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

Annual project report 2014-2015

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Version	Release history	Date
1.0	Initial draft document	26/10/2015

Publisher:
Bushfire and Natural Hazards CRC

October 2015

Citation: Setunge S, Quig Li C, McEvoy D, Zhang K, Mullett J, Mohseni H, Mendis P, Ngo T, Herath N, Karunasena K, Lokuge W, Wahalathantri B, Amaratunga D, 2015, Enhancing resilience of critical road infrastructure: bridges, culverts and flood-ways under natural hazards: Annual project report 2014-2015, Bushfire and Natural Hazards CRC

Cover: Infrastructure works in the Lockyer Valley, Queensland.

Photo: Hessam Mohseni

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EXECUTIVE SUMMARY

The project aims to develop vulnerability models for critical road structures: bridges, culverts and floodways under natural hazards of flood, bushfire and earthquakes. In the second stage of the project, optimized maintenance and strengthening regimes required to enhance resilience of critical road structures will be identified and a decision making tool will be developed.

During the past year, the research focused on analysis of the case studies available from end user partners and development of the methodology for vulnerability modeling of bridges and floodways under natural hazards of flood, earthquake and bushfires. A field study was undertaken to examine the community impact due to failure of road structures during the 2011 and 2013 floods in the Lockyer Valley region in Queensland. Researchers spent one week conducting semi-structured interviews of the community and identified the major community impacts due to failure of road structures.

Four workshops and a number of informal meetings were held during the year with excellent participation of end users researchers. During the workshops, case study data were identified and the methodology for vulnerability modeling was refined. Future data needs were communicated to the end users.

Two new Ph.D candidates commenced work with the research team on APA scholarships and two more will commence in July 2015. Each of the four strands of the project has recruited a researcher to engage in the project.

Major outcomes during the past year can be summarized as development of the vulnerability modeling methodology for critical road structures exposed to extreme events and demonstration of the methodology using four case studies. This work has been published in three peer reviewed conference papers and submitted as four journal papers. One journal paper has been accepted for publication. In addition, work was presented as invited papers at three industry events.

END USER STATEMENT

Leesa Carson, Branch Head, Community Safety
Community Safety & Earth Monitoring Division, **GEOSCIENCE AUSTRALIA**

Road networks play a key role in Australia's economy and resilience of communities. This project is filling an important gap in understanding the vulnerability of road infrastructure to natural hazards and the impact to communities.

The focus of the work this year has been in developing vulnerability model methodology for critical road infrastructure and assessing the impact to community due to road structure failure from flood. The project has had a positive 12 months; successful stakeholder engagement, compilation of information on road structure and failure due to natural hazard events as well as building an understanding of community resilience associated with road systems.

The stakeholder engagement by the project team is very proactive and provides a good example on how to approach stakeholder engagement. Engagement to date has included; presenting reports to key stakeholders, several workshops, meeting with stakeholders, and researchers engaging with the community to understand their perspective.

This project provides end-users with an understanding of the nature of road assets and useful description of damage to natural hazard. An equally important aspect the project may want to consider is reviewing the road structure that did not exhibit damage to the natural hazard event and understand why.

Measuring community resilience is a challenging topic and is not an easy problem that the project is trying to address. Translating the information gathered and making the linkages between community resilience and transport infrastructure will be a key element in understanding community resilience. The case study in the Lockyer Valley provides insight into one community's experience, which provides value information. The disruption of the road network impacted of their livelihood but more importantly their social network.

Geoscience Australia (GA) would welcome the research team discussing the project further in particular aspects of bridge performance to earthquake and the costing framework. GA would like to explore how this project can enhance our work and strengthen linkages with other BNHCRC projects.

INTRODUCTION

What is the problem?

Australia has a climate that naturally includes extreme climate events such as floods and bushfires; and these are increasing in intensity and occurring more frequently. Whilst earthquakes are less common, intraplate earthquakes expected in Australia are less predictable than interplate earthquakes. Australia also relies very heavily on its road network, which plays a vital part in the national economy as well as reducing the vulnerability of the community at large before, during and after extreme climate events [1]. Questions which require answers are: how does the road network - especially critical road structures such as bridges, culverts and floodways – cope with extreme natural hazards and how can the resilience of these be improved? This project aims to fill a major gap in critical road infrastructure research related to risk identification, assessment and monitoring using an integrated multi-hazard approach.

This project will take a hardening mode approach and for critical road structures this requires consideration of three aspects:

1. Vulnerability modeling of structures under extreme events, considering the design loads, standards and changed loading conditions under extreme events
2. Methods of enhancing resilience of road structures using optimised maintenance and strengthening
3. Understanding the effect of vulnerability of road structures on the community resilience before, during and after an extreme event.

