# Newsletter

## Issue 35, March 2023 Contents

President Report	1
Vehicle assisted Bridge Health Monitoring	13
Time-dependent resilience as a generalization of time-dependent reliability	21
Conference News	30
Social Media	30
Call for Articles	31

President Message Tommy Chan

Professor in Civil Engineering, Queensland University of Technology

Dear All,

Recently the chatbot ChatGPT developed by OpenAI becomes a hot topic amongst social media as well as in various universities. Some universities like the University of Hong Kong banned their students from using ChatGPT and Artificial Intelligence (AI) -based tools for coursework. Other universities like QUT, do not intend to ban the use of ChatGPT and similar tools. Instead, they will formulate policies outlining what to do with content generated by AI as their assessment submissions. Besides, QUT will continue to design authentic assessments, and this may include the use of AI tools.

Not sure if it is because Bing has incorporated ChatGPT into its new version, Bill Gates considered AI will be the "biggest thing in this decade" and he is excited about ChatGPT. On the other hand, Elon Musk, who is also co-founder of OpenAI warns AI is one of the biggest risks to civilisation. It raises questions like whether opening doors to ChapGPT will be harmful or beneficial, and how it affects our SHM community and the SHM technology.



## Newsletter

Actually, the chatbot-type software application to conduct chat conversations using AI is not new. We all experience having a conversation with our smartphones when we call, "Hey Siri" on our iPhones or iPads, or "Hey Google" on our Android smartphones. However, it seems that when we talk to "Siri" or "Google", we know we are talking to a machine. However, for ChatGPT, people are amazed by how it could provide the information that they are looking for, while some worry that it will eventually replace the human. As a matter of fact, since the industrial revolution, we develop machines to assist us in our daily lives. We should not be too concerned about having machines replace humans as we humans are always superior and there are a lot of capabilities that could not be replaced by machines.

Going back to ChatGPT, one of its main functions is to provide knowledge. Searching engines could provide you with various links to know better a topic and it still relies upon us to determine which sources of information are more reliable than others. For ChatGPT, instead of giving you different links, its algorithms will lead it to make a final decision from its knowledge base and give you the best or the most correct information regarding what you are asking for. Is it better or worse? Below I show you some experience in using ChatGPT relating to SHM technologies and ANSHM, and hopefully, you can find an answer from these examples.

First of all, I tried to see how ANSHM is known to the public so I asked ChatGPT, if it knows ANSHM. It seems that it knows us a bit and provides some information. Please see Fig 1 below for our conversation.



## Newsletter

TO	I am Tommy. How should I call you?			
\$	Hello Tommy! You can call me ChatGPT. How can I assist you today?	۵	<i>Ţ</i>	
то	Hi ChatGPT. Do you know anything about Australian Network of Structural Health Monitoring?			
\$	Yes, I can provide you with some information about the Australian Network of Structural Health Monitoring (ANSHM).	۵	9	
	ANSHM is a network of researchers and industry partners in Australia who are interested in the development and application of structural health monitoring (SHM) technologies. SHM is an emerging field of research that involves using various types of sensors and data analysis techniques to continuously monitor the performance and condition of structures such as bridges, buildings, and other civil infrastructure.			
	ANSHM was established in 2003 and is currently coordinated by the University of Technology Sydney. The network's primary goal is to foster collaboration between researchers and industry partners, with the aim of advancing the state of the art in SHM and promoting its adoption in industry.			
	ANSHM hosts a range of events, including workshops, seminars, and conferences, to bring together researchers, industry partners, and other stakeholders in the field of SHM. The network also provides a platform for sharing knowledge and best practices, and for identifying and addressing key challenges in the field.			
	I hope this information is helpful. Let me know if you have any further questions!			

### Figure 1

It's good to know even a machine knows us. But, it provides incorrect information as we established in 2009 instead of 2003, etc. It states that it is currently coordinated by UTS. I tried to correct it and see how it responds. Please see Figure 2 for our conversation subsequently.



AUSTRALIAN	N NETWORK OF STRUCTURAL HEAL	TH MONITORIN CIVIL ENGINEERS ANSHIV	
то	It seems that you made a mistake. It's not coordinated by UTS. It's President is Prof Tommy Chan, who is based at QUT.		
<b>S</b>	I apologize for the mistake. You are correct that the President of ANSHM is Prof Tommy Chan, who is based at Queensland University of Technology (QUT). Thank you for bringing this to my attention. As you mentioned, Prof Tommy Chan is the current President of ANSHM and has been actively involved in the development and application of structural health monitoring technologies for many years. He has also led various research projects and collaborations with industry partners in this field, and has contributed significantly to advancing the state of the art in SHM.	۵. <del>۹</del>	
	I hope this corrected information is helpful. Let me know if you have any further questions!		

### Figure 2

I am aware that ChatGPT could conduct machine learning algorithms and enhance the knowledge base of an individual account, so I asked ChatGPT again few days later to see if it knows any better after realising it made a mistake. However, it still made mistakes, e.g. ANSHM has nothing to do with ARC CAS. Please see Figure 3 for our conversations.



## Newsletter

information.

Do you know anythin	g about Australian	Network of Structural	Health Monitoring?
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Yes, I do have information about the Australian Network of Structural Health Monitoring 00 (ANSHM). ANSHM is a research network that focuses on advancing the science and technology of structural health monitoring in Australia. It is a collaboration between researchers, industry partners, and government agencies who are interested in developing and applying structural health monitoring techniques for the maintenance and safety of critical infrastructure such as buildings, bridges, and tunnels. The network aims to foster interdisciplinary collaboration and knowledge-sharing among its members through workshops, seminars, and other events. ANSHM also supports research and development projects that address key challenges in structural health monitoring, such as developing new sensing technologies, data analysis techniques, and decision-making tools. ANSHM is part of the Australian Research Council's Centre of Excellence for Autonomous Systems (CAS) and is supported by funding from the Australian government and industry partners. The network's activities are primarily based in Australia, but it also has collaborations with international organizations and research institutions. If you have any specific questions about ANSHM, I'd be happy to try and provide more

### Figure 3

Since I notice that it gives incorrect information for some general topics, so I would like to see if it can provide information on SHM technology. I tried to see if it knows anything about methods to identify prestress forces for existing concrete bridges of which together with my team, we developed three effective methods. Please see Figure 4 for our conversation.



## Newsletter

Is there a method to identify prestress force in an existing prestressed concrete bridge?

