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ENHANCING RESILIENCE OF CRITICAL ROAD INFRASTRUCTURE: BRIDGES, CULVERTS AND FLOOD-WAYS UNDER NATURAL HAZARDS

Annual report 2018-2019

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Cover: On site view of Tenthill Creek Bridge. Photo: RMIT University

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EXECUTIVE SUMMARY

The overarching aim of the proposed second stage of the project is to work closely with key stakeholders to implement the methodologies that have been developed for vulnerability modelling of road structures to priorities vulnerable structures for improvements, to quantify the cost of reconstruction and/or cost of hardening of structures, and to integrate community resilience considerations into the decision-making process.

During the last financial year, the research team has published seven peer-reviewed journal papers (5 Scimago Q1 journal papers), 13 national/international conferences papers and one technical report, while there are eight journal papers under review now.

The major research activities include the generic analysis of bridges in terms of structural analysis, community impact model for decision making on strengthening, floodway inspection methodology, and strengthening options for different hazard types and levels. A floodway inspection and maintenance framework were also developed to guide the future inspection and maintenance of those bridges, especially for those have undergone hazard events.

Four workshops and four meetings were held during the second year of Stage 2 of the project. Two workshops were held at RMIT University to discuss with end users and colleagues regarding the feedback and comments of the project progresses. One workshop was held at the University of Southern Queensland and the Queensland University of Technology, respectively. Feedbacks from these end users have largely benefited the research progress.

Four major utilization activities have been identified and are in progress.

Our next step is to focus on the remaining milestones and engaging with those end users to tailor the research direction and fulfill their urgent research needs. The final project completion report will be also submitted then for the review of BNH CRC.

END-USER PROJECT IMPACT STATEMENT

It is pleasing to see the project progress to implementation/utilization phase and continuing to work closely with key stakeholders to ensure the methods and modelling are being used in decision making processes and the research is meeting the needs of the end user.

The team is ensuring their research is broadly available to other researchers and potential end users through the publication of peer review papers and presentations at conferences. The active engagement with end users and researcher continues to be a theme of this project which ensures there is open and ongoing opportunity for feedback.

The ability of end users to prioritise bridges for strengthening, maintenance and repairs will be beneficial with asset management to optimise limited expenditure budget.

Ms. Leesa Carson, Geoscience Australia

PRODUCT USER TESTIMONIALS

VicRoads (now as part of Department of Transport (DoT), Victoria) has participated in most of the events organised by the Project team and, also attended several End User engagement activities organised by the CRC.

The Project team has cohesive team members to work on this project. They faced several challenges due to unavailable data or literature review, but the Project team has overcome the challenges. The Project team has performed well and delivered in according to the project scope and plan.

DoT is working closely with the Project team on the delivery outcomes to be used and implemented in the DoT. DoT is also currently working with the Project team on a utilisation project proposal.

Dr. Yewchin Koay, VicRoads

INTRODUCTION

What is the problem?

One of the seven goals of Sendai Framework for disaster risk reduction (2015-2030) is minimizing the damage to vulnerable critical infrastructure by enhancing their resilience. The majority of academic literature discuss either a framework or a computational method to assist in the decision making process on interventions after an extreme event so that the decision makers can priorities the rehabilitation process [1]. The primary focus of rehabilitation is to increase the resilience of road infrastructure by reducing the recovery time.

A major gap in research is the lack of assessment techniques and decision support tools that reduce the vulnerability of road structures and enhance both community and structural resilience [2].

During stage 1 of the project, disaster risk was understood in terms of the vulnerability of road structures, and the impacts of road failure on local communities. Stage 2 aims to enhance disaster preparedness, inform more effective responses, and ensuring that damaged structures are built back better during the recovery. The tasks in this project, therefore, align well with the four priorities for action identified in the Sendai framework.

Why is it important?

In recent years there has been significant damage to road networks throughout Australia from floods and bushfires that have cost both State and Federal governments millions of dollars to repair. The effect of damage to road networks from natural hazards goes far beyond the immediate damage incurred by people whose homes and businesses are directly affected, and if the damage is widespread, it can have an impact on the regional and national economy. The cost of repairing the road network alone is huge. For instance, the 2010-2011 floods in Queensland severely damaged 9,170 kilometers of the road network including bridges, floodways, and culverts and cost the State and Federal government hundreds of millions of dollars to repair [3]. In Victoria, VicRoads spent over $17 million on repairing the road network after the bushfires in 2009 and over $200 million repairing the road network after the 2011 flood [4]. Creating a road network that can better withstand future natural hazards and a better understanding of the impact on the community will be of great importance in reducing the cost to the community and road authorities as well as local councils.

