**Institution: University of Surrey**

**Unit of Assessment: UOA 15 General Engineering**

**Title of case study:**

**Asset management of aging cast iron water distribution network systems**

## 1. Summary of the impact (indicative maximum 100 words)

The condition of aging cast iron infrastructure is a major challenge for the water industry. Our research has improved understanding of the deterioration, residual strength and failure mechanisms of buried cast iron pipes. Thames Water Utilities Ltd (TWUL) have used Surrey's findings for small diameter (distribution) mains, to support their case with the regulator for increased funding for pipe lining and replacement programmes resulting in more than 100 M£ of additional investment being made available. Surrey's work on large diameter (trunk) main is being used by TWUL to shape new approaches to the assessment and management of water networks both within their own area and at a national level through UKWIR.

## 2. Underpinning research (indicative maximum 500 words)

Research at Surrey, carried out by Professor Paul Smith and Dr Mike Mulheron over a 16 year period (1997-2013), into both small and large diameter cast iron pipes has shown they behave differently after long periods in service despite being manufactured from the same material. By understanding the role of deterioration on material strength and pipe performance they have been able to explain why small diameter pipes (below 150 mm diameter) are less able to cope with deterioration, and have higher rates of failure, than large diameter trunk main.

Initial research (1997-2006) focused on the origins of defects in *small diameter cast iron distribution mains* and their effect on the residual strength and failure mechanisms in buried pipe networks. A key insight was that a number of different defect populations existed within cast iron pipes in service (**1**). The initial defect population reflects the microstructure of the cast iron, the method of pipe manufacture and wall thickness and controls the strength variations of the as-manufactured pipe. In-service exposure leads to degradation processes, such as graphitization, that create a new population of defects. As these defects grow in size, and number, a point is reached where they can initiate failure under normal service loads. Subsequent work, with Dr Hal Belmonte, developed a (Weibull) statistical approach to inform the asset management of the distribution pipe network at both street and area level (**2, 3**). The work identified the various defect populations that control failure and characterized their effect on residual pipe strength (**4**).

Field evidence demonstrates that in-service failures are not always the result of pipe breakage. As a consequence, work was undertaken, with Dr Brian Le Page, to review the capacity of the "lead-run" joint that exists between the bell and socket of adjacent pipes to accommodate thermal movement. This confirmed the limited ability of aged "lead-run" joints to accommodate movement without leakage and demonstrated, for the first time, that both pipe and joint failure can be generated by relatively small changes in temperature (**5**). By confirming theoretical predictions the work highlighted the need for improved methods for assessing the condition of "lead-run" joints.

Since 2006 the focus of Surrey's research has shifted to the failure behaviour of *large diameter trunk main* with significant input from Dr David Jesson. Part of this work has focussed on the static and dynamic fracture properties of comparatively thick sections (30-45 mm) of degraded cast iron. A key finding was that where the layer of graphitised material is of uniform thickness, the associated strength reduction is modest, but where the section loss is localised, the strength reduction can be significant, e.g. a 10% loss of section can produce a 50% loss in strength. Based on this knowledge, the appropriate application of simple strength-of-materials and fracture mechanics approaches were found to provide reasonable bounds for the strength data (**6**). The significance of that work led to the award of a 4-year, £1.2 million project (started June 2011) to the University, funded by industry and supported by two EPRSC EngD studentships. The work has demonstrated that the statistical approach developed previously cannot be simply scaled to trunk main.

As a consequence, two independent predictive models are being developed to enable improved asset management at both the network (systems) and individual pipe level. The outputs of the on-going programme, e.g. the individual Pipe Assessment Tool (iPAT) (which links pipe condition to pipe performance), are being used by TWUL to develop new approaches to the assessment and management of their water network.

**3. References to the research** (indicative maximum of six references)


1. K.Atkinson, J.Whiter, P.A.Smith and M.Mulheron, "Failure of small diameter cast iron pipes", Urban Water, 4, 263 - 271 (2002). DOI: 10.1016/S1462-0758(02)00004-3
2. H.M.S.Belmonte, M.J.Mulheron and P.A.Smith, "Weibull Analysis, extrapolations and implications for condition assessment of cast iron water mains", Fatigue and Fracture of Engineering Materials and Structures, 30, pp.964 - 990 (2007). DOI: 10.1111/j.1460-2695.2007.01167.x
3. H.M.S.Belmonte, M.J.Mulheron, P.A.Smith, A.Ham, K.Wescombe and J.T.Whiter, "Weibull based methodology for condition assessment of cast iron water mains and its application", Fatigue and Fracture of Engineering Materials and Structures, 31, pp.370 - 385 (2008). DOI: 10.1111/j.1460-2695.2008.01233.x
4. H.M.S.Belmonte, M.J.Mulheron and P.A.Smith, "Some Observations on the Strength and Fatigue Properties of Samples Extracted from Cast Iron Water Mains", Fatigue and Fracture of Engineering Materials and Structures, 32, pp.916 - 925 (2009). DOI: 10.1111/j.1460-2695.2009.01395.x
5. D.A.Jesson, B.H.Le Page, M.J.Mulheron, P.A.Smith, A.Wallen, R.Cocks, J.Farrow and J.T.Whiter, "Thermally induced strains and stresses in cast iron water distribution pipes: an experimental investigation"; Journal of Water Supply: Research and Technology – Aqua; Vol. 59, pp.221 - 229 (2010). DOI: 10.2166/aqua.2010.078
6. D.A.Jesson, H.Mohebbi, J.Farrow, M.J.Mulheron and P.A.Smith, "On the condition assessment of cast iron trunk main: The effect of microstructure and in-service graphitisation on mechanical properties in flexure", Materials Science and Engineering A, 576, pp.192 - 201 (2013). DOI: 10.1016/j.msea.2013.03.061