Yes, there are methods available to identify the prestress force in an existing prestressed concrete bridge. Here are some of the common methods used:

- Non-Destructive Testing: This method involves using techniques such as ultrasonic testing, magnetic particle testing, and radiography to detect the presence of prestressing tendons and estimate the level of prestress force. Non-destructive testing can provide valuable information on the condition of the prestressing system without causing any damage to the bridge.
- Strain Gauges: Strain gauges can be installed on the prestressing tendons to measure the strain in the tendons, which can be used to calculate the level of prestress force. This method requires access to the tendons and can be time-consuming.
- Releasing the Tension: This method involves releasing the tension in a tendon and measuring the resulting deformation. By knowing the modulus of elasticity and crosssectional area of the tendon, it is possible to calculate the level of prestress force. However, this method can be risky as releasing the tension can cause damage to the bridge.
- 4. Finite Element Analysis: Finite element analysis (FEA) is a numerical method used to simulate the behavior of structures. FEA can be used to estimate the level of prestress force by analyzing the stress and strain distribution in the bridge.

It's important to note that determining the prestress force in an existing bridge can be challenging, and it's recommended to consult with a structural engineer who has experience in prestressed concrete bridges.

#### Figure 4

Again, it provides some information and also gives warnings suggesting consulting a structural engineer. From what it provides, it contains mistakes again, e.g. Method 3 is incorrect and I think it is referring to Residual Stress Method<sup>1</sup>, and Method 4 is confusing.

<sup>&</sup>lt;sup>1</sup> ASTM Standard E837, 2008e1, "Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage







Then I go further to ask if it can provide any supporting literature, and then it gives me some information as shown in Figure 5.

то	Can you cite references to support what you state above?
6	Certainly! Here are some references to support the methods mentioned above for identifying prestress force in existing prestressed concrete bridges:
	<ul> <li>Kim, Y., Park, S., &amp; Kim, S. (2015). Non-destructive evaluation of prestressed concrete structures: A review of techniques and methods. Sensors, 15(5), 10936-10970. <u>https://doi.org/10.3390/s150510936</u></li> </ul>
	2. Strain Gauges:
	<ul> <li>Pan, L., &amp; El-Rich, M. (2013). Identification of prestressing force in existing prestressed concrete structures using strain gauges: A review. Journal of Civil Structural Health Monitoring, 3(1), 1-19. <u>https://doi.org/10.1007/s13349-012-0027-y</u></li> </ul>
	3. Releasing the Tension:
	<ul> <li>Lu, Y., Liao, W., Huang, L., &amp; Lin, Y. (2007). Application of tension release method to evaluate the prestressing force of existing pre-tensioned concrete beams. Engineering Structures, 29(3), 420-429. <u>https://doi.org/10.1016/j.engstruct.2006.05.009</u></li> </ul>
	4. Finite Element Analysis:
	<ul> <li>Seracino, R., &amp; Nanni, A. (2002). Nondestructive assessment of prestressed concrete bridge beams using finite element analysis. Journal of Bridge Engineering, 7(5), 318-327. <u>https://doi.org/10.1061/(ASCE)1084-0702(2002)7:5(318)</u></li> </ul>
	I hope this helps!
	© Regenerate response

### Figure 5

The literature shown seems like some supporting literature. However, none of them is true reference and they are all fake, as no such references exist. Now I began to realize that it is pretending to be an expert and in order to convince you, it tries to fool you by fabricating fake references!

Method," ASTM International, West Conshohocken, PA, 2008, DOI: 10.1520/E0837-08E01, www.astm.org





Since I also have references on identifying prestressing force, so I tried to see if it knows my work on the topic. Please see how it responded as shown in Figure 6.

TO	Prof Tommy Chan has been working on it. Do you know any of his methods?	
<b>(</b>	<ul> <li>Yes, Professor Tommy Chan has published several papers on the topic of identifying prestress force in existing prestressed concrete bridges. One of his methods is called the "forced vibration method," which uses a non-contact laser vibrometer to measure the natural frequency of the bridge under forced vibration. By analyzing the measured frequency and mode shape, the level of prestress force in the bridge can be estimated.</li> <li>Here are some references to Professor Chan's work on this method:</li> <li>Chan, T. H. T., Wong, Y. L., &amp; Au, F. T. K. (2004). Dynamic identification of prestress force in prestressed concrete bridges. Journal of Sound and Vibration, 271(1-2), 353-376. <a href="https://doi.org/10.1016/S0022-460X(03)00518-8">https://doi.org/10.1016/S0022-460X(03)00518-8</a></li> <li>Chan, T. H. T., Ko, J. M., &amp; Wong, Y. L. (2006). Identification of prestress force in a prestressed concrete bridge using measured acceleration data. Engineering Structures, 28(2), 226-235. <a href="https://doi.org/10.1016/j.engstruct.2005.07.007">https://doi.org/10.1016/j.engstruct.2005.07.007</a></li> <li>Chan, T. H. T., Wong, Y. L., &amp; Au, F. T. K. (2007). Estimation of prestress force in prestressed concrete bridge using measured acceleration data. Engineering Structures, 28(2), 226-235. <a href="https://doi.org/10.1016/j.engstruct.2005.07.007">https://doi.org/10.1016/j.engstruct.2005.07.007</a></li> <li>Chan, T. H. T., Wong, Y. L., &amp; Au, F. T. K. (2007). Estimation of prestress force in prestressed concrete bridge using response factor and forced vibration method. Journal of Sound and Vibration, 303(1-2), 123-142. <a href="https://doi.org/10.1016/j.jsv.2007.01.043">https://doi.org/10.1016/j.jsv.2007.01.043</a></li> </ul>	
	I hope this helps! G Regenerate response	

### Figure 6

I was surprised at first and then disappointed reading its responses. I was surprised because it seems that they cited my papers as Chan, T.H.T. et al. It knows 'Tommy Chan' published papers as 'Chan, T.H.T.' I was disappointed because those papers look like my publications but yet they are all fake! Once again, we could see how dangerous if we rely on ChatGPT as a knowledge provider. It always pretends to be an expert to lead you to trust its answers and it will even provide fake answers. Just joking, if I consider ChatGPT as my student, I will fail it or even forward it to our Student Misconduct Team as it fabricated data and provided fake results. I hope it could do other jobs better.

Below are the updates for the month.







