At the halfway mark - an overview

Overall overview by Chief Investigator Jayantha Kodikara, 27 May, 2014.

At the halfway mark of the Advanced Condition Assessment and Pipe Failure Prediction Project, we (three lead investigators) are pleased to provide brief overview reports. There is also a report from Mike Shepherd of UK WIR.

Activity 1 Overview

By Jayantha Kodikara, 27 May, 2014.

At Monash University we were charged with addressing the question "*how, where and when do critical pipes fail in a water pipe network?*" We very well knew that to do justice to answer this *well tried* question is going to be certainly challenging. So we derived motivation from the Einstein's quote "*We cannot solve our problems with the same level of thinking that created them*". This is quite fitting because these old pipes have been designed a long time ago generally with a factor of safety more than 10, and we know that the factor of safety is a kind of "factor of ignorance". So, there was a lot of margin to hide our ignorance in calculating the influence of external and internal factors, for example, considering the influence of traffic loads using conservative stress calculation models. In fact, even today, designing a pipe in the ground is easy, but the question asked from us is altogether different and quite challenging. Some people might even say that it is impossible to predict where a pipe would fail, because it appears so random. Demotivating and complex as it may be, we derived courage to go forward from another one of Einstein's quotes; "*God does not play dice".* (This was the great man's, as it turned out, somewhat foolish response to the development of quantum mechanics that relied on probabilistic theory). It meant that pipe failure is still a deterministic process masked only by uncertainty of the input variables, giving an appearance that it is an inherently random process, like quantum positions of an electron.

So we knew that we needed to get all the help we can from practitioners, failure data, forensic analysis, and field measurements to refine the calculation input for internal/external factors and establishing the pipe failure mechanisms and states. So our first task was to undertake a data collection exercise from all our partners. This turned out be painful on many counts. First, it was difficult to get the data from all partners, not to mention the frustration of my staff. Second, when we completed a 70 page report on the data analysis, some reminded us that they had seen such data analysis countless times before, since much past research has been *on just that only*. But our intention was to get the "pulse" of our partners to focus our effort, develop a database that we could use throughout the project and glean any "tell-tale signs" from even somewhat unreliable sets of data. We achieved all these outcomes and, in particular, we developed three corrosion categories (uniform, patch and pit corrosion) to refine pipe stress analyses.

Having been a practitioner myself (during Paul Keating's *had to have recession*), I very well knew that it is the Utility Manager's apprehension that, while it is a good idea to hire a bunch of seasoned academics to solve their problem through fresh thinking, they could also go off on tangents and make it a theoretical problem and produce results that industry cannot use. So I tried to lay their fears aside by coining the phrase that we intend to produce "Goldilocks solutions – Not too empirical and oversimplified, not too complicated and theoretical, but Just Right". However, we did not sway from our trusted university approach of "Bottom Up Analysis – understand and analyse things in detail and then simplify, with knowledge of simplification errors, to practical use".

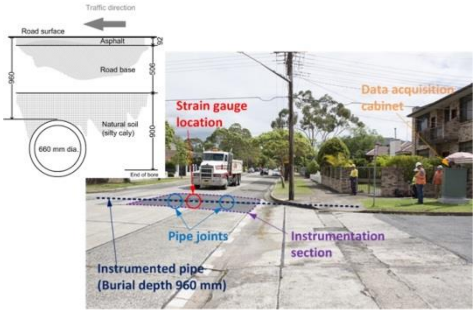
As noted previously, there was uncertainty in relation to influence of traffic loading on critical pipes since many were laid under roads. There was anecdotal evidence that more failures happen at traffic lights and bends etc.

With the generous support of Sydney Water, we instrumented a section in Strathfield and measured the response of the test bed pipe under live traffic and simulated traffic with and without water pressure. It turned out that under moderate corrosion conditions, traffic load induced pipe stresses are about one eighth of those due to water pressures, and the influence of breaking and cornering etc., was not that significant. And our numerical model was able to reproduce this. Backed by this validation and running numerical models for over 1000 computer hours, we were able to produce an equation and a TOOL for stress calculation of <u>uniformly corroded pipes</u> (the first Goldilock's solution). Subsequently, stress concentration factors (SCF) were found to modify this solution for patch corrosion.