Often during the reconstruction period, neither the road authorities nor the governments have adequate funding, technological knowledge, and resources to build better. Optimized decision making required front-end planning to ensure community resilience at the next disaster event. We need to move from a reactive decision-making approach to a proactive approach where the vulnerability is known, challenges are known, and the disaster recovery is well planned so that we can build better. The current reactive approach has raised concerns that the Engineering profession is detached in enhancing the resilience of the community during disasters.

Quantifying vulnerability of road structures considering the variability of frequency and intensity of disasters will enable managing authorities and funding bodies to make informed decisions on when, where and what to invest in.

How are we going to solve it?

In Stage 2 of this project, research will continue to apply the methods developed in Stage 1 to examine the vulnerability of categories of road structures for decision making. In addition to the assessment of structural vulnerability, a decision support framework will be developed through collaboration with other research projects of the BNH CRC such as decision making and fire modeling.

The overarching aim of the proposed second stage of the project is to work closely with key stakeholders to implement the methodologies that have been developed for vulnerability modelling of road structures to priorities vulnerable structures for improvements, to quantify the cost of reconstruction and/or cost of hardening of structures, and to integrate community resilience considerations into the decision-making process. In achieving this aim, the following specific objectives are identified:

- Map vulnerable road structures considering the hazard maps for the assessment area;
- Using a generic methodology for vulnerability modeling, develop fragility curves which present the probability of occurrence of a given damage level for all vulnerable structures;
- Develop a method for prioritizing vulnerable structures which require hardening; with explicit consideration of economic impacts and community resilience parameters;
- Develop methods for the optimized betterment of prioritized structures; and
- Identify the design process required for a resilient floodway under extreme flood events.

BACKGROUND

Australia's variable climate has always been a factor in natural disasters that have had a significant impact on evolving road infrastructure and on the communities that rely on the roads. The following figure (Fig. 1) shows the average annual cost of natural disasters by state and territory between 1967 and 2005.

State and territory	Flood	Severe storms	Cyclones	Earthquakes	Bushfires	Total
		Cost ($ million in 2005 Australian dollars)[a]				
NSW	172.3	217.1	0.6	145.7	23.9	559.6
VIC	40.2	23.8	0.0	0.0	36.7	100.6
QLD	124.5	46.7	99.3	0.0	0.7	271.2
SA	19.3	16.7	0.0	0.0	13.0	49.0
WA	4.7	13.0	43.3	3.1	4.6	68.7
TAS	6.9	1.2	0.0	0.0	11.5	19.5
NT	9.1	0.4	138.5	0.3	0.0	148.3
ACT	0.0	0.5	0.0	0.0	9.7	10.2
Australia	**376.9**	**325.2[b]**	**281.6**	**149.1**	**100.1**	**1232.9**
Share of total *(per cent)[c]*	30.9	26.7	23.1	12.2	8.2	100.0

a. These figures exclude the cost of death and injury.
b. Figure includes costs associated with a storm involving several eastern states ($216.7 million) which has not been allocated to any individual state data in the table.
c. Figures may not add to totals due to rounding.
Source: BITRE analysis of Emergency Management Australia database <www.ema.gov.au>.

FIGURE 1: AVERAGE ANNUAL COST OF NATURAL DISASTERS BY STATE AND TERRITORY, 1967-2005 (BITRE, 2008:44)

From these data, during the period of severe storms and cyclones inflicted the most economic damage, followed by flooding. The data are strongly influenced by three extreme events - Cyclone Tracy in NT (1974), the Newcastle earthquake in NSW (1989) and the Sydney hailstorm also NSW (1999), as well as three flood events in Queensland (South East Qld, 2001: Western Qld, 2004; and the Sunshine Coast, 2005). Climate change has increased the risk from extreme events and the update of this table that includes data for the years 2007 to 2013 - during which there were extreme climate events in Qld, Vic, SA, and NSW.