### **Recent Successes in Grant Applications**

Let's congratulate Prof Tuan Ngo and Prof Richard Yang for their recent successes in securing two ARC Linkage Grants separately as follows:

Prof Tuan Ngo;	Ultralow Emission Panel Systems for Rapid Modular Construction
Dr Rackel San	- Funding Awarded: \$ 545,173
Nicolas; Prof Lu	- Scheme: ARC Linkage Projects
Aye; Dr Tuan	This proposed project aims to develop an innovative ultra-low emission precast
Nguyen; Dr	panel comprising a novel ultra-low carbon concrete mixture that is cast in
Abdallah	vertical battery moulds. The new precast panels will have several significant
Ghazlan; Dr	enhancements compared to traditional precast panels, including faster
Philip	manufacturing, reduced cost, and a much lower carbon footprint and life-cycle
Christopher; Mr	costs. A holistic theoretical and design framework will be developed for
Jason Hughes	predicting the behaviour of the innovative precast panel under structural, fire
	and impact loading. The panel will offer desirable benefits such as industry
	leading durability, ease of construction and assembly, economy and recyclability.
Prof Richard	Transforming Pastefill Delivery System for Next-generation Mining
	Transforming rusterin Denvery System for Next generation string
(Chunhui)	System
<b>(Chunhui)</b> Yang; Prof Yixia	<ul> <li>System</li> <li>Funding Awarded: \$ 362,000.</li> </ul>
<b>(Chunhui)</b> <b>Yang;</b> Prof Yixia (Sarah) Zhang;	<ul> <li>System</li> <li>Funding Awarded: \$ 362,000.</li> <li>Scheme: ARC Linkage Projects</li> </ul>
<b>(Chunhui)</b> <b>Yang;</b> Prof Yixia (Sarah) Zhang; A/Prof Kejun	<ul> <li>System</li> <li>Funding Awarded: \$ 362,000.</li> <li>Scheme: ARC Linkage Projects</li> <li>This project aims to develop a new type of mining pipeline design platform that</li> </ul>
<b>(Chunhui)</b> <b>Yang;</b> Prof Yixia (Sarah) Zhang; A/Prof Kejun Dong; Dr	<ul> <li>System <ul> <li>Funding Awarded: \$ 362,000.</li> <li>Scheme: ARC Linkage Projects</li> </ul> </li> <li>This project aims to develop a new type of mining pipeline design platform that can vastly improve pastefill (slurry) delivery systems. Using an Artificial</li> </ul>
<b>(Chunhui)</b> <b>Yang;</b> Prof Yixia (Sarah) Zhang; A/Prof Kejun Dong; Dr Zhongpu Zhang;	<ul> <li>System <ul> <li>Funding Awarded: \$ 362,000.</li> <li>Scheme: ARC Linkage Projects</li> </ul> </li> <li>This project aims to develop a new type of mining pipeline design platform that can vastly improve pastefill (slurry) delivery systems. Using an Artificial Intelligence-based design platform, understanding complex and numerous</li> </ul>
(Chunhui) Yang; Prof Yixia (Sarah) Zhang; A/Prof Kejun Dong; Dr Zhongpu Zhang; Mr Scott	<ul> <li>System <ul> <li>Funding Awarded: \$ 362,000.</li> <li>Scheme: ARC Linkage Projects</li> </ul> </li> <li>This project aims to develop a new type of mining pipeline design platform that can vastly improve pastefill (slurry) delivery systems. Using an Artificial Intelligence-based design platform, understanding complex and numerous variables in the fluid dynamics of abrasive pastefill flow will inform a new</li> </ul>
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(Chunhui) Yang; Prof Yixia (Sarah) Zhang; A/Prof Kejun Dong; Dr Zhongpu Zhang; Mr Scott Cheevers	<ul> <li>System <ul> <li>Funding Awarded: \$ 362,000.</li> <li>Scheme: ARC Linkage Projects</li> </ul> </li> <li>This project aims to develop a new type of mining pipeline design platform that can vastly improve pastefill (slurry) delivery systems. Using an Artificial Intelligence-based design platform, understanding complex and numerous variables in the fluid dynamics of abrasive pastefill flow will inform a new pipeline design. Consisting of a vertical casing, with our new composite pipeline chokes to replace costly friction loops, improvements in flow efficiency and pipeline deterioration can significantly reduce maintenance costs. This novel and</li> </ul>
<b>(Chunhui)</b> <b>Yang;</b> Prof Yixia (Sarah) Zhang; A/Prof Kejun Dong; Dr Zhongpu Zhang; Mr Scott Cheevers	<ul> <li>System <ul> <li>Funding Awarded: \$ 362,000.</li> <li>Scheme: ARC Linkage Projects</li> </ul> </li> <li>This project aims to develop a new type of mining pipeline design platform that can vastly improve pastefill (slurry) delivery systems. Using an Artificial Intelligence-based design platform, understanding complex and numerous variables in the fluid dynamics of abrasive pastefill flow will inform a new pipeline design. Consisting of a vertical casing, with our new composite pipeline chokes to replace costly friction loops, improvements in flow efficiency and pipeline deterioration can significantly reduce maintenance costs. This novel and adaptable next-generation pipeline design and analysis platform can be</li> </ul>
(Chunhui) Yang; Prof Yixia (Sarah) Zhang; A/Prof Kejun Dong; Dr Zhongpu Zhang; Mr Scott Cheevers	<ul> <li>System <ul> <li>Funding Awarded: \$ 362,000.</li> <li>Scheme: ARC Linkage Projects</li> </ul> </li> <li>This project aims to develop a new type of mining pipeline design platform that can vastly improve pastefill (slurry) delivery systems. Using an Artificial Intelligence-based design platform, understanding complex and numerous variables in the fluid dynamics of abrasive pastefill flow will inform a new pipeline design. Consisting of a vertical casing, with our new composite pipeline chokes to replace costly friction loops, improvements in flow efficiency and pipeline deterioration can significantly reduce maintenance costs. This novel and adaptable next-generation pipeline design and analysis platform can be employed by the manufacturing and mining sectors for pipeline failure analysis,</li> </ul>





### First Executive Committee Meeting in 2023

Our 1<sup>st</sup> Executive Committee Meeting in 2023 was held on 8 Feb 2023. Based on the tasks identified during the discussions in the last Advisory Board Meeting (ABM) on 24 November 2022 and the last Annual General Meeting (AGM) on 25 November 2022, we have allocated the EC members' roles and duties for the year 2023 as follows.

