners (Figure 1). These defects/imperfections may significantly affect the performance of the lined pipes. Literature review reveals that little research was conducted to investigate the effect of these defects/imperfections on the mechanical behaviours of the lined water pipes. This paper sets out the results of three-dimensional finite element analyses used to investigate and quantify the effect of the defects/imperfections on the performance of the lining for spray lined pipes. For a 150mm diameter host pipe, various sizes of circular holes, different levels of uneven thickness in the polyurethene liner, values of internal pressure and friction coefficients for the interface between the cast iron pipe and liner are considered.

Figure 1. Uneven thickness in the spray liner (Ellison et al. 2010)

2. FINITE ELEMENT MODELLING

Numerical analysis using a commercial finite element software ABAQUS (2017) was firstly conducted to examine the effect of the size of a circular hole in the cast iron pipe on the maximum stresses in the lined pipe. In this study, the cast iron host pipe has a nominal diameter of 150 mm and a thickness of 9 mm while the spray liner has a thickness of 3 mm. The material properties of cast iron and polyurethane spray liner used in the numerical models are presented in Table 1. The Young's Modulus 2.5 GPa of the liner is assumed to be the long-term modulus. Various sizes of the hole (5 mm, 15 mm, 25 mm, 50 mm, 80 mm) were considered in the host pipe. Two values of internal pressure, 0.6 and 1.6 MPa (60m and 160m hydrostatic head) were considered and applied on the internal surface of the spray liner.

Table 1. Sample table for the as explained in the requirements for papers.

Material properties	Cast iron	Spray liner
Young's Modulus (GPa)	100	2.5
Poisson's ratio	0.3	0.4

Due to symmetry, only a quarter of the lined pipe was modelled as shown in Figure 2. Hexahedron elements were used for both the cast iron pipe and the spray liner. The loading and boundary conditions were also shown in Figure

2. In terms of contact, a Coulomb-type frictional interface was employed to describe the contact surface between the cast iron pipe and the liner. The tangential behaviour was defined with a coefficient of friction. Two values of the coefficient of friction f, namely, 0.0 and 0.3 were considered in the study. The normal contact behaviour was defined as "hard" contact to ensure any defelections of the spray liner were contained within the circumference of the inside of the pipe. In addition, separation was allowed between the liner and the cast iron pipe after contact. For each hole size, a convergence study was conducted to determine a proper mesh for both the host pipe and liner to ensure accuracy.

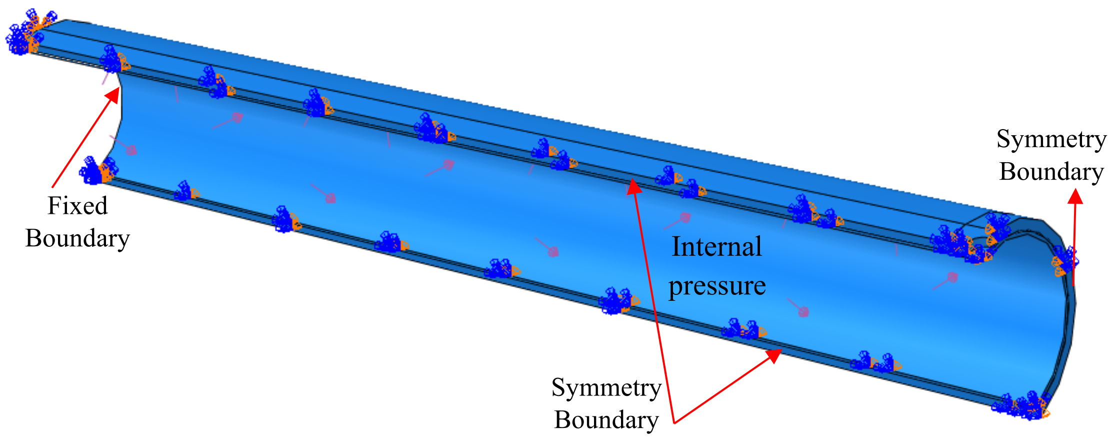

Figure 2. Geometrical model of the spray lined cast iron pipe with a circular hole together with the loading and boundary conditions (Quarter model)