Internally, water pressure and transient pressure development was identified as an issue by our partners during scoping. So we instrumented the Hunter Water network and monitored the pressure development, unprecedentedly failing a pipe during our interference. Not only could we model the transient developments, we could also calculate pressure development even in the reticulation system. Currently, some Goldilock's solutions are being developed to cater for estimating the transient pressures without detailed numerical work.

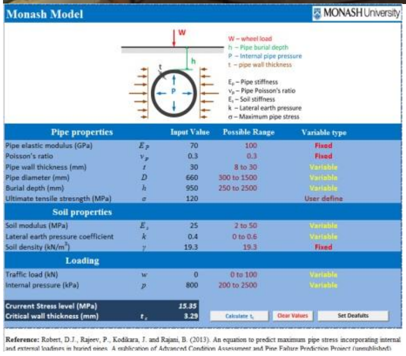
In order to draw confidence in our developed models, we follow a three pronged approach: (a) "ball park" validation against failure data which have limited information; (b) detailed validation through forensic analysis of major failures; (c) full scale laboratory tests. In case of (b), the forensic analysis of the Sydney Water Harris Street failure which occurred without much corrosion was quite engaging and insightful. We were able to explain the major pipe burst as *unstable fast fracture* induced by a crack that grew to critical length after initiating at the joint. However, it raised the question, how did the crack grow sub-critically to the critical length? Given that similar failures have occurred in the UK and the USA too, we decided to investigate this by setting up a PhD project on fatigue failure of cast iron pipes. In case of (c), we developed a facility for full scale pipe bursting, where we failed a variably corroded pipe section obtained from the decommissioned pipeline of the Sydney Water test bed. This pipe withstood water pressures of 360m, about 6 times the field water pressure. *This test itself highlights the value of this Advanced Condition Assessment and Pipe Failure Prediction Project in that this pipe could have been left in the ground for another 50 years or so, if only we knew more accurately the pipe condition, pipe corrosion rate and how to calculate the pipe failure state.*

While we have achieved more than what we anticipated at this project's half way mark, it was not without frustrations. Unfortunately, I lost two of my able researchers, who looked for more stable and permanent positions to further their careers, which on the bright side, is an achievement by itself of training staff. Mostly, unaided management of a diversified and packed academic portfolio is not without frustrations, but the feeling that our work is appreciated tends to calm the nerves. With new recruitments in place and Round 2 beginning, we are soldiering ahead to the second half of this project with the intention of producing a lasting solution to the problem that we are entrusted with. This will certainly be an interesting and hopefully fruitful and eventful journey as we deal with remaining lifetimes of pipes, failure probabilities and fatigue, trying to put the jigsaw together.



Traffic instrumentation

Burst test facility



W – wheel load
h – Pipe burial depth
P – Internal pipe pressure
t – pipe wall thickness

E_p – Pipe stiffness
ν_p – Pipe Poisson's ratio
E_s – Soil stiffness
k – Lateral earth pressure
σ – Maximum pipe stress

Pipe properties		Input Value	Possible Range	Variable type
Pipe elastic modulus (GPa)	E_p	70	100	Fixed
Poisson's ratio	ν_p	0.3	0.3	Fixed
Pipe wall thickness (mm)	t	30	8 to 30	Variable
Pipe diameter (mm)	D	660	300 to 1500	Variable
Burial depth (mm)	h	950	250 to 2500	Variable
Ultimate tensile stresngth (MPa)	σ	120		User define
Soil properties				
Soil modulus (MPa)	E_s	25	2 to 50	Variable
Lateral earth pressure coefficient	k	0.4	0 to 0.6	Variable
Soil density (kN/m^3)	γ	19.3	19.3	Fixed
Loading				
Traffic load (kN)	w	0	0 to 100	Variable
Internal pressure (kPa)	p	800	200 to 2500	Variable
Crurrent Stress level (MPa)		15.35		
Critical wall thickness (mm)	t_c	3.29		

Reference: Robert, D.J., Rajeev, P., Kodikara, J. and Rajani, B. (2013). An equation to predict maximum pipe stress incorporating internal and external loadings in buried pipes. A publication of Advanced Condition Assessment and Pipe Failure Prediction Project (unpublished)

TOOL for stress analysis

Activity 2: Direct Condition Assessment

Jaime Valls Miro

Gamini Dissanayake

Half-way Mark Statement
10 June 2014

The project has just ticked over the half-way mark. For a project of this magnitude, with so many parties - from all over the world - with a shared objective but at the same time each with their own internal agendas and needs, that it is still pushing ahead as one is, in our humble opinion, an achievement in itself.