#### i) General

- Prof Tommy Chan (President): Tommy will continue to lead and chair the Executive Committee and the Advisory Board to work on the tasks identified during the discussions in the last ABM and the last AGM on 25 November 2023 and plan for ANSHM to achieve the ANSHM Aims and Objectives.
- Prof Jianchun Li (ANSHM Who's Who): Because of organising the last two ANSHM Workshops (13<sup>th</sup> and 14<sup>th</sup>) and the interference of Covid, the work on preparing ANSHM Who's Who has been affected much. The preparation work of ANSHM Who's Who could be re-started and hopefully could be completed in the year.
- Prof Alex Ng (Membership Officer): Alex will continue working on the role coordinate membership matters, renewing and approving the corresponding annual core membership and updating the member contact details. He will also work with other EC members to have more members from the industry contribute to the organisation and participate in various ANSHM activities.
- Dr Andy Nguyen (External Affair Coordinator): In 2023, the role of External Affair Coordinator will maintain our relationship with ISHMII and EA (from state to national levels), emphasizing promoting ANSHM while communicating with externals.
- •A/Prof Colin Caprani (SHM Specification Development): He will continue to work on the development and try to provide updates in the forthcoming Issues of the ANSHM Newsletter including a few controversial topics to get more engagement.
- Prof Hong Guan (ANSHM Website Maintenance and Development): Hong will continue to work on the role and keep improving ANSHM Website and adding information, updates, ANSHM Workshop video proceedings, etc. to ANSHM website. She will also work with her team on protecting our website from cyberattacks. As an update, a basic reCAPTCHA function (type 4 random characters in a box) has been added for the application form submission to prevent abusive non-human application form submissions.
- Mr John Vazey (Industry Coordinator): John will continue to work on the role and seek assistance from other academics and members of the industry to assist him in carrying out the role. He will also work with other EC members to have more members from the industry contribute to the organisation and participate in various ANSHM activities.





## Newsletter

- •A/Prof Jun Li (Newsletter Editor and ANSHM Who's Who): He will continue to be ANSHM Newsletter Editor with Mehri and Richard. He will also work on ANSHM Who's Who with Jianchun.
- Dr Lei Hou (Web forum & Social Media Coordinator): Lei will be working on the role and he plans to organise the 1st web forum in the coming months.
- Dr Mehrisadat Makki Alamdari (ANSHM Newsletter Editor): Mehri will continue to work on the role together with the other two ANSHM Newsletter Editors, Richard and Jun. She will also work on Technical Notes with Xinqun as well.
- Prof Richard Yang (Technical Workshop Coordinator and Newsletter Editor): Richard will continue to work on these roles.
- Dr Ulrike Dackermann (Workshop Coordinator and SHM Specification Development): As mentioned earlier that the 15<sup>th</sup> ANSHM Annual Workshop will be hosted by Rockfield in Townsville. Ulrike will work on assisting Dr Govinda Pandey, the CEO of Rockfield Technologies Australia Pty Ltd to organise the 15<sup>th</sup> ANSHM Workshop as our Workshop Coordinator. Ulrike will also review our current ANSHM Workshop Hosting Guideline, which was developed in 2016, to see if any revisions are required after organising our annual Workshop for many years including the two online workshops in 2021 and 2022, and a hybrid workshop in 2023. She will also prepare a document as Workshop Sponsor Guidelines. She will also work with Colin on the development of SHM Specifications.
- Prof Tuan Ngo (Research Collaboration): the Research Collaborating Task Force will organize some events in Sydney and Melbourne to promote research collaboration within ANSHM
- A/Prof Xinqun Zhu (Technical Note Coordinator and Technical Workshop Coordinator): Xinqun will continue to work on the role of Technical Note Coordinator together with Mehri. Besides, he will continue to organise a technical workshop, which has been stopped for two years because of Covid.
- ii) Action Plan for suggestions raised in ABM/AGM

Besides, the following roles have been allocated to consolidate what have been suggested in the ABM/AGM:

- SHM Leadership of ANSHM in Australia: Tommy with the EC
- Review of NSW Smart Infrastructure Policy and Plan accordingly: Mehri





- Exploration proposals for ARC Industrial Transformation Research Program (ARC-ITRP): The Research Task Force (Tuan, Jianchun, Alex, Colin, and Tommy)
- Exploring ways to encourage industry/academics to contribute new ideas for ANSHM in line with the current R&D trend in civil engineering: All EC members led by TC and the Research Task Force
- Identify different areas of SHM and encourage collaboration with more universities accordingly: The Research Task Force
- Encourage more members from the industry to assist in working for ANSHM Objectives: John (with EC support)
- Seek opportunities for Higher Degree Research (HDR) students working in the industry: John (with EC support)
- Review of the ANSHM Rules: Lei

In the next sections, we will have two articles from our members. Cao Wang of Univeristy of Wollongong together with Bilal Ayyub of University Maryland, USA, presented an explicit measure for the time-dependent resilience of repairable structures as a natural extension of time-dependent structural reliability concepts, taking into account the effects of structural performance deterioration and nonstationary external loads. Zhu et al. of University of Technology Sydney presented an overview of vehicle-assisted bridge health monitoring by utilising the vehicle and bridge responses for bridge condition assessment. The field study to extract the time-varying characteristics of the bridge and drive-by modal identification is presented.

### With kind regards,

Professor Tommy H.T. Chan PhD, ThM, MDiv, BE (Hons I), FHKIE, MIE Aust, CP Eng, NPER, MICE, C Eng, RPE, MCSCE
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Research profile | Research publications | Google Scholar citations





## Vehicle assisted Bridge Health Monitoring

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#### Abstract

The accurate in-service performance prediction of the bridge structure is critical to prevent catastrophic structure collapse and provide quantitative data for effective and economic lifecycle bridge management and maintenance. The vehicle passing over the bridge basically generates a wealth of data containing the rich information for structural condition assessment. The vehicle can serve as a moving excitor for the bridge and a mobile sensor to capture the bridge response. Vehicle-assisted bridge health monitoring has attracted the interest of many researchers and engineers. The paper presents an overview of these two aspects to utilise the vehicle and bridge responses for bridge condition assessment. The field study to extract the time-varying characteristics of the bridge and drive-by modal identification is presented.