To investigate the effect of uneven thickness of the spray liner along pipe circumference (Figure 1) on the maximum stress in the liner, additional finite element models were created to take into account the variation of the liner thickness along the pipe circumference. In these models, the values of the wall thickness varied from 2.5 and 3.5 mm, and the minimum wall thickness was located at the hole area to simulate the worst case scenario. One of these models was shown in Figure 3.

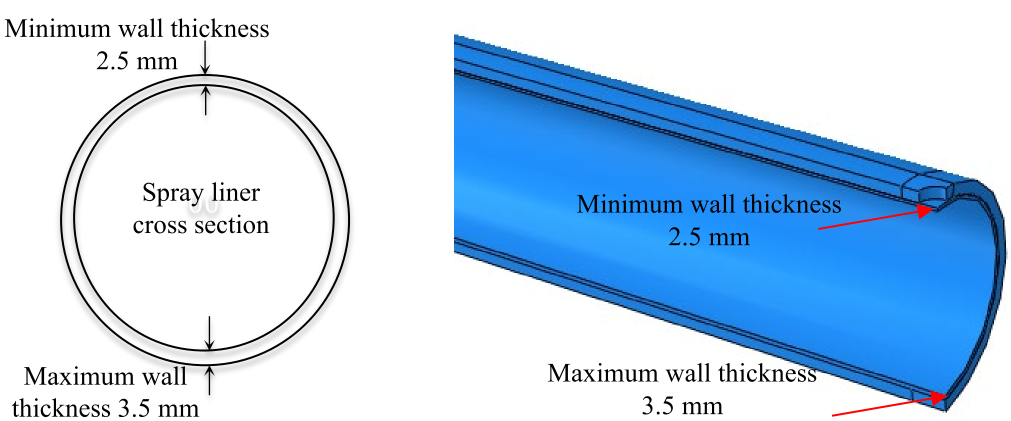

Figure 3. Geometrical model of the spray lined cast iron pipe with a circular hole and uneven liner thickness (Quarter model)

3. RESULTS AND DISCUSSIONS

Figure 4 shows a close-up view of the stress distribution around the circular hole (diameter 25 mm, friction coefficient 0.3 and internal pressure 0.6 MPa) in one of the lined pipe models. The maximum stresses in the host pipe and spray liner under different conditions are presented in Figures 5 and 6. For both the cases with internal pressure 0.6 MPa and 1.6 MPa, it can be see that the maximum stress in the spray liner initially increases with the increase of the hole size. For a 150mm diameter pipe when the hole size is larger than a critical limit (50-60 mm), the maximum stress tends to be constant. This is because when the ratio of the hole size to the diameter is large enough, the spray liner will function as a stand-alone pipe and the stress in the spray liner is governed by hoop stress, which is a function of the internal pressure, the diameter and thickness of the liner. When the internal pressure is 1.6 MPa, FE results indicated that the maximum stresses in the host pipe and spray liner are quite high. However, the host pipe is still safe as a typical value of the tensile strength of cast iron is 100 MPa. Therefore, whether the lined pipe will fail or not will depend on the long-term strength of the spray liner.

