AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING

CIVIL ENGINEERS ANSHM

Newsletter

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Contents

President Report

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Dear All,

Queensland Earthquake to celebrate my Birthday

On August 16, 2025—coincidentally, my birthday—Queensland experienced a magnitude 5.6 earthquake near Kilkivan. Someone joked that the earth was shaking to celebrate my birthday! This event was personally memorable but also historically significant, as earthquakes of this strength are very rare in Queensland, a region not known for seismic activity. The quake was widely felt across eastern Australia, from Cairns in the north to Wollongong in New South Wales, making it one of the strongest onshore earthquakes in the state's recent history.

I was in a Zoom meeting when the quake struck. I felt the shaking and asked the others if they had noticed anything unusual. They said my voice sounded unstable during the meeting, likely affected by the tremor. To me, the shaking felt mild, but afterwards I saw some furniture and my bookshelves had shifted a few centimetres.

For comparison, the 1989 Newcastle earthquake—also magnitude 5.6—was a major disaster causing 13 deaths, 160 injuries, and nearly AU $4 billion in damage (Wikipedia – 1989 Newcastle Earthquake). Centred near Boolaroo, close to Newcastle's business district, it struck a densely populated area with significant destruction. Though similar in magnitude, the Kilkivan earthquake's impact was much less severe due to its rural epicentre. There were no casualties and only minor structural damage and temporary power outages. This contrast highlights a key lesson for those of us working on Structural Health Monitoring (SHM): earthquake magnitude alone does not determine the outcome. Population density, infrastructure quality, and preparedness are critical factors. The Newcastle quake led to important reforms in building standards and emergency response. The Kilkivan event, while less damaging, reminds us that even low-risk regions must remain vigilant.

We must continue advancing SHM, including developing smart sensing technologies, investing in resilient infrastructure, and fostering collaboration across sectors. Because resilience is not just about surviving the expected—it's about being ready for the unexpected.

Discussion on Gen AI (again?) – how it affects our future engineers

At our last Monthly (August) RIIS Hub Directors Meeting, we discussed how generative AI (Gen AI) is impacting teaching and learning across universities. Each institution shared its unique journey, highlighting both opportunities and challenges. When I brought up the issue of "fake knowledge", which I highlighted in the ANSHM Newsletter Issue 35, a colleague responded that after two years of development, Gen AI has improved and this is no longer a major problem; instead, we should focus on its impact on the workforce and job redundancy, and how it affects the teaching and learning of our engineering students. Due to limited time, I didn't argue but agreed that Gen AI indeed benefits our daily work—helping with tasks like taking meeting minutes, which I discussed in my last ANSHM monthly updates on 30 June 2025, generating images, and especially through Retrieval-Augmented Generation (RAG) techniques. Combined with Model Context Protocol (MCP), AI tools like ChatGPT, Ms Copilot, and Perplexity, can access and interact with real-time external data, improving relevance and accuracy.

However, my recent experience suggests that the fake knowledge problem still persists, which I mentioned in the ANSHM Newsletter Issue 35 in 2023. Asking the same questions from two years ago and requesting references with MCP, I still received fabricated citations authored by 'T.H.T. Chan', which were not my papers or even a real publication. Further, I tested several Gen AI tools to identify any Samsung phones with dual SIM and a separate (not hybrid) SD card slot. Despite my explicitly specifying "separate," all tools suggested incorrect models, probably from similar databases. Even when I referenced official Samsung information, they did not admit their mistakes, merely stating that I was correct. This highlights ongoing content reliability issues with Gen AI.

In late July, when QUT Semester 2 began, we ran several workshops to equip educators with strategies to integrate Gen AI for teaching, learning, and assessment. Topics included empowering educators with Gen AI, future-proofing assessments, smart teaching tools, and creating strategic AI roadmaps for meaningful instruction. These sessions emphasized strategic integration, not blind adoption. However, the main concern is whether Gen AI will help the students or rot their brains, as discussed in articles like MIT Media Lab's "rotten brain" and AI's complex effects on cognition.

Transitions like this are not new—we had previously worried about shifts from slide rules and four-figure tables to calculators, and debated whether such changes might undermine learning quality or diminish engineering skills due to design software. Some may recall that when design standards were first introduced, educators worried these frameworks might stifle engineers' creativity. The key, however, lies in managing how such tools influence student learning—ensuring they enhance creativity and critical thinking rather than replace or diminish them.

I encourage my students to treat generative AI as a subordinate—not a superior. While it can assist and accelerate their work, it's prone to errors and must be critically evaluated. Blind reliance risks perpetuating flawed outcomes. Consider the infamous Bhopal flyover in India: a so-called "perpendicular bridge" with a jarring 90-degree turn, often cited as a cautionary tale in design failure. If we stop questioning AI outputs, such missteps may not just persist—they could become the norm.

