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

Annual project report 2017-2018

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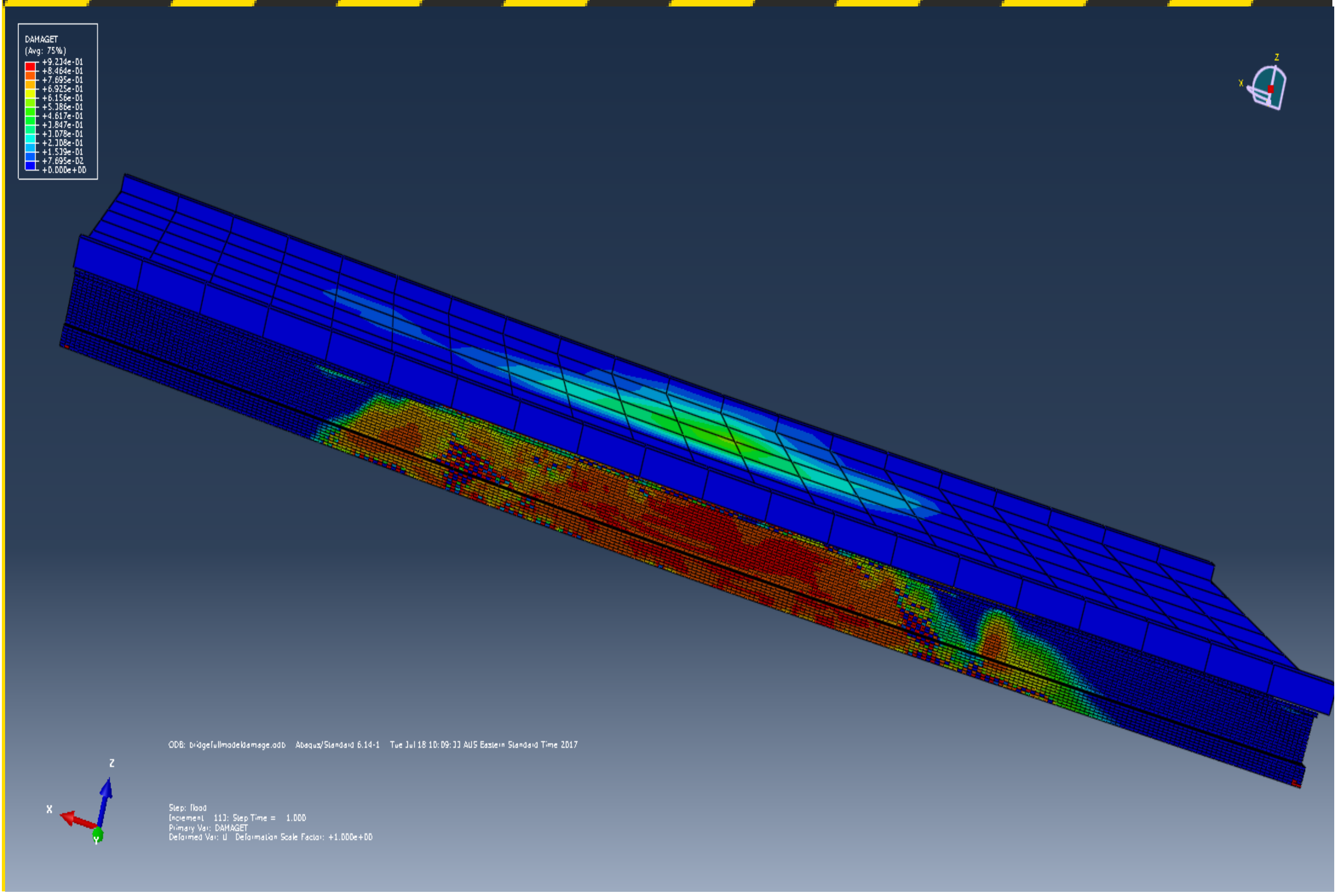
RMIT University, The University of Melbourne, The University of Southern Queensland, The University of Huddersfield & Bushfire and Natural Hazards CRC



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Cover: Simulation of Concrete Girder Bridges under Flood Hazard - by Farook Kalendher

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EXECUTIVE SUMMARY

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. 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. 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.