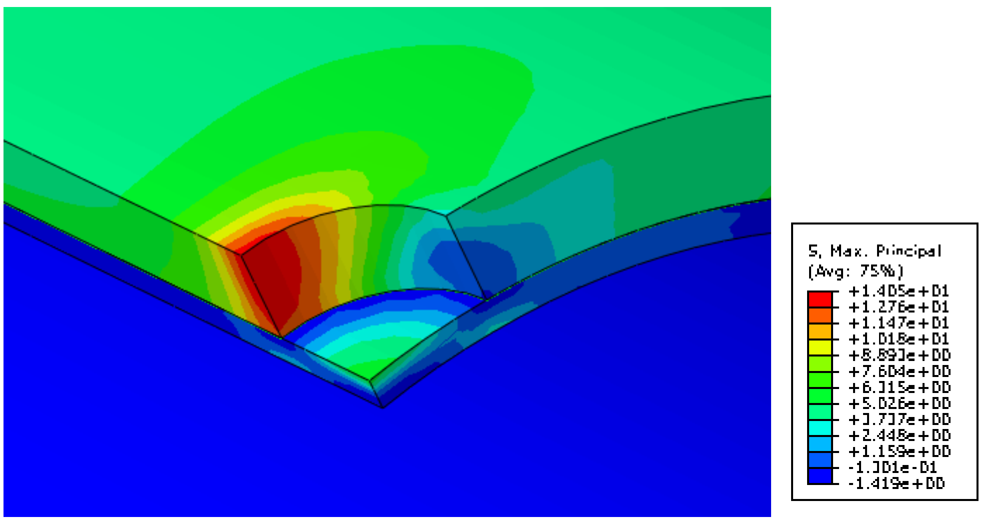

Figure 4. Stress distribution around the circular hole with a diameter of 25 mm

As most current liner designs follow ASTM F1216 (2016), a comparison was made between the numerical results and the design formula in ASTM F1216 (2016). For the case of internal pressure p = 0.6 MPa, the results were shown in Figure 7. For the cases modelled a discrepancy was found between the numerical results and those from the design formula in ASTM F1216. It can be seen that the design formula in ASTM F1216 (2016) overestimates the stress in the spray liner when the host size is small (< 40 mm). However when the host size is larger than 40 mm, reliance on the formula for ring tension alone underestimates the maximum stress in the spray liner as a consequence of local increases in flexural stress around the boundary and at the centre of the hole. It should be noted in the numerical models, the lined pipe is modelled as a composite pipe with interactions considered between the host pipe and the liner, which simulated the actual interactive behavior of the spray lined cast iron pipe. In ASTM F1216 (2016), for partially deteriorated pipes the liner within the host area is considered to act like a uniformly pressurised round plate with fixed edges as shown in Figure 8 while for fully deteriorated pipes the liner is considered to function as a standalone plastic pipe. It should be noted that when the host pipe is flexible, idealizing the lined pipe as a pressurized round plate with fixed edges is not valid. Therefore, the use of ASTM F1216 for flexible pipes will lead to inaccurate results. It should also be noted that plates are good approximations of pipes only when the ratio of pipe diameter to thickness is larger than 20.