The recent flood events in Queensland of Australia had an adverse effect on the country's social and economic growth. Queensland state-controlled road network includes 33,337 km of roads and 6,500 bridges and culverts [5]. 2011-2012 flood in Queensland produced record flood levels in southwest Queensland and above-average rainfall over the rest of the state [6]. The frequency of flood events in Queensland, during the past decade, appears to have increased. In 2009 March flood in North West Queensland covered 62% of the state with water costing $234 million damage to infrastructure [7]. Theodore in Queensland was flooded three times within 12 months in 2010 and it was the first town, which had to be completely evacuated in Queensland. 2010-2011 floods in Queensland had a huge impact particularly on central and southern Queensland resulting in the state-owned properties such as 9,170 road network, 4,748 rail network, 89 severely damaged bridges, and culverts, 411 schools and 138 national parks [8]. Approximately 18,000 residential and commercial properties were significantly affected in Brisbane and Ipswich [9] during this time. More than $42 million support was provided to individual, families, and households while more than $121 million in grants have been provided to small businesses, primary producers and not-for-profit organizations. Furthermore, more than $12 million in concessional loans to small businesses and primary producers have been provided (Rebuilding a stronger, more resilient Queensland, 2012). The Australian and Queensland governments have committed $6.8 billion to rebuild the state.

Pritchard [6] identifies that urban debris, such as cars, and the insufficient bridge span for debris to pass through are the main causes for damaging bridges in the aftermath of the 2011/2012 flood in Queensland. Using 2013 flood event in Lockyer Valley, Lokuge and Setunge [10] concluded that it is necessary to investigate the failure patterns and the construction practices adopted during the initial construction and rehabilitation stages in the lifetime of bridges. These findings raised a question that what are the failure mechanisms and contributing factors which requires consideration in designing of bridges to be resilient to extreme flood events.

THE PROJECT

Multi-hazard vulnerability modeling at a detailed level which aids managing authorities of road structures to prioritize hardening of structures, considering the intensity of disasters, vulnerability of structures and the impact on community resilience is not available to date. The overarching aim of the proposed Stage 2 of the project is to work closely with key stakeholders to implement the methodologies that have been developed for vulnerability modelling of road structures to prioritise vulnerable structures for improvement, to quantify the cost of reconstruction and/or cost of hardening of structures, and to integrate community resilience considerations into the decision-making process.

During the first year of Stage 2, several research objectives have been achieved, including hazard mapping for Victoria and Queensland, categorization of road structures, and floodway design process. The related methodologies are introduced below one by one.

Regarding the generic analysis methodology for vulnerability modeling, a detailed numerical modeling methodology has been developed for bridges under flood, bushfire and earthquake loading and floodways under flood loading. To simplify the methodology for network-level analysis, a generic method using a bridge modelling software was developed. This method was refined by comparing numerical models developed for girder bridges, u slab structures, and Super T structures. The methodology is similar to that used by HAZUS in the USA but has incorporated a more rigorous analysis and cover the complexities of bridge structures including the structural form.

A flood/bushfire map for Victoria was developed with the assistance of the Department of Environment, Land Water and Planning (DELWP). Bridge structures pre-1992 have been designed for 1:100 year return period flood loading and the current code requires design according to 1:2000 year return period flood loading. Two scenarios were covered and the structures falling into the two categories were identified. Queensland Reconstruction Authority (QRA) hazard maps were used to identify vulnerable structures in Queensland. A time-temperature curve for bushfire impact was developed for different regions of Victoria. Fire spread prediction project of the BNH CRC was engaged to provide a time-temperature curve for the states. Earthquake hazard map for Victoria was developed using Geoscience Australia information as well as the outcomes of the Earthquake resistant buildings project of the CRC.

In terms of categorization of road structures, the generic modeling of bridges requires categorization of road structures considering structural form, construction materials and the design period. The design standard used in design impact on the structural capacity as well. This analysis was undertaken by the researchers under the guidance of VicRoads structures team.

About the floodway design process, analysis of the failure of the floodways has established the gaps in design which lead to failure under flood loading. Also, the comparison of damage indices has demonstrated the most expensive elements of floodways which contribute to the reconstruction cost. In this stage, the outcomes of the previous stage were used to develop the basic design process for a resilience floodway.

RESEARCH APPROACH

The whole project can be further divided into three stages, including different activities and approaches. The details can be seen as follows.

YEAR 1

Generic analysis methodology for vulnerability modelling. A detailed numerical modelling methodology was developed for bridges under flood, bush fire and earthquake loading and floodways under flood loading. In order to simplify the methodology for network-level analysis, a generic method using a bridge modelling software was developed. This method was refined by comparing numerical models developed for girder bridges, U slab structures, and super T structures. The methodology is similar to that used by HAZUS in the USA but has incorporated a more rigorous analysis and cover the complexities of bridges structures including the structural form.

Hazard mapping for Victoria and Queensland. A floor/bushfire map for Victoria was developed with the assistance of the Department of Environment, Land Water and Planning (DELWP). Bridge structures pre 1992 have been designed for 1:100 year return period flood loading and the current code requires design according to 1:2000 year return period flood loading. Two scenarios were covered and the structures falling into the two categories were identified. Queensland Reconstruction Authority (QRA) hazard maps were used to identify vulnerable structure in Queensland.