The major research activities include numerical modeling of concrete bridges under hazards of flood, earthquake, and bushfire, with the fast and rapid simulation based on CSi bridge software and the development of a coupled computational fluid dynamics model with discrete element model. A reliability-based assessment framework was developed to quantify the damage accumulation of the bridges caused by multiple earthquakes and progressive deterioration throughout their service life. Furthermore, the hazard maps of bridges under bushfire and flood were developed with the identification of the bridges under the risks.

Four workshops and four meetings were held during the first year of Stage 2 of the project. Two workshops were held at RMIT University to discuss with end users and colleagues regarding the feedbacks and comments of the project progresses. Two workshops were held at the University of Southern Queensland The University of Melbourne, respectively. Feedbacks from the end users in Queensland state and colleagues at the University of Melbourne have largely benefited the research progress.

Six Ph.D. candidates work with the research team at RMIT, where three researchers were recruited at USQ and RMIT to working on the project. One Ph.D. candidate was graduated at RMIT based on this project during the last year. There were also 3 field trips to city councils regarding the interview survey, including the Lockyer Valley Regional Council and the Queensland Reconstruction Authority. We have attended 6 conferences to present our research.

Regarding the research outputs, we have published four international journal papers, including three Scimago Q1 journal papers, where 10 journal papers are under review. Four conference papers were presented at the national and international conference, where 11 conference papers were accepted for publication in the proceedings.

END USER STATEMENT

VicRoads has been attending the monthly meetings of the project and is also end user workshops when they are scheduled. During the monthly meetings, the students and the researchers present on the project progress and VicRoads provides input on the possible utilisation measures. VicRoads has initiated an introduction to a team from the University of Melbourne to explore the use of Intelligent Disaster Decision Support System (IDDSS) platform for predicting the effect of disruption of the bridge network on the road network and the community. This is now in progress.

VicRoads will be working closely with the research team to incorporate the vulnerability modelling of the bridges in to decision making on bridge management.

Dr. Yewchin Koay
Team leader, Structural technology and assets, 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 marking process on interventions after an extreme event so that the decision markers 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 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.

PROJECT BACKGROUND

Australia's variable climate has always been a factor in natural disasters that have had a significant impact on an 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, 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 rebuilding the state.

Pritchard [6] identifies that urban debris, such as cars, and the insufficient bridge span for debris to pass through are main causes for damaging bridges in the aftermath of 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 SUA 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.

PROGRESS TO DATE

RESEARCH ACTIVITIES

During the past year, the research methodology has been further refined and presented to the end users. Several main research areas as given below were conducted to achieve the objectives:

1. Two bridges have been numerically modeled 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. Reliability-based ABAQUS modeling of the concrete girder bridges under flood loading has been repeated using the CSi bridge software. The latter is an off the shelf product which can be used to perform analysis of the bridges with a reasonable accuracy and less computational time.
3. General thermo-mechanical behavior modeling of composite steel bridges under bushfire has been completed. The simulation of timber bridge behavior under bushfire was completed using the fluid-structure interaction modules of ANSYS based on the comparison with full-scale experimental results in the literature.
4. Different load patterns and load discretization methods have been compared with respect to the performance of the bridge. Two different methods have been implemented for the application of the flood loading on the structure. The fragility of the bridge under different loads schemes has been analyzed using the two-main intensity measure, flood velocity and inundation depth.
5. The hazard data have been obtained for the risk of bushfire and flood in Victoria, while the GIS map of Victoria bridges has been confirmed. The combination platform for hazard data and GIS map has been determined. The related bridges under the risks have been identified accordingly.
6. A coupled Computational Fluid Dynamics model with Discrete Element Model (CFD-DEM) has been developed, while the numerical results have been validated by literature data. Developed and compared mono- and poly-dispersed models to calibrate the mono-dispersed model and replace it with the poly-dispersed model.
7. Reliability analysis of damage accumulation in bridge structures subjected to multiple earthquakes in Australia. A reliability-based assessment framework was developed to quantify the damage accumulation of the bridges caused by multiple earthquakes and progressive deterioration throughout their service life.
8. Prioritisation of bridges considering earthquake impacts. The transportation systems highly depend on the performance of bridges in the network and failure of a single bridge could lead to catastrophic impacts to the economy of the region. This study aims to identify and prioritize bridges in Victoria under earthquake impacts. Multi decision criteria method was used in ranking the bridges located in Victoria using an inventory of approximately 3500 bridges.