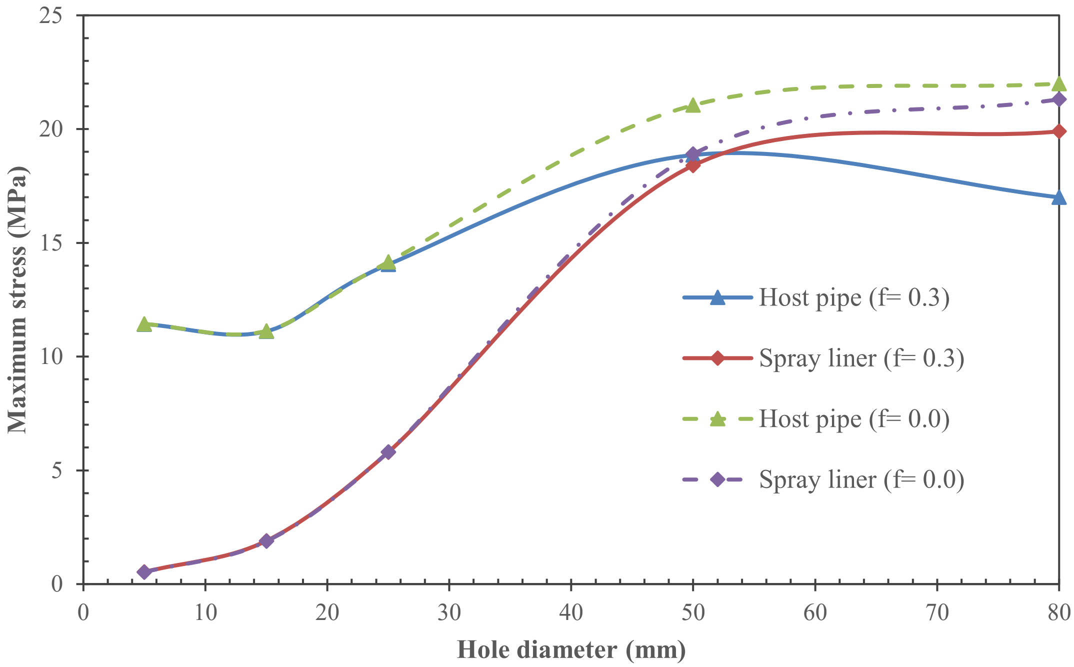

Figure 5. Maximum stresses in the host pipe (nominal diameter 150 mm and thickness 9 mm) and spray liner (thickness 3 mm) for different friction coefficient f (internal pressure 0.6 MPa)

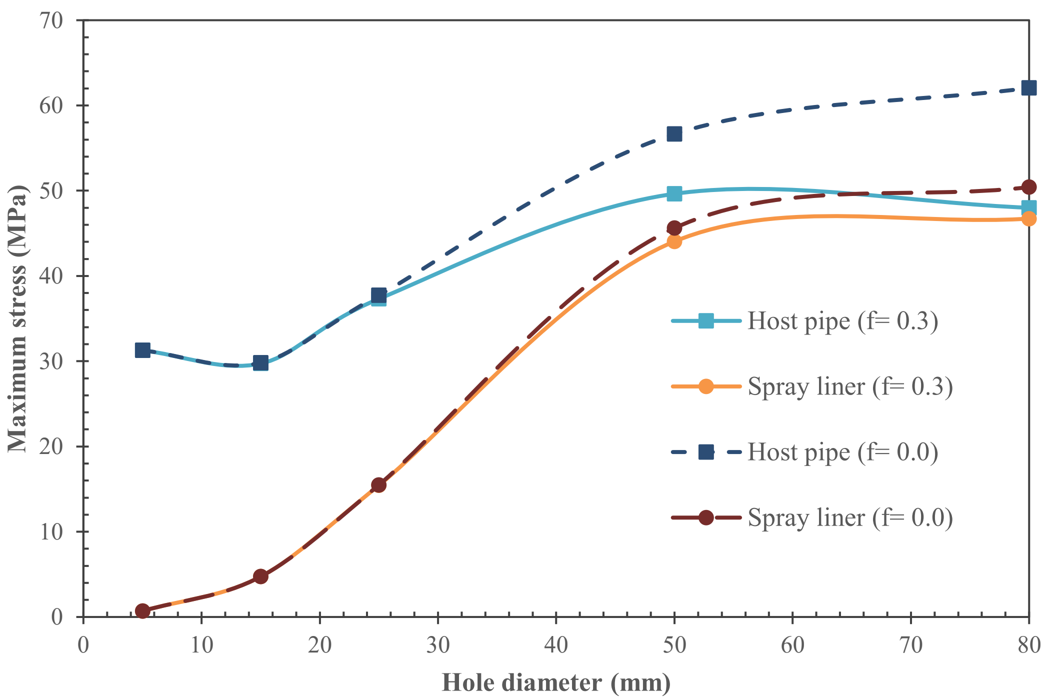

Figure 6. Maximum stresses in the host pipe (nominal diameter 150 mm and thickness 9 mm) and spray liner (thickness 3 mm) for different friction coefficient f (internal pressure 1.6 MPa)

