COST-EFFECTIVE MITIGATION STRATEGY DEVELOPMENT FOR BUILDING RELATED EARTHQUAKE RISK

Annual project report 2016-2017

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Version	Release history	Date
1.0	Initial release of document	13/09/2017

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Publisher:
Bushfire and Natural Hazards CRC

September 2017

Citation: Griffith, M. C., Derakhshan, H., Lumantarna, E., Tsang, H-H., Goldsworthy, H., Wilson, J., Lam, N. T. K. & Edwards, M. (2017) Cost-effective mitigation strategy development for building related earthquake risk: annual project report 2016-2017. Bushfire and Natural Hazards CRC, Melbourne.

Cover: Dust clouds of the Feb 2011 Christchurch earthquake (© Gillian Needham

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EXECUTIVE SUMMARY

The 1989 Newcastle Earthquake caused damage to 70,000 properties, with an associated total economic loss of AU$ 4 billion. Consistently, the insurance industry has estimated the economic risk posed by a moderate earthquake in any of the capital cities in Australia to be of the order of billions of dollars. A major reason for this risk 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 rebuild estimated at ~ 20% national GDP!) even though buildings there have been designed for earthquakes for many decades.

This project includes collaborative research from 4 partner institutions to establish:

1) The relative vulnerabilities to earthquake shaking of the most common forms of building construction in Australia;
2) 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;
3) With industry end-user support, conduct proof of concept tests on some of the most promising seismic retrofit techniques on buildings scheduled for demolition by the SA state government;
4) Use the new damage and economic loss models developed over the first 3 years of this project to undertake a seismic risk assessment case study of the Melbourne metro area; and
5) Advance a series of end user focused research utilization projects in the areas of improved building regulation, community risk reduction, design profession guidance and insurance industry engagement with their policy holders. These will include an Earthquake Mitigation Case Study for the historic town of York in Western Australia and Development of a Rapid Visual Screening procedure for Australian buildings

Finally, using the new damage loss models and costings for seismically retrofitting buildings, make recommendations for the development of seismic retrofit guidelines and policy based on the strong evidence base developed.

END USER STATEMENT

Leesa Carson, *Geoscience Australia, Commonwealth*

During the past 12 months significant number of meeting and workshops were held with potential end users. These included the 03 Aug workshop in Adelaide, AFAC 2016 side meetings in Canberra, meetings held with the Council of York Shire in WA, and also during the Adelaide Showcase event and subsequent meetings in the University of Adelaide. These activities have been further discussed in this report.

A key end-user to this project is the WA Department of Fire and Emergency Services. The State has a town, York, which has a large number of heritage unreinforced masonry buildings. The Council considers earthquake to be a significant threat to the heritage town and the tourism industry. The category of unreinforced masonry buildings is a major focus of this project, and therefore we have a developed a very good end-user program.

It has been proposed to complete a precinct case study of cost-benefit analysis of seismic retrofit for York. The Council of York Shire has agreed to start on development of a community engagement program, with our researchers expected to travel to WA for a field survey of the buildings and the community engagement programs later this year.

Research aspects of the project are progressing with a number of publications and conference presentations on preliminary and final results.

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.

This 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 recognized 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 centers.

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.

WHAT THE PROJECT HAS BEEN UP TO

CONFERENCE AND WORKSHOP ATTENDANCE

Project workshop 1 and End Users meetings (03 Aug 16) – Partner institutions met in the morning in Adelaide to discuss the project and outcomes followed by an Industry End User engagement meeting in the afternoon. The delegates included Ron De Veer from Australian Building Code Board (ABCB), Scott Munter from Steel Reinforcement Institute of Australia, Warren South from Cement Concrete and Aggregates Australia, David Millar from Concrete Institute of Australia, Stephen Gray from WA Department of Fire and Emergency Services, and Paul Waterhouse from Think Brick Australia. Potential End User projects were scoped in this meeting.

AFAC'16 (30 Aug -01 Sep 16) – Hossein Derakhshan, Elisa Lumantarna, Ryan Hoult, and Mark Edwards attended with 2 posters and papers (Elisa and Ryan) and an oral presentation by Ryan Hoult. Mark Edwards presented an overview of the project. The conference also provided opportunity to meet Ron De Veer from Australian Building Codes Board representative to discuss a utilization project.

Project workshop 2 (21-22 Sep 16) - A follow-up meeting to the 03 August workshop was held in Swinburne to revamp the core research objectives for the second phase of the CRC alongside the research plans, timelines and resource needs for each of the proposed end user projects.

AEES16 (25-27 Nov 16) – 8 papers were presented at the Australian Earthquake Engineering Society (AEES) conference, which was held in late November in Melbourne. The presentations included a keynote paper by Mike Griffith on recent advances in unreinforced masonry building structural analysis and testing. A side meeting was held between researchers from the Universities of Adelaide, Newcastle, and Auckland to discuss an ongoing Stone Masonry project, which is related to this CRC project.

24ACMSM (06-09 Dec 16) - Researchers from Swinburne Uni, Melbourne Uni and Adelaide Uni attended the 24th Australasian Conference on the Mechanics of Structures and Materials, which was held in Perth in Dec 2016. The researchers presented 4 CRC-related papers, which are listed below.

16WCEE (09-13 Jan 17) – Researchers involved in this project presented 3 papers in the 16th World Conference on Earthquake Engineering, which was held in Santiago, Chile. Details of the papers are listed below.

