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COST-EFFECTIVE MITIGATION STRATEGY DEVELOPMENT FOR BUILDING RELATED EARTHQUAKE RISK

Annual project report 2014-2015

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Version	Release history	Date
1.0	Initial release of document	17/11/2015

Australian Government
Department of Industry and Science
Business Cooperative Research Centres Programme

Publisher:
Bushfire and Natural Hazards CRC

November 2015

Citation: Griffith M, 2015, Cost-effective mitigation strategy development for building related earthquake risk: Annual project report 2014-2015, Bushfire and Natural Hazards CRC

Cover: The Arts Centre restoration and seimic retrofit project, Christchurch, New Zealand. Photo by Michael C. Griffith

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EXECUTIVE SUMMARY

The seismic risk posed by earthquakes to buildings in our major cities in Australia is significant with the world insurance market rating a modest magnitude 6 earthquake occurring in Sydney to be in their world's top 10 of financial risks. A major reason for this is that Australia has not designed buildings for earthquake-induced forces until 1995 so that a large portion of our building stock is seismically vulnerable. As demonstrated in Christchurch New Zealand in 2010-11, a magnitude 6 earthquake can have a devastating impact on a city and country (damage build estimated at ~ 20% national GDP!) even though buildings have been designed for earthquakes for many decades.

This project will sift through the data that is available from the Christchurch experience to establish what earthquake retrofit techniques worked and what didn't as a starting point in developing a 'menu' of economically feasible seismic retrofit techniques that could be used in Australian cities. This information will then be fed into a 'decision support tool' being developed in project A7 that will be used by end users to develop consistent national policies for the application of seismic design of new buildings and retrofit of existing buildings.

END USER STATEMENT

Leesa Carson, *Geoscience Australia*

The recent cluster of earthquake events off the Queensland coast have highlighted how earthquakes can occur without warning with sometimes severe consequences for more vulnerable building. Raising awareness of the seismic risk to buildings in Australia's major cities is an important element of this project as well as considering how the project output can be used to influence building standards, particular for existing buildings.

The project has presented at the Australian Earthquake Engineering Society conference in November 2014, which is an excellent forum to discuss research activities and there has been two workshops for the project. I would like to see the project actively engage with potential end users to communicate the seismic risk, and the project objectives and outputs for retrofitting buildings. In turn, this will ensure the utility of the outcomes in influencing and informing mitigation activity within the jurisdictions.

The project has several studies, including experimental work on materials, which have been conducted or are underway, however it is unclear how these elements will link together for a cohesive end product that will be useful for an end user. Hopefully the workshop in October will bring the project team together to form a unified project with clear outputs and identify some key end users to engage with.

INTRODUCTION

This project arose out of the on-going research efforts by the group involving structural engineering academics at the Universities of Adelaide, Melbourne and Swinburne with Geoscience Australia experts all working towards seismic risk reduction in Australia. Most of the research team are actively involved in the revision to the Australian Earthquake Loads standard (AS1170.4) as well as being members of the Australian Earthquake Engineering Society which is a Technical Society of Engineers Australia. The devastating impact of the 2010 – 11 earthquakes in the Christchurch region on the New Zealand economy and society has further motivated this group to contribute to this CRC's aims of risk reduction for all natural hazards in Australia.

PROJECT BACKGROUND

The project will address the need for an evidence base to inform decision making on the mitigation of the risk posed by the most vulnerable Australian buildings subject to earthquakes. While the focus of this project is on buildings, many of the project outputs will also be relevant for other Australian infrastructure such as bridges, roads and ports, while at the same time complementing other 'Natural Hazards' CRC project proposals for severe wind and flood. Earthquake hazard has only been recognised in the design of Australian buildings since 1995. This failure has resulted in the presence of many buildings that represent a high risk to property, life and economic activity. These buildings also contribute to most of the post-disaster emergency management logistics and community recovery needs following major earthquakes. This vulnerability was in evidence in the Newcastle Earthquake of 1989, the Kalgoorlie Earthquake of 2010 and with similar building types in the Christchurch earthquake. With an overall building replacement rate of 2% nationally the legacy of vulnerable building persists in all cities and predominates in most business districts of lower growth regional centres. The two most vulnerable building types that contribute disproportionately to community risk are unreinforced masonry and low ductility reinforced concrete frames. The damage to these will not only lead to direct repair costs but also to injuries and disruption to economic activity. This research project will draw upon and extend existing research and capability within both academia and government to develop information that will inform policy, business and private individuals on their decisions concerning reducing vulnerability. It will also draw upon New Zealand initiatives that make use of local planning as an instrument for effecting mitigation. Findings from the New Zealand Royal Commission on the Christchurch earthquake will also be used and opportunities for insurance industry linkages will be explored such as with the Insurance Council of Australia Building Resilience Rating Tool development by the consultant Edge Environment (http://buildingresilience.org.au/). The latter aims, in part, to provide metrics to support insurance premium incentives but does not presently include earthquake.