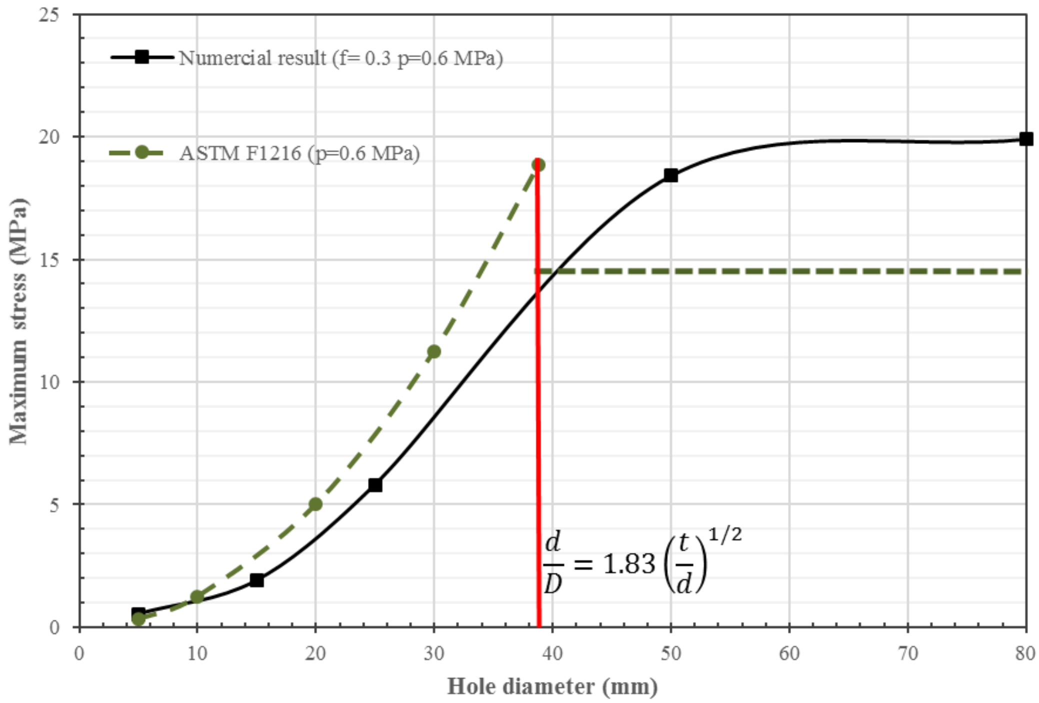

Figure 7. Comparison of numerical results with those from ASTM F1216 (2016) (pipe nominal diameter 150 mm, pipe thickness 9 mm and liner thickness 3 mm)

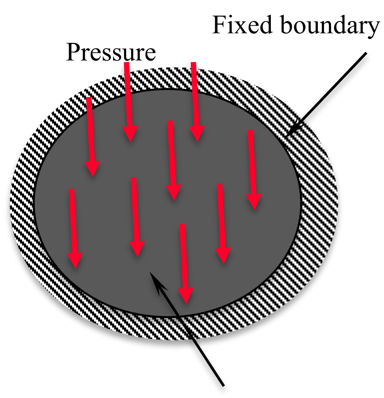

Figure 8. Simplified model in ASTM F1216 (2016)

The results from the finite element models with uneven thickness were summarised in Table 2 for both the case with friction coefficient 0.3 and the frictionless case. It can be seen that compared with the lined pipes with even liner thickness along the pipe circumference, the maximum stress of those with uneven wall thickness might be increased by up to 35% for the deteriorated cast pipes under an operating pressure of 0.6 MPa. This is more than the 16% that can be attributed solely to the reduction in thickness at the hole from 3.0mm to 2.5mm. This shows the importance of limiting the unevenness of the liner thickness to an acceptable level during the installation process.

