AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING

CIVIL ENGINEERS ANSHM

Newsletter

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President Message

Tommy Chan

Professor in Civil Engineering, Queensland University of Technology

Dear All,

The first ITRP Workshop to promote our proposed ANSHM ARC Industrial Transformation Research Hub (ITRH)/Industrial Transformation Training Centre was held on August 13, 2024. The workshop aimed to introduce its initiatives, highlight the benefits of participation, invite participation, and provide updates on our progress. I believe those who attended will agree that the workshop was a great success. Attendance was by invitation, and we had 45 participants—26 in person and 19 online.

I would like to take this opportunity to thank all the presenters and attendees who contributed valuable insights during the workshop, especially those who travelled to Brisbane by flight specifically for this afternoon event.

For those who could not attend, I summarized below each presentation and the discussions based on my notes and understanding. Please note that these summaries have not been confirmed by the presenters or those who shared their views during the Open Discussion.

The first presentation was given by Prof. Ana Deletic, the Executive Dean of the Faculty of Engineering at QUT. Since she had already planned a trip to Sydney when I invited her, she could only present online. She provided an overview of the ARC Industrial Transformation Research Program, highlighting the differences between the ARC Industrial Transformation Research Hubs (ITRHs) and ARC Industrial Transformation Centres (ITTCs), and offered insights on how we could better prepare for a successful bid. She also emphasized the importance of ensuring that the industry ecosystem we aim to transform through the ITRP Research Program has a strong commercial edge.

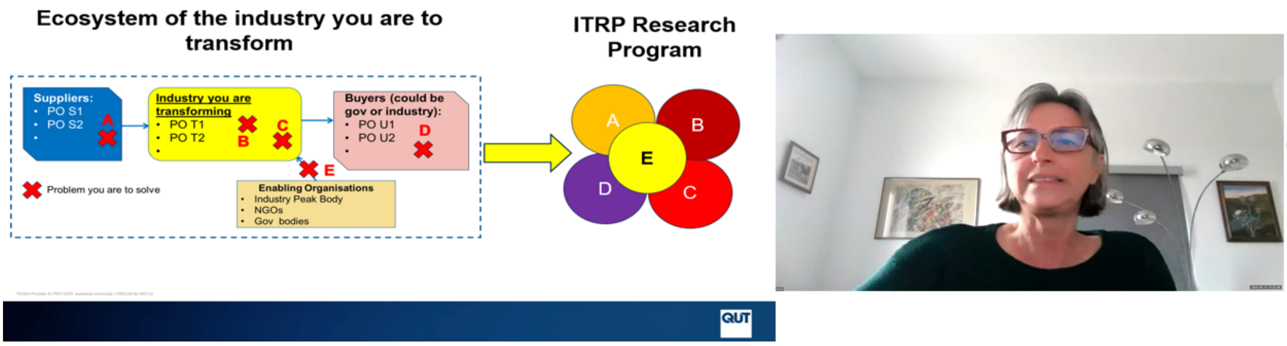

Figure 1: Prof. Ana Deletic, the Executive Dean of the Faculty of Engineering at QUT, giving her presentation

I then gave a presentation about ANSHM, noting that we are celebrating our 15th anniversary in 2024. We look forward to commemorating this milestone by establishing the ANSHM ARC ITRH/ITTC for SHM. I highlighted the tireless efforts of ANSHM Executive Committee and Advisory Board members over the past 15 years to promote SHM technologies and their installation for the benefit of our countries. It's time for us to strengthen our collaboration with industry and secure funding from the Australian Research Council (ARC) to shape the future of infrastructure operation, maintenance, and management through transformative digital and AI capabilities using SHM. The proposed ITRH/ITTC will provide research and training to help key Australian industries in infrastructure-rich sectors (such as transport, energy, utilities, and mining) future-proof our infrastructure, leveraging structural health monitoring technologies to address challenges and achieve commercial, resilience, sustainability, and social goals.

Figure 2: Overview of ANSHM and ARC ITRP Opportunities presented by me as the President of ANSHM

Figure 3: Infrastructure Research Needs presented by Dr. Torill Pape, Acting Deputy Chief Engineer (Structures), the Queensland Department of Transport and Main Roads

Next, Dr Torill Pape, Acting Deputy Chief Engineer (Structures) from Queensland Department of Transport and Main Roads (TMR), presented on "Infrastructure Research Needs". She began by sharing her experience in her 'Post-Professor' life. Dr Pape explained how her team with around 80 team members, is responsible for managing approximately 33,000 km of roads and around 8,000 major structures across Queensland, which include bridges, tunnels, gantries, retaining walls, major culverts and buildings, overseeing all aspects of the asset lifecycle. She concluded by emphasizing the importance of collaboration in research programs to better understand asset behaviour and performance, particularly with the use of new materials, and how data-driven insights are crucial for informed decision-making.

Dr Huadong Mo of UNSW, along with Mr Dobby Guo of Advanced United Technologies Pty Ltd and Mr Chunyang Zhang, an Industry PhD student with Sungrow Australia Group Pty Ltd, gave a presentation on "Health Monitoring for Energy Assets: Its Significance and the Benefits of Academic-Industry Collaboration." Dr Mo began by explaining the critical role of electrification and energy systems networks in decarbonization. He emphasized that the design, integration, operation, and monitoring of these systems in energy infrastructure present several challenges that must be addressed for successful decarbonization. He then shared examples of his successful collaborations with industry partners in health monitoring renewable assets.

Figure 4: Dr. Huadong Mo of UNSW presenting successful examples of research collaboration between industry and academia

Prof. Tuan Ngo of the University of Melbourne, a Professor and Research Program Leader of Building 4.0 CRC & Research Director of the ARC Centre for Advanced Manufacturing of Prefab Housing (ARC CAMP.H), and an Executive Committee member of ANSHM, recorded his presentation as he was on a flight back to Melbourne from Vietnam. Drawing on his extensive experience in industry collaboration through Building 4.0 (Total Value: $130M) and ARC CAMP.H ($4M ARC funding plus matching industry funding), Prof. Ngo discussed the three key success factors for industry-academic partnerships: i) Understanding industry partners' needs, ii) Building trust, and iii) Creating win-win partnerships. He also highlighted how these collaborations lead to the development of new materials, systems, techniques, and processes, including new financing and supply-chain models, improved productivity and safety in construction, lower life cycle costs, upskilling of the existing workforce, and the advancement of high-value manufacturing capabilities.