A time-temperature curve for bush fire impact was developed for different regions of Victoria. Fire spread prediction project of the BNH CRC was engaged to provide time-temperature curves for the states.

Earthquake hazard map for Victoria was developed using Geoscience Australia information as well as the outcomes of the Earthquake resistant buildings project of the CRC.

Categorization of road structure. The generic modelling of bridges requires categorization of road structures considering structural form, construction material and the design period. The design standard used in design will impact on the structural capacity as well. This analysis was undertaken by the researchers under the guidance of VicRoads structures team.

Floodway deism process. Analysis of the failure of the floodways has established the gaps in design which lead to failure under flood loading. Also, a comparison of damage indices has demonstrated the most expensive elements of floodways which contribute to the reconstruction cost. In this state, the outcomes of the previous stage were used to develop the basic design process for a resilient floodway.

YEAR 2

Generic analysis to identify vulnerable structures. Applying the method developed in year 1 and integrating the hazard maps, vulnerable structures were identified for the two stages: Victoria and Queensland. These were identified in a GIS map.

Community impact model and the prioritized structures. Considering the level of importance of structures and vulnerability identified, a methodology was developed for recognizing the structures which affect evacuation, disaster responses, and post-disaster services. This methodology was used to derive a shortlist of bridges structures and floodways which requires hardening and/or long term reconstruction

Floodways inspection and management. Inspection manual for floodways was developed which align with the existing bridge inspection manual. This can be used for routine maintenance as well as during the recovery stage after an extreme flood event.

Strengthening/betterment. Strengthening options were developed for typical failure models. Using cost-benefit analysis and considering the project constraints and sustainability, optimal rehabilitation/reconstruction strategy was proposed for the prioritized structures in the two states. This is helpful in the decision-making process of betterment projects in these regions.

YEAR 3

Cost estimation linking with damage categories. The end-user focus group will be established to cooperate with the cost structure associated with the damage level of each category of the structure identified. These will include direct and indirect costs as well as tangible costs due to failure of road structures.

Community Impact quantification. In order to establish the community impacts, as capabilities based approach developed in stage 1 will be implanted. For example, the inability to attend school will be quantified as a percentage of days affected during the school year.

The environmental impact will be quantified using the life cycle analysis considering carbon emissions, eutrophication potential, and nonrenewable energy use.

Prioritization and decision making. Prioritization decision making will require integration of three impacts: economic, social and environmental. This will be achieved using the analytical hierarchical process combined with the pairwise comparison. Engagement of the BNH CRC researchers working on the project: a decision support system for assessment of policy and planning investment options for optimal natural hazard mitigation will be made to incorporate the latest findings in this field.

Validation and implementation. Validation of the developed tools will be undertaken by using a recent disaster event where road structures were affected. The data for 2011 and 2013 Lockyer Valley floods are available for this purpose.

Floodway design guide. Having received the feedback for the floodway design process from the end users, the floodway design guide will be developed. Organizing this as the nationally accepted publication is anticipated.

KEY MILESTONES

YEAR 1

The key milestones for year 1 are listed as below:

- Comparison between numerical modelling and structural design software output
- Hazard maps/demand curves for Victoria and Queensland for flood, bushfire, and earthquakes
- A paper on the resilient floodway design process to Australian Journal of Civil Engineering
- Draft floodway design guide submitted for end-user feedback
- Categorization of bridge structures for analysis

YEAR 2

The key milestones for year 2 are listed as below:

- Generic analysis of bridges (structural group)
- Community impact model for decision making on strengthening
- Floodway inspection methodology
- Strengthening options for different hazard types and levels

YEAR 3

The key milestones for year 3 are listed as below:

- Determine costs for treatment options
- Multi-criteria decision-making methodology developed
- Prioritization of structures for betterment, development of a vulnerability database
- Prototype tool (identify vulnerable structures and decide on optimum maintenance) developed and tested
- Resilient floodway design guide submitted to IPWEA/AUSTROADS

UTILISATION AND IMPACT

SUMMARY

During the last financial year, the research team has published 7 peer-reviewed journal papers (5 Scimago Q1 journal papers), which have contributed to the knowledge base of the discipline.

Through a number of end-user engagement activities, some specific utilization outcomes have been identified.