WORKSHOPS OF RESEARCHERS AND END USERS

During the past year, following end-user engagement activities were completed:

1. July 24, 2017, an end user workshop was held at RMIT University to engage end users in the second phase of the project. This was attended by the following delegates: Catherine Dear, Director Asset services, VicRoads, Leanne Simpson, Director Emergency Services, VicRoads, Dr. Hessam Mohseni, TFV, Dr. Yew Chin Koay, Team Leader, Structural Technology and Assets, VicRoads, Henry Luczak, Manager Technology and Assets, VicRoads, Kieran Dibb, Director, Technical Service, Operations, Queensland Reconstruction Authority, Dwayne Honor, Project manager, Bunderberg regional Council and the CRC project team.
2. October 9, 2017, end user and researcher workshop at University of Southern Queensland. Outcomes of Stage 1 of the projects were presented to the end user representatives from Queensland Transport Main Roads, Lockyer Valley Regional Council and Institute of Public Works Engineering Australasia. Feedback from the end users was received for Stage 2 of the project during this workshop.
3. October 16, 2017, a Workshop was held at RMIT with delegates from Victoria University. This was attended by Victoria University delegates: Associate Professor Khalid Moinuddin; Rahul Wadhwani; and Dr. Duncan Sutherland.
4. November 15, 2017, a workshop was held at Melbourne University to explore the use of the disaster resilience platform developed by Melbourne on bridge prioritisation. The attendees include Prof Majid Sarvi, Dr. Saeed Bagloee, A/Prof Russell Thompson, Dr. Benny Chen from Melbourne Uni; Prof Sujeeva Setunge, Dr. Long Shi and Mohamed Farook from RMIT; and Dr. Yew Chin Koay from VicRoads.
5. November 29, 2017, USQ researchers (Dr. Weena Lokuge, Prof Karu Karunasena, 2 honors students) and a Ph.D. student from RMIT had a meeting with LVRC end users to discuss in detail about the research activities related to floodways and culverts. Discussing how to obtain the information related to social and economic impact on the community was another key focus of the meeting.
6. May 3, 2018, USQ researchers met with the Asset coordinator of LVRC to source the information related to inspections and maintenance of floodways and culverts.
7. May 7, 2018, USQ researchers had a teleconference with RMIT researchers on developing a mobile app for asset management mainly for floodways and culverts.
8. June 20, 2018, deterioration modeling workshop for regional offices of VicRoads.

RECRUITING DURING THE PAST YEAR

1. Dr. Wasanthi Wickramasinghe was appointed as a researcher to work on floodways and culverts (USQ) till the end of 2017.
2. Ms. Elahe Etemadi is currently appointed as a researcher to work on floodways.

3. Dr. Farook Kalendher is currently appointed as a researcher to work on the hazard maps at RMIT University.

MAJOR EQUIPMENT PURCHASES

- No major equipment purchases

MAJOR FIELD TRIPS

1. November 24, 2017, an interview Survey at the Lockyer Valley Regional Council with John Keen, Tony McDonald, Myles Fairbairn, Michelle Kocsis.
2. March 1, 2018, an interview survey at the Lockyer Valley Regional Council with Myles Fairbairn, Peter Hillcoat, Belinda Wellband, Helen McCraw, Elizabeth Jones and Neil Williamson.
3. March 2, 2018, an interview Survey at the Queensland Reconstruction Authority with Kieran Dibb.