Bhopal railway overbridge in India (The Times of India, 12 June 2025)

AI and machine learning remain vital tools—many of the projects in our last proposed SSI Hub would leverage them extensively. Overall, while Gen AI holds huge promise to personalize education and boost efficiency, vigilance and thoughtful integration, not blind trust, are essential to ensure that its outputs are accurate and support true learning.

Collapse of the Sichuan-Qinghai Railway Bridge

On August 22, 2025, a section of the Sichuan-Qinghai Railway Bridge under construction in northwest China's Qinghai Province collapsed due to a steel cable snapping during a tensioning operation. Many video clips of this collapse can be located on YouTube. The failure caused the central arch span, about 108 meters long, to plunge into the Yellow River below. At the time, 16 workers were on site, but according to the news, 12 were confirmed dead and 4 remain missing because of this accident. Experts analyzing the accident point to possible causes, including steel strand breakage under tension, inadequate quality control, or improper installation procedures. The cable failure led to a catastrophic structural collapse during a critical phase.

Collapse of the Sichuan-Qinghai Railway Bridge (Captured from SCMP 25 August 2025)

Lessons from this tragic accident highlight the need for stricter enforcement of safety regulations and rigorous inspection during tensioning and other high-stress operations on steel bridge components. Especially for large-scale and unprecedented structures like this, real-time monitoring of material integrity and high-risk operations, even during construction, is crucial and can provide early warnings. China's rapid infrastructure growth sometimes faces challenges with safety standards, underscoring the importance of balanced development prioritizing worker safety and engineering reliability. Such industrial accidents serve as reminders that advanced engineering projects demand top-tier quality assurance and emergency preparedness to protect lives and maintain public trust.

Drafting of the commentary of AS5100.7 Section 16 SHM

I am honoured to be appointed as the lead of the subcommittee drafting the commentary for AS5100.7 Section 16 on Structural Health Monitoring (SHM). With valuable assistance from Shah Parves of TfNSW, I have recently formulated the draft commentary and submitted it to the committee for review. At the last BD-090-07 monthly meeting in August, we completed reviewing the commentary up to Section 16.4. We expect to complete the full review at the upcoming meeting.

ANSHM Workshops or ANSHM Conferences?

At our last Executive Committee meeting on 22 August 2025, we discussed the possibility of renaming our flagship annual event—the ANSHM Workshop—as a "Conference." The suggestion stemmed from concerns that the term "Workshop" may not accurately reflect the scale of the event. As attendance has grown, some participants already perceive it as a conference. However, others noted that ANSHM workshops have maintained their format and even their size for many years. Moreover, the size or format of such an event may not be the determining factor. Prominent international events such as the International Workshops on Structural Health Monitoring (IWSHM), with the next one scheduled for September 2025 as the 15th IWSHM (https://iwshm2025.stanford.edu/), and the European Workshops on SHM (EWSHM), with the next one set for July 2026, the 12th EWSHM (https://www.ewshm2026.com/), continue to use "Workshop" in their titles. Both are biennial events that attract hundreds of delegates and feature conference-style programs, including parallel sessions and exhibitions. An alternative suggestion was to retain the legacy term "Workshop" while adopting "Conference" as the primary label—perhaps as part of a hybrid naming convention.

We agree that any changes to the event's name or branding should be approached thoughtfully. In the meantime, we welcome further input, including examples of hybrid models or naming practices from similar Workshops or Conferences. We aim to preserve the legacy and spirit of the ANSHM Workshops while ensuring its continued growth and clarity for all participants.

Below are the updates for the month (August).

17th ANSHM Workshop

Please see below the details for our important annual event, the 17th ANSHM Workshop, in Newcastle.

Hosted by:	EngAnalysis & University of Newcastle
Date:	20th to 21st November 2025
Venue:	Q Building, 16B Honeysuckle Drive, The University of Newcastle, NSW 2300.
Theme:	Custodianship

Gold Sponsors:

Sterling. Rockfield

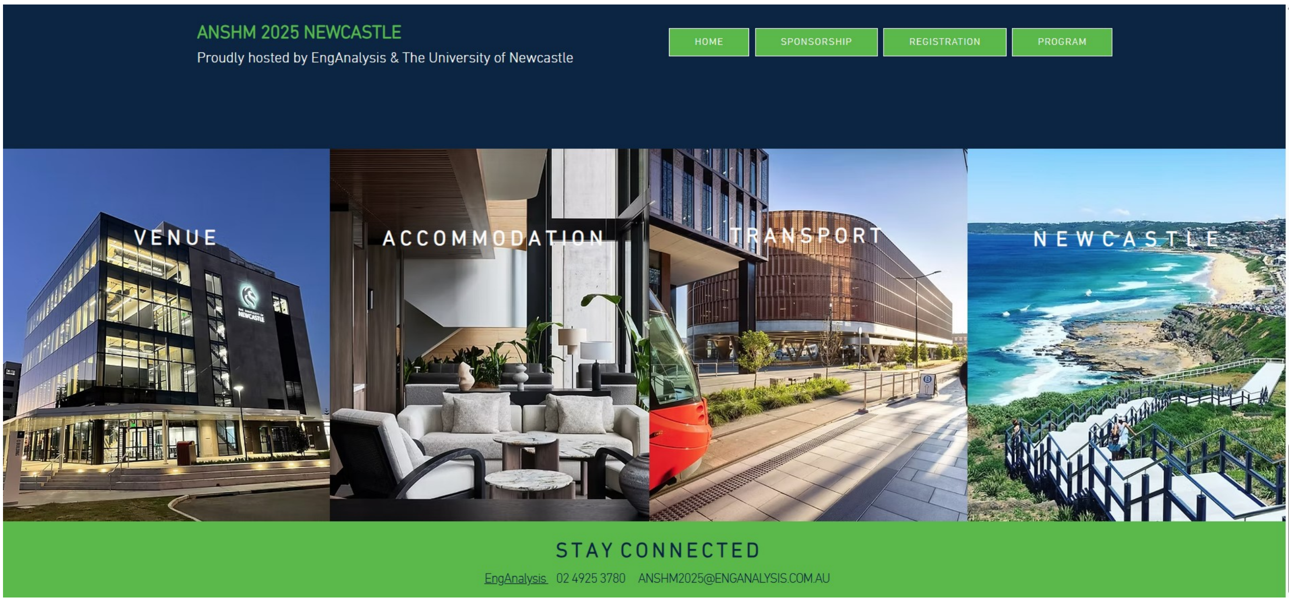
Bronze Sponsors (& Trade Desks)

John Morris GROUP BESTECH Sensors & Teaching Equipment NVMS

Abstract submission deadline: **<u>10 September 2025</u>**

If you have insight from research or the application of monitoring technologies to inform asset management and are happy to share the successes and shortcomings, please submit an abstract via https://easychair.org/cfp/ANSHM-2025. There is a TMR "So What" award for the most impactful research, presentation and deployment.

Other details of the Workshop, like Registration, Accommodation, Transport, and Call for Sponsorship and Exhibition via the Workshop Official Site: https://www.17anshm2025.com.au/. Make sure to scroll down to have the information like below:



There will be no registration fee for ANSHM Executive Committee (EC) members and Advisory Board (AB) members to recognise their contributions to ANSHM. Members of ANSHM EC and AB should use their designated discount codes during online registration to access the waived fee. In addition, ANSHM members prior to 1 June 2025 will benefit from a discounted registration rate, and research students will only be required to pay a minimal fee, ensuring broad accessibility and participation.

Resubmission of ANSHM ARC SSI Hub

In my last update, I shared the disappointing news that our application for the ARC Research Hub for Sustainable Smart Infrastructure through Digital Transformation (ARC SSI Hub) was unfortunately unsuccessful. Despite months of dedicated effort—burning the midnight oil through close collaboration between academics and industry partners—our proposal narrowly missed the funding threshold. Of the applications submitted, six Research Hubs were awarded funding by ARC, and ours was ranked seventh.

Following the announcement, I received an outpouring of encouragement from many of our Chief Investigators (academics) and Partner Investigators (industry representatives). Given how close we came, several suggested that we consider resubmitting the proposal. After consulting with members of the ARC College of Experts, we have decided to move forward with a resubmission.

I genuinely believe we have a strong chance of success—especially if we maintain or increase the level of industry cash contributions. In our previous submission, we requested A$5 million from the ARC, the maximum funding available for a proposed research hub, supported by substantial industry funding. Encouragingly, within just three weeks of deciding to resubmit, we have already secured A$4.89 million from 19 companies, including A$600,000 from four companies in Mainland China (who were also Partner Organisations in our previous submission). The remaining contributions come from local companies and one overseas research centre—surpassing the amount raised in our initial application.

Many of the industry partners in the last submission have committed to matching their previous contributions, and we've also welcomed new partners on board. This strong show of support underscores the significance of the proposed Hub and the pressing need for its establishment to address the needs of the individual industry partners, as well as infrastructure challenges, for the benefit of the country.

We are optimistic about securing an additional A$1.3 million from four more companies and are actively engaging others for further contributions. I'm deeply grateful to everyone who has worked tirelessly to secure these commitments and to the industry partners who continue to contribute cash to support and promote our vision.

Together, we are building momentum toward a successful resubmission—and a transformative future for sustainable smart infrastructure.

Special Issue in Journal of Infrastructure Intelligence and Resilience

As previously announced, Journal of Infrastructure Intelligence and Resilience (Scopus Q1) will publish a Special Issue featuring papers derived from presentations at the 15th and 16th ANSHM Workshops. Please note that the submission deadline has been extended to **30 September 2025**. It is expected that we could have 20 papers to be included in this Special Issue.