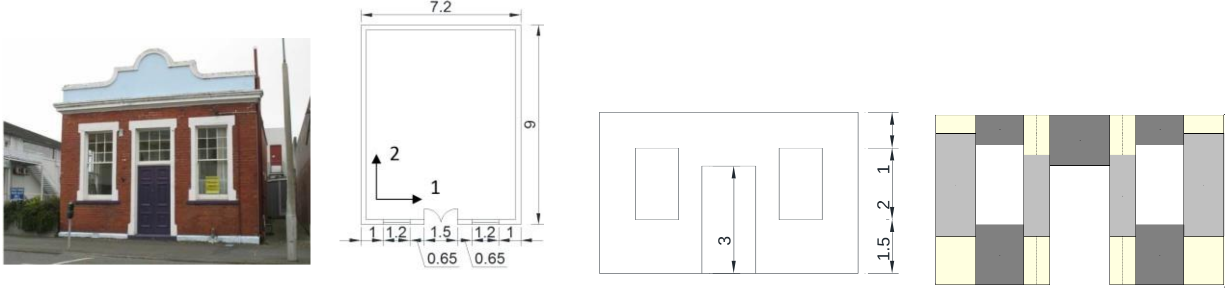
SEISMIC EVALUATION OF NON-STRUCTURAL COMPONENTS IN UNREINFORCED MASONRY BUILDING

A part of research activities has been focused on the improvement of the seismic assessment of non-structural URM components by studying the "height amplification" factor. This factor is applied to ground accelerations to obtain the amplified accelerations that are applied to URM components. The currently available methods have a shortcoming that floor vibrations are excluded. This limitation becomes problematic when assessing older URM buildings that typically have timber floors/roof. A further limitation is that the current code formulae were derived by studying ductile reinforced concrete buildings. The first stage of the research that was focused on buildings with rigid floors is complete and the results are to be presented in the upcoming Australasian Masonry Conference (10AMC) in Newcastle (Feb 2018). An improved, more comprehensive study will be submitted to an international journal.

A brief summary of the findings are reported below.

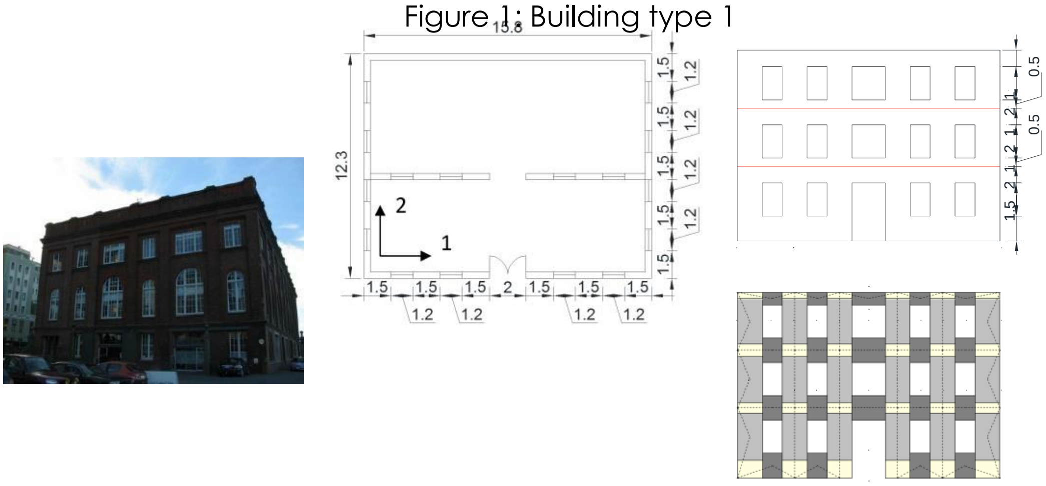
<u>Brief summary of the research methodology</u>

Six different building typologies were developed and representative model created in computer software for URM building analysis (TREMURI). The models were subjected to earthquake motions. Two of these typologies are shown in Figure 1 and Figure 2, as examples.



(a) Example building (b) Building plan (c) Front elevation (d) Front wall model in Tremuri