The shape of things to come really became apparent in July 2009, when the Condition Assessment Planning workshop for the Australian Research Council Linkage Project proposal took place in Sydney. At the end of that meeting, our first real engagement with the sector and the key industry partners, we thought there was no way we could pull this off. The need was all but crystal clear to all those present, a large list of national and international attendees.

As outsiders to the industry, the vast apparent gap integral to the decision making process - made overwhelmingly clear to us all at the time, the sheer scale of the problem and, in particular in the case of Activity 2, the somewhat reluctance of the technology providers to participate in it, felt almost insurmountable at the time. It really felt that viewing the issues surrounding condition assessment from the periphery was actually an asset in this case: a fresh angle to an old problem could really bring a positive change in this space to the ultimate benefit of the project partners: the water utilities.

A great challenge at the beginning was setting up the administrative structure. Business cases needed to be made, mechanisms for proper management had to be put in place, legal matters needed to be clarified, teams had to be put together. That was painful at times, still is today, with constant reminders in terms of research services agreements, risk assessments, non-disclosure agreements, carefully managed communications with providers, Technical Assessment Committee documents, publication disagreements, occupational health and safety, storage space, research plans, and awards documentation.

On the one hand, two and a half years after the project started, we are all aware of the unique opportunity this project has brought to all the players. We were able to recruit excellent staff, bringing in expertise from electromagnetic theory, machine learning, optimisation and probabilistic robotics to deal with this challenging problem. The project also attracted a number of PhD students who have proven to be of very high calibre. Currently we have five University of Technology Sydney academics who contribute to the project, three research fellows and a research engineer funded by the grant, and five PhD students.

The project has brought to the surface benefits to the players by thinking outside the box, and we're starting to bear fruits. This is exciting. We have engaged five technology providers with one more on the way. We managed to conduct extensive trials at the test bed and even outside of it. We were able to come up with new methods for interpreting data acquired in the trials and delivered software modules to three of the technology providers. We have overcome the challenge of establishing the mechanism to evaluate new and former methods for data interpretation. We are pushing ahead with a number of innovative adaptations of the basic electromagnetic techniques used for condition assessment. We have come to grips with acoustic techniques that give information about the average condition of the pipe. We are now well set to tackle the most challenging part of the project – interpretation of the pipe condition along its whole length from a limited set of measurements.

On the other hand, the biggest challenge to date has been managing the engagement with the technology providers. Being small players, they were concerned about IP and there was a reluctance to participate. We have persevered with our legal team putting together a sound framework for engagement. Now we have four providers well engaged with the research team and already it is reaping benefits, although we have another one that is yet to be convinced. At a more personal level, it is hard not to feel somewhat frustrated about the impression of being caught in the middle of a tug-of-war where utilities, technology vendors, research bodies, marketing departments, and agendas… are pulling in all directions, and as project leaders we are attempting to isolate the research team from all these so that they have enough clear air to get on with the real work and make a significant contribution to tackle this important national and international problem.

Assessment of Overall Progress - Activity 3

Rob Melchers

March 2014

This report provides an overall assessment of the progress achieved and the likelihood of achieving the original target outcomes for Activity 3 of the Advanced Condition Assessment and Pipe Failure Prediction Project. The aim of Activity 3 is to produce a (mathematical) model to allow better quality predictions of the likely exterior corrosion of water pipelines and to provide estimates of the likely rate of future corrosion. This Activity is at about the halfway stage of the research plan.

Research for developing models can be done in various ways. One simply correlates observations and data. Our previous research has shown that this is not particularly satisfying or insightful. It ignores knowledge already available. Our approach builds on (or adapts) existing models for long-term trending observed for ferrous material corrosion in a variety of environments. These models are based on scientific principles. They can be expressed by physico-chemical relationships. They provide trends for the development of general corrosion loss with time as a function of environmental influences. Similar models apply for maximum pit depth.

The research plan envisaged the conceptual model being calibrated mainly to literature data. For example, earlier researchers, principally in Japan, had reported extensively on statistics of the corrosion of cast iron pipes. Despite repeated efforts, the data appears no longer available. This, of course, raises serious doubts about the validity of the outcomes reported by these researchers.

Right from the beginning we knew that the corrosion of ferrous pipes in the ground depends primarily on the soil environment. A key driver is soil moisture but even the famous work of Romanoff does not report this adequately. As a result more effort is being put into estimation of soil moisture where it cannot be measured directly.

The project plan was based on only a small amount of data being available from actual pipes exhumed by the water utilities. In actual fact one of the utility partners, Hunter Water, contributed a considerable amount of data on the condition of actual pipes. This was a major break-through and showed other water utilities what was possible. One important outcome was the development of a data collection protocol. For the first time this sets out how data from the field should be collected. It is a ‘first’ for the water industry and provides a way to obtain consistent data for current and for future research activities. The protocol is being rolled out to other water utilities in Australia and overseas. A second outcome, with major consequences for actual progress, was the availability of infrared scanning equipment to record the surface profile of the exhumed pipes. Not foreseen originally, it has provided data never previously available for building models. It also is already helping us start to construct probability models for pitting corrosion - we will report more subsequently.

Rather than researchers sitting in their offices developing computer codes, it is our view that better, more relevant model development is achieved by observation and understanding of the practical aspects as well as theoretical concepts. All our corrosion research has worked this way, and the pipes project is no exception. Our research people have spent considerable time 'in the field' working with Hunter Water and Sydney Water field staff. Similarly, insights were gained through discussions with operational staff in the UK (and to a lesser extent in the USA). It sets the work in Activity 3 apart from previous research and development of in-ground corrosion of ferrous pipes anywhere. One outcome is that the way the trenches were backfilled in the past and thus the degree of contact between backfill soil and pipe achieved is a critical factor, known in the industry, but not mentioned or considered in any previous research work. How to deal with this as a parameter in the modelling work is an exciting research issue.

Obviously, the project is developing and progressing in a manner somewhat different from originally envisaged - it is now skewed away from reliance on literature data to much greater reliance on actual field data. This is a very positive development, both for industry and for the researchers (but not necessarily for research project managers). Such unforeseen development is very much in the nature of research - otherwise the project could have been contracted out to a consultant. The important corollary is that the project outcomes are likely to be more rational and relevant to practical application. But the eventual model may take longer to develop!

It is anticipated that with data collection protocols in place, and more field data expected, with less direct involvement of research staff, attention now can be transferred back to model calibration and the role of influencing parameters. It is considered at this time, about half-way through the project, that Activity 3 will achieve its primary aims within the intended timeframe.

From Mike Shepherd, UWWIR 25 March 2014

“The Advanced Condition Assessment and Pipe Failure Prediction Project is a large and complex project involving considerable theoretical work carried out by a number of academic institutions yet is of vital importance in addressing the very practical objective of enabling water utilities to make important and expensive investment decisions on the maintenance of their buried infrastructure and the provision of high quality service to customers. When large projects such as this have a high academic content involving a number of separate institutions, there are always the dangers of researchers into different aspects of not co-ordinating their efforts towards the common goal and/or pursuing interesting side-lines thrown up by their work that are not relevant. The Advanced Condition Assessment and Pipe Failure Prediction Project has avoided these pitfalls by establishing a management structure that safeguards against these dangers. The Technical Advisory Committee ensures that all aspects of the research are co-ordinated while the overall Committee of Management ensures that all work is focused on the outcome specified by the end users whilst permitting the research work to deviate from the original plans where this is felt to be beneficial to the end goal. As a result of this approach, the project has already achieved meaningful results although only just over halfway through, all within budget, and with no deviations that did not contribute to the desired end result.”