If you intend to submit, please aim to do so by mid-September. This will allow sufficient time for the review process and ensure you receive feedback by the end of September, giving the best chance for early publication.

The details of submission are as follows:

Title: ANSHM Special Issue on Monitoring Infrastructure: Quantifying Safety & Resilience for a Sustainable Future

Editor-in-Chief: Prof. Yaozhi Luo

SI Guest Editors: A/Prof Lei Hou (RMIT University, Lei.hou@rmit.edu.au)

Prof Tommy Chan (QUT, Tommy.chan@qut.edu.au)

Prof Jun Li (Curtin University, Junli@curtin.edu.au)

Prof Rabin Tuladhar (Central Queensland University, r.tuladhar@cqu.edu.au)

Dr Govinda Pandey (Rockfield Technologies, Govinda.Pandey@rocktech.com.au)

Submission Link: https://www2.cloud.editorialmanager.com/jiir/default2.aspx

To ensure correct identification for the Special Issue, authors should select "VSI: ANSHM - Original Research Articles" when submitting research, full-length, or original articles.

We look forward to receiving high-quality contributions and advancing research in infrastructure monitoring, resilience, and safety. So far, we have already received four manuscripts.

Advertorials in the ANSHM Newsletter

As mentioned earlier, Dr. Ali Hadigheh of Sydney U has suggested a great initiative to enrich the ANSHM Newsletter and boost industry-academic collaboration: a dedicated section for industry-partner Advertorials. This new section will showcase brief, technically sound case studies that highlight real-world applications of Structural Health Monitoring (SHM) technologies. For those members from the industry who are interested in this, please refer to the guidelines for Advertorial Submissions provided in my last monthly updates on 30 June 2025.

In the next sections, we will have two articles from our members. Lei et al. of Curtin University presented a physics-guided deep learning approach for damage identification in large-scale structures. Experimental tests on a large-scale bridge are conducted to validate the feasibility and performance of the proposed approach. Groenendaal and Talebian of Bond University presented discussions on reforms needed to better manage the structural health of above-three-storey buildings in Queensland.

With kind regards,

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President, ANSHM
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Research profile | Research publications | Google Scholar citations

Reforms needed to better manage structural health in community title schemes above three storeys in Queensland

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The definition of structural health (SH) is limited to the condition or state of the structural integrity of a building in relation to its ability to carry the loads it is designed for. The importance of SH is highlighted in the Mascot Towers case Sydney where lot owners recently received around 25c in the dollar five years after forced evacuation due to a major structural health problem in their building in 2019. With limited or no structural health knowledge or foresight, and after builders' warranty expiry or bankruptcy, lot owners in similar strata schemes in Queensland which are called Community Title Schemes (CTS), are at the same mercy. The consequences of such an event can leave lot owners and their tenants with no recourse to remedy, immense emotional distress and possible financial ruin. In extreme cases, a building can collapse causing death plus a heavy burden on rescue and health services.

Currently, the status of SH in Queensland's CTS above three storeys in unknown. My PhD study at Bond University, supervised by Professor Nima Talebian, attempts to identify the risks lot owners in CTS face in Queensland when it comes to SH plus ways to overcome or reduce such risks.

We have also found that the current tools and mechanisms used in the regulatory framework governing SH in Queensland are deficient in direct legislation, informational regulation, and self-regulation. This results in significant management deficiencies of SH, inadequate maintenance practices and insufficient regulatory oversight by various stakeholders in the CTS value chain including preventative recourse between neighbouring bodies corporate where the construction of one building compromises the structural health of another. To compound matters, there is a shortage of qualified structural engineers servicing the CTS sector above three storeys in Queensland.

Under the current circumstances, lot owners in the Queensland CTS sector are at high risk of major and unaffordable structural repairs, forced permanent or temporary evacuation, or partial or full building collapse.

It is the responsibility of government to play an active role in the design of society and ensure services and safeguards are in place. At the same time, lot owners must take up the responsibility for the SH of their building. The Queensland government currently has tools and mechanisms in place under the Queensland Building and Construction Commission Act 1991 (BC Act), the Body Corporate and Community Management Act 1997 (QBCC Act) and Building Act 1975 which does not serve the best interests of the lot owner when it comes to SH.

Against this background, the Queensland government may consider a reset of these tools and mechanisms that could reduce the risk for lot owners an improve the overall standard of SH in the CTS sector in Queensland. These include:

1. Mandatory Structural Health Inspection Plus Database Registry

The introduction of mandatory structural health inspection every ten years for new buildings and every five years for buildings thirty years and older, could be implemented by the Queensland Government, to provide relief to the plight of the lot owners. Alternatively introducing mandatory inspection every five years for all CTS regardless of age may reduce and eliminate the plight of the lot owner all together.