CONFERENCES ATTENDED REPRESENTING THE BNH-CRC

1. The 12th World Congress on Engineering Asset Management & 13th International Conference on Vibration Engineering and Technology of Machinery, Brisbane, August 2017.
2. The 7th International Conference on Building Resilience, Bangkok, Thailand, November 2017.
3. AFAC Conference - Australian and New Zealand National Council for fire, emergency services, September, 2017.
4. Austroads Bridge Conference, Melbourne, March 2017.

PUBLICATION LIST

Journal papers

- Published journal papers (SJR ranking)
  - Kafele, B., Zhang, L., Mendis, P., Herath, N., Maizuar, M., Duffield, C., Thompson, R., (2017) Monitoring the dynamic behaviour of the Merlynston creek bridge using interferometric radar sensors and finite element modelling, International Journal of applied mechanics, 9(1):1750003-1-20. (**Q1**)
  - Maizuar, M., Zhang, Miramini, L., Mendis, P., Thompson, T., (2017) Detecting structural damage to bridge girders using radar interferometry and computational modeling. Structural Control and Health Monitoring, 24(10): 1-6 (**Q1**)
  - Herath, N., Mendis, P., Zhang, L.H., (2017), A probabilistic study of ground motion simulation for Bangkok soil. Bulletin of Earthquake Engineering 2017; 15(5): 1925-1943 (**Q1**)
  - Nasim, M., Setunge, S., Zhou, S., Mohseni, H., Study on the water flow pressure on the pier of bridge structures when increasing the flood intensity - how to simulate the loads and a comparison to the Codes suggestion, Structure and Infrastructure Engineering, 2017. (**Q1**)
  - Lokuge, Weena, and Wilson, Matthew and Tran, Huu and Setunge, Sujeeva (2017) Predicting the failure of timber bridges by using current inspection reports. Engineering for Public Works (7). pp. 85-89.
- Submitted journal papers
  - 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**)
  - Lokuge, W., Wilson, M., Tran, H., Setunge, S., (2017) Predicting the probability of failure of timber bridges using Fault Tree Analysis, Structure and Infrastructure Engineering. (**Q1**)
  - Lokuge, W., Etemadi, E., Greene I., Karunasena, W., (2017) Role of structural analysis in floodway design process, Australian Journal of Civil Engineering. (**Q4**)
  - Kalendher, F., Setunge, S., Robert, D., Mohseni, H., (2017). Application of fragility curves to estimate concrete girder bridge damage under flood hazard: a case study of Lockyer Valley Region, Queensland, Australia, Journal of the International Society for the Prevention and Mitigation of Natural Hazards.
  - Kalendher, F., Setunge, S., Robert, D., Mohseni, H., (2017). Methodology for the development of probabilistic fragility curves for concrete girder bridges under flood hazard, Journal of the International Association for Earthquake Engineering.
  - Qeshta, I.M.I., Hashemi, J., Gravina, R., Setunge, S., (2018) Response of highway bridges to flood-hazard forces: a review. Engineering Structures. (**Q1**)

- Qeshta, I.M.I., Hashemi, J., Gravina, R., Setunge, S., (2018) Fragility assessment methodology for bridges subjected to extreme hydrodynamic forces. Journal of Bridge Engineering; Journal of Structural Engineering. (**Q1**)
- Akvan Gajanayake, Kevin Zhang, Tehmina Khan and Hessam Mohseni, (2018) A review on post-disaster impact assessment of road infrastructure, International Journal of Disaster Risk Reduction. (**Q1**)
- Nasim M., Setunge, S., Damage estimation for the Reinforced-Concrete Model under Uniform Pressure Loading; a comparison of the deflection and energy based approaches, Structure and Infrastructures Engineering, 2018. (**Q1**)

Keynote Presentations

- S.Setunge, Enhancing disaster preparedness by building resilience of critical infrastructure, The 7th International Conference on Building Resilience; Using scientific knowledge to inform policy and practice in disaster risk reduction, Bangkok, Thailand 27 – 29 November 2017.

