Understanding how the deterioration of cast iron pipes evolves into leakage

Edward John[1], Luca Susmel[1], Joby Boxall[1], Richard Collins[1], Elisabeth Bowman[1], Dennis Dellow[2]
[1]University of Sheffield, [2]Uk Water Industry Research

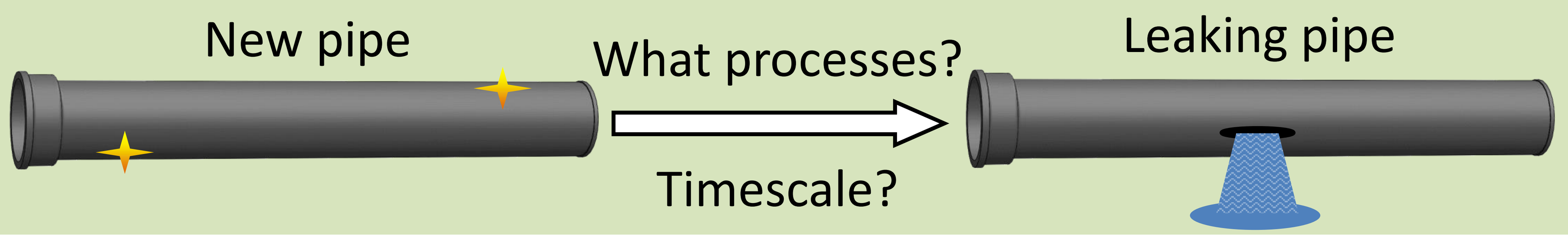
WATER INFRASTRUCTURE AND RESILIENCE WIRe
EPSRC Centre for Doctoral Training

Project overview

- Little is known about how leaks develop in grey cast iron (GCI) water distribution pipes, making it difficult to implement preventative measures.
- This project will use experiments to generate leaking fatigue cracks in GCI pipes, producing data that will be used to validate a predictive model.

What is leakage and why is it important?

- 22% of all drinking water produced in the UK is lost via leakage[1].
- Reducing leakage will improve drought resilience and lower emissions[2,3].
- Understanding the mechanisms that cause leaks to form, and how long the process takes, will enable pipe replacement before leakage begins.



Grey Cast Iron (GCI) pipes:

- Are old; many are 50 to 100 years old[1].
- Are one of the most common types of water pipe[1,4].
- Have high failure rates compared to other pipe materials[5].
- Are vulnerable to corrosion[6].
- Demonstrate brittle cracking behaviour[6].

Graphite flakes cause brittle behaviour

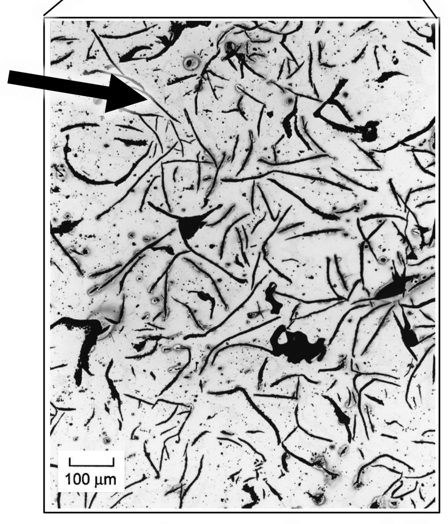
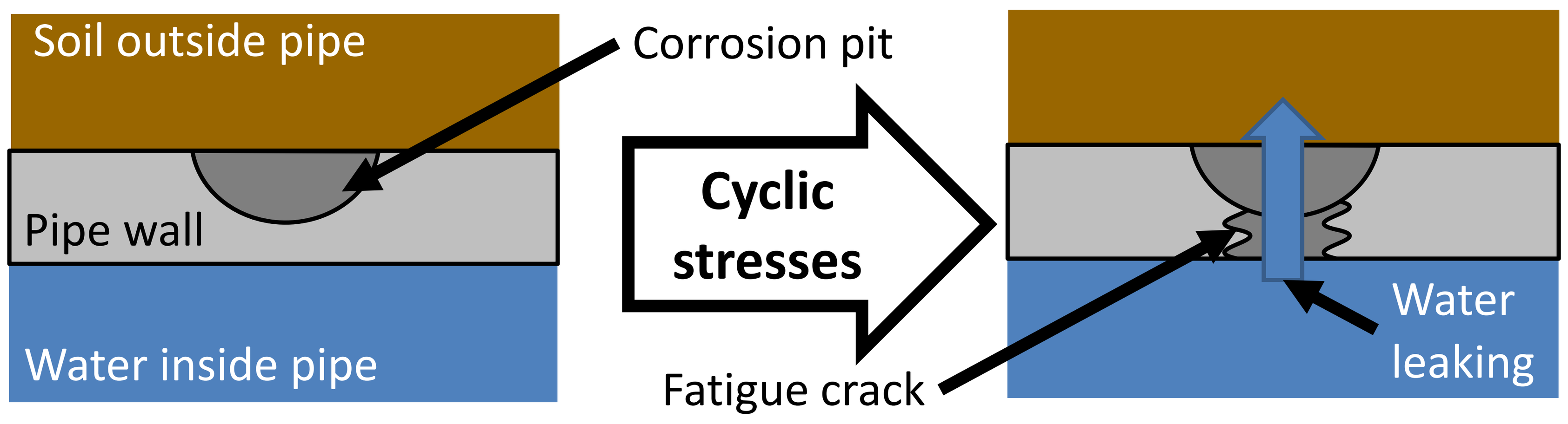