The purpose of enforced structural health inspection by an independent authority ensures impartiality plus determines status at a given point in time which is recorded. It also alerts the BC to repairs that need to be undertaking and the associated costs involved which may expose inadequate funding for such repairs. It may also improve public awareness of the importance of SH and recognition of the property owner's legal responsibilities in this respect.

The inspection criteria (the standard), determined by the Queensland Building and Construction Commission (QBCC) alongside industry professionals and academics, must consider the local context and challenges. The tools to make the legislative changes lies in amending both QBCC and BC Act. The responsibility of implementing the new rules (the mechanisms) could be carried out by the BC or QBCC. In both scenarios, a qualified structural health inspector will undertake the inspection before builders warranty period has expired and file a report to be presented to the BC as well as registered and uploaded online to a central database (registry) established by the QBCC. As a result, an accurate record of the structural health of CTS buildings in Queensland can be established and categorized into low, medium, and high risk through an online platform. This platform would offer real-time information to city and town councils, lot owners, and the extended CTS value chain, including potential investors. This and other potential legislative changes are illustrated in Figure 1 below.

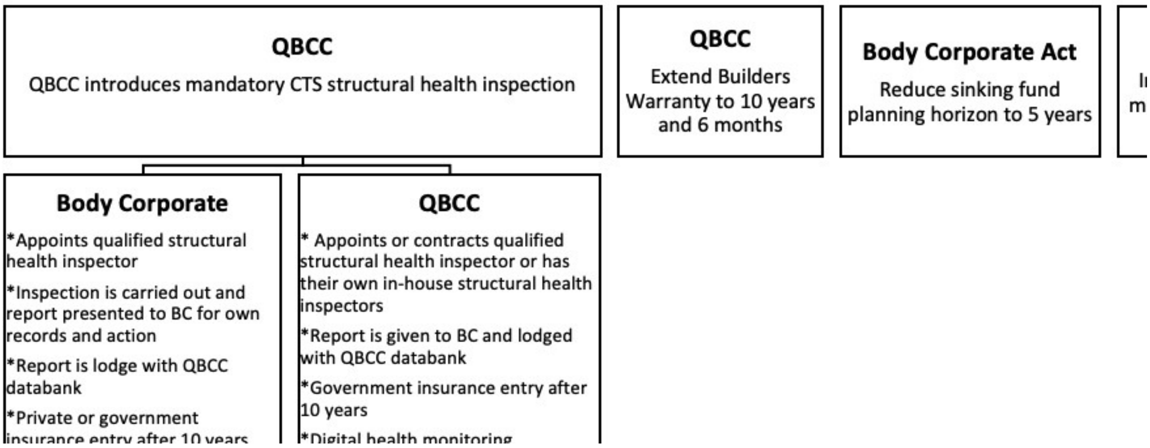

Fig 1. Legislative changes to reduce the risk for CTS lot owners when it comes to structural health

1.1 BC Retains Responsibility

To maintain building stock properly and promote public safety in a sustainable manner, it is crucial to ensure that building owners will take up the responsibility for inspecting and repairing their own properties on a regular basis (Chan & Choi, 2015). In countries with mandatory structural health inspections, the BC or its management service provider usually appoints a qualified inspector to conduct timely inspections and report based on established criteria. Amendments to the BC Act could facilitate this by mandating building registration and report submission to a database managed by the QBCC. This database would also need regular updates following any structural repairs. However, this system might allow bias in favor of the BC and risk compromised quality due to the BC's potential lack of capacity and expertise.

1.2 Queensland Government Manages Structural Health Inspection

In this scenario, the QBCC appoints an independent and qualified structural health inspector to conduct the inspection and submit the findings to both the BC and a state-managed database. The QBCC Act serves as the primary framework, providing guidelines and rules for implementation and database updates. This impartial approach could enhance the quality of inspections and reports.

2. Extend Builders Warranty Period

If the government decides to introduce mandatory health inspection every ten years, then the builders warranty period could be extended to ten years and six months so that the first inspection falls within the warranty period. The QBCC Act will be the driving tool for this change.

3. Reduce Sinking Fund Planning Horizon

Shortening the sinking fund planning horizon for structural health to five years can improve planning in response to rapid building cost inflation and the escalating expenses for structural repairs. The BC Act is the driving tool for this change which could also provide a buffer against sudden hikes in insurance premiums.

4. Introduce peer to peer review of structural health between BCs

The BC Act facilitates addressing risks to the structural health of CTS buildings, especially when they are neglected or during nearby construction activities. It emphasizes the need for oversight and review by the BC to manage threats posed by construction on adjacent sites.

5. Increase awareness of digital structural health monitoring

Digital SH health monitoring may represent a more reliable and cost-effective step change from traditional methods of structural health inspection; however, we found that around 70% of stakeholders (including body corporate members) are unaware that SH can be monitored digitally using artificial intelligence. This implies that the sector is unaware of the broader potential benefits of accuracy of reporting, record keeping and cost saving using digital technology to manage SH.