WHAT THE PROJECT HAS BEEN UP TO

CONFERENCE AND WORKSHOP ATTENDANCE

Researchers from all participating institutions (GA, Swinburne Uni, Melbourne Uni and Adelaide Uni) attended the 2014 Australian Earthquake Engineering Society conference in Lorne, Victoria. As part of this event researchers involved in this project presented 5 conference papers and had involvement in an additional 3 additional presentations. The details of the presented papers are listed in the publications list below.

Workshops of researchers and end users was held over 3 days in Melbourne (2-4 Dec 2014) where research group leaders presented to all CRC members and end users an overview of their research topics after which two days of discussions and workshops took place to consolidate potential project linkages and streamline activities where possible duplications were identified. Specifically some clarity was obtained from end users on useful outputs for the CRC.

More recently a workshop was held on 25 June 2015 at Swinburne for Melbourne-based researchers and PhD students to present and discuss their research projects.

ONGOING RESEARCH

A summary of the research undertaken over the previous year is outlined below.

- An analytical study has been undertaken to determine rock hazards and generalised response spectra on rock for varying return period. The generalised response spectra have been determined based on probabilistic seismic hazard assessment employing five Ground Motion Prediction Equations (GMPEs) developed worldwide.
- A detailed study has been conducted to investigate the effects of local site conditions on ground shaking. Parameters investigated include shear wave velocity on site, depth of soil to bedrock and the intensity of ground motion. Soil response spectra have been proposed for various site conditions based on correlations between initial site properties and site response parameters.
- A simplified method to estimate drift demands of irregular buildings is currently being developed based on the developed rock and site response spectra. The irregularities are quite common features in existing building stock and can be in a form of plan asymmetry and vertical irregularities (e.g., vertical irregularity caused by discontinuity in load resisting elements or non-structural elements such as masonry infills).
- Studies on lightly reinforced concrete walls are being conducted. Experimental works have been undertaken in Swinburne's state-of-the-art Smart Structures Laboratory to assess the global out-of-plane buckling and the local buckling of vertical reinforcement failure mechanisms of RC walls, and the general instability failures of lightly reinforced RC walls. Analytical study is currently being undertaken to develop a model which provides

estimates of the plastic hinge length and displacement capacity of the RC walls, and a force-displacement backbone curve for the wall.

- Studies are being conducted on reinforced concrete frames. Experimental works consisting of quasi-static cyclic test and pseudo dynamic simulation test have been conducted in Swinburne's state-of-the-art Smart Structures Laboratory to assess drift capacity of corner columns of multi-storey of ordinary moment resisting frames. Analytical studies have also been undertaken to model force-displacement curve and displacement capacity of the moment resisting frames, which takes into account the component capacity of beams, columns, and beam-column joints within the non-ductile moment resisting frames.
- A review of vulnerability assessment for damage loss modelling has been undertaken. Studies are being conducted to construct fragility and vulnerability curves for a selected RC building type.
- An in-depth progress report into the economic loss modelling of earthquake damaged buildings has been prepared and submitted to the CRC as part of the 3rd quarter deliverables. At the request of the CRC this deliverable is being converted to BNHCRC report format for publication/general release.
- Experimental work into the seismic retrofit of masonry elements is ongoing. The experimental plan developed in the 1st quarter of 2014-2015 and subsequently finalised in the 2nd quarter has now entered production. The program has been slightly delayed due to substandard material properties of key components that were supplied by a 3rd party. This issue has now been resolved and new components received. The first test specimen is currently undergoing instrumentation and testing should take place in early August. Subsequent specimens will be tested over the following months.

PUBLICATIONS LIST

JOURNAL PAPERS

- Hoult, R.D., Goldsworthy, H.M., Lumantarna, E. (2015). "Relationship between longitudinal reinforcement ratio and ductility in RC walls," Magazine of Concrete Research. In review
- Hoult, R.D., Lumantarna, E., Goldsworthy, H.M. (2015). "Spectral Shape Factors for Low-to-Moderate Seismic Regions," Soil Dynamics and Earthquake Engineering. In review
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- Oehlers, D.J., Visintin, P. and Lucas, W. (accepted 30/06/2015). "Flexural Strength and Ductility of FRP-Plated RC Beams: Fundamental Mechanics Incorporating Local and Global IC Debonding," Journal of Composites for Construction (ASCE).
- Sivanerupan, S., Wilson, J., Gad, E., Lam, N.T.K. (2014). "Drift performance of point fixed glass façade systems," Advances in Structural Engineering. Vol. 17, no. 10, pp. 1481-1495.
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- Wibowo, A, Wilson, J.L., Lam, N.T.K., Gad, E.F. (2014). "Drift capacity of lightly reinforced concrete columns," Australian Journal of Structural Engineering. Vol. 15, no. 2, pp. 131-150.
- Wibowo, A., Wilson, J.L., Lam, N.T.K., Gad, E. F. (2014). "Drift performance of lightly reinforced concrete columns," Engineering Structures. Vol. 59, pp. 522-535.