### Introduction

Structural condition monitoring and damage identification is critical to prevent catastrophic structure collapse and provide quantitative data for effective and economic lifecycle structural management and maintenance. The current two main issues are methods for effective data collection and reliable evaluation of structural conditions. The vehicle passing over the bridge generates a wealth of data containing damage fingerprints for structural damage detection. Recent, the vehicle-bridge interaction (VBI) information has been included in the structural identification to reduce the variability (Zhu and Law, 2015). Sensors are often installed on the bridge deck for direct response measurements of structures under dynamic loading. Since the local damages are not known, a dense array of sensors should be used at different positions of the structure in practice to estimate the location and extent of the structural damage. Incorrect identification may occur when the sensor is



far away from the local damage and the local responses are sensitive to local damages (Zhu and Law, 2015). The vehicle can serve as a moving excitor over the bridge. The measurement from one sensor with the moving excitor is equivalent to that by a dense array of sensors.

Also, the design life of structure is usually much longer than the reliable lifespan of most sensors. The centralized long-term monitoring system requires costly onsite sensor maintenance due to the harsh operational environments. There is also a large stock of short and medium bridges, and most of them do not have such a system in practice. These form the main obstacles for general application of most existing damage detection algorithms. Sensors have been installed on the axle or the vehicle body instead of the bridge deck to enable the vehicle to serve as both an exciter and a sensory system. Drive-by bridge parameter identification using an instrumented vehicle has drawn great attention in the field of bridge structure health monitoring. The feasibility of the drive-by inspection methods has been verified by a number of studies. However, most of the studies are conducted with numerical simulations and the successful field application for bridge parameter identification requires more factors to be taken into consideration. Influences from road surface roughness, vehicle moving speed, uncertainties in vehicle models and measurement noise etc., may make the drive-by parameter identification challenging and impede its practical application. This paper presents the field study on these two aspects of vehicle-assisted bridge health monitoring to show the feasibility and challenges for the practical implementation.

### Methodology

#### Vehicle-bridge interaction

The fundamental base of the vehicle-assisted bridge health monitoring is the vehicle-bridge interaction dynamics (Zhu and Law, 2015). The dynamic interaction between the moving vehicle and the bridge deck can be described by two sets of second-order differential equations of motion. The equation of motion for the bridge deck can be written as,

$$\mathbf{M}_{b}\ddot{\mathbf{Q}} + \mathbf{C}_{b}\dot{\mathbf{Q}} + \mathbf{K}_{b}\mathbf{Q} = \mathbf{H}_{b}\mathbf{F}_{b}^{\text{int}}$$
(1)

where  $M_b, C_b, K_b$  are the mass, damping and stiffness matrices of the bridge structure respectively;

 $F_b^{\text{int}}$  is the vector of interaction force under the moving wheels;  $H_b$  is a location matrix with zero entries except at the degrees-of-freedom (DOFs) corresponding to the nodal displacement of the





finite elements on which the load acts; **Q** is the nodal displacement vector, and  $\dot{Q}, \ddot{Q}$  are the first and second derivatives of **Q**.

The equation of motion of the vehicle is as follows,

$$M_{\nu}\ddot{Z} + C_{\nu}\dot{Z} + K_{\nu}Z = F_{\nu}^{\text{int}}$$
<sup>(2)</sup>

where  $F_{\nu}^{\text{int}}$  is the vehicle-bridge interaction force vector;  $M_{\nu}, C_{\nu}, K_{\nu}$  are, respectively, the mass,

damping and stiffness matrices of the vehicle system and Z is the displacement vector.

The two sets of equations are coupled via the contact time varying forces between the wheels of the vehicle and the bridge deck. The road surface roughness is usually defined by a power spectral density and its effect is usually included in the interaction force study.

There are mainly two types of algorithms to solve the coupled sets of equations. The first type of approaches treats the vehicle and bridge as two sub-systems and they are solved independently with a time integration scheme. The compatibility conditions and the force equilibrium equations at the vehicle tyres and bridge deck interface are needed to be satisfied iteratively. These approaches typically employ implicit schemes of integration such as Newmark- $\beta$  or Wilson- $\theta$  methods to solve equations for each subsystem with convergence of computation after a number of iterations. The second type of approaches eliminates the dynamic interaction forces in Equations (1) and (2) to form the combined equation of motion of the vehicle-bridge system. A step-by-step integration scheme such as Newmark- $\beta$  or Runge-Kutta methods with a small-time step is usually used to solve the equation at each time instant. The time-varying system matrices are updated at each time step.





#### The moving vehicle as an excitation



(b) Sensor location Figure 1 Long-term monitoring of a cable-stayed bridge

The VBI system has time-variant feature and the vehicle can serve as a moving excitor to extract the time-varying characteristics for bridge monitoring. There are some advanced signal processing techniques to extract the time-frequency feature. The synchroextracting transform has the high energy concentration of the time-frequency representations and it is adopted to extract the time-varying feature of the VBI system (Li et al., 2020). A field study is used to verify the proposed method.

A long-term monitoring system has been installed on a cable-stayed bridge as shown in Figure 1(a). The structure carries a single lane highway with a span of 46m and a width of 5m. The bridge connects the South and North campuses of the Western Sydney University. There are 24 accelerometers on the bridge deck, and a strain gauge is installed on each cable supporting the deck. Figure 1(b) shows the sensor locations. A data acquisition system continuously records the data from sensors with a sampling rate of 600Hz. The vehicle-induced responses of the bridge will be analysed for this study.



## Newsletter



Figure 2 Time frequency trajectories of responses for different traffic conditions

Responses from sensor A10 under three different traffic conditions are measured. Case 1 has no vehicle on the bridge. Case 2 has one vehicle moving on the bridge from North to South and Case 3 has one vehicle moving on the bridge from South to North. There is a roundabout at the southern entrance of the bridge. When there is no traffic on the bridge, only the first bridge frequency can be identified in the response spectrum. For the other two cases with moving vehicle on top of the bridge, the higher bridge vibration modes are more prominent due to the vehicular excitations. The time frequency analysis results of the responses under different traffic conditions are presented in Figure 2. When there is no traffic on the bridge, the instantaneous frequency trajectory of the first bridge vibration mode shows little variation. For the cases with moving vehicle, the instantaneous frequency trajectories corresponding to the bridge vibration modes are smaller than those when the vehicle moves from North to South. This may be due to a lower vehicle speed when the vehicle approaches the roundabout at the South entrance of the bridge.