Excluding macro-economic elements and weather conditions, the proposed changes hold the potential to bridge numerous gaps which pose a risk to lot owners in Queensland when it comes to SH.

Physics-Guided Deep Learning for Damage Identification of Large-Scale Bridge Structures

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Abstract

Recently, the rapid development of deep learning (DL) has advanced structural health monitoring and damage identification, yet its black-box nature raises concerns over interpretability and generalization. Existing studies are mostly limited to small-scale laboratory structures, with rare applications to large-scale structures. To address these limitations, this study incorporates physical knowledge into deep learning, forming a physics-guided deep learning (PGDL) framework for damage identification in large-scale structures. By balancing data-driven learning and physical laws, the method aims to mitigate overfitting and enhance performance. A large-scale bridge is used to validate the feasibility and superiority of the proposed method. Results from training curves and damage identification show that physics-based guidance effectively directs network optimization toward the global solution, improving accuracy in both damage localization and quantification.

Introduction

In recent years, structural health monitoring (SHM) and damage identification have drawn extensive attention, particularly for large-scale structures such as high-rise buildings and long-span bridges [1, 2]. Traditional vibration-based methods rely on finite element model (FEM) updating, where damage identification is transformed into an optimization problem [3]. However, these methods demand accurate FEMs and efficient optimization algorithms, and for large-scale structures the high degrees of freedom and computational cost often reduce efficiency and accuracy [4]. Model reduction techniques have been developed to address these issues [5], but challenges remain for complex structures. With advances in computer science, deep learning (DL) has been increasingly applied in SHM to map structural responses to health conditions. Progress has been made in network design (autoencoders [6], residual networks [7]) and feature extraction (modal flexibility, autoregressive coefficients, time–frequency features) [8]. Nevertheless, DL is often criticized as a "black box" with poor interpretability and generalization. To overcome this, physics-guided approaches have emerged, introducing FEM updating, modal sensitivity, or physics-based loss functions into networks to improve robustness and physical consistency [9]. Most existing physics-guided studies focus on small-scale laboratory structures, with limited applications to large-scale real structures. Thus, this study proposes a physics-guided deep learning (PGDL) integrating modal sensitivity analysis and model reduction techniques. Validation on a numerical continuous rigid-frame bridge demonstrates that the PGDL achieves superior training stability and more accurate damage localization and quantification on polluted data, outperforming the plain DL.

Proposed method

Physics-based loss function for damage identification of large-scale structures

The original input, formed based on eigenfrequencies and eigenvectors of the damaged structure, of the traditional deep learning method is extended by adding the additional physical features from the FEM for subsequent calculation of the physics-based loss function. The extended input is shown as

$$X_{Ext} = [\lambda^{input}; \varphi^{input}; \lambda^0; \varphi^0; S_\lambda^R; S_\varphi^R] \quad (1)$$

where λ^{input} and φ^{input} stand for the eigenvalues and eigenvectors of the structure with damage, respectively; λ^0 and φ^0 are eigenvalues and eigenvectors of the intact structure, respectively, which could be obtained from the baseline FEM of the health structure or measured from the intact structure; S_λ^R and S_φ^R are the eigenvalue and eigenvector sensitivity matrices of the reduced structure, respectively, which can be calculated based on Weng et al. [5]. Based on the extended input and the eigenpairs sensitivity analysis, the proposed physics-based loss function can be written as

$$Loss_{FCR} = \frac{1}{Nm}\frac{1}{ns}\sum_{k=1}^{ns}\sum_{i=1}^{Nm}\left|\frac{\lambda_{ki}^{input} - \lambda_{ki}^{d}}{\lambda_{ki}^{d}}\right| \quad (7)$$

$$Loss_{MAC} = \frac{1}{Nm}\frac{1}{ns}\sum_{k=1}^{ns}\sum_{i=1}^{Nm}\frac{1-\sqrt{MAC_{ki}}}{MAC_{ki}} \quad (8)$$

where Nm and ns are the considered mode number and the number of input samples, respectively; λ_{ki}^{input} is the i-th structural eigenvalue in the k-th input sample; $\lambda_{ki}^{d} = \lambda_i^0 - [S_\lambda^R \cdot \mathrm{ReLU}(\hat{y}_k)]$ is calculated based on sensitivity analysis and predicted damage label using the current network model, in which λ_i^0, $\hat{y}_k$ and ReLU() are the i-th eigenvalue of the intact structure, the k-th predicted damage label and the linear rectification function; MAC_{ki} is the i-th modal assurance criterion (MAC) of the k-th input sample, which can be written as

$$MAC_{ki} = \frac{\{[\varphi_{ki}^{input}]^T \varphi_{ki}^d\}^2}{\{[\varphi_{ki}^{input}]^T \varphi_{ki}^{input}\}\{[\varphi_{ki}^d]^T \varphi_{ki}^d\}} \quad (9)$$

where φ_{ki}^{input} means the i-th eigenvector of the k-th input sample; $\varphi_{ki}^d = \varphi_i^0 - S_\varphi^R \cdot \mathrm{ReLU}(\hat{y}_k)$, in which φ_i^0 is the i-th eigenvector of the intact structure. In final, the proposed physics-based loss function is $Loss = Loss_{MSE} + Loss_{FCR} + Loss_{MAC}$, in which $Loss_{MSE}$ is the mean square error loss.

