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ENHANCING RESILIENCE OF CRITICAL ROAD INFRASTRUCTURE

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1. Overview

Road network and critical road structures such as bridges, culverts and floodways have a vital role before, during and after extreme events to reduce the vulnerability of the community being served. Understanding the resilience of existing structures to known natural hazards empowers the road authorities in risk mitigation and emergency management. Whilst there are high level frameworks to enhance resilience of infrastructure, tools and techniques which enable road authorities and local government agencies to quantify the vulnerability of road structures to multi-hazard events are not available to date. With the limited available funding to manage their assets, optimised decision making to enhance resilience of life line structures of a road network is an extremely challenging task for the managing authority. Lack of clear quantitative methods for prioritisation of investment is a current gap in knowledge and also practice.

Reinstating failed road structures after a disaster has a direct impact on the community resilience. Identifying the structures which offer the best return on investment in the context of resilience of the community requires a multi hazard vulnerability modelling technique which considers structural resilience of road structures under extreme events and the community infrastructure interface. This project will address this gap in knowledge.

The project will use two selected case study regions to identify failure modes of structures, analyse the gaps in design standards which led to identified failure modes and will quantify probability of failure of most vulnerable structural forms with different intensities of disaster events. A vulnerability modelling methodology such as damage index, fault tree method, structural reliability analysis and artificial neural networks will be examined as possible modelling techniques to integrate the failure of structures under multi hazard events. Major resources available to researchers to address the complex problem are the recent case studies of extreme events where failures of infrastructure and resultant impact on community have been captured by some road authorities. For example, 2010-2011 floods in Queensland in Australia had a huge impact particularly on central and southern Queensland resulting in the state owned properties such as 9170 km road network, 4748 km rail network, 89 severely damaged bridges and culverts, 411 schools and 138 national parks (*Rebuilding a stronger, more resilient Queensland*, 2012).

The eight year overall objective of the research is the development of tools and techniques to: derive vulnerability models for three types of critical road structures (bridges, culverts and flood-ways); understand the community/infrastructure interface and derive design and maintenance regimes to optimise resilience of lifeline infrastructure affecting performance of roads before, during and after a disaster. Multi-hazards of floods, fire and earthquakes are being examined including the implications of climate change and taking into account the interface between assets and community. In the 3.5 year first stage of the project, vulnerability models will be developed for three different types of road structures when exposed to natural hazards.

1. Introduction

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)

It is evident that during the above 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).

A more recent example is the 20111 and 2013 floods in Queensland, which severly affected the state controlled road network including 33,337 km of roads and 6,500 bridges and culverts (Kuhlicke, 2010). 2011-2012 flood in Queensland produced record flood levels in southwest Queensland and above average rainfall over the rest of the state (Pritchard, 2013). 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 (*Increasing Queensland's resilience to inland flooding in a changing climate*, 2010). 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. Approximately 18,000 residential and commercial properties were significantly affected in Brisbane and Ipswich (*Queensland floods: The economic impact Special Report*, 2011) 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 (2013) 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 (Lokuge and Setunge, 2013) 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 demonstrated the need for a detailed analysis of the failure mechanisms and contributing factors which requires consideration in designing of bridges to be resilient to extreme flood events.

Evacuation during a fire is heavily dependent on the integrity of the critical road structures during a fire. Resilience of road structures during a bush fire event is therefore directly related to community resilience.

Whilst earthquake damage in Australia has been limited to Newcastle Earthquake in 1989, this event demonstrated the need for basic earthquake design of structures and led to the development of the earthquake loading code. However, older road structures haven't been designed to these effects and in the event of an earthquake will be a weak link in our road infrastructure, significantly affecting the community vulnerability.

The project aims to quantify the vulnerability of road structures under extreme events of flood, bush fire, earthquake accounting for the increase in frequency of hazard events resulting from climate change.

2. 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 Modelling
    a) Analysis of case studies of failure – Lockyer Valley and Great Ocean Road
    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 idnetified
    f) Vulnerability modelling of road network for failure of road structures
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

4. Progress to date

4.1 Recruitment of researchers

Researchers have been recruited for all three strands.

Strand 1: RMIT, Dr. Hessam Mohseni, Full time

Strand 2: RMIT, Dr. Jane Mullet, part-time

Strand 3: The University of Melbourne, Dr. Nilupa Herath, Dr. Damith Mohotti, Part time

Strand 4: The University of Southern Queensland, Dr. Buddhi Wahalathantri, Part time

4.2 Case studies

Data from two case study regions have been sourced. Structural inspection reports have been obtained from Lockyer valley structures which failed during the 2013 floods. Also, major requirements in flood way designs have been identified. Three conference papers have been published from the preliminary analysis of these structures.

Condition data from all road structures of VicRoads has also been provided to the research team. Currently these are being analysed to understand the structures which would be vulnerable to hazard events: flood, bush fire, earthquake and climate change.

4.3 Researcher workshops

A research meeting was held at USQ in Brisbane on 17 February 2014 (Karunasena, Lokuge and Setunge) to progress data collection from Lockyer Valley Regional council

A researcher workshop was held at RMIT University on 08 April 2014. Representatives from all strands attended the workshop. Research methodology development and end user consultation was planned during this workshop.

A second meeting was held between researchers and Krishna Nadampili of Geoscience Australia on 2 July. Availability of data for the analysis was discussed during this meeting. Dr. Nadampilli provided an overview of available exposure information.

A monthly teleconference is held among researchers to discuss progress and clarify any issues.

4.4 End user engagement

End user engagement has been progressing well. A teleconference was conducted with Dr. Ross Pritchard of TMR Queensland to identify major gaps in design standards. Mr. Nigel Powers of VicRoads had a number of meetings with the research group to identify the case study region in Victoria. RMIT researchers have collaborated in a bid with QTMR and VicRoads to bring the international association for bridge management and safety (IABMAS) conference to Melbourne in 2018. This bid has been successful.

A very successful end user workshop was held with Lockyer Valley Regional Council on 25 July. This workshop is a milestone for June 2014. However, due to the availability of key people, this was scheduled for July 25th.

Figure 3: Attendees, workshop at USQ, 25 July 2014

4.5 Papers and reports

- Draft report : Failure of road structures under natural hazards
- LOKUGE, W., SETUNGE, S., MOHSENI, H. & KARUNASENA, W. 2014. Vulnerability of road bridge infrastructure under extreme flood events. *AFAC.* Wellington, New Zealand: Paper submitted.
- KALENDHER, M., LOKUGE, W., SETUNGE, S. & ZHANG K. 2014 Failure mechanisms of bridge infrastructure in an extreme flood event. *ICIFC Melbourne, Australia*.
- LOKUGE, W., SETUNGE, S. & KARUNASENA, W. 2014. Investigating the performance of flood ways in an extreme flood event. *ICIFC Melbourne, Australia.*

5. Project 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 • Mr. Jayantha Withanaarachchi	• Dr. Krishna Nadimpalli • Mr. Myles Fairbairn • Mr. Neil Head • Mr. Nigel Powers • Dr. Ross Pitchard • Ad Prof. Wije Ariyaratne

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