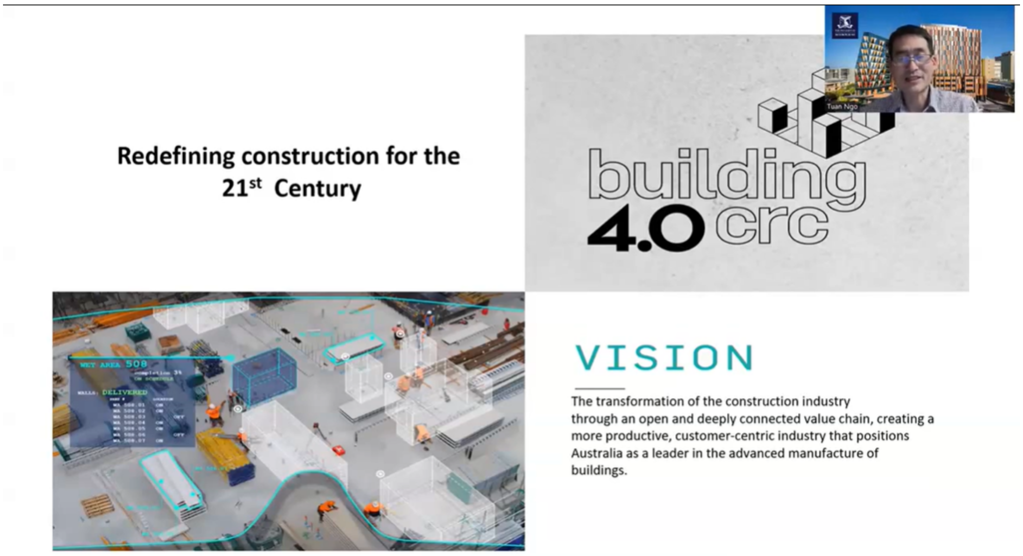

Figure 5: Prof. Tuan Ngo discussing successful examples of research collaboration between industry and academia in ARC CAMP.H and Building 4.0 CRC and other projects

Lee Hellen, Co-Founder and CEO of Kurloo Technology Pty Ltd, then spoke about the reasons for joining the proposed ITRH/ITTC. He began by sharing the success story of developing Kurloo, a commercial product that frequently and accurately acquires vital 3D displacement and settlement data at scale. He provided real-life applications of the device, such as assisting Queensland Rail by using 35 devices over a 10 km length, which took less than 1.5 days to install and provided superior information for inspections and maintenance. Other examples included monitoring slopes, bridges, and highway works. Lee emphasized that all projects under the proposed ITRH/ITTC could incorporate a commercialization component. He believes that joining the proposed ITRH/ITTC could help shape the right ideas and visions to attract future investment.

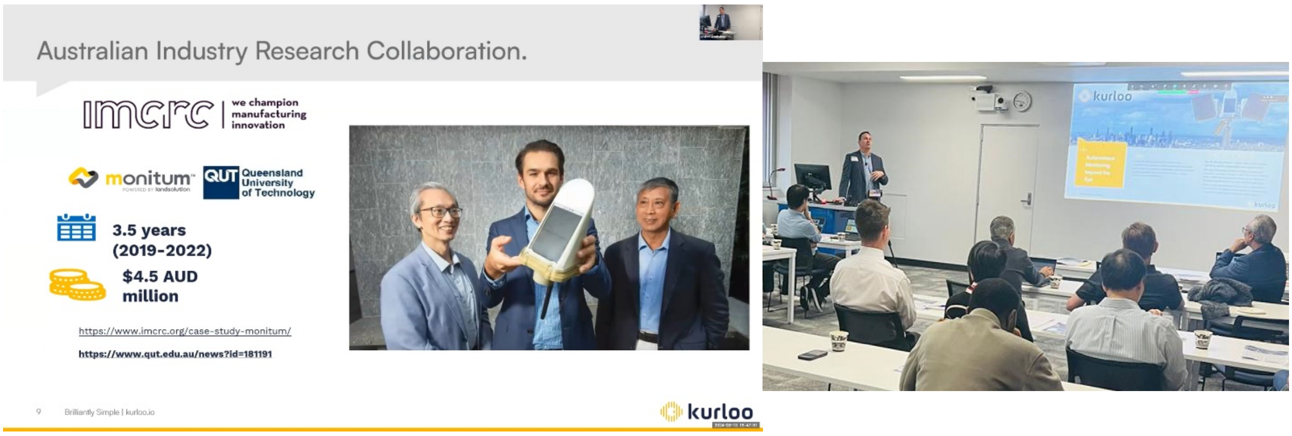

Figure 6: Lee Hellen talked about how research collaboration between universities and industry led to the development of Kurloo

Our final presenter was Dr. Govinda Pandey, CEO of Rockfield Technologies Australia Pty Ltd and a long-standing member of the ANSHM Advisory Board, serving almost since its inception. Govinda, who hosted our last Annual Workshop in Townsville—one of the best in the series—discussed "Infrastructure Monitoring Opportunities and Gaps." He began by addressing strategies for managing aging infrastructure and highlighted his collaboration with QUT, which began in 2014 with a Research in Business project. In this project, one of my PhD students worked at Rockfield for 12 months after completing his degree. The project was successful, and the PhD graduate is now a staff member at Rockfield. He also outlined other collaborative projects, including partnerships with CSIRO Data 61, Monash University, and James Cook University. He emphasized the need for physics-informed data science supported by AI, which could be a major component in the proposed ITRH/ITTC. He concluded by discussing the "Innovation Valley of Death," the gap between government and universities (Technology Readiness Levels 1-5) and the private sector (Technology Readiness Levels 6-9). Govinda believes the proposed ITRH/ITTC could help bridge this critical gap.