Architecture of the physics-guided network

A deep ResNet network architecture is constructed based on residual blocks to form physics-guide deep learning (PGDL) for structural damage identification. Several different layers, including conventional, rectified linear unit (ReLU), Batch Normalization and a shortcut connection, are used to construct the Residual blocks. Based on the above residual block, the proposed ResNet architecture is constructed based on Conv2d layer, BatchNorm2d layer, 5 residual blocks, AdaptiveAvgPool2d layer and fully connection layer.

Example application

Example description and baseline FEM

A continuous rigid frame bridge is used to validate the proposed method. A total of 17 sensors are installed on the deck of the bridge to collect the vertical acceleration based on sample frequency of 20Hz and then to identify the 1st to 4th modal parameters. Figure 1 and Figure 2 illustrate the overall view and the measured modal parameters. The baseline FEM of this bridge is constructed in MATLAB with 3D spatial beam elements. The elastic modulus, mass density and Poisson's ratio are 3.45×10^{10} Pa, 2500 kg/m^2 and 0.2, respectively. 74 elements are adopted to simulate the superstructure, four piers are divided into 11 elements, respectively. The total number of structural elements is 118. The boundary conditions are applied based on the practical situation. Due to the discrepancy between the FEM and the actual structure, FEM updating is conducted to obtain the baseline FEM by modifying the structural element stiffness. After model updating, the differences between 1st -4th experimental and analytical frequencies are both less than 4%, and modal assurance criteria all exceed 0.97.

Figure 1: View of the continuous rigid frame bridge (Red box mark)

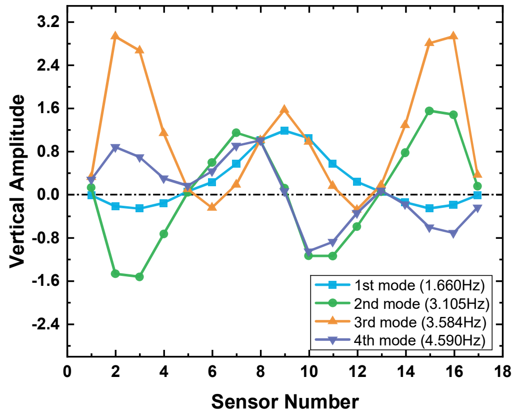


Figure 2: Measured modal parameters

Training dataset preparation and network training

The baseline FEM is used to generate the training dataset to validate the proposed method, including one-element, two-element, and three-element damage cases. These damage cases are introduced randomly between 74 elements of the superstructure with a severity of 5%-75%. The first four eigen-frequencies and mode shapes are gathered to form the dataset. The dataset is split with ratios of 0.7,0.15, and 0.15 for training, validation and testing data. The training epoch, batch size and learning rate are 1000, 128, and 3e-5, respectively. Adam optimizer and cosine annealing learning rate schedule are adopted to optimize the network. R-value curve and training and validation loss curves are exploited to investigate the training process. The random noise is introduced to the input data to simulate the environmental interference based on the following equation

$$\psi^p = \psi \cdot [1 + (2 \cdot rand - 1) \times \eta] \tag{10}$$

where ψ^p and ψ are the clean and noise-polluted data, respectively; $rand$ and η are a random constant within [0,1] and noise level, respectively. Meanwhile, regarding the limited sensors, the spare mode shape is considered according to the following equation

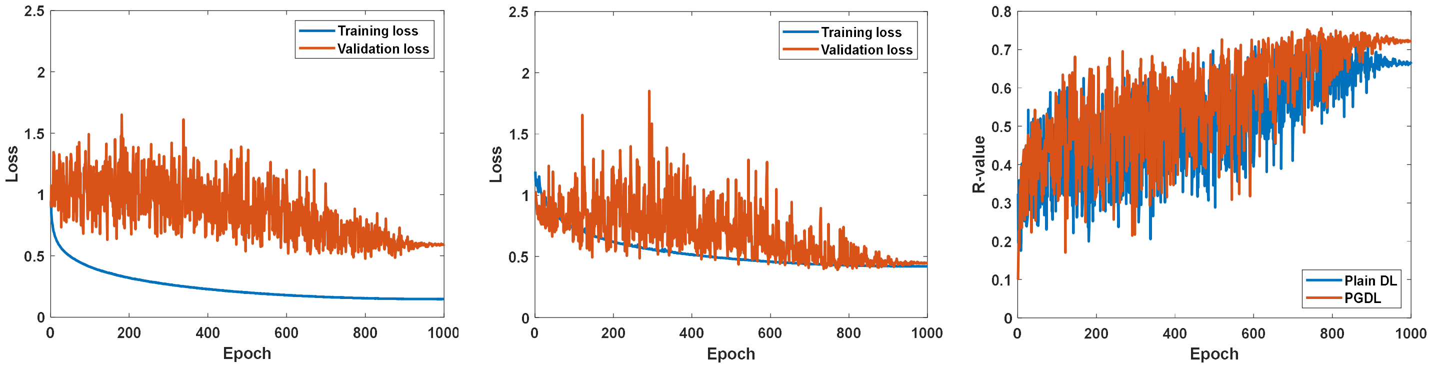
$$\varphi^s = \varphi^F \cdot I \tag{11}$$

where φ^s and φ^F indicate the sparse mode and full mode, respectively; I is the identity matrix.

Damage Identification Results

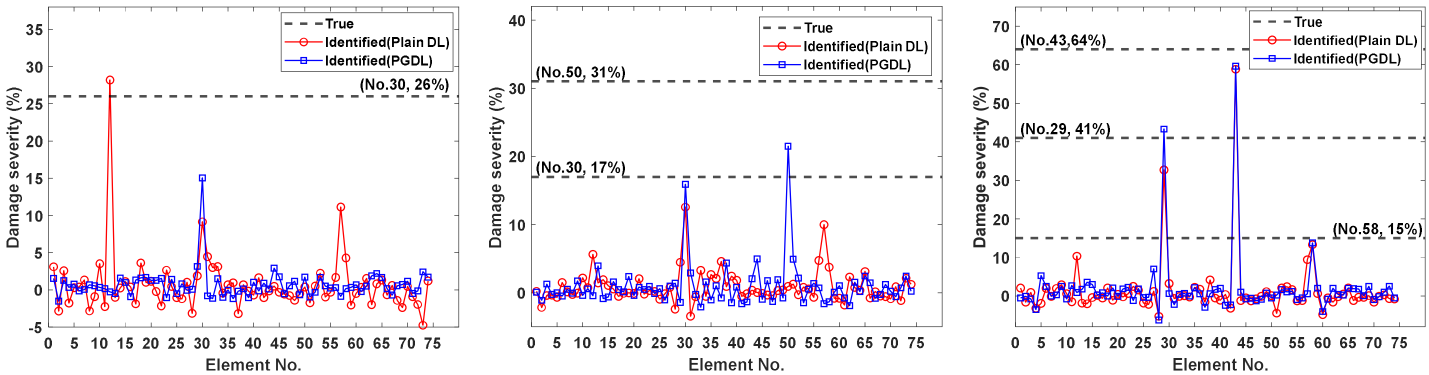
The dataset is polluted with 30% noise, and only 5 sensors are considered in the gathered mode shapes. Then the training data is input to train the network. The training curves and R-value of the plain DL and PGDL are shown in Figure 3. It can be noted that the proposed PGDL achieves a more accurate network fitting on the training dataset, while the plain DL model suffers from overfitting.

This is reflected in the clear gap between the training and validation loss curves. Furthermore, the R-value curves show that the PGDL consistently attains higher R-values than the plain DL, indicating that its predictions are expected to be more reliable. As shown in Figure 4, the accuracy of both damage localization and quantification is reduced due to the influence of random noise and sparse measurements. Numerous small errors can be observed in the identification outcomes, and even some false detections appear in the results of both methods. As shown in Figure 5, the plain DL produces serious false identifications at elements No.10, No.12, No.57, No.58, and No.73 in the single-element damage case; at elements No.12, No.29, No.56, No.57, and No.58 in the two-element damage case; and at elements No.12 and No.57 in the three-element damage case. By contrast, the proposed PGDL demonstrates superior performance in localizing damaged elements and quantifying the damage extent. These results confirm that the incorporation of a physics-based loss function improves the noise robustness and enhances the overall damage identification capability of DL.



(a) (b) (c)

Figure 3: Loss and R-value curves of plain DL model and PGDL framework under 30% noise and sparse measurements: (a) Loss curves of plain DL model, (b) Loss curves of PGDL framework and (c) R-value curves



(a) (b) (c)

Figure 4: Typical damage identification results under 30% noise and sparse measurements: (a) One-element damage, (b) Two-element damage; and (c) Three-element damage

Conclusions

This paper proposes a PGDL framework that integrates modal sensitivity analysis with model reduction to improve large-scale structural damage identification. By incorporating a physics-based loss function derived from modal sensitivity, the framework enhances network performance and is evaluated using loss and R-value curves. The effects of noise and incomplete measurements are also considered. A continuous rigid-frame bridge example validates the method, showing that the PGDL framework achieves accurate damage localization and quantification under interference, while outperforming the plain DL model in both training stability and identification reliability.

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