Figure 1: Building type 1

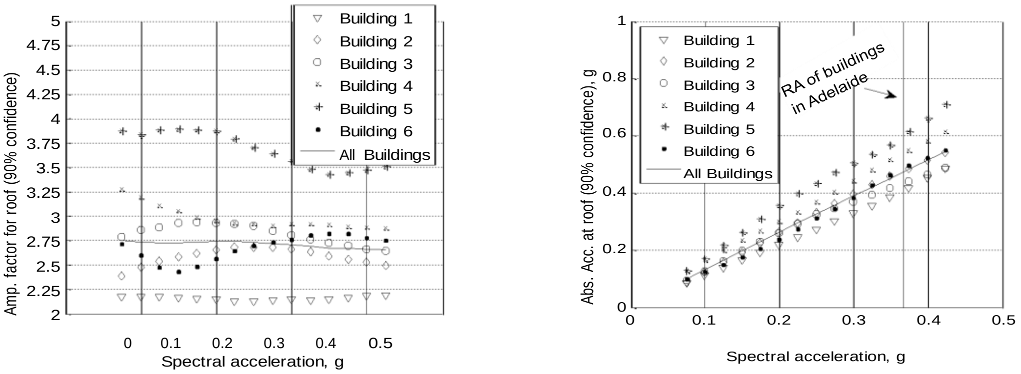


(a) Example building (b) Building plan (c) Front and internal wall elevation

Figure 2: Building type 4

Results

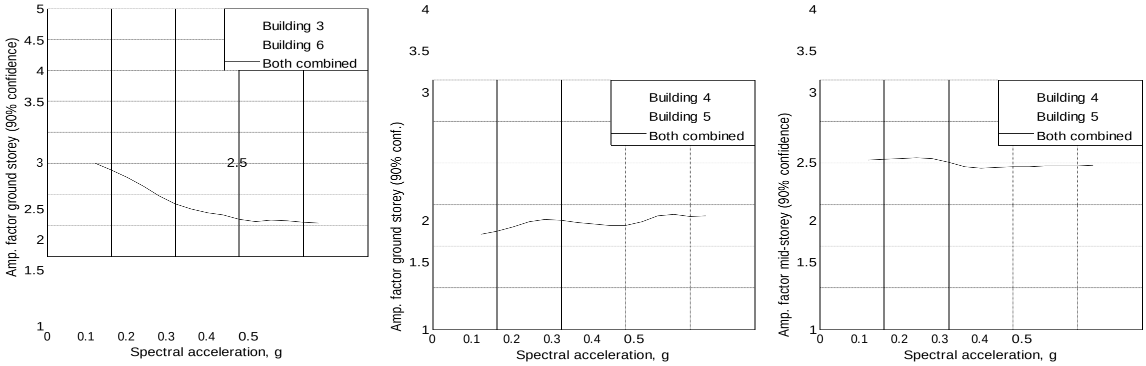
A statistical evaluation of the analyses from 30 earthquake records shows (Figure 3a) that the roof accelerations are amplified by a factor between 2.5 to 3 for majority of cases, with some outliers. The amplification factors appear to remain fairly constant with increase in acceleration intensity (represented by Response Acceleration, RA). Based on this study, the average acceleration applied on non-structural URM components in the Australian capital city with the greatest seismic hazard (Adelaide) ranges from 0.4g to 0.6g for different buildings (Figure 3b).



(a) Roof amplification factor vs. S_a (b) Roof absolute acceleration vs. S_a

Figure 3: Roof amplification factor vs. spectral accelerations at each building period

Similarly, Figure 4 show the amplification pattern for floors below roof level. A comparison of the results for different floors of the same building reveals different relationship between height and amplification factor. For most buildings, the acceleration increases with height except for some intensities in Buildings 6. However, the relationship is not linear as assumed in the AS1170.4. For example for Building 5, the amplification factors for both ground (Figure 4b) and second storeys (Figure 4 c) are in a narrow range of 2 to 2.75, but the values for the top-storey are much larger and up to nearly 4 (Figure 3a). Lower intensity shaking (Sa<0.3g) in Building 6 resulted greater amplification factor in the ground storey than that occurring in the top-storey.



(a) Ground storey of double-storey buildings

(b) Ground storey of triple-storey buildings

(c) Middle storey of triple-storey buildings

Figure 4: Floor amplification factor vs. spectral accelerations at each building period

Comparison with codes and recommendation

A comparison of the results with Australian (AS1170.4), New Zealand (NZ1170.5), and USA (ASCE-SEI 41-06) loading standards/guidelines suggests that with the exception of ASCE-SEI 41-06, the other provisions underestimate the applied accelerations to building parts, especially for single-storey and double-storey buildings.

The Australian and NZ codes stipulate amplification factors that increase with height and can reach a maximum of about 3 for the roof of the taller buildings (height>12m), with the AS1170.4 further limiting the absolute accelerations applicable to building parts to 0.5g. For shorter buildings or for floors located at smaller elevation, a smaller amplification factor is obtained. This is contrary to some of the results obtained in this study, which suggests a relatively uniform amplification factor may be more suitable.

While a detailed tabulated comparison of the accelerations are to be published in the upcoming Australian Earthquake Engineering Society Conference, this study suggests that a roof amplification factor of 3 can be recommended to be used with all URM buildings. This factor being approx. 10% greater than the 90% confidence-level value (~2.75) that was obtained for the
6 buildings and was fairly constant with S_a. This recommendation is also consistent with the ASCE-SEI 41-06 guidelines.

For lower floors, the amplification factor was found to range between approx. 2 to 3, hence an amplification factor of 3 would be a conservative assumption but is more suitable than the current formula in the AS1170.4 code.

IN-SITU OUT-OF-PLANE STRENGTH OF TWO-WAY SPANNING URM WALLS

With the support of the Department of Planning, Transport and Infrastructure, South Australia, we have been allowed access to test 8 brick cavity walls and 3 chimneys in four houses that have since been demolished as part of the government's South Road Corridor project. The results of our wall and chimney tests were published in a conference paper, submitted to an Australian journal paper, with an improved, internationally scoped version to be submitted to an international journal. The reports were also submitted to the CRC earlier this year.

In summary, three critical findings of this research were that: 1) masonry bond strength was significantly smaller than default values recommended in the Australian Masonry Standards, AS3700; 2) Existing formula for out-of-plane strength prediction correlate well with the in-situ wall strength measurements subject to reasonable assessment of the wall in-situ boundary conditions (which can be difficult in many cases and assessed conservatively) and subject to inclusion of strength terms that incorporate plaster effect into the predictive equations; and 3) There are unusual URM construction details that can be discovered by survey of existing buildings, for example it was found that only the external leaf of the cavity wall buildings were load-bearing, while the common assumption among the URM experts was that only the internal leaves are load-bearing.

We anticipate that we will be given similar access in the coming year to some small commercial buildings that will be demolished for road widening purposes. In these future tests, commercial organizations will be invited to apply their techniques as seismic strengthening options for us to test as 'proof of concept' demonstrations to the engineering profession to enhance rapid take-up of the technologies for seismic risk mitigation in the future.