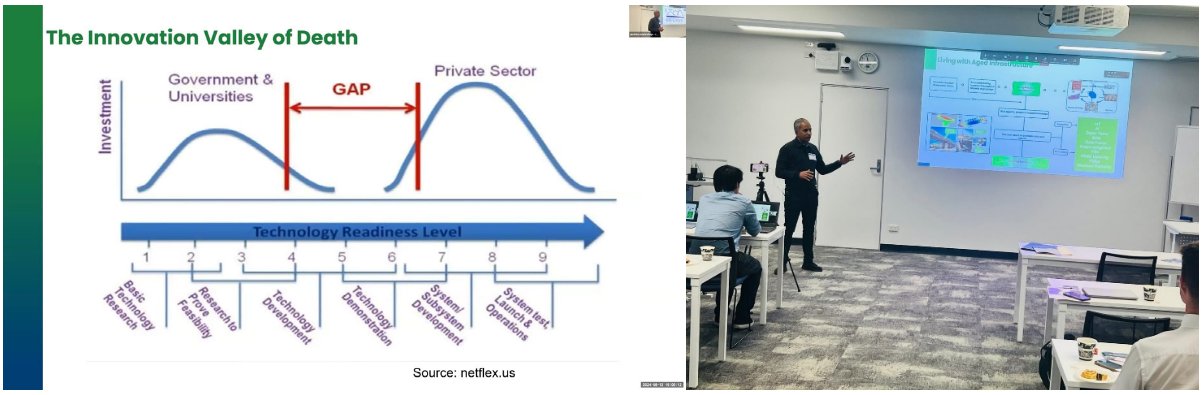

Figure 7: Dr. Govinda Pandey of Rockfield Technologies Pty. Ltd. discussing how the proposed ITRH/ITTC could help academia and industry bridge the gap between government/universities and the private sector

After all the presentations, we had an open discussion facilitated by Prof. Hong Guan of Griffith University and A/Prof. Chaminda Gallage of QUT. During this session, all the industry partners (except the presenters) introduced themselves and explained their reasons for attending the workshop. We collectively acknowledged the gap between academia and industry, with some participants noting that this gap seems to be widening. I then explained that the objective of the proposed ITRH/ITTC is to transform this culture and help bridge the gap. It is also expected that the proposed ITRH/ITTC could help to keep the analytics credible and useful. Questions regarding IP issues and the governance of the proposed ITRH/ITTC were addressed, with details provided in the two documents distributed during the workshop. In conclusion, I stated that in the coming weeks, we will consult with industry partners who have confirmed cash contributions to gather their expectations and the issues they would like the proposed ITRH/ITTC to address, so that we can shape the Research Training Hub accordingly.

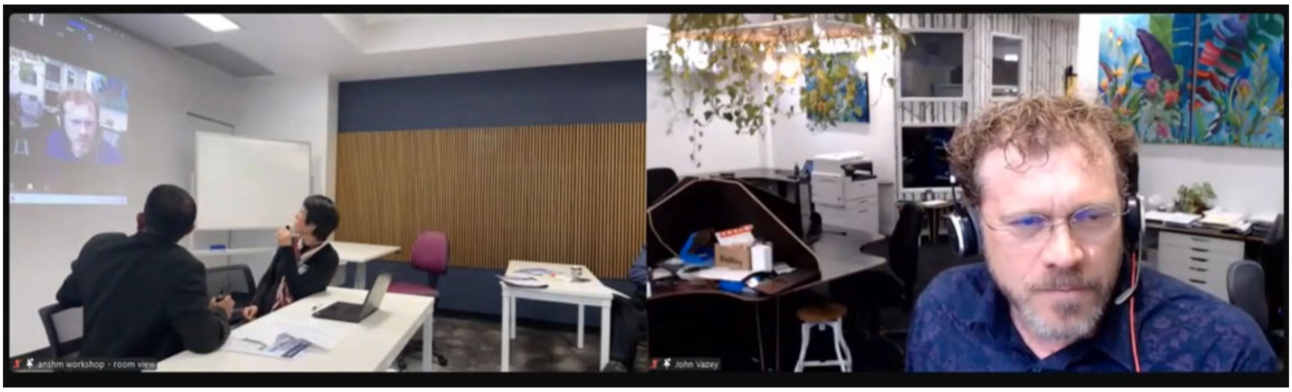

Figure 8: Open discussion facilitated by Prof. Hong Guan (Griffith University) and A/Prof. Chaminda Gallage (QUT) as John Vazy of EngAnalysis shares his views

Below are the updates for the month.

ANSHM ARC Industrial Transformation Research Hub (RH)/Training Centre (TC)

It can be seen from my summary above on the IRTP Workshop on 13th August 2024, that the preparation of the proposal to establish ANSHM ARC Industrial Transformation Research Hub (RH)/Training Centre (TC) on Shaping Future Infrastructure Operations, Maintenance and Management with Transformative Digital and AI Capacities is progressing well. Using the term "Confirmed" to refer to those IPs who have agreed in principle to participate with cash contributions and are ready to prepare the Letters of Support, "Likely" are those with conversations at an advanced state, and all the others we have approached excluding those who have indicated that they are not interested at the moment as "Prospective", the update of the cash contributions are as follows:

- Confirmed: A$3.35 M from 13 companies
- Likely: A$2.325M from 13 companies
- Prospective: $4.4 M from 23 companies

As mentioned above we prepared two documents for us to share with the potential industry partners for them to know better about this proposed ITRH/ITTC and how to participate:

1. ITRP 2025 for SHM_Call for participation_Print Ready_V6(A3).pdf (A3 double side fit on short page) – as a compact document explaining more on the needs of establishing this Hub/Centre, which you have used earlier to approach your PIPs.
2. ITRP 2025 for SHM_Overview v3.pdf - Overview of proposed research Hub/Centre for SHM with more details of the program/research themes, benefits, key dates and governance.

The documents were also distributed at the ITRP Workshop on 13th August. Please email me if you would like to have an electronic copy of each of these two documents.

At this stage, we only need a Letter of Support from our Industry Partners who have confirmed their cash contributions. The Letter of Support has a certain format to follow and ARC will only provide the template for the required format when they open the application on 9 Oct 2024. It would be too late if we start to work on the Letters of Support when ARC provides the template. Hence, we will help the Industry Partners with confirmed cash contributions to prepare the LOS as much as we can now. Once the template is available, then the IPs could sign on the LOS with the standard required format and then it could be collected for the proposal to be submitted in November. If we are successful in the application, which will be announced by ARC in July 2025, there will be a standard ARC agreement to be signed, of which the terms are negotiable, including IP terms and the exact amounts contributing to the ITRH/ITTC (cash and in-kind), and the work to be done, and the payment schedule, etc. ARC allows a maximum of 12 months for the agreements with the Industry Partners to be signed. Hence the Industry Partners will only need to commit their cash contribution after the agreements are signed by July 2026. As I stated in the ITRP Workshop above, meanwhile we will also consult industry partners with confirmed contributions to align the proposed ITRH/ITTC with their expectations and needs to prepare for the proposal.

16th ANSHM Workshop

Please find below the details of the 16th ANSHM Workshop:

Title:	The 16th Australian Network of Structural Health Monitoring Workshop
Theme:	Monitoring Infrastructure: Quantifying Safety & Resilience For a Sustainable Future
Host:	RMIT University
Organizers:	A/Prof Lei Hou (RMIT), A/Prof Kate Nguyen (RMIT), Prof Tuan Ngo (UoM), A/Prof Colin Caprani (Monash Uni)
Dates:	21- 22 November, 2024 (Please mark the dates on your calendar)
Venue:	Building 80, Level 6, Room No. 5, RMIT City Campus, Melbourne CBD

Topics:

- Advancements in Structural Health Monitoring Technologies
- Quantifying Infrastructure Resilience: Metrics and Methodologies
- Integration of AI and Machine Learning in Infrastructure Safety Monitoring
- Remote Sensing and Drones in Infrastructure Inspection and Safety
- Sustainable Practices in Infrastructure Monitoring and Maintenance.
- Impact of Climate Change on Infrastructure Resilience
- Economic Implications and Public Policies and Regulations

Please click here to download the Flyer of the Workshop.

Please click here to Register your attendance by **31 October 2024**

Industry News

Please find below the industry updates and views shared by John Vazy of EngAnalysis, our Industry Liaison Officer:

- The Australian SHM industry supports the ARC's Industrial Transformation Research Hub/Training Centre initiative.
- Industry leaders with integrity hope the promotion of the SHM-ITRH/ITTC will foster data-driven decision-making and expose the superficial use of tech buzzwords and flawed concepts.
- It's crucial and timely to educate the public, or even the engineering industry on the following points:
  - SHM and monitoring technologies can reduce carbon emissions by managing risks when extending the life of aging infrastructure.
  - Defining operational loads and calibrating idealized models with short-term measurements is a cost-effective starting point for infrastructure monitoring.
  - SHM technologies complement visual inspections but are unlikely to replace them, especially for aging infrastructure.
  - SHM provides increased vigilance, objectivity, and persistence for specific tasks, though its effectiveness is limited by the finite number of sensors.
  - Intelligent monitoring focuses on providing data necessary to quantify risk.
  - AI, Big Data analytics, sensors, and modal analysis are tools, not solutions.
  - Measuring a structure's natural frequency under unknown loading rarely provides health insights.
  - The term "health metric" is meaningless.
  - Accurate data in engineering units can inform; poor data likely magnifies loss.
  - For effective project outcomes, the proposed ITRH/ITTC, with the right structure, could offer a valuable opportunity for industry-academic collaboration.

- The initiative of establishing the ANSHM proposed ITRH/ITTC presents an opportunity to rethink outdated, unsuccessful models and demonstrate how ARC support can complement existing commercial projects, efficiently transforming our industry.
- Examples of active SHM projects this month:
  - Estimating the fatigue response of castings at elevated temperatures (>400°C).
  - Understanding the complexity of a monitored pipeline that twists with diurnal heating (an unexpected outcome).
  - Quantifying the effectiveness of shear panel reinforcement on post-tensioned road bridge girders (in-situ).
  - Quantifying the effect of conveyor dither on localized bending in conveyor head pulleys (FEA load case definition).
  - Addressing the risks of high-cycle fatigue in steel structures.
  - Define loads in power distribution equipment.

Special Issue in Journal of Civil Structural Health Monitoring (CSHM)

We are handling eight papers of this Special Issue, of which six have been accepted and two are still under review. Two other papers are handled by the Chief Editor of CSHM. There should be 5 more papers to be submitted. If you would like to submit papers to this special issue, please submit your papers via the journal submission system Editorial Manager. During the submission process you will be asked whether you are submitting to a special issue, MAKE SURE TO SELECT "***Recent Developments in Digital Transformation and Intelligent Infrastructure in Australia for Structural Health Monitoring***" from the dropdown menu.

Please also note that as a policy of the journal, all submissions submitted to JCSHM require either experiments or field instrumentation components. Manuscripts with data analysis alone will not be accepted. Please refer to the aims and scopes of JCSHM on the website:

https://link.springer.com/journal/13349/aims-and-scope.

As mentioned before, although on the website, the deadline stated is 31 October 2024. However, it is the date that the Editor-in-Chief requested us to finalise everything by 31 October 2024. Please also note that all papers must be prepared in accordance with the Instructions for Authors at: https://link.springer.com/journal/13349/submission-guidelines.

ANSHM Symposium at EASEC-18

For those who are planning to attend the ANSHM Symposium at the Eighteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-18), 13–15 November 2024 at the Shangri-La Chiang Mai, Thailand, with the topic, Australian Network of Structural Health Monitoring (ANSHM) mini-symposium: Emerging techniques for structural health monitoring of civil infrastructure, please note the following:

1. The tentative program is published at https://easec18.org/conferenceprogram.
2. The early bird registration deadline is **15 Sep 2024**.

Special Session at IABSE Tokyo 2025

As mentioned before, Dr Fabien Rollet, and Dr David Lo Jacono, Technical Directors at Jacobs are organising a special session at the International Association for Bridge and Structural Engineering (IABSE) is organising their Symposium in Tokyo at Waseda University and Rihga Royal Hotel from 18 to 21 May 2025 (IABSE - Tokyo 2025), with the support of ANSHM. The theme of the symposium is Environmentally Friendly Technologies and Structures: Focusing on Sustainable Approaches. The session will be on dynamic bridge assessment and performance that leverages Digital Twin monitoring.

Submission Guidelines are as follows:

1. Abstracts should be submitted through the Symposium Website.
   Symposium page: https://www.iabse.org/Tokyo2025
   Submission page: https://app.oxfordabstracts.com/stages/6961/submitter
2. During the abstract submission process, please select the symposium topic that most closely aligns with your research from the listed topics. The option to select a specific special session will not be available at this stage.
3. After the abstract review and acceptance, you will have the opportunity to select your desired special session when submitting your full paper, which is due on December 15, 2024.

In the next sections, we will have two articles from our members. The first article, from Western Sydney University, discusses recent advances in smart sensing technologies for concrete wastewater pipe infrastructures. In the second article, researchers from University of Melbourne present the way they make use of the IBIS-FS interferometric radar system and advanced machine-learning techniques to assess the structural integrity of aging infrastructure with an application to a bridge.

Stay safe and healthy!

With kind regards,
Tommy Chan
President, ANSHM
www.ANSHM.org.au

Recent Advances in Smart Sensing Technologies for Concrete Wastewater Pipe Infrastructures

Karthick Thiyagarajan and Richard (Chunhui) Yang

Centre for Advanced Manufacturing Technology (CfAMT), School of Engineering, Design and Built Environment, Western Sydney University, Penrith 2751, Australia.

Abstract

Wastewater pipe systems, crucial underground infrastructure assets for any nation, face significant challenges due to microbial-induced corrosion, particularly in ageing networks. This widespread issue poses serious threats to public health and imposes substantial economic burdens on water utilities. To prevent catastrophic pipe failures, effective management of these assets necessitates the early identification of high-risk, corroded areas. Sensors combined with machine learning methods have emerged as a powerful tool in this domain, enabling water utilities to pinpoint vulnerable regions with greater accuracy than traditional inspection procedures. This article delves into the cutting-edge advancements in smart sensing technologies and their applications in wastewater pipe infrastructure inspection practices. A variety of innovative methods are present, including the identification of corrosion hotspot areas, real-time estimation of corrosion levels, and quality assurance sensing for pipe linings. These advancements have significantly improved the ability to monitor and assess the condition of wastewater pipes. Finally, future directions for research and development in this field are discussed, emphasising the potential for combining smart sensing, robotics, and machine learning to further enhance the resilience and efficiency of wastewater pipe infrastructure management.

Concrete Wastewater Pipe Infrastructure Corrosion

A functional network of underground wastewater pipes is essential infrastructure in today's modern civilisation, and it applies to both developed and developing nations. Numerous concrete wastewater pipes, including those in Australia, are ageing and failing as they convey effluent from industrial and residential areas. According to the literature [1], microbial-induced corrosion is mostly to blame for this degradation. This problem has long plagued water utilities around the globe. There are four steps of microbially-induced corrosion [2]. Sulphates in the waste stream are converted into aqueous hydrogen sulphide in the first step by sulfate-reducing bacteria in biofilms below the waterline. In the second step, turbulent wastewater flow causes this hydrogen sulphide to be discharged as gaseous hydrogen sulphide into the wastewater pipe's environment. The third step involves the conversion of gaseous hydrogen sulphide into sulfuric acid moisture on the wastewater pipe walls by aerobic sulfur-oxidising bacteria. In the last step, the cement material of the pipe is penetrated by sulfuric acid, which reacts with the concrete matrix and gradually dissolves the material while chemically attacking the reinforcing bars. Inaction on the part of the microbiota may result in catastrophic pipe failures that have negative effects on the environment, the economy, and society.

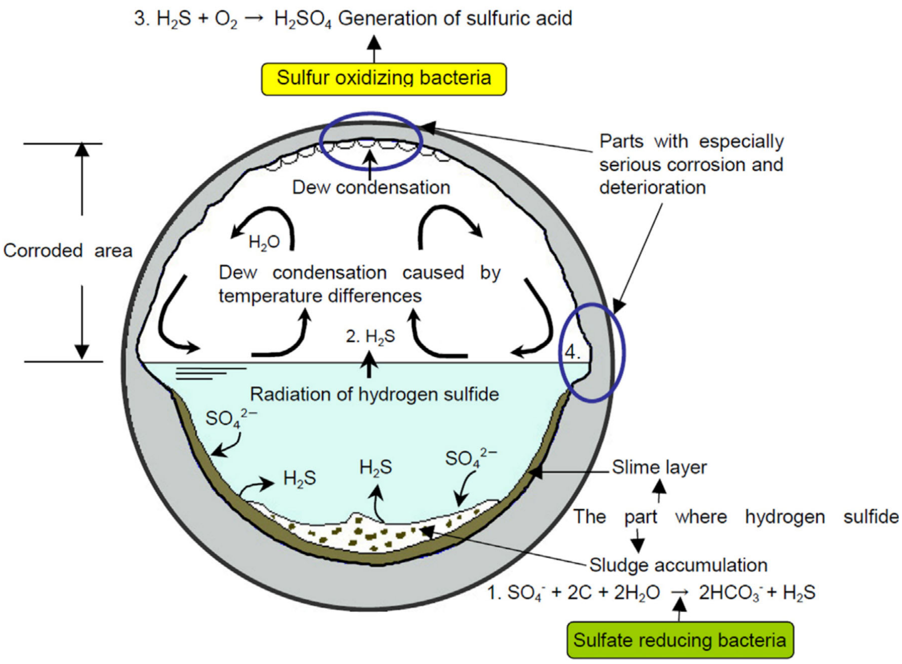

Figure 1. Illustration schematic of key events in microbiologically influenced corrosion of concrete in wastewater pipe environments, adapted from [2]

Worldwide, wastewater pipe networks made of concrete span millions of kilometres. According to the literature [3], the infrastructure assets of these wastewater pipe networks are valued at over $1 trillion in the United States and $100 billion in Australia. It was estimated that the yearly cost of corrosion-related damage to wastewater pipe assets is £104 billion in the UK, 4 million euros in Belgium, US$36 billion in the USA, and 100 million euros in Germany [4]. Wastewater networks are essential elements of urban infrastructure in contemporary societies. Beyond their primary function of collecting and transporting wastewater, these systems are crucial for safeguarding public health by preventing human contact with unsanitary sewage and reducing the risk of sewage-related illnesses. Advancements in smart sensing technologies enable water utilities to efficiently manage their multibillion-dollar wastewater pipe assets from catastrophic failures. etc.

Estimating Corrosion Through Smart Multimodal Sensing

Researchers have developed various machine learning and numerical models to estimate hotspot corroded regions in the wastewater pipe network. These models rely on environmental data, such as ambient temperature, ambient humidity, and gaseous hydrogen sulfide concentration in the air, as well as human traverse data. Although these models are functional, they face efficiency issues in prediction. This is due to the absence of critical environmental data, such as concrete pipe surface temperature and moisture conditions at desired locations. In addition to utilising commercially available sensors to monitor ambient temperature, ambient humidity, and gaseous hydrogen sulfide concentration in the air, the predictive model [5] also incorporates data from custom-developed sensors that measure concrete surface temperature [6] and surface moisture conditions [7]. This comprehensive data input enhances the model's ability to cost-effectively identify high-risk corroded regions within the wastewater pipe network.

After identifying the hotspot regions for corrosion in the wastewater pipe network, it is crucial to assess the actual corrosion conditions within the pipes. This real-time data can also be fed back into the predictive analytics model to enhance its predictive accuracy. Researchers in Australia have developed an in-pipe sensing robot (Figure 2) that can handle pipes with diameters ranging from 900 mm to 1,500 mm [8]. This robot employs CCTV cameras for visual inspection of concrete wastewater pipe surfaces, three 3D cameras to construct the 3D structure of the pipes, a pulsed Eddy current sensor to estimate the distance to concrete reinforcing bars from the pipe surface, and ground-penetrating radar to assess the thickness of the corroded layer. By integrating data from these sensors, this in-pipe robotic technology uses non-destructive sensing method to determine the thickness of the corroded layer and estimate the amount of intact concrete remaining before reaching the rebar. This advanced robotic tool overcomes the limitations of CCTV-based inspections, which only provide surface information, by also offering insights into subsurface conditions.

Figure 2. In-pipe sensing robot for condition assessments of concrete wastewater pipes [8].

Sensing Technologies for Quality Assurance of Wastewater Pipe Linings

Water utilities must decide whether to replace the affected sections of pipe after assessing the corrosion levels. Replacing damaged pipes can be extremely costly, often amounting to millions of dollars, and can cause significant disruptions to the public and surrounding areas. The water utilities employ pipe linings to mitigate pipe degradation and enhance the structural integrity of wastewater pipe lines. Utilising lining technologies tailored to specific applications presents an opportunity to extend the lifespan of wastewater infrastructure while reducing capital and operational costs. However, there is a lack of industry standards, specifications, and tools to verify the performance of linings after installation and over time.

To address these challenges, the Commonwealth Government of Australia has funded a Cooperative Research Centres Project (CRC-P) on "*Smart Linings for Pipe and Infrastructure*." This initiative aims to establish standards and specifications, as well as develop application-specific lining capabilities. The project is a collaborative effort involving the Water Services Association of Australia (WSAA), lining manufacturers, applicators, water utilities, and researchers. Its goal is to enhance the use and performance of pipe linings, ensuring they meet the necessary requirements for durability and effectiveness.

Even when pipe linings are used, adverse environmental conditions in wastewater pipes can lead to corrosion over time. As part of the aforementioned project, researchers have conducted a study to identify key parameters that require monitoring both after the application of linings and in the long term. The study determined that monitoring the thickness of concrete pipe linings and acid permeation are essential quality indicators. Currently, water utilities inspect the thickness of the linings by extracting small core samples and manually measuring them. They take core samples and analyse them under laboratory conditions to check for acid permeation.

Researchers have developed an advanced smart sensing method that uses ultrasonic technology to non-destructively estimate the thickness of concrete wastewater pipe linings in real time [9]. This innovation addresses the limitations of traditional destructive core sampling methods for assessing lining thickness. Compared to core samples, these sensors worked very well in the field for measuring concrete pipe linings made of calcium aluminate cement and geopolymer. This sensing technique can assess the quality of applied linings to ensure they meet desired thickness specifications and monitor any changes in lining thickness over time, aiding field operators in efficient decision-making.

Additionally, researchers have created a sensing suite for real-time estimation of acid permeation conditions [10]. This suite, however, still requires a destructive process to obtain pH measurements (Figure 3). It involves drilling holes to specific depths and using sensors to measure pH levels at these depths. A pH value below 7 indicates the presence of acid permeation. This approach mitigates the limitations of traditional core sampling and laboratory analysis, which are time-consuming, by streamlining the process. To improve field operation efficiency, future developments should focus on obtaining pH conditions at desired depths through non-destructive methods.

Figure 3. Measurements of the pH levels in concrete pipe linings on-site for evaluations of the state of acid permeation [10].