BRIDGE PRIORITISATION MODEL FOR VICROADS

Output Description

In order to prioritise bridges for strengthening, maintenance and repairment, a new model has been developed considering the impact on the community after removal of the bridge from the network. The model included analysis of the length of detour using a current transport platform, the impact of that on the environment, community and the emergency services.

Extent of Use

- Prioritization framework and the tool has been provided to VicRoads

Utilisation Potential

- The bridge prioritization tool enables VicRoads to prioritise the structures to be strengthened to reduce the vulnerabilities under disasters.

BRIDGE DETERIORATION MODEL AND AN ASSET MANAGEMENT SYSTEM

Output Description

Early in the project, it was identified that the vulnerability of bridges will be increased if the bridge condition is inferior at the time of the event. In order to predict the future bridge conditions, deterioration models have been developed for major bridge elements using the level 2 inspection data collected by the road authority. This project had a contribution from an ARC-funded project entitled "Deterioration prediction of bridge structures" as well.

Extent of Use

The deterioration prediction models have been Incorporated into an asset management platform and have been trialed by the seven regions of VicRoads. Further modifications are currently in progress.

Utilisation Potential

The deterioration prediction models will provide much-needed input parameters for vulnerability modelling of bridge structures.

PREDICTING THE PROBABILITY OF FAILURE OF TIMBER BRIDGES USING FAULT TREE ANALYSIS

Output Description

Timber bridges are a weaker link of the Australian road network and they often provide critical access to the rural communities. This research uses a number of bridge inspection reports to develop a method to predict the probability of failure of a timber bridge. The inspected condition states of the elements in the timber bridge are used to develop a Markov Chain based model and Gamma process model to predict the deterioration of each element. The probability of condition state movement for each element thus calculated were used in fault tree analysis to estimate the likelihood of failure of a bridge in a given time period. Although the developed method is based on limited data and it has several limitations, the model can be further refined with the availability of more inspection reports.

Utilisation Potential

- The method developed is demonstrated using an inspection report for a timber bridge, which was not used in the development of the models. The study will provide an important guide on the design and maintenance of timber bridges.

FLOODWAY DESIGN METHODOLOGY

Output Description

Floodways are a type of low-cost road crossings, which are expected to be overtopped during a flood event and then be functional after the subsidence of flood water. In rural Queensland, it was observed that after a flood event, most of the floodways are damaged and do not provide the anticipated functionality during the recovery stage. In Lockyer Valley region, it was noted that there are up to 30 floodways between the community and the township. Some observations made by the community indicated that this is a recurrent issue and often floodways reconstructed after one flood event are damaged again in the next event. Thus, the project focused on the failure modes of floodways and a method for resilient design.

An Austroads publication titled 'Guide to Road Design- Part 5B: Drainage- Open Channels, Culverts, and Floodways' is the nationally accepted design guideline for floodway construction in Australia. In addition, two state authorities, the Department of Transport and Main Roads in Queensland (TMR) and Main Roads Western Australia have prepared their own design guidelines to best represent the practices undertaken within their respective states. These three design guidelines primarily detail floodway design based upon hydraulic design principles. To enhance the resilience, a need was identified to consider the structural design of floodways. One of the major outcomes delivered by the project is a design guide for resilient floodways based on structural failure. The team has completed the required research and have compiled a document covering different floodway types and the structural design charts for the floodways. This document will be a companion document for existing floodway design guide and the Main Roads Western Australia document which will be publicly available.

Utilisation Potential

We have contacted the Institution of Public Works Engineers Australia (IPWEA) who publish guidelines for local councils to consider our document to be published. They require us to submit the document in a standard format and they will then appoint a panel to review the document. We will need to comply with any changes and then have to sign an agreement with them on this. Subsequently, we need to develop a training program to socialise the floodway design guide among IPWEA members. We need some support to compile the information in the required format and present to the IPWEA for review. Health assessment of a pedestrian bridge deck using ground penetrating radar.

FLOODWAY ASSET MANAGEMENT SYSTEM

Output Description

In one of the project workshops conducted in 2017, the stakeholders identified that the optimised maintenance of floodways is also extremely important and that regular inspections and life cycle predictions would reduce the vulnerability of the floodways. Thus, the need for an asset management system for floodways was identified as a major need for the local councils. We have initiated a sub-project on developing an asset management system for floodways. This includes an inspection guide and life cycle predictive models for the condition of floodways.

RMIT University has the capability to develop a cloud-hosted platform for the asset management of floodways which can be deployed among interested local councils prone to flood events. USQ has a team who has been conducting inspections of floodways and compiling cost data as input for asset management of floodways.

Utilisation Potential

There is significant utilization potential if the asset management system can be developed for the local councils in Australia where flooding risk is present.

NEXT STEPS

During the coming year, we will be working on the following aspects to make sure the success of this project:

- Determine the cost of the treatment options for the main hazards of flood, bush fire, and earthquakes;
- Develop the multi-criteria decision-making methodology for the assessment and impact analysis of the main hazards of flood, bush fire and earthquakes;
- Prioritize the structures for the betterment and develop a vulnerability database for flood, bush fire, and earthquakes;
- Develop and test the prototype tool to identify vulnerable structures and decide on optimum maintenance;
- Develop the resilient floodway design guide and submit it to IPWEA/AUSTROADS;
- Engage with the end users to tailor the research direction and fulfill their urgent research needs; and
- Complete the final project completion report and submit it to BNH CRC.

PUBLICATIONS LIST

PEER-REVIEWED JOURNAL ARTICLES

1. Nasim M., Setunge S., Mohseni H., Zhou Sh. "An investigation into the water flow pressure distribution on the bridge pier under flood loading" Structure and Infrastructure Engineering Journal, 2018; 15: 219-229. (**Q1**)
2. Wahalathantri, B, Lokuge, W., Karunasena, W., Setunge, S. (2018), Quantitative assessment of flood discharges and floodway failures through cross-cultivation of advancement in knowledge and traditional practices, International journal of disaster resilience in the built environment, Vol 9, Issue 4/5, pp 435 – 456 (**Q1**).
3. Lokuge, Weena and Wilson, Matthew and Tran, Huu and Setunge, Sujeeva (2019) Predicting the probability of failure of timber bridges using fault tree analysis. Structure and Infrastructure Engineering. ISSN 1573-2479 (**Q1**)
4. M. Maizuar, E. Lumantarna, M. Sofi, Y. Oktavianus, L. Zhang, C. Duffield, P. Mendis. Dynamic behaviour of Indonesian bridges using interferometric radar technology. Electronic Journal of Structural Engineering 2018; 18(1): 23-29. 34.
5. S. Miramini, M. Sofi, A. Aseem, A. Baluwala, L. Zhang, P. Mendis, C. Duffield. Health assessment of a pedestrian bridge deck using ground penetrating radar. Electronic Journal of Structural Engineering 2018; 18(1): 30-37.
6. Gajanayake, A., Zhang, G., Khan, T. and Mohseni, H., (2019) Post-disaster Impact Assessment of Road Infrastructure: A State of the Art Review, Natural Hazards Review, 10.1061/(ASCE)NH.1527-6996.0000343. Accepted on 23/5/2019 (**Q1**)
7. Qeshta IMI, Hashemi MJ, Gravina R, Setunge S, Review of resilience assessment of coastal bridges to extreme wave-induced loads, Engineering Structures, 2019(185): 332-352. (**Q1**)

CONFERENCE PAPERS

1. Nasim M, Setunge S, Zhou SW, Mohseni H, IBMAS2018 conference, Bridge Engineering Conference, 2018, "A U-Slab Bridge Pier's Behaviour under Flood Intensity", oral presentation, Melbourne, Australia
2. Greene, I., Lokuge, W., Karunasena, W. (2018). Floodway design process re-visited. In: The 25th Australasian Conference on the Mechanics of Structures and Materials (ACMSM25), Brisbane, December 2018.
3. Lokuge, W. and Fraser, C. and Karunasena, W. (2019) Performance of bridges with damaged elements in extreme flood events, In: 25th Australasian Conference on Mechanics of Structures and Materials (ACMSM25), December 4 – 7, 2018, Brisbane Convention and Exhibition Centre.
4. Jethro Cohen, Weena Lokuge and Nilupa Herath (2018), "Effect of snipe depth on the performance of timber bridge girders", 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, pp. 2075-2079.
5. Rahmin Borzou and Weena Lokuge "Rehabilitation of timber bridge piles using a FRP wrapping system", 9th International Conference on Bridge Maintenance, Safety and Management (IABMAS 2018), Melbourne, pp. 2069-2074.
6. 21st International Conference on Civil, Construction and Geological Engineering, 18-19 Apr 2019, Paris, France, (**Best Presentation Award**)
7. Jethro Cohen, Weena Lokuge, Nilupa Herath, Effect of snipe depth on the performance of timber bridge girders", The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.
8. Gajanayake, A., Khan, T. and Zhang, G (2019) Post-Disaster Decision Making in Road Infrastructure Recovery Projects - An Interview Study with Practitioners in Queensland. In: 8th Australian & New Zealand Disaster & Emergency Management Conference, Gold Coast, Australia, 12-13 June 2019.
9. Tran, H.D., Setunge, S., Shi, L. (2018), A Case Study On The Remaining Strength of Stormwater Drainage Pipes, 25th Australasian Conference on Mechanics of Structures and Materials (ACMSM25) Edited by C.M. Wang, J.C.M. Ho and S. Kitipornchai, Brisbane, Australia, December 4 – 7, 2018
10. ABC2017conference: "An Investigation to the Behaviour of water flow on Bridge Pier in Flood Event", oral presentation, Melbourne, Australia
11. IBMAS2018 conference, Bridge Engineering Conference, 2018, "A U-Slab Bridge Pier's Behaviour under Flood Intensity", oral presentation, Melbourne, Australia
12. CSTX 2018 Conference, Computers and Structures Conference, oral presentation, "Vulnerability Assessment for the Reinforced Concrete Beam Exposed to Monotonic Loading Using Different Damage Indexes", oral presentation, Barcelona, Spain
13. CIA 2019 Conference, Biennial National Conference of the Concrete Institute of Australia, How the mass of a dropping hammer can influence on the damage scenario of a reinforced concrete beam oral presentation"