Conference papers

- Conference papers presented
  - Abbott, T., Gamage, N and Setunge, S. and Lokuge, W (2017) Predicting the remaining life of timber bridges. In: The 12th World Congress on Engineering Asset Management & The 13th International Conference on Vibration Engineering and Technology of Machinery, Brisbane, 2-4 August 2017.
  - Akvan Gajanayake, Hessam Mohseni, Guomin Zhang, Jane Mullett, Sujeeva Setunge, Community adaptation to cope with disaster related road structure failure, The 7th International Conference on Building Resilience; Using scientific knowledge to inform policy and practice in disaster risk reduction, Bangkok, Thailand 27 – 29 November 2017.
  - Dissanayake, A., Venkatesan, S., Setunge, S., Robert, D., Mohseni, H., Nasim, M., Thermal response analysis of composite steel girder bridges subjected to bushfires, Austroads Bridge Conference, Melbourne, March 2017.
  - Nasim M., Setunge S., Zhou S., Mohseni H., An Investigation to the Behaviour of water flow on Bridge Pier in Flood Event, Austroads Bridge Conference, Melbourne, March 2017.
- Conference papers accepted
  - 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.
  - Rahmin Borzou, Weena Lokuge, Rehabilitation of timber bridge piles using a FRP wrapping system", The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.

- Kalendher, F., Setunge, S., Robert, D., Mohseni, H., Fragility curves for concrete girder bridges under floor hazard, The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.
- Tran, H.D., Setunge, S., Koay Y.C., Luckzac, H., 2018, What are the attributes of a superior bridge management system, The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.
- H.D. Tran, S. Setunge, Y-C. Koay & H. Luckzac, 2018, Predictive modeling of the deterioration of Australian state bridge network, The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.
- H.D. Tran, S. Setunge, Y-C. Koay & H. Luckzac, 2018, A simulated maintenance costing using a Markov deterioration model for bridge components, The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.
- Qeshta, I.M.I., Hashemi, J., Gravina, R., Setunge, S., (2018) Fragility analysis of non-ductile RC bridges subjected to extreme hydrodynamic forces, The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.
- Dissanayake, A.P., Setunge, S., Venkatesan, S., Numerical assessment of composite bridges subjected to Wildland Urban Interface (WUI) fires, The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.
- Nasim M., Setunge S., Zhou S., Mohseni H., Computational Investigation on the Piers of a U-Slab Bridge under Raising Flood Intensity, The 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, 2018.
- Nasim M., Setunge S., Zhou S., Mohseni H., Nazem M., Damage Index Investigation for The RC Bridge Pier Exposed to Flood Loading, Australasian Structural Engineering Conference, 2018.
- Nasim M., Setunge S., Zhou S., Nazem M., Mohseni H., Vulnerability Assessment for the Reinforced Concrete Beam Exposed to Monotonic Loading Using Different Damage Indexes, GSTX 2018, Barcelona.

LIST OF CURRENT INTEGRATED TEAM MEMBERS

Researchers	Research Students	End Users
Prof. Sujeeva Setunge Prof. Kevin Zhang Dr. Long Shi Prof. Chun Qing Li 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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2. Austroads, *Improved Bridge Deterioration Models, Predictive Tools and Costs*. 2015.
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4. in *Herald Sun*. 2011.
5. Kuhlicke, C., *Resilience: a capacity and a myth: findings from an in-depth case study in disaster management research.* Natural Hazards, 2010.
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10. Lokuge, W. and S. Setunge, *Evaluating disaster resileince of bridge infrastructure when exposed to extreme natural events*, in *International conference on disaster resilience*. 2013: Sri Lanka.