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 kilometres of road network including bridges, flood ways and culverts and cost the State and Federal government hundreds of millions of dollars to repair [1]. 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 [2]. Creating a road network that can better withstand future natural hazards and better understanding of the impact on community will be of great importance in reducing the cost to the community and road authorities as well as local councils.

How are we going to solve it?

Long term aims will be develop tools and techniques to model the vulnerability of bridges, floodways and culverts leading to a better understanding of the cost of reconstruction and the impact of the failures on the community. Outcomes of the research will contribute to improving design and maintenance regimes of bridges, floodways and culverts so that they are more resilient under natural hazards. The generic research methodology developed can be used for other critical structures such as transmission towers or water mains considering the interaction between the natural hazard, the infrastructure and the community.

Specific objectives will include:

- Understanding the vulnerability of road structures to potential multi-hazard impacts (eg: floods, bush fires, earthquakes and climate change) taking into account current maintenance and design regimes as well as geographic location and local context.
- To develop a vulnerability assessment framework for different sections of the community, and produce guidelines that increase community resilience before, during and after an extreme event (towards communities that are better prepared and more self-reliant).
- Capturing impact of failure of critical road structures on the community as well as the managing authority.
- Develop analytical methods to evaluate impact of hazards on critical road structures.
- Develop an assessment framework for community resilience based on what type of impact on infrastructure affects which community groups and in what ways e.g. tourism operators v actual tourists. Resilience measures will differ for each grouping.
- Developing performance thresholds for road structures based on structural performance, economy and community resilience.
- Developing optimum maintenance, refurbishment and design regimes for critical road structures.

PROJECT BACKGROUND

Australia's variable climate has always been a factor in natural disasters that have had 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 it can be seen that during this period 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 include 33,337 km of roads and 6,500 bridges and culverts [3]. 2011-2012 flood in Queensland produced record flood levels in southwest Queensland and above average rainfall over the rest of the state [4]. 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 [5]. 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 [6]. Approximately 18,000 residential and commercial properties were significantly affected in Brisbane and Ipswich [7] 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 organisations. 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 [4] identifies that urban debris, such as cars, and the insufficient bridge span to through the debris are main cause for damaging bridges in the aftermath of 2011/2012 flood in Queensland. Using 2013 flood event in Lockyer Valley, Lokuge and Setunge [8] 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 modelling at a detailed level which aids managing authorities of road structures to prioritise hardening of structures, considering the intensity of disasters, vulnerability of structures and the impact on community resilience is not available to date. The project aims to deliver following outcomes over the first stage of 3.5 years currently funded by the BNH-CRC.

- Advancement in understanding input hazard parameters for quantifying impact of hazards on road structures
- Understanding failure mechanisms under different hazard types and vulnerable structural forms – clustering of structural forms according to vulnerability
- Quantifying community impact of failure of critical road structures
- Multi hazard vulnerability profile for road structures in case study regions

Multi hazards included are flood, earthquake, bush fire and climate change.

In the second stage of the project, the derived vulnerability models for the two case study regions will be used to develop a tool which can be used for vulnerability modelling of any given region in Australia. This will be further developed as a GIS based software tool. Thus the outcomes of the second stage will be:

- GIS based software tool for vulnerability modelling of road structures for a given region with required input parameters
- Road infrastructure retrofitting options and optimisation strategies

- Generic framework for vulnerability assessment of infrastructure

To achieve the above outcomes, following approach will be adopted by the researchers.

1. Stage 1: Vulnerability Modeling
    a) Analysis of case studies of failure – Lockyer Valley and critical regions in Victoria
    b) Input exposure parameters for multi hazard analysis will be sourced
    c) Critical failure mechanisms and modes will be established
    d) Community Impact of failure of road structures will be quantified
    e) Australian design standards for road structures will be examined and gaps in design practice will be identified
    f) A methodology for vulnerability modeling of road network to understand the risk of failure of road structures will be developed.
2. Stage 2: Prototype tool for vulnerability of road structures, Optimised strengthening
    a) Develop a GIS tool to map vulnerability
    b) Calibrate the vulnerability models with two other case study areas
    c) Identify strengthening methods
    d) Deliver a methodology and a tool for optimised strengthening of structures

PROGRESS TO DATE

RESEARCH ACTIVITIES

During the past year the research methodology has been developed and presented to the end users. Specific activities associated with this are summarised below:

1. Literature review completed to
    a. identify methods of developing vulnerability of critical road structures
    b. evaluate community impact upon failure of critical road structures
    c. understand methods of quantifying economic consequences of failure of road structures
2. Case study areas were identified and data on case study road structures were obtained from partners.
3. A methodology for vulnerability modelling was developed and presented to the key end users. Feedback was obtained and the methodology was refined. A major outcome of this was a consequence driven methodology was also identified as important by road authorities in addition to structural vulnerability modelling.
4. Case studies of structural analysis of three bridges were completed covering flood, bush fire and earthquakes. Three journal papers developed based on these analysis.
5. A comprehensive study on calculation of a cost based damage index for floodways was undertaken. The journal paper accepted for publication in the ASCE journal of Natural Hazards Review on this work.

WORKSHOPS OF RESEARCHERS AND END USERS

1. First end-user workshop was conducted on 25 July 2014, with participation of all Australian researchers at the USQ Springfield campus. All day workshop covered the methodology, workload allocation, project planning and an in-depth discussion of first case study, Lockyer Valley floods.

2. The second end user workshop was conducted at the department of Transport and Main Roads Queensland (QTMR) on 30 Oct.. 2014. During this workshop, feedback on the first report was obtained and the vulnerability modelling methodology was discussed.

3. During the week of 16/02/15 - 20/02/15, researchers worked at the Lockyer Valley council and conducted community interviews.

4. On 26 March 2015, the third end-user workshop was held with all Australian researchers at Queensland Department of Main Roads Offices. Floodway research and findings from the community interviews were presented to the QTMR and feedback was obtained. Further case studies were

identified and a consequence driven vulnerability modelling was proposed.

5. A symposium is planned for 13 July 2015 with all researchers and end users as well as wider stakeholders.

RECRUITING DURING THE PAST YEAR

- Mr. Farook Kalendhar (PhD candidate, RMIT Scholarship)
- Mr. Albert Zhang (Master student)
- Ms. Maryam Nasim (PhD candidate, APA Scholarship)
- Mr. Amila Dissanayake (Ph.D Candidate, APA Scholarship)
- Dr. Nilupa Herath (Post-Doc)
- Dr. Hessam Mohseni (Post-Doc)
- Dr. Jane Mullet (Post-Doc)
- Dr. Buddhi Wahalathantri (Post-Doc)

MAJOR EQUIPMENT PURCHASES

- No major equipment purchases

MAJOR FIELD TRIPS

Case study 1: Exploring community resilience to road network failure in the Lockyer Valley

16 – 20 February 2015.

Semi-structured interviews were conducted in the Lockyer Valley between 16 and 20 February 2015 by RMIT researchers Jane Mullett and Hessam Mohseni. Thirteen households (eighteen people N=18) were interviewed face-to-face and another four people (N=4) were interviewed over the phone as a result of Cyclone Marcia (20 February 2015) which interrupted the final day's interviews.

CONFERENCES ATTENDED REPRESENTING THE BNH-CRC

1. International Conference on Bridge Maintenance, Safety and Management (IABMAS), July 2014
2. 4th International Conference on Building Resilience, September 2014
3. AFAC Conference, September 2014
4. VicRoads Structures Conference, April 2015
5. Safeguarding Australia - Blast and other extreme events -Design and Modelling Forum, May 2015
6. 5th International Conference on Building Resilience, July 2015

PUBLICATION LIST

Journal papers

- WAHALATHANTRI, B.L., LOKUGE, W., KARUNASENA, W. & SETUNGE, S. 2015. Vulnerability of floodways under extreme flood events. ASCE journal of Natural Hazards Review, **accepted for publication**.
- WITHANAARACHCHI, J. & SETUNGE, S. 2014. Decision making on transport network planning and the impact on community, economy and the environment. 4th International Conference on Building Resilience, 8-11 September 2014, published in the journal of Procedia Economics and Finance, 18, 882-891
- HAYAT, E. & AMARATUNGA, D. 2014. The Impact of the Local Political and Socio-Economic Condition to the Capacity of the Local Governments in the Maintenance of Post-Disaster Road Infrastructure Reconstruction Assets, 4th International Conference on Building Resilience, 8-11 September 2014, Salford Quays, United Kingdom , Economics and Finance Procedia, © 2014 Published by Elsevier B.V
- LOKUGE, W., MOHSENI, H., SETUNGE, S. & SIMPSON, S. 2015. Evaluation of a case study concrete bridge in Victoria under effect of bushfire. 5th International Conference on Building Resilience 16-17 July 2015, **submitted to** journal Economics and Finance Procedia, Published by Elsevier.
- WAHALATHANTRI, B.L., LOKUGE, W., KARUNASENA, W. & SETUNGE, S. 2015. Emergency service demand in Queensland during natural disasters. 5th International Conference on Building Resilience, **submitted to** journal Economics and Finance Procedia, Published by Elsevier.
- WEDAWATTA, G., KULATUNGA, U., AMARATUNGA, D. & and PARVEZ, A. (in press) Disaster risk reduction infrastructure requirements for south-western Bangladesh: perspectives of local communities. Asian Journal of Environment and Disaster Management (AJEDM)
- Herath, N., Mendis, P.A., Ngo, T., Mohseni, H. and Setunge, S., "Failure mechanism of a typical girder bridge in Australia due to seismic loads", **Approved by the CRC, not submitted to a journal yet.**