KEYNOTE PRESENTATIONS

1. Mendis. P, China Construction Summit, Hangzhou, China, May 2019
2. Mendis. P, ACI Conference, Mumbai, India, December 2018
3. Setunge, S., ACMSM conference, Brisbane, Australia, December 2018

TECHNICAL REPORTS

1. Sujeeva Setunge, Weena Lokuge, Karu Karunasena, et al., Floodway inspection and maintenance framework, BNH CRC, 2019;

JOURNAL PAPERS UNDER REVIEW

1. *Nasim M., Setunge S., Mohseni H., Maqsood T., "A Study on Effect of the Mass of a dropped Hammer on the Dynamic Response on a Reinforced Concrete Beam", manuscript submitted to ACI Structural Journal*

2. *Nasim M., Setunge S., Mohseni H., Maqsood T., "Damage estimation for the Reinforced-Concrete Model under Uniform Pressure Loading; a comparison on the deflection and energy-based approaches" manuscript under review.*
3. *Nasim M., Setunge S., Mohseni H., Maqsood T., "A Study on Effect of the Mass of a dropped Hammer on the Dynamic Response on a Reinforced Concrete Beam", manuscript submitted to ACI Structural Journal.*
4. *Nasim M., Setunge S., Mohseni H., Maqsood T., "Log Impact Forces on a U-Slab Bridge Pier: A Parametric Study on Dynamic/Nonlinear Response of a Bridge Pier Exposed to an Object Impact" manuscript is under supervision revision*
5. *Weena Lokuge, Elahe Etemadi, Isaac Greene and Warna Karunasena, "Role of structural analysis in floodway design process", Australian Journal of Civil Engineering (Received comments for minor revision)- Q3*
6. *Herath, N., Zhang L.H., Mendis, P., Lokuge, W., Setunge, S., (2019) Life cycle performance of bridges under multiple seismic actions, ACI Structural Journal (Q1)*
7. *Herath, N., Zhang L.H., Mendis, P., Setunge, S., (2017) Reliability analysis of damage accumulation in concrete bridges subjected to multiple earthquakes in Australia, Journal of Infrastructure systems. (Q2)*
8. *Farook, K., Sujeeva, S., Dilan, R., (2019), Vulnerability modelling of concrete girder bridge decks under flood loading,* Natural Hazards Review

WORKSHOPS

1. *July 6, 2018, an end user workshop was held at RMIT University to engage end users. The team members who attended the meeting include Sujeeva Setunge, Weena Lokuge, Karu Karunasena, Nilupa Herath, Priyan Mendis, Lihai Zhang, Maryam Nasim, Amila Dissanyake, Zeinab Yazdanfar, Ismail Qeshta, Akvan Gajanayake. The end users include Yew Chin Koay and Henry Luczak from VicRoads, Dominic Di Martino from the City of Brimbank.*
2. *October 9, 2018, A workshop was held at The University of Southern Queensland, Springfield Campus, with team members of Sujeeva Setunge, Long Shi, Karu Karunasena, Ween Lokuge, Nulupa Herath. The end users include Quentin Underwood from Lockyer Valley Regional Council, Bot Barrett and Georgy Illic from Transport and Main Roads of Queensland, Dawayne Honor from Bunderberg Regional Council;*
3. *November 21-22, 2018, Research advisory forum at QUT where the floodway design process was presented to the end users of the project (Tony McDonald from Lockyer Valley Regional Council and Myles Fairbarn now from Brisbane City Council but earlier from LVRC).*
4. *14th June, 2019, a Bushfire CRC workshop was held at RMIT University within the team members from RMIT, USQ and MelUni, including Sujeeva Setunge, Long Shi, 7, Kevin Zhang, Maryam Nasim, Karu Karunasena, Ween Lokuge, Nulupa Herath, Priyan Mendis, Lihai Zhang, Akvan Gajanayake, Huu Tran, and Isaac Greene;*