Table 2. Comparison of maximum stresses in the spray liner with even or uneven thickness

Hole diameter (mm)	Maximum stress (MPa)					
	Friction coefficient = 0.3			Friction coefficient = 0.0 (Frictionless)		
	Even liner thickness	Uneven liner thickness	Difference (%)	Even liner thickness	Uneven liner thickness	Difference (%)
5	0.533	0.61	14	0.526	0.685	30
15	1.9	2.49	31	1.88	2.54	35
25	5.8	7.68	32	5.81	7.71	33
50	18.4	22.57	23	18.9	23.42	24
80	19.9	22.22	12	21.31	23.49	10

4. CONCLUSIONS

In this paper, the effect of defects/imperfections in spray lined cast iron pipes has been investigated using three-dimensional finite element analyses. It has been found that increasing the size of the hole in the cast iron pipe will increase the maximum stress in the spray liner until the hole size reaches a threshold level where the effects of hoop stresses takes over and the maximum stress will tend to be constant. It has also been found that an uneven thickness may increase the maximum stress of the spray liner more than can be attributed to the reduction in thickness, which will consequently reduce the pressure containing capacity of the liner. Therefore, it is important to limit the unevenness of the spray liner thickness to an acceptable level. The results of this study will assist engineers and asset managers in having a better understanding of the design of spray liners for rehabilitation of their deteriorated pipelines.

This paper presented some preliminary results of the numerical study, which is limited one pipe diameter and one spray liner thickness. Future work will include parametric studies to consider a wide range of diameters, thickness values and material properties of the host pipe and the spray liner. Based on the results, the maximum stresses in the spray liner will be drived as a function of various dimensionless parameters (hole size to diameter ratio, liner/pipe wall thickness to diameter ratio, liner modulus to pipe modulus, etc.).

5. ACKNOWLEDGEMENTS

The smart linings for pipe infrastructure project (CRC-P) is a collaborative project funded by the Australian Government Business Cooperative Research Centres Program, Water Services Association of Australia, Coliban Region Water Corporation, Hunter Water Corporation, Icon Water Limited, Melbourne Water Corporation, South Australian Water Corporation, South East Water Corporation, Sydney Water Corporation, Northern SEQ Distributor – Retailer Authority, Water Corporation, Bisley & Co PTY LTD, Insituform Pacific Pty. Limited, Kerneos Australia Pty Ltd, Parchem Construction Supplies Pty Ltd, Abergeldie Watertech Pty Ltd, Interflow Pty Ltd, Ventia Pty Ltd, Metropolitan Restorations Pty Ltd, ITS/Downer Pipetech Pty Ltd, Monadelphous Group Limited, UKWIRm Water Research Foundation, Water Environment and Research Foundation, Calucem, Milliken, and Sanexen Environmental Services.

Research Partners are Monash University, University of Sydney and University Technology Sydney (UTS).

6. REFERENCES

ABAQUS. (2017) "Version 6.17 documentation", Dassault Systèmes Simulia Corp., Providence, RI, USA.

ASTM F1216. (2016). “Standard practice for rehabilitation of existing pipelines and conduits by the inversion and curing of a resin-impregnated tube”, In ASTM F1216. ASTM International, West Conshohocken, PA, USA, pp. 1–8.

Ellison, D., Sever, F., Oram, P., Lovins, W., Romer, A., Duranceau, S.J. and Bell, G. (2010). “Global Review of Spray-On Structural Lining Technologies”, The Water Research Foundation, Report no. 4095.

Kodikara, J. (2018). “Advanced Condition Assessment and Failure Prediction Technologies for Optimal Management of Critical Water Supply Pipes”, The Water Research Foundation, Project no. 4326.

Marcino, S. and Blate, M. (2015). “Structural Lining for Water Mains”, *2015 PA AWWA Conference Presentations*, Hershey Lodge and Convention Center, Hershey, PA, 21-23 April 2015.