**4. Details of the impact** (indicative maximum 750 words)

**1. Distribution mains**

During the 1990s and early 2000s, the extent of leakage for the TWUL small diameter pipe network of some 8000 km was well known, and highly criticised, and the company had considerable difficulties in trying to reduce leakage using traditional 'find and fix' activities. However, based on the research work carried at Surrey, TWUL was able to submit proposals to Ofwat which explained why it was necessary to replace significant quantities of London's Victorian mains, in order to reduce the loss of water - clearly linked to deterioration in asset condition. The resulting Victorian Mains Replacement (VMR) programme was a major factor in TWUL being able to achieve its leakage targets over recent years, vindicating the under-pinning research and bringing direct benefit to the environment (through reduced water loss and associated impacts), TWUL's customers (through reduced disruption from 'find and fix' activities) and TWUL itself. The impact began in the ‘run-up’ to PR04 – which led to approval by Ofwat for the VMR programme – continued through AMP4 (2005 to 2010) with delivery of the VMR programme and is continuing into the future through the Distribution Mains Replacement (DMR) programme which aims to identify, and replace, selected cohorts of pipes in ‘poor’ condition.

**2. Trunk Mains**

Whilst the failure of small diameter pipes has limited (local) impact, trunk main failure results in a loss of water supply to thousands of customers and can have significant (life-threatening) impact on the surrounding environment through the flooding of underground assets such as basements and sewers and associated closure of transport systems. There are some 300 - 400 failures per year in the London trunk main network and it is particularly difficult to control the risks reactively as much of the damage occurs immediately after pipe failure. The work undertaken at Surrey has improved the ability to both identify, and reduce, the risk of trunk main failures. However, it is very difficult to justify major capital investment (and cost to customers) based on the consequence of failure alone. For a true reduction in risk, and control it at acceptable levels, it is necessary to understand the causes of failure. Such understanding underpins the ability to predict the likelihood of failure at any location enabling improved asset management so that TWUL can take appropriate actions. The underlying research at Surrey to address this issue, starting in 2005 in collaboration with National Research Centre of Canada (NRC), was to enable TWUL to provide Ofwat with a credible plan as part of the PR09 submission, to achieve:-

i. Initial risk reduction / mitigation during AMP5 (2010 to 2015) and
ii. Production of suitable tools and processes to achieve on-going risk reduction for future AMP rounds (2015 onwards).

Under this collaboration, the research focussed on the probability of failure, based essentially on the extent of loading on pipes (NRC) and their resistance (University of Surrey). The results and understanding gained from the research were used to support TWUL’s PR09 submission for trunk mains, which Ofwat rated as ‘Commendable’ and led to additional spend being made available for investment in targeted main rehabilitation and replacement.

The new thinking that has been developed by the academic team in collaboration with industry is being used by TWUL to both modify their asset assessment and management techniques and to develop their case with the regulator for the targeted replacement of high risk trunk main. The beneficiaries are again Thames Water’s customers - who will ultimately be subject to fewer interruptions in supply - and other stakeholders in London and throughout the Thames region - who will be subject to less disruption. The guiding principles developed for management of risk are also being viewed by other Water companies and were taken into the principles adopted by UKWIR (UK Water Research).

Surrey’s research has been, and continues to be, used by the network operator, TWUL. By gaining scientific credibility for their arguments with the regulator, it has had direct impact on the company’s ability to secure substantial additional investment in both distribution and trunk mains. According to one source **(c)**:

**“The resilience of ageing infrastructure is a serious problem for the water industry. Large programmes of pipe replacement based on simple criteria such as age or consequence of failure, would result in a highly disruptive and vastly expensive solutions. We need to develop the tools and processes to enable us to carefully target investment that will result in reductions in risk down to acceptable levels at reasonable cost and with minimal disruption. The research carried at the University of Surrey over the past 16 years has been a significant factor for both distribution and trunk mains, in the development of such tools.”**

**5. Sources to corroborate the impact** (indicative maximum of 10 references)

**a)** Ofwat's determinations for PR04 and PR09 will include information on the funding approved for mains replacement and trunk mains - although these do not specifically mention the under-pinning research. http://www.ofwat.gov.uk/pricereview/pr09faqs/

**b)** The UKWIR study - Large Diameter Trunk Main Failures (09/WM/08/39) – which is based on the basic principles developed in our research, e.g. pipe age, material, soil type, corrosion, etc, which then lead into statistical methods.

**c)** Consulting Engineer (Formerly Thames Water Utilities Ltd) Contact details provided.

**d)** Project Manager (Environmental Agency) Contact details provided.

**e)** Consulting Engineer (Project auditor for TWUL/Surrey research programme) Contact details provided.

**f)** Innovation Programme and Water Network Research Manager (Thames Water Research Ltd) Contact details provided.