Summary

This article explores the latest advancements in smart sensing methods for assessing the condition of concrete wastewater pipe infrastructure. While current sensing technologies can estimate corrosion levels and evaluate the state of pipe linings, autonomously obtaining data across various dimensions of concrete wastewater pipes remains a challenge. Integrating robotics with sensors can significantly address this issue. Robots can be deployed through manholes and navigated to different sections, though designing robots compatible with most wastewater pipes presents its own set of challenges. Additionally, collecting data for an entire pipe network is both time-consuming and costly. Here, machine learning becomes invaluable, offering spatial-temporal predictions across the network. Combining smart sensing, robotics, and machine learning holds great promise for enhancing the resilience and efficiency of wastewater pipe infrastructure management.

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Damage detection of a bridge using an interferometric radar system

Ali Yaghoubzade[1], Massoud Sofi[1], Elisa Lumantarna[1], and Nilupa Herath[1]

[1]*Department of Infrastructure Engineering, University of Melbourne*

As urbanisation and infrastructure growth continue, the need for advanced structural health monitoring (SHM) of aging bridges becomes critical. Our recent study focused on the pedestrian bridge at the University of Melbourne, showcasing a cutting-edge approach using the IBIS-FS (Image by Interferometric Survey-Frequency for Structures) system. This method can thoroughly analyse the bridge's structural integrity, using advanced machine-learning techniques for damage detection.

Case Study: University of Melbourne's Pedestrian Bridge

Constructed in 1976, the pedestrian bridge at the University of Melbourne spans Swanston Street, connecting the David Caro building with the Earth Science building. With a width of 2.8 meters and a centre span of approximately 22 meters, the bridge's highest point is 5.3 meters above the ground. The structure is supported by pre-cast I profile steel core concrete beams, which cantilever out from two piers, creating a gently arched middle span.

Figure 1 Pedestrian bridge over Swanston Street, Parkville, Australia

Methodology and Data Collection: Using Interferometric Radar for Structural Health Monitoring

In this project we used the Interferometric Radar system, to address the challenges of monitoring the structural health of the bridge. This radar can capture the displacement time histories of the selected measurement points simultaneously with a precision of 0.01 mm. The Radar setup includes essential components such as a PC, tripod, radar head, and antennas. Data collection was carried out from the side of Swanston Street at 11:00 pm to minimise the impact of traffic. The radar beam was specifically directed to cover the bridge's middle span to avoid capturing interference and noise. The bridge was dynamically excited to capture radial displacement history and natural frequencies. The different time series (R_{bin}) with the highest signal-to-noise ratio were selected. Then they were later refined with further investigation of their quality using the polar graphs as shown in Figure 3. Next, the operational modal analysis (OMA) was applied to different displacement times with the highest accuracy. This analysis obtained 3 modes and associated mode shapes of the structure. The mode shape plots for both the finite element (FE) model and IBIS-FS results illustrated in Figures 4 to 6 show quite good data quality. Most of the IBIS-FS data points are close to the mode shape obtained from FEM, which validates the accuracy of IBIS-FS measurements. However, several data points do not match well with the FEM mode shape. One reason

Figure 2 Interferometric radar schematic setup

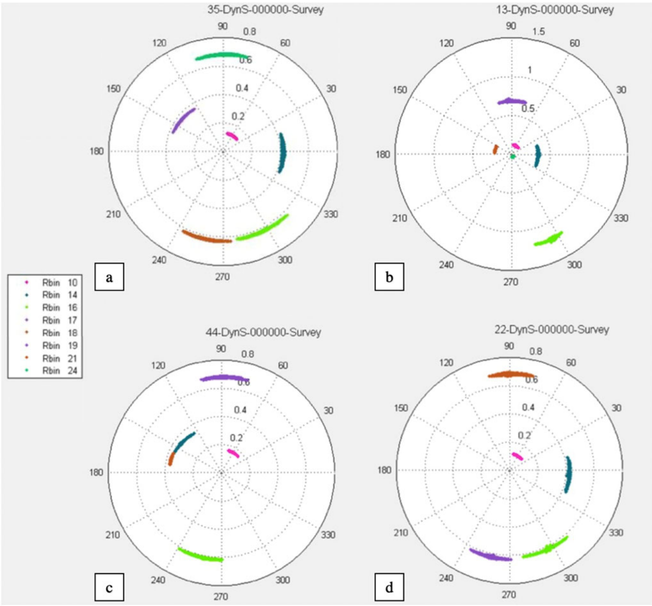

Figure 3 Polar graphs of (a) data set 35, (b) data set 13, (c) data set 44, and (d) data set 22

is that the data quality is not quite good at these points, which the polar graphs can directly reveal. Despite the observed scatters, the results are generally acceptable.

Comparisons between the OMA and FE model results indicated that the developed FE models need to be updated to reduce modeling errors. Therefore, ten modes from the FE model and three modes from OMA are used for model updating. The results of model updating in presented in Figure 7. The updated FE model can be used as a baseline FE model for damage detection procedures.

In the second phase of this project the capability of IBIS-Fs in damage detection is investigated. In a project aimed at evaluating the performance of RF and XGBoost models with incomplete data, where modal values from 70 nodes were omitted, the findings highlight distinct differences between the two models. As shown in Figure 8 to 10, RF maintains a robust performance despite a slight dip in accuracy, demonstrating its resilience and reliability in accurately identifying true damage under challenging conditions. Conversely, XGBoost appears more sensitive to data completeness, experiencing significant drops in precision which may lead to a higher incidence of false positives. Both models exhibit declines in recall, with XGBoost particularly affected when working with fewer modes and higher noise levels, which suggests it has difficulties in capturing all actual damage cases. Despite these challenges, RF maintains a superior balance between precision and recall, as evidenced by its higher F1 score compared to XGBoost, indicating that it handles incomplete data more effectively. RF and XGBoost continue to exhibit strong performance in explaining the variance in damage severity, even when working with incomplete mode shapes. This robustness underscores their capability to accurately predict the extent of damage, ensuring they remain reliable tools for assessing damage severity in structural health monitoring applications.

To investigate if IBIS-FS can be used for damage detection, only three non-torsional modes and the associated

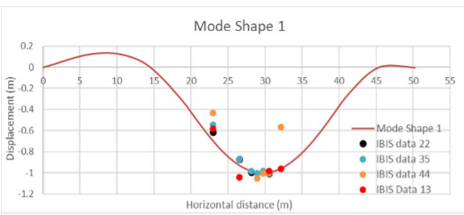

Figure 4 Mode shape #1 obtained from numerical modal analysis and IBIS-FS

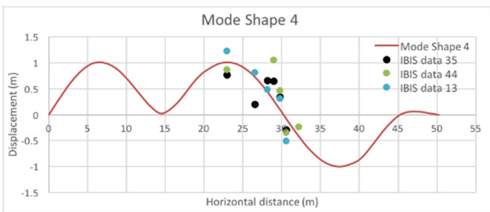

Figure 5 Mode shape #4 obtained from numerical modal analysis and IBIS-FS

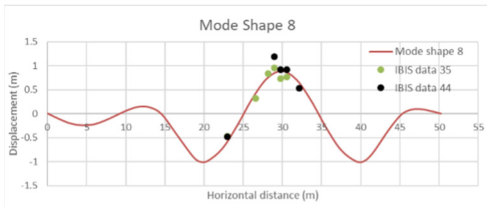

Figure 6 Mode shape #8 obtained from numerical modal analysis and IBIS-FS

vertical displacement of seven nodes from the midspan of the bridge were used. The results of the RF process are shown in Figure 8. Only seven nodes were selected as it is unlikely that IBIS-FS can measure the mode shapes at all nodes (with six DoFs) of the structure. This is due to the complexity of the structure, the limited number of IBIS-FS and the difficulties in synchronising IBIS-FS. Therefore, only translational DoF (the vertical z-direction) at the selected nodes: #23, #26, #28, #29, #30, #31, and #32 (see Figure 4 to 6) were used for damage detection. The RF process was used in this case with spatially incomplete data and 10% noise-polluted mode shapes associated with modes #1, #4, and #8. As shown in Figure 11, among the assessed models, the RF model excels, demonstrating a commendable balance between precision and recall, and indicating fewer prediction errors with its high R^2 score. XGBoost, though not far behind, surpasses RF in precision but falls short in recall and overall prediction consistency, as reflected by its R^2. On the other hand, GBDT lags in all key metrics, indicating a lower classification efficacy and the highest prediction errors, making RF the most reliable for damage detection in this study. The results indicate the possibility of damage detection using IBIS-FS with the RF method.

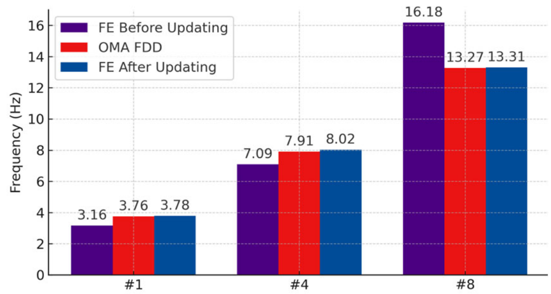

Figure 7 Non-torsional modes obtained from FEM and OMA

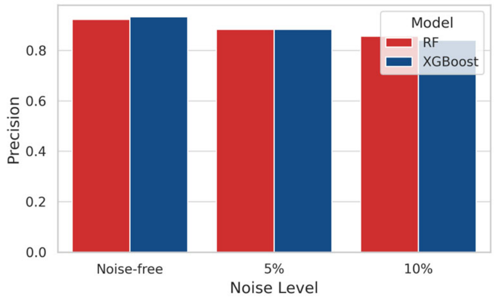

Figure 8 Damage detection using incomplete mode shapes-Precision

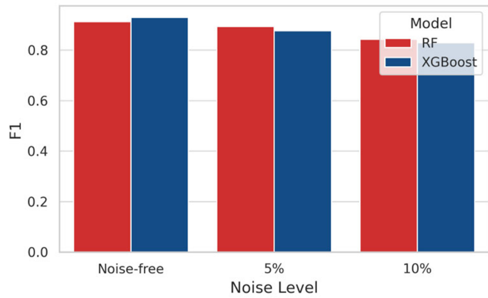

Figure 9 Damage detection using incomplete mode shapes-F1 metric

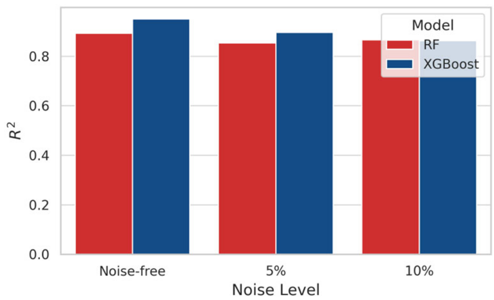

Figure 10 Damage severity detection using incomplete mode shapes

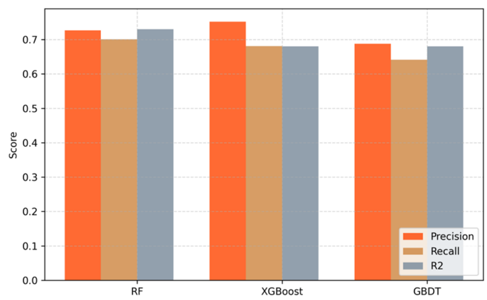

Figure 11 Damage detection in IBIS-FS simulated environment

Conference News

1. **24^{th} International Conference on Construction Applications of Virtual Reality (CONVR 2024)**
   The intersection of digital transformations and virtual innovation in sustainable and net-zero built environments
   Date: 4-6 November 2024
   Location: Western Sydney University, Peter Shergold Building, 169 Macquarie Street, Parramatta NSW, 2150
   Website: https://convr2024.com/

2. **First International Conference on Engineering Structures (ICES2024)**
   Date: 8-11 November 2024
   Location: Guangzhou, China
   Website: https://www.ices2024.cn/

3. **Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2025 (SSN06)**
   Date: 17-20 March 2025
   Location: Sheraton Vancouver Wall Centre, Vancouver, B.C., Canada
   Website: www.spie.org/SSN06call
   Submit abstracts by 11 September 2024

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