Refereed Conference papers

- SETUNGE S., LOKUGE, W., MOHSENI, H. & KARUNASENA, W. 2014. Vulnerability of road bridge infrastructure: Under extreme flood events. AFAC and Bushfire & Natural Hazards CRC Conference, September 2014
- HASAN, S., SETUNGE, S. & LAW, D. 2014 Deterioration forecasting of concrete bridge elements in Victoria, Australia using a Markov Chain – Proceedings, 7th International Conference on Bridge Maintenance, Safety and Management (IABMAS), Shanghai, China, July 2014.
- WAHALATHANTRI, B.L., LOKUGE, W., KARUNASENA, W. & SETUNGE, S. 2015. Framework to inspect floodways towards estimating damage. AFAC and Bushfire & Natural Hazards CRC Conference September, 2015 **(submitted)**

Invited presentations

- HASAN, S., SETUNGE, S., LAW, D. & MOHSENI, H. , Effect of commercial vehicle traffic on deterioration trend of concrete bridge structures, VicRoads Structures Conference April, 2015, Wangarrata.
- MOHSENI, H., SETUNGE, S. & MENDIS, P., Risk assessment of critical road infrastructure subjected to extreme natural disasters, Safeguarding Australia Blast and other extreme events -Design and Modelling Forum, May 2015, Canberra.
- S.Setunge, "Doing more with less , in managing civil Infrastructure, current challenges and knowledge required for optimised and sustainable decisions., National Local Government Infrastructure and Asset Management Conference, 14-15 May 2015, Melbourne.

LIST OF CURRENT INTEGRATED TEAM MEMBERS

Researchers	Students	End Users
Dr. Buddhi Wahalathantri Prof. Chun Qing Li Dr. Damith Mohotti Prof. Darryn McEvoy Prof. Dilanthi Amaratunga Dr. Hessam Mohseni Dr. Jane Mullett A/Prof. Karu Karunasena A/Prof. Kevin Zhang Dr. Nilupa Herath Prof. Priyan Mendis Prof. Sujeeva Setunge Dr. Tuan Duc Ngo Dr. Weena Lokuge	Mr. Farook Kalendher Ms. Maryam Nasim Mr. Amila Dissanayake Mr. Albert Zhang	Dr. Ross Pritchard, Executive Director, structures, QTMR Leesa Carson, Branch Head, Community Safety, Geoscience Australia Ralph Smith, Branch Manager, Environmental Protection Branch, Department of Fire & Emergency Services WA Myles Fairbairn CEO, Lockyer Valley Regional Council Mr. Nigel Powers, Manager, Technology and Assets, VicRoads

REFERENCES

1. Queensland-reconstruction, *Managing the cost of damage to road infrastructure caused by natural disaster - national pool approach, Australian government Actuary.* 2012.
2. in *Herald Sun*. 2011.
3. Kuhlicke, C., *Resilience: a capacity and a myth: findings from an in-depth case study in disaster management research.* Natural Hazards, 2010.
4. Pritchard, R.W., *2011 to 2012 Queensland floods and cyclone events: Lessons learnt for bridge transport infrastructure.* Australian Journal of Structural Engineering, 2013. **14**(2): p. 167-176.
5. *Increasing Queensland's resilience to inland flooding in a changing climate*. 2010 [cited 2012 20 April]; Available from: http://www.ehp.qld.gov.au/climatechange/pdf/inland-flood-study.pdf.
6. *Rebuilding a stronger, more resilient Queensland*. 2012 [cited 2013 22 April]; Available from: http://www.qldreconstruction.org.au/u/lib/cms2/rebuilding-resilient-qld-full.pdf.
7. *Queensland floods: The economic impact Special Report*. 2011 [cited 2013 April 2013]; Available from: http://www.ibisworld.com.au/common/pdf/QLD%20floods%20special%20report.pdf.
8. 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.