RESEARCH ACTIVITIES

1. *U-Slab bridges as the old and vulnerable structure have been numerically modelled using ABAQUS to address the effect of flood, debris and log impact force on the bridge superstructure considering uncertainties in concrete material and flood hazard intensity. The methodology of modeling the concrete pier has been developed and validated by an experiment from literature.*
2. *The research is conducted in different phases of studying hydrodynamic response of water flow on the pier, study damage assessment of the pier based on the proposed damage index, study the structural damage response under impact and to generalise it for a bridge pier when it is under log or any unknown object impact.*
3. *River scour have been modelled using a coupled CFD-DEM model. The model has been validated against experimental data. A parametric study has been done and several numerical models with different domain configuration, flow conditions and sediment properties have been developed. Simulations are computationally expensive and result production is still under construction.*
4. *Research activities were conducted to prioritise the bridges in Victoria depending on the vulnerability and impact of earthquakes. A framework was developed considering the risk and vulnerability of bridges using risk assessment and multi-criteria analysis methods. After identifying the critical bridges located within the Melbourne CBD, a reliability-based road network assessment was conducted.*
5. *Dynamic behaviour of 2 bridges in Victoria was monitored using non-destructive testing methods and finite element models were developed. A framework was developed to capture the real-time dynamic behavior of the bridge and dynamic characteristics of the bridge.*
6. *Preparation of floodway design guidelines is on-going. Design charts for two floodway types out of the four types have been prepared. Publication of this design guide is being discussed with IPWEA.*
7. *Inspection framework and an inspection guide for floodway and culvert maintenance were completed. Development of this as a maintenance tool is identified as a utilisation project.*
8. *Bridge Prioritization Tool for VicRoads was developed. Consequence of bridge closure in monetary value to road users, affected economy, public and environment was quantified. Individual bridges according to consequence of bridge closure costs for 3024 bridges managed by VicRoads Metropolitan and five rural regions were ranked. Given the limited annual funding budget, Road agencies can utilise the developed prototype excel sheet to pick the topmost bridges for maintenance, rehabilitation and reconstruction work.*
9. *CSI Bridge software was utilised to model the vulnerability of the bridges under flood hazard given its simplicity for modelling large stocks of bridges as compared to using ABAQUS/ANSYS software that takes huge computational time and complicated modelling procedure. CSI Bridge has the features of different inbuilt bridge geometries that require simple modification of parameters to suit our requirement.*
10. *A framework to identify and measure social, environmental and economic (SEE) impacts of disaster-related road failure were developed. An excel based tool catered for road asset owners was developed to measure SEE impacts in real-life scenarios. The SEE impacts for two case study bridges in the Lockyer Valley Regional Council were estimated using the above tool.*
11. *Deterioration of floodways and culverts have been modelled and predicted using the Markov model.*
12. *Deterioration of bridge components by structure types have been developed and predicted for budget forecast.*

TEAM MEMBERS

Researchers	Research Students	End Users
Prof. Sujeeva Setunge Prof. Kevin Zhang Prof. Chun Qing Li Dr. Long Shi Prof. Dilanthi Amaratunga Prof. Priyan Mendis Dr. Hessam Mohseni Prof. Karu Karunasena Dr. Weena Lokuge Dr. Lihai Zhang Dr. Nilupa Herath Dr. Tuan Duc Ngo Dr. Farook Kalendhar	Mr. Amila Dissanayake Mr. Ismail Qeshta Ms. Maryam Nasim Ms. Zeinab Yazdanfar Mr. Akvan Gajanayake	Dr. Yewchin Koay, Team leader, Structural Technology and assets, VicRoads Mr. Henry Luczak, Manager, structural technology and assets, VicRoads Ms. Leesa Carson, Branch Head, Community Safety, Geoscience Australia Mr. Kieran Dibb, Director Engagement and Technical Services, Operations Queensland Reconstruction Authority Mr. Bob Barrett, Manager (Structures Stewardship), Structures Management Engineering & Technology, Department of Transport and Main Roads

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