#### The moving instrumented vehicle as a mobile sensory system

The vehicle can also serve as a mobile sensor to capture the bridge response. The bridge modal



## Newsletter

information can be obtained from the responses of the passing vehicle. The vertical response of the vehicle passing over the bridge is a multi-component signal, which mainly includes the bridge, vehicle and driving response components. There are adaptive signal decomposition techniques to extract the bridge response components and a method based on the successive variational mode decomposition has been developed to estimate the bridge modal parameters (Li et al., 2022). The field study has been conducted on the cable-stayed bridge as shown in Figure 1(a). A vehicle of Hyundai Tucson 2006 model with a gross weight of 1.5t is used. A wireless accelerometer (manufactured by BeanAir) is installed on the top surface of the dashboard as shown in Figure 3. The vehicle is driven multiple times on the ground with the speed 10km/h. The dynamic responses measured from the wireless sensor are used for spectrum analysis with Fourier transform. The first three vibration frequencies of the vehicle body when it is moving are 1.2,  $1.5 \sim 1.8$  and  $2.2 \sim 2.7$  Hz, respectively.



(a) Vehicle used for the test(b) Vehicle instrumentationFigure 3 Vehicle for test and instrumentation with wireless sensor

The dynamic response measured from the wireless sensor when the vehicle passes the bridge at a speed 10km/h. SVMD is used to decompose the vehicle response and Figure 4 shows the decomposed components and their spectra. The first two components are around 1.05Hz and 1.56Hz and they are related to the vehicle dynamic responses. Other three components are around 2.05Hz, 3.56Hz and 6.23Hz. Compared with the results using sensors on the bridge, these three components are corresponding to the first, second and fourth dynamic modes of the bridge respectively. The results show that the successive variational mode decomposition (SVMD) can successfully extract the bridge related dynamic components from vehicle response.



## Newsletter



Figure 4 The decomposed components using SVMD

### Conclusions

The paper has presented two aspects of vehicle-assisted bridge health monitoring. The field test results show the potential practical applications of the proposed method. With the advancement of vehicular sensing networks, the vehicles are becoming powerful mobile sensing, communication, computing and storage platforms. Next step is to improve the efficient and reliable monitoring of large bridge networks through crowdsourced vehicles.

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### References

[1] Li J.T., Zhu X.Q., Law S.S. and Samali B. (2020) "Time-varying characteristics of bridges under





the passage of vehicles using synchro-extracting transform." *Mechanical Systems and Signal Processing*, 140, 106727.

- [2] Li J.T., Zhu X.Q. and Guo J. (2022) "Bridge modal identification based on successive variational mode decomposition using a moving test vehicle." *Advances in Structural Engineering*, 25(11), 2284-2300.
- [3] Zhu X.Q. and Law S.S. (2015) "Structural health monitoring considering vehicle-bridge interaction: development and challenges." *Advances in Structural Engineering*, 18(12), 1999-2015.





## Time-dependent resilience as a generalization of time-dependent

## reliability

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### Abstract

Civil structures and infrastructures are often subjected by design to the impacts of natural and human-caused hazardous events, and accordingly may suffer from damages, functionality loss, and failure. In order to quantitatively measure the associated likelihood and consequences for quantifying risks, an appropriate measure of structural reliability and resilience is essentially required. This work presents an explicit measure for the time-dependent resilience of repairable structures as a natural extension of time-dependent structural reliability concepts, taking into account the effects of structural performance deterioration and nonstationary external loads. The proposed resilience measure is a function of the duration of considered service period, and is in a closed form. Remarkably, the time-dependent resilience can be treated as a generalized form of the time-dependent reliability. A numerical example is presented to demonstrate the accuracy and applicability of the proposed resilience measure.

### Introduction

Planners and designers of civil structures and infrastructures consider the impacts of natural and human-caused hazardous events, and accordingly recognize that they may suffer as a result from damages, functionality loss and failure. Reliability and resilience are two significant indicators of structural performance under the impact of hazardous events. The former is defined as the probability of structural survival (i.e., the load effect does not exceed the structural resistance). On the other hand, the resilience of a structure exposed to hazardous events is indicative of the structural ability over the entire adverse cycle to prepare for and adapt to adverse events, and to withstand and



## Newsletter

recover rapidly from disruptions (McAllister, 2013; Ayyub, 2014; Reda Taha et al., 2021). These notional definitions clearly indicate that the reliability is nested within resilience as a broad ability. Enhancing structural reliability and resilience could result in economic savings and risk reduction through improving the structural performance and expeditious recovery.

The aggressive environmental or operational conditions may impair structural performance significantly (Ayyub et al., 2015; Wang et al., 2017), resulting in deterioration of structural capacity of resisting hazardous events below a level as assumed for new ones. Furthermore, many types of natural hazards have nonstationary characteristics on the temporal scale due to the potential impact of climate change. The sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2021) warns that human-induced climate change has already been affecting many weather and climate extremes around the world, and the global surface temperature will continue to increase until at least 2050 under all emissions scenarios considered. As a result, the time-variation of both structural performance and the external hazardous events should be well captured in structural reliability and resilience analysis. Correspondingly, these two quantities would be dependent on the duration of the service period of interest. They are known as *time-dependent reliability* and *time-dependent resilience*, respectively, under this context.

Despite of the descriptive definition of structural resilience, it is often challenging to develop a quantitative resilience measure, since some requirements drawn from the measure theory should be logically satisfied. In this work, the focus is on the resilience of a single repairable structure, which refers to such a structure that it suffers from functionality/performance loss due to the impact of hazardous events, and can be restored (via repair measures) to the pre-hazard state or some other states to account for adaptability. Note that the definition of resilience for a structure can be naturally extended to that for a system (consisting of multiple structures), e.g., infrastructure systems, networks, and a community.

Bruneau et al. (2003) defined the resilience loss as  $\int_{t_0}^{t_1} [1 - Q(t)] dt$ , in which Q(t) is the

performance/quality of a structure (taking a value between 0 and 1),  $t_0$  is the occurrence time of hazard (disruption), and  $t_1$  is the time of full recovery. Attoh-Okine et al. (2009) further proposed a normalized resilience model, denoted by  $R_e$ , as follows,

$$R_{e} = \frac{1}{t_{1} - t_{0}} \int_{t_{0}}^{t_{1}} Q(t) dt$$
 (1)



which yields a dimensionless measure for structural resilience. However, the definition in Eq. (1) does not account for the random occurrence of hazardous events and the probability of performance loss conditional on the occurrence of load event. Ayyub (2015) developed a resilience measure for a planning horizon of  $[0, t_l]$ , but did not consider the impacts of structural performance deterioration and the non-stationarity in external loads.

This work presents a measure for time-dependent resilience of repairable structures in the presence of nonstationary loads and deterioration. The computation formulas for structural time-dependent reliability and time-dependent resilience are compared. It is observed that the former is a specific case of the latter. As such, a linkage is established between the two key indicators of a structure: reliability and resilience. A numerical example is presented to demonstrate the applicability of the proposed resilience measure.

#### Proposed formulation of time-dependent resilience

In this section, a measure for structural time-dependent resilience is developed. It is representative of structural resilience within a reference period of  $[0, t_l]$  in the presence of performance deterioration and repeatedly occurring load events. The following assumptions are made: (i) The occurrence of load events is modelled by a non-homogeneous Poisson process with a time-variant occurrence rate of  $\lambda(t)$  (that is, on average  $\lambda(t)$  event(s) occur within unit time at time t). (ii) The post-hazard structure is fully restored/repaired to the desired state before the occurrence of next event. (iii) The recovery processes of the structure associated with different load events are statistically independent.

Fig. 1 presents a schematic representation of the resilience problem considering a reference period of  $[0, t_l]$ . Let *N* be the number of load events within  $[0, t_l]$ , which is a Poisson random variable. The probability mass function (PMF) of *N* is as follows for n = 0, 1, 2, ...,

$$\Pr(N=n) = \frac{\left(\int_0^{t_l} \lambda(t) dt\right)^n \exp\left(-\int_0^{t_l} \lambda(t) dt\right)}{n!}$$
(2)

in which Pr() = probability of the event in the brackets. A Bernoulli random variable  $B_i$  is introduced for the *i*th load event (occurring at time  $t_i$ , i = 1, 2, ..., N), which takes a value of 1 if the structure fails and 0 otherwise. With this, the PMF of  $B_i$  is,

$$\Pr(B_t = 1) = p(t_t), \ \Pr(B_t = 0) = 1 - p(t_t)$$
(3)

in which  $p(t_i)$  is the probability of failure conditional on the occurrence of one load event at time  $t_i$ .



## Newsletter

Similar to Eq. (2), the PMF of *effective* load events (i.e., events causing structural failure),  $N_e$ , is as in Eq. (2), but with  $\lambda(t)$  being replaced by  $\lambda_e(t) = \lambda(t)p(t)$ . Let  $R_{e,i}$  be the resilience measure associated with the *i*th effective load event. Similar to the resilience model in Ayyub (2015), the resilience measure for a reference period of  $[0, t_i]$  is defined as follows,

$$R_{\mathfrak{s}}(0,t_{\mathfrak{l}}) = \mu \left( \prod_{t=1}^{N_{\mathfrak{s}}} R_{\mathfrak{s},t} \right) \tag{4}$$

where  $\mu$ () denotes the mean value of the variable in the brackets. Based on Eq. (4), using the law of total expectation, it follows that,

$$R_{\mathfrak{s}}(0,t_{l}) = \mu\left(\mu\left(\prod_{t=1}^{N_{\mathfrak{s}}} R_{\mathfrak{s},t} \left| N_{\mathfrak{s}} \right)\right) = \mu\left(\left(\frac{\int_{0}^{t_{l}} \lambda_{\mathfrak{s}}(t)\mu(R_{\mathfrak{s}},t)dt}{\int_{0}^{t_{l}} \lambda_{\mathfrak{s}}(t)dt}\right)^{N_{\mathfrak{s}}}\right)$$
(5)

in which  $\mu(R_e, t)$  denotes the mean value of resilience measure associated with a single failure-causing event occurring at time *t*. Substituting the PMF of  $N_e$  into Eq. (5) yields the following based on the law of total probability,

$$R_s(0,t_l) = \exp\left(-\int_0^{t_l} \lambda(t)p(t)[1-\mu(R_s,t)]dt\right)$$
(6)

Eq. (6) is the proposed measure for structural time-dependent resilience, where the non-stationarity in the load occurrence process, as well as the time-variation of  $\mu(R_e)$  (due to, e.g., aging effect, time-variation of resourcefulness) can be taken into account. If further considering the uncertainty associated with the deterioration process of structural performance, Eq. (6) can be extended by using the law of total probability. For example, in the presence of a linear deterioration process with a rate of  $\Theta_a$ , it follows that,

$$R_s(0,t_l) = \int_0^\infty \exp\left(-\int_0^{t_l} \lambda(t) p(t) [1 - \mu(R_s,t)] dt\right) f_{\Theta_a}(x) dx \tag{7}$$

in which  $f_{\Theta_a}(x)$  is the PDF of  $\Theta_a$  (note that in Eq. (7),  $\mu(Re, t)$  is conditional on  $\Theta_a = x$ ). It would be

more convenient, in some occasions, to use the term *nonresilience*, denoted by  $\bar{R}_s(0, t_l)$ . It is the



## Newsletter

complement of structural resilience, i.e.,  $\bar{R}_s(0, t_l) = 1 - R_s(0, t_l)$ .

Finally, some discussions on the proposed resilience measure (see Eqs. (6) and (7)) are presented in the following.

• The item  $\mu(R_e, t)$  in Eqs. (6) and (7) is representative of the time-variation of resilience measure associated with a single hazardous event, while Rs (0,  $t_l$ ) reflects the overall resilience of the structure within a reference period of [0,  $t_l$ ], referred to as time-dependent resilience.

• In Eq. (6), if there exists a function  $\mu_{\max}(R_e, t)$  so that  $\mu(R_e, t) \le \mu_{\max}(R_e, t)$  holds for  $\forall t \in [0, t_l]$ , then an upper bound for the resilience measure would be achieved by substituting  $\mu_{\max}(R_e, t)$ , i.e.,

$$R_{s}(0,t_{l}) \leq \exp\left(-\int_{0}^{t_{l}} \lambda(t)p(t)[1-\mu_{\max}(R_{s},t)]dt\right)$$
(8)

The item  $\mu_{\max}(R_e, t)$  is the upper bound of structural resilience subjected to one disruptive event occurring at time *t*, which corresponds to the case of the greatest residual functionality and the most expeditious recovery profile. In particular, if  $\mu_{\max}(R_e, t) \equiv 1$ , then  $R_s$  (0,  $t_l$ ) in Eq. (6) equals 1, which is consistent with the definition of resilience measure. On the other hand, the case of  $\mu(R_e, t) \equiv 0$  would yield a lower bound for  $R_s$  (0,  $t_l$ ) in Eq. (6), and this point is discussed in the next section.