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- Derakhshan, H., Griffith, M.C. and Ingham, J.M. (2014). "A numerical model to assess the dynamic response of out-of-plane loaded one-way spanning URM walls connected to flexible diaphragms," Proceedings, 9th International Masonry Conference, Guimaraes, Portugal, 7-9 July 2014, 11p.

- Hashemi, M. J., Al-Ogaidi, Yassamin, K. F., Wilson, J., Abdouka, K. (2014). "Collapse simulation of multi-story RC buildings through hybrid testing," Australian Earthquake Engineering Society 2014 Conference, Nov 21-23, Lorne, Victoria.
- Hashemi, M. J., Tsang, H. H., Menegon, S., Rajeev, P., Wilson, J. (2014). "Modelling 3D limited-ductile RC frame structures for collapse risk assessment," Australian Earthquake Engineering Society 2014 Conference, Nov 21-23, Lorne, Victoria.
- Hoult, R.D., Goldsworthy, H.M., Lumantarna, E. (2015). "Seismic assessment of non-ductile reinforced concrete C-shaped walls in Australia," Paper presented at the Eighth International Structural Engineering and Construction Conference, Sydney, Australia.
- Hoult, R. D., Goldsworthy, H.M., Lumantarna, E. (2015). "Improvements and difficulties associated with the seismic assessment of infrastructure in Australia," Paper presented at the Australasian Fire and Emergency Service Authorities Council (AFAC) 2015 conference, Adelaide, South Australia.
- Hoult, R.D., Goldsworthy, H.M. and Lumantarna, E. "Seismic Performance of Typical C-Shaped Reinforced Concrete Shear Cores in Australia," Australian Earthquake Engineering Society 2014 Conference, Nov 21-23, Lorne, Victoria.
- Hoult, R.D., Amirsardari, A., Sandiford, D., Lumantarna, E., Goldsworthy, H.M., Gibson, G. and Asten, M. "The 2012 Moe Earthquake and Earthquake Attenuation in South Eastern Australia," Australian Earthquake Engineering Society 2014 Conference, Nov 21-23, Lorne, Victoria.
- Hyeuk, R., Wehner, M. and Edwards, M. "Proposed Australian Building Stock Categorisation for Bushfire and Natural Hazards CRC Earthquake Project," Australian Earthquake Engineering Society 2014 Conference, Nov 21-23, Lorne, Victoria
- Lumantarna, E., Lam, N., Tsang, H.H., Wilson, J., Gad, E. and Goldsworthy, H. "Review of Methodologies for Seismic Vulnerability Assessment of Buildings," Australian Earthquake Engineering Society 2014 Conference, Nov 21-23, Lorne, Victoria.
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- Shahi, R., Lam, N.T.K., Gad, E.F., Saifullah, I., Wilson, J.L., Watsou, K. (2014). "Choice of intensity measure in incremental dynamic analysis," Australian Earthquake Engineering Society 2014 Conference, Nov 21-23, Lorne, Victoria.

CURRENT TEAM MEMBERS

RESEARCHERS

University of Adelaide:	Prof M Griffith (Project Leader), Prof M Jaksa, Assoc Prof AH Sheikh, Dr C Wu, Dr MMS Ali, Dr T Ozbakkaloglu, Dr A Ng, Dr P Visintin
University of Melbourne:	Assoc Prof NTK Lam, Assoc Prof H Goldsworthy
Swinburne University:	Prof J Wilson, Prof E Gad
Geoscience Australia:	Mr M Edwards, Dr H Ryu, Mr V Juskevics

CRC FUNDED POST-DOC RESEARCHERS

University of Adelaide:	Dr W Lucas
University of Melbourne:	Dr E Lumantarna

STUDENTS

University of Adelaide:

- Yasuto Nakamura: Improved seismic assessment technique for URM buildings
- Bambang Setiawan: Quantifying the Seismic and Site Amplification Characteristics of Adelaide's Regolith
- Yunita Idris: FRP retrofit of non-ductile RC columns

University of Melbourne:

- Ryan Hoult
- Anita Amirsardari
- Mehair Yacoubian
- Shanker Dhakal
- Alireza Mehdipanah

Swinburne University:

- Scott Menegon: Seismic collapse behaviour of non-ductile RC walls
- Yassamin K Faiud Al-Ogaidi: FRP retrofit for non-ductile RC frames

END USERS

Ralph Smith (WA)