Image from [6]

Leaks caused by fatigue cracking

- Fatigue is the process by which **repeated stress cycles cause a crack to form**, even though the individual stresses are too small to cause cracking by themselves.
- GCI pipes frequently experience surface corrosion pitting which causes localised stress concentrations, creating sites for fatigue crack initiation.
- No validated model to predict the formation of leaking fatigue cracks in GCI pipes currently exists – this project aims to address this gap.



What loads do buried pipes experience?

Internal Water Pressure

$P(t)$

Source: Water carried
Frequency: Often >1 load cycle per day

Vertical Loads

$F(t)$ $F(t)$

Source: Soil and vehicle weight (if under road)
Frequency: 100s per day for vehicle load

Thermal Loads

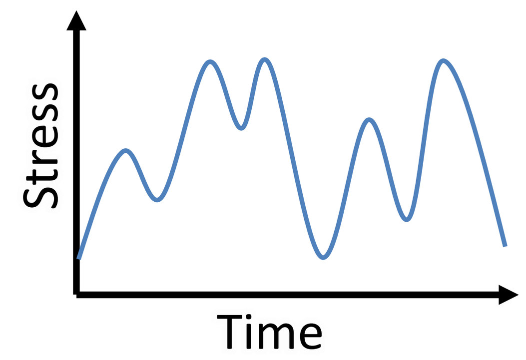
20°C to 3°C

Source: Reducing pipe temperature when pipe is axially constrained
Frequency: Seasonal

Soil Swell

Source: Soil expansion during wet weather
Frequency: Seasonal

Cyclic loads cause cyclic stresses:



In summary, buried pipes experience **cyclic loads** which cause complex, **multiaxial stress fields**

Research questions

- How can the formation of leaking fatigue cracks in GCI pipes be reproduced experimentally?
- How many stress cycles are needed for a leaking fatigue crack to form, and what is the crack's size, shape and position?
- How can fatigue theory be used to predict the number of cycles to leaking crack formation under both experimental and real-world conditions?

Methodology

1. Design and build the experiment.
2. Fatigue test GCI pipe specimens using the experiment.
3. Use experimental data to validate a predictive fatigue model.

The Experiment

Testing pipes is the only way to recreate the complex, multiaxial stress fields seen in reality. High-magnitude, high frequency stresses will be used to **speed up the cracking process from decades to days**.

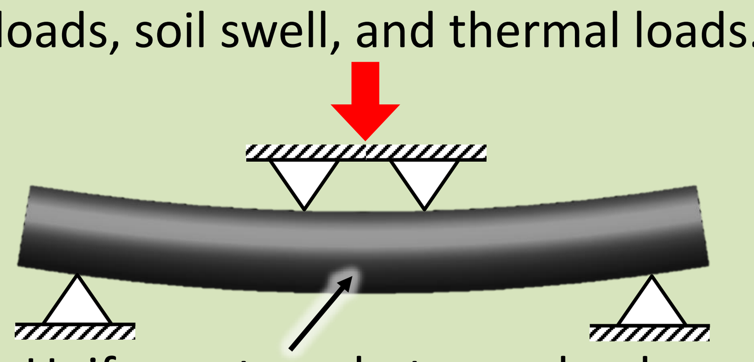
Loads applied:

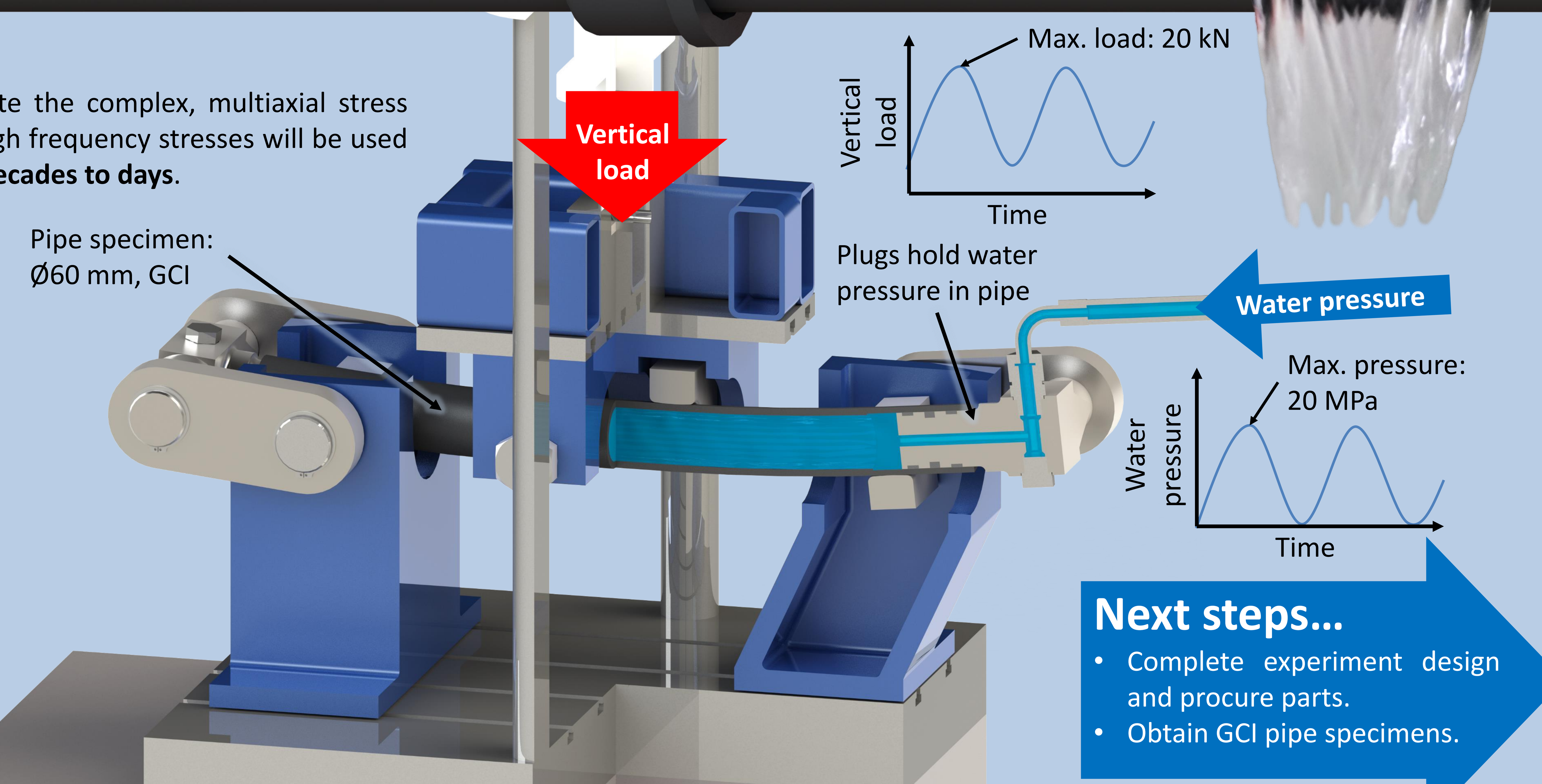
Cyclic Water Pressure

Stresses representative of internal water pressure loading.

Cyclic Four-Point Bending

Stresses representative of vertical loads, soil swell, and thermal loads.





Next steps...

- Complete experiment design and procure parts.
- Obtain GCI pipe specimens.

[1] J. Farrow, D. Jesson, M. Mulheron, T. Nensi, and P. Smith, "Achieving zero leakage by 2050: The basic mechanisms of bursts and leakage," UK Water Ind. Res., no. 17, 2017.
[2] National Infrastructure Commission, "Preparing for a drier future: England's water infrastructure needs," Apr. 2018. Accessed: Dec. 15, 2020. [Online]. Available: https://nic.org.uk/nic-preparing-for-a-drier-future-26-april-2018/.
[3] Discover Water, "Energy & Emissions," Find out how water companies in England & Wales are performing, 2020. https://www.discoverwater.co.uk/energy-emissions (accessed Jan. 22, 2021).
[4] J. B. Boxall, A. O'Hagan, S. Pooladsaz, A. J. Saul, and D. M. Unwin, "Estimation of burst rates in water distribution mains," 2007, doi: 10.1680/wama.2007.160.2.73.
[5] Barton, N. A. et al. (2019) 'Improving pipe failure predictions: Factors effecting pipe failure in drinking water networks', Water Research, 164, p. 114926. doi: 10.1016/j.watres.2019.114926.
[6] Makar, J. M. and Rajani, B. (2000) 'Gray Cast-Iron Water Pipe Metallurgy', Journal of Materials in Civil Engineering. doi: 10.1061/(asce)0899-1561(2000)12:3(245).

www.cdtwire.com

For further information:
edajohn1@Sheffield.ac.uk

UKWIR UK Water Industry Research
The University Of Sheffield.
UKRI Engineering and Physical Sciences Research Council