• In Eq. (4), the resilience measure for a reference period of  $[0, t_l]$  has been formulated by considering the multiplication of the resilience measures associated with individual load events. An alternative approach is to consider the summation of each  $R_{e,i}$  to derive the time-dependent resilience (Yang and Frangopol, 2019; Wang and Zhang, 2020). Compared with the alternative approach, the features of  $R_s(0, t_l)$  in Eq. (4) are, (i) it is more sensitive to each  $R_{e,i}$  having a small value (for example, when  $R_{e,1} \approx 0$ ,  $R_s$  (0,  $t_l$ ) is approximately 0, even if the remaining  $R_{e,i}$  's are all close to 1); (ii) it establishes a unified framework for assessing structural reliability and resilience, as is demonstrated in the next section.



## Newsletter



Fig. 1. Concept of time-dependent resilience over a reference period of  $[0, t_l]$ .

#### Comparison between time-dependent resilience and reliability

In this section, the resilience measure in Eq. (6) is compared with structural time-dependent reliability. To this end, the reliability method proposed by Li et al. (2015) is first reviewed. Fig. 2 illustrates the time-dependent reliability problem, where the structural resistance (*R*) deterioration and the randomness associated with the load process (*S*) are considered. At time *t*, conditional on the occurrence of one load event, the structure fails if the load effect exceeds the degraded resistance. The load process is modelled by a non-homogeneous Poisson model with an occurrence rate of  $\lambda(t)$ , and the CDF of load effect is  $F_S(s, t)$  at time *t*. Within a reference period of  $[0, t_l]$ , if a sequence of load effects  $S_1, S_2, ..., S_N$  occur at times  $t_1, t_2, ..., t_N$ , the time-dependent reliability,  $R_l$  (0,  $t_l$ ), is defined as

$$R_{l}(0, t_{l}) = \Pr(R(t_{1}) > S_{1} \cap R(t_{2}) > S_{2} \cap \dots \cap R(t_{N}) > S_{N})$$
(9)

in which  $R(t_i)$  is the resistance at  $t_i$  for i = 1, 2, ..., N. The hazard function h(t), which is defined as the probability of structural failure during  $(t, t + dt] (dt \rightarrow 0)$  conditional on structural survival within [0, t], can be linked to structural reliability according to

$$R_l(0,t_l) = \exp\left(-\int_0^{t_l} h(t)dt\right) \tag{10}$$

For the reliability problem in Fig. 2, the hazard function is computed as follows,

$$h(t) = \lambda(t)[1 - F_S[R(t), t]]$$
<sup>(11)</sup>





with which Eq. (10) becomes (Li et al., 2015),

$$R_l(0,t_l) = \exp\left(-\int_0^{t_l} \lambda(t) [1 - F_S[R(t),t]]dt\right)$$
(12)

Recall the item p(t) in Eq. (6), which equals  $1 - F_s[R(t), t]$ . As such, Eq. (11) is rewritten as  $h(t) = \lambda(t)p(t)$ , and correspondingly, Eq. (12) becomes,

$$R_l(0,t_l) = \exp\left(-\int_0^{t_l} \lambda(t) p(t) dt\right)$$
(13)



Fig. 2. Illustration of structural time-dependent reliability

Comparing the time-dependent reliability in Eq. (13), and the time-dependent resilience in Eq. (6), it is observed that,

• The time-dependent reliability is a specific case of time-dependent resilience. In fact, if assigning  $\mu(R_e, t) \equiv 0$ , Eq. (6) reduces to Eq. (13).

• The reliability method does not account for the recovery process of a post-hazard structure; it is a lower bound for structural resilience, since  $\mu(R_e, t) \leq 1$  holds for  $\forall t \in [0, t_l]$ .

• The resilience of a repairable structure is greater than that of a non-repairable one (i.e., the post-hazard functionality/performance loss cannot be restored) in the presence of the same configuration. For a non-repairable structure, the two quantities of reliability and resilience are consistent with each other in the context of a physical space.

## Newslette

#### **Concluding remarks**

In this work, a new resilience measure has been developed for repairable structures subjected to nonstationary loads and deterioration. The non-homogeneous Poisson process is used to describe the nonstationary load process, and the time-variation of performance loss, conditional on load occurrence, is taken into account. The time-dependent resilience can be treated as a generalized form of structural time-dependent reliability, and the difference between the two quantities is whether the recovery process of the post-hazard structure is considered. Furthermore, the reliability is a lower bound of structural resilience numerically.

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#### References

Attoh-Okine, N. O., Cooper, A. T., and Mensah, S. A. (2009). "Formulation of resilience index of urban infrastructure using belief functions." *IEEE Systems Journal*, 3(2), 147–153.

Ayyub, B. M. (2014). "Systems resilience for multihazard environments: Definition, metrics, and valuation for decision making." *Risk Analysis*, 34(2), 340–355.

Ayyub, B. M. (2015). "Practical resilience metrics for planning, design, and decision making." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, 1(3), 04015008.

Ayyub, B. M., Stambaugh, K. A., McAllister, T. A., de Souza, G. F., and Webb, D. (2015). "Structural life expectancy of marine vessels: Ultimate strength, corrosion, fatigue, fracture, and systems." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering*, 1(1), 011001.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., and Von Winterfeldt, D. (2003). "A framework to quantitatively assess and enhance the seismic resilience of communities." *Earthquake Spectra*, 19(4), 733–752.

IPCC (2021). *Climate change 2021: The physical science basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Li, Q., Wang, C., and Ellingwood, B. R. (2015). "Time-dependent reliability of aging structures in the



## Newsletter

presence of non-stationary loads and degradation." *Structural Safety*, 52, 132–141.

McAllister, T. (2013). *Developing guidelines and standards for disaster resilience of the built environment: A research needs assessment*. US Department of Commerce, National Institute of Standards and Technology, Maryland, US.

Taha, M.R., Ayyub, B. M., Soga, K., Daghash, S., Heras Murcia, D., Moreu, F., and Soliman, E. (2021). "Emerging technologies for resilient infrastructure: Conspectus and roadmap." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, 7(2), 03121002.

Wang, C. and Zhang, H. (2020). "Assessing the seismic resilience of power grid systems considering the component deterioration and correlation." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering*, 6(2), 020903.

Wang, C., Zhang, H., and Li, Q. (2017). "Reliability assessment of aging structures subjected to gradual and shock deteriorations." *Reliability Engineering & System Safety*, 161, 78–86.

Yang, D. Y. and Frangopol, D. M. (2019). "Life-cycle management of deteriorating civil infrastructure considering resilience to lifetime hazards: A general approach based on renewal-reward processes." *Reliability Engineering & System Safety*, 183, 197–212.





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