REINFORCED CONCRETE STRUCTURES

Types of Buildings Considered

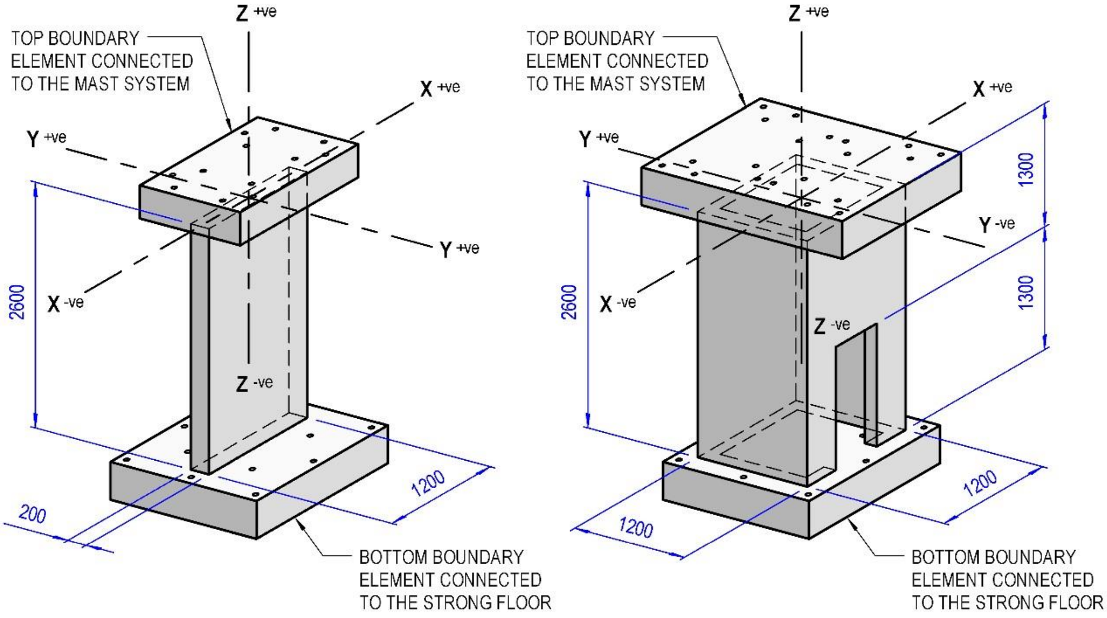
The project team decided that three broad types of reinforced concrete (RC) structures will be considered in the project:

1. Building with soft-storey that will collapse by column or beam-column joint failure, especially those without walls at the soft-storey level. They can be further classified into two construction types, namely, precast column and in-situ column.
2. Building with walls as major lateral load resisting systems, including singly-reinforced wall panels.
3. Building with both MRF and walls as lateral load resisting systems, including those with significant discontinuity (or offset) of gravitational load carrying elements.

Displacement Behaviour of RC Wall Buildings

The majority of the experimental testing program has been completed, which included one reinforced concrete (RC) rectangular wall specimen and four RC building cores specimens. The specimens were tested using the MAST system at Swinburne University of Technology. The rectangular wall specimen and one of the four building core specimens were monolithic cast in-situ specimens (Figure 5) and the remaining three building core specimens were jointed precast specimens. Preliminary tests results of the rectangular wall and cast in-situ building core specimen are shown in Figure 6. In addition to the large-scale RC wall testing, seven boundary element prism tests have also been performed.

The large-scale RC wall testing performed to date has been presented at two international conferences. It was firstly presented at the 2016 New Zealand Society of Earthquake Engineering Technical Conference held in Christchurch, New Zealand between 1-3 April 2016 (Menegon et al. 2016a). It was later also presented at the 16th World Conference of Earthquake Engineering held in Santiago, Chile between 9-13 January 2017 (Menegon et al. 2017). The conference had approximately 3,000 participants and is the prominent international conference on earthquake engineering, which is held every four years. The testing was presented during a special session on RC wall research. In addition to the above, the testing was presented at two local conferences, being the Australasian Structural Engineering Conference held in Brisbane between 23-25 November 2016 (Menegon et al. 2016b) and the Australian Earthquake Engineering Society Conference held in Melbourne between 25-27 November 2016 (Menegon et al. 2016c).



SPECIMEN S01 3D VIEW **SPECIMEN S02 3D VIEW**

Figure 5: Rectangular wall and building core specimens (cast in-situ monolithic specimens)

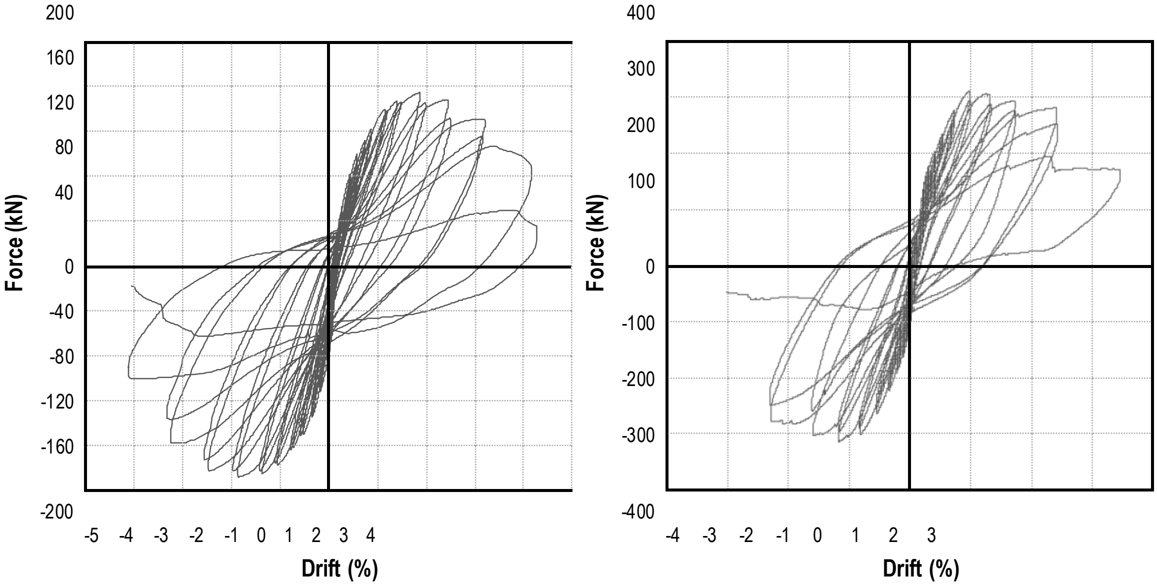
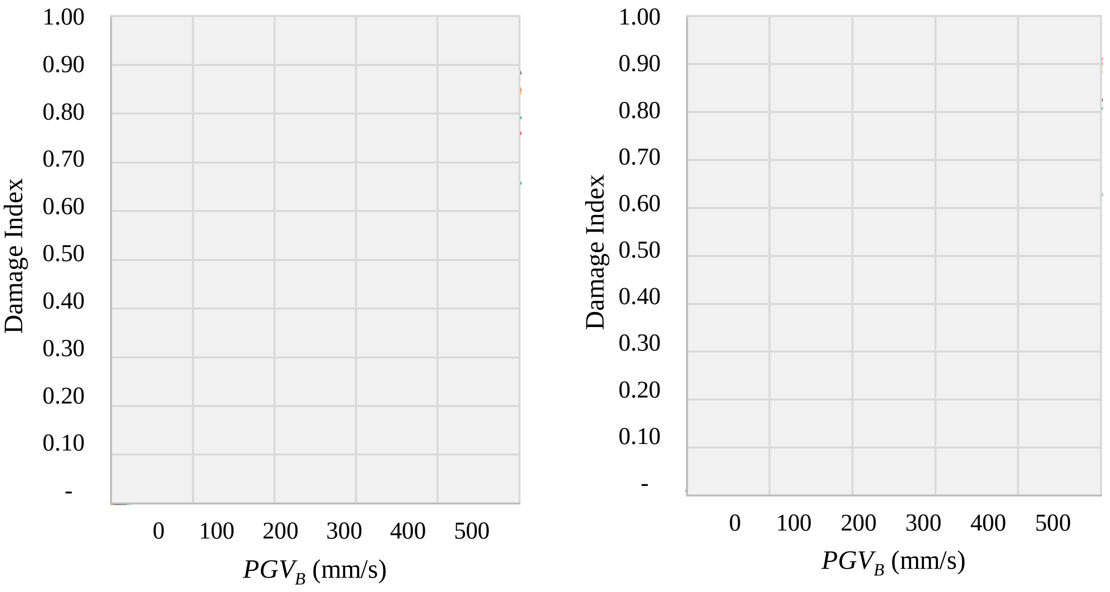


Figure 6: Preliminary test results. Left: rectangular wall specimen. Right: cast in-situ building core specimen.

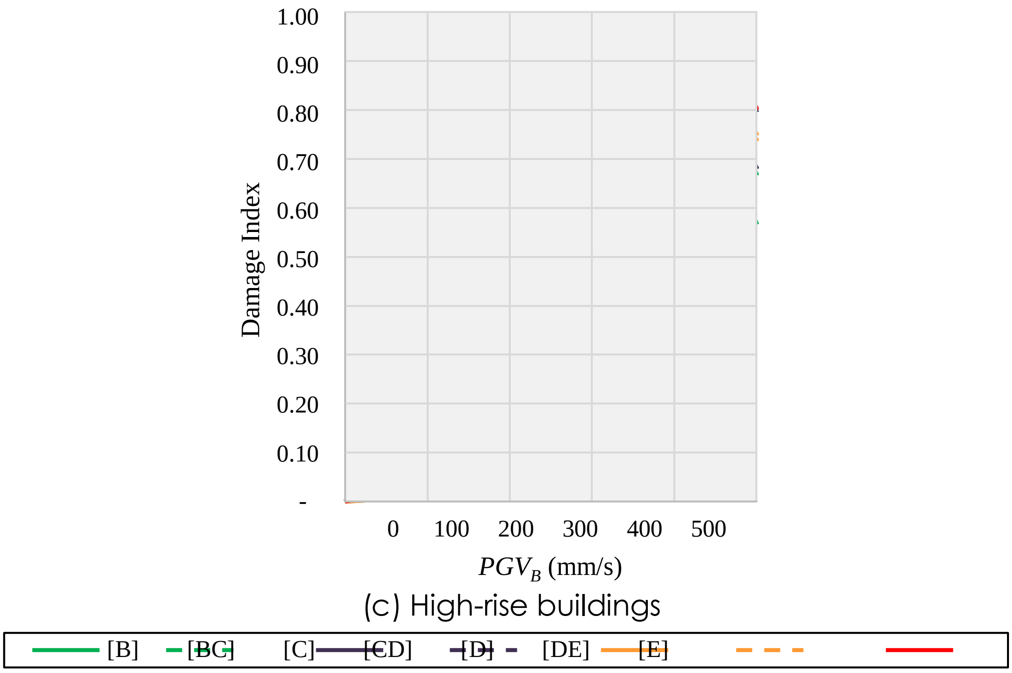
Numerical modelling of reinforced concrete walls has been largely completed. A simple expression was developed to estimate the longitudinal reinforcement ratio that is required in a wall to trigger secondary cracking at high levels of wall displacement. The longitudinal reinforcement ratio required in the wall was commonly found to be much higher than the current minimum requirement (of 0.15%) in AS 3600:2009. The onset of secondary cracking for the rectangular walls was found to occur at much higher values of the ratio of the ultimate moment capacity (Mu) to the cracking moment (Mcr) of the wall relative to the 1.2 value that is typically used in design of a RC section for in-plane bending (e.g. AS 3600:2009). A plastic hinge length expression has been derived using the results from a large number of VecTor2 analyses and a multiple linear regression analysis to provide a better estimate of the equivalent length over which plasticity will occur for lightly reinforced and unconfined rectangular walls. Equations that provide estimates for displacement capacities for the rectangular walls have been derived. Results have been presented at two the Australasian Structural Engineering Conference held in Brisbane between 23-25 November 2016 (Hoult et al. 2016a) and the Australian Earthquake Engineering Society Conference held in Melbourne between 25-27 November 2016 (Hoult et al. 2016b) and published in Journal of Earthquake Engineering (Hoult et al. 2017).

Numerical studies have also been conducted using VecTor3 on lightly reinforced unconfined C-shaped walls. Equivalent plastic hinge length (L_p) equations have been derived for three directions of loading; about the major axis, minor axis with web in compression (WiC) and with web in tension (WiT). The equations are dependent on the wall length, axial load ratio, effective height and average normalised shear stress parameter. Equations for displacement capacities have also been derived. Further numerical analyses were conducted on the C-shaped walls but with some confinement provided in the boundary regions. The results from the models that included confinement indicated that these walls would have a larger equivalent plastic hinge length, resulting in substantial increase in the displacement capacity of the walls.

Fragility curves have been constructed for representative buildings supported by RC walls. Building inventory data provided by the City of Melbourne were used to aid with deriving realistic seismic demands and capacities for individual buildings. An initial study was conducted on two case study buildings using two different methods: the Capacity Spectrum (CS) method and the Nonlinear Dynamic Time-history Analysis (NDTHA) method. The results showed that the more time consuming and rigorous method of NDTHA gave similar results to those obtained using the CS method. The capacity spectrum method was then used to construct the fragility curves of the buildings. The fragility curves for the representative short-, medium- and high-rise buildings are presented in Figure 7.



(a) Low-rise buildings (b) Medium-rise buildings



(c) High-rise buildings

Figure 7: Fragility curves for buildings with walls as major lateral load resisting systems

Seismic Performance of Irregular Buildings

Buildings with vertical and plan irregularities

Analytical studies have been conducted on buildings featuring vertical irregularities caused by discontinuities and/or offset of gravitational load carrying elements. Seismic response of 75 buildings with various locations and extent of irregularities in elevation was evaluated based on linear dynamic analyses. It was found from the analyses that the vertical irregularities do not have significant effects on the displacement behaviour of the buildings. A simple and accurate method (called Generalised Lateral Force Method of Analysis – GLFM) that enables the displacement demands of the buildings to be estimated based on a simple static analysis was developed.

Further analyses were conducted on high-rise buildings with vertical irregularities. Results have been used to extend the GLFM to account for higher modes effects based on generalised modal displacements. The method has also been extended to account for the effects of torsion due to plan asymmetry to produce estimates of the maximum displacement demand at the edges of torsionally unbalanced (TU) buildings.

The results of the studies on irregular buildings have been presented at the Australasian Structural Engineering Conference held in Brisbane between 23-25 November 2016 (Mehdipanah et al. 2016a) and the Australasian Conference on the Mechanics of Structures and Materials (Mehdipanah et al. 2016b).

Studies based on non-linear push over analyses are currently being conducted. A systematic analytical modelling technique for the simulation of limited-ductile beam-column elements was developed and validated against published experimental data. Using the proposed technique, non-linear push over analyses were conducted on three-dimensional case study buildings using

OpenSEES. Preliminary results have shown that the displacement behaviour of limited ductile irregular buildings (caused by discontinuities of gravitational load carrying elements) is not significantly different to that of regular buildings (Figure 8).

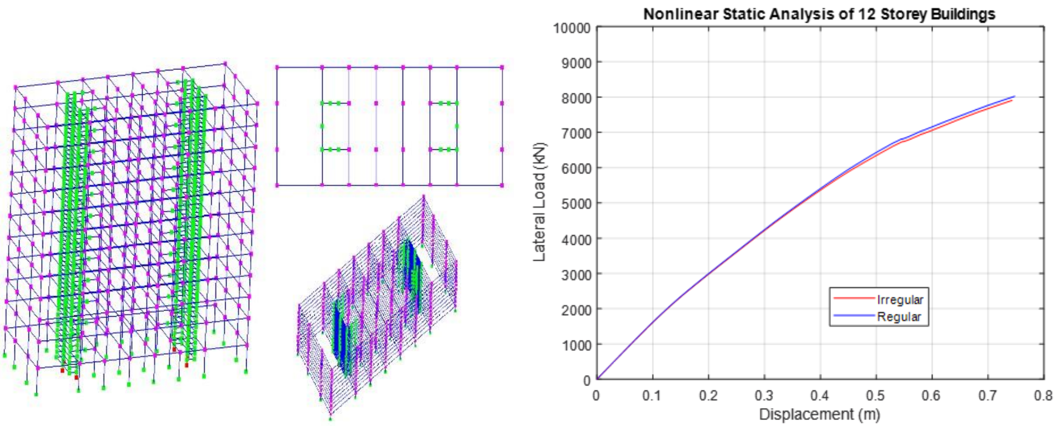


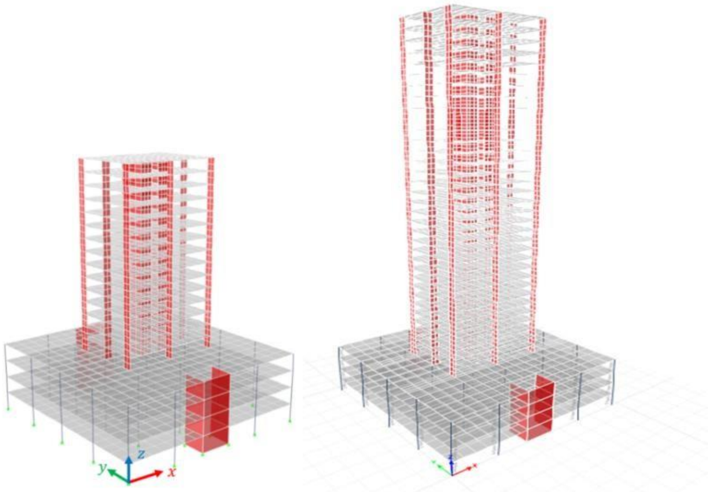
Figure 8: Force displacement behaviour of regular vs irregular buildings

Buildings with transfer plate

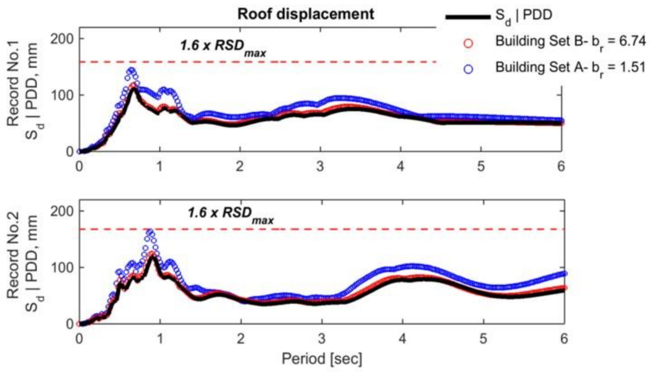
Analytical studies have been conducted on buildings featuring transfer plate. The effects of load-path discontinuity and transfer plate flexibility on the displacement behaviour of the buildings were investigated. The rotational and translational demands of the buildings were found to exhibit displacement-controlled behaviour. Predictive expressions for the peak displacement and rotational demands have been proposed based on the displacement- controlled behaviour. The predictive expressions have been validated for buildings with heights of up to 120m (Figure 9).

Further, the extent of the effect of transfer plate flexibility on the local response behaviour of the supporting (transferred) structural walls has been investigated. Flexible index parameter has been introduced to account for the flexibility of the transfer plate on the local shear demands of the transferred structural walls.

The outcomes of the investigation have been presented at Australasian Structural Engineering Conference held in Brisbane between 23-25 November 2016 (Yacoubian et al. 2016a) and the Australian Earthquake Engineering Society Conference held in Melbourne between 25-27 November 2016 (Yacoubian et al. 2016b).



Building A Building B (a)
Building models



(b) Peak Displacement Demand (PDD)
Figure 9: Peak Displacement Demand of buildings featuring transfer plates

Seismic Retrofitting of RC Beam-Column Joint

In the previous year, it was found that exterior beam-column joint is typically the weakest link in a limited-ductile RC frame structure. Hence, seismic retrofitting may be needed for this type of buildings.

Amongst all available options, the use of diagonal haunch element has been considered as a desirable seismic retrofit option for preventing brittle failure of the joint. In the past one year, the feasibility of using single haunch system as a less-invasive and more architecturally favourable retrofit option to enhance the seismic behaviour of the beam-column joint and accordingly whole structure was developed analytically.

In summary, the outlines of work done over the last 12 months are listed as follows:

- An easy-to-understand failure hierarchy assessment approach (Figure 10) was introduced to estimate the most probable failure mode, and the associated limiting base shear force, of an RC beam-column joint subassembly.

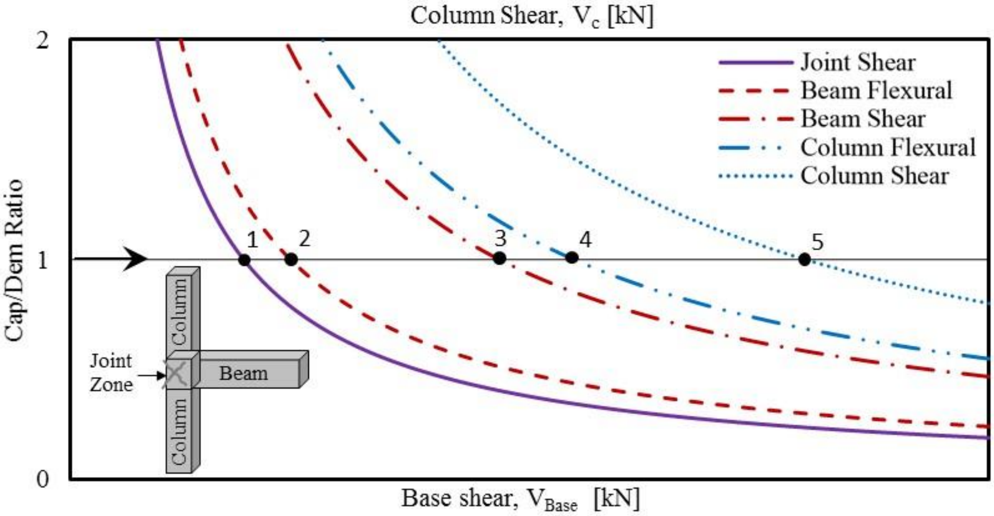
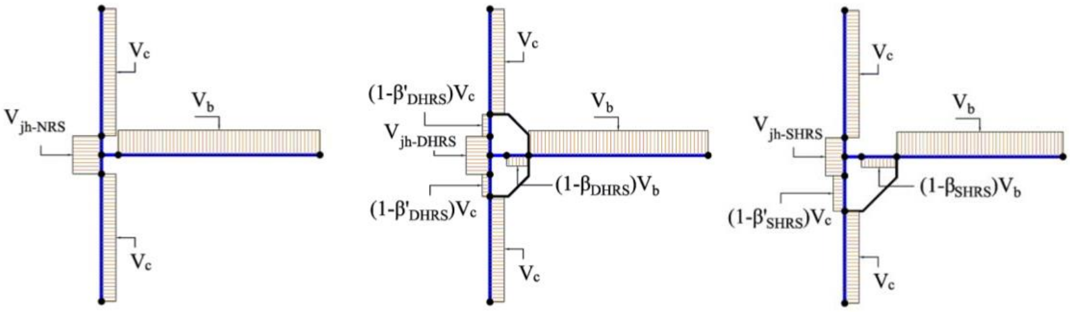


Figure 10: Conceptual representation of the strength hierarchy assessment

- Investigation of changes in shear demand at the joint zone after applying single diagonal haunch and comparison with non-retrofitted subassembly and double haunch retrofitting system (Figure 11).



(a) NRS (b) DHRS (c) SHRS

Figure 11: Shear force distribution: (a) Non-retrofitted subassembly (NRS); (b) Double haunch retrofitting system (DHRS); and (c) Single haunch retrofitting system (SHRS).

- Derivation of the key formulations for the implementation of single diagonal haunch.
- Generalization of the formulations for all three systems: the non-retrofitted subassembly (NRS), the double haunch retrofitting system (DHRS), and the single haunch retrofitting system (SHRS).
- Examine the efficiency of SHRS by comparing it with NRS and DHRS through a parametric study.

Post-Peak Drift Capacity of RC Columns

A project on the drift capacity of high-strength reinforced concrete (HSRC) columns was undertaken since mid-October 2016. In the first phase of the project, an extensive literature review about the seismic performance of reinforced concrete (RC) columns was conducted. It was found that, while many post-peak drift models exist for normal-strength reinforced concrete (NSRC) columns, very limited work has been done in this area on high-strength reinforced concrete (HSRC) columns. Thus, a comparative study was undertaken to evaluate the capability of existing drift models to predict the post-peak drift capacity of both NSRC and HSRC columns. The study was conducted using a comprehensive database of 190 RC columns (79 HSRC and 111 NSRC) from past experimental studies. In this regard, 10 post-peak drift models (5 lateral load failure drift models and 5 axial load failure drift models) were evaluated. The results of the comparative study indicated that existing drift models give reasonable predictions of post-peak drift capacity of NSRC columns. However, most of these models overestimate the drift capacity of HSRC columns.

The next phase of the project focussed on developing a set of unified drift capacity models by achieving a balance between the behaviour of NSRC and HSRC columns in such a way that the proposed models could predict the drift capacity of NSRC as well as HSRC columns with a reasonable accuracy. In this respect, a unified lateral load failure and an axial load failure drift model were developed. The proposed models were calibrated using a very comprehensive database of normal-strength and high-strength RC columns from the literature. The proposed models relate the post-peak drift capacity of RC columns with design parameters, namely, axial load ratio (n), transverse reinforcement ratio (ρ_h), concrete compressive strength (f'_c), transverse reinforcement yield strength (f_{yh}) and aspect ratio (a/h) and have a very wide range of applicability. These models can serve as tools for structural design engineers to estimate drift capacity of lightly to moderately reinforced concrete columns at an early design stage. Moreover, the proposed models can also be used for assessing the drift performance of lightly reinforced concrete columns in existing vulnerable buildings and thus can aid in decision-making regarding the necessity of rehabilitation or retrofitting of such columns.

During the literature review, few potential research gaps for experimental testing were identified as well. A survey of the literature showed that while axial load collapse behaviour of NSRC columns has been widely investigated, very few experimental studies explored the collapse behaviour of HSRC columns. Moreover, most of the previous experimental testing on HSRC columns focussed on moderately to fully ductile HSRC columns. However, in low to moderate seismic regions, limited ductile RC columns having widely spaced transverse reinforcement are rampant. Similarly, it was found that HSRC columns have not been tested under bi-directional cyclic loading so far, whereas, literature review shows that the drift capacity of RC columns is highly dependent on the direction of loading. Therefore, to address these gaps a proposal for testing eight lightly reinforced high-strength RC columns has been made. Concrete strength, axial load ratio and direction of loading are proposed to be the variable parameters. Four of these columns are proposed to be tested under uni-directional cyclic loading while remaining four are proposed to be tested under bi-directional cyclic loading. Currently, work is being done to finalize things regarding experimental testing.

ONGOING RESEARCH

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

- The second stage of the research on height amplification factor that includes buildings with flexible floors is near completion and the results is expected to be submitted to the upcoming Int. Masonry Conf. in Newcastle.
- Research in ongoing to produce URM building fragility curves for the non-structural URM building components. Significant research has been undertaken by University of Auckland by collecting empirical data from the 2010-2011 Canterbury earthquake swarm. This information will be supplemented by analyses of more scenarios to generate fragility curves that would be one of the deliverables in the second phase of Project A9.
- The data from in-situ testing of URM walls and laboratory testing of retrofitted cavity URM walls were analyzed and submitted to two journals (one international and one Australian). Upon completion of the third journal paper, the main contribution of the in-situ testing will be an improvement in predicting the out-of-plane strength of URM walls that have plaster finish.
- Experimental work into the durability of seismic retrofit of masonry elements is ongoing. FRP-strengthened specimens were subjected to environmental condition since the 2nd quarter of 2014-2015 and tested at different milestones of 6 months, 1 year, and 18 months. The last testing stage (24 months) is to be completed in the next few weeks.
- A force-based seismic assessment method for a haunch retrofitting method for limited-ductile reinforced concrete beam-column joint has been developed as described above. A displacement-based assessment method, with the consideration of nonlinear response behaviour, is currently under development. Swinburne University is planning for small-scale experiments on the response behaviours of selected anchoring systems under combined axial (tension and compression) and shear loads, as well as a large scale experiment on a non-retrofitted joint and a retrofitted joint using a single diagonal metallic haunch.
- An analytical modelling technique to predict the load deformation behaviour of lightly reinforced beam-column elements has been developed. The non-linear behaviour of reinforced concrete buildings supported by reinforced concrete walls and moment resisting frames (including those featuring vertical irregularities caused by discontinuities in columns) is currently being investigated, adopting the developed modelling technique. Seismic vulnerability assessments for this type of buildings will be conducted in the following months.
- The post-peak drift performance of both normal strength and high strength reinforced concrete column is under investigation. A critical review on existing models for estimating lateral load failure drift capacity and axial load failure drift capacity has been conducted in the past few months. A new model is currently under development, and large scale experiment will be conducted in the next few months on high strength reinforced concrete columns.

PROJECT REVISION – REVISED SCOPE AND GOING FORWARD

Following the August and September 2016 Workshops, which included End User meetings a number of research utilisation projects were proposed and discussed. This projects were discussed further during the last few months, and an overview of each project is presented below:

Earthquake Mitigation Case Studies for a WA Regional Town:

The WA town of York includes many historical, heritage, buildings that are the focus of the WA Department of Fire and Emergency Services (DFES) for their earthquake risk. A precinct case study of economic feasibility of seismic retrofit to these buildings will provide a good model for other towns. Site inspections and building typology study will be completed in the first quarter of 2017-2018. This information will be augmented to the building exposure data available from NEXIS in a follow-up desktop study. In early 2018, heritage-sensitive choices of seismic retrofit methods will be developed/formulated and costing that will provide the basis for cost-benefit analysis will be undertaken. End user demonstration of seismic retrofit methods is currently being planned on buildings that are scheduled for demolition.

Holistic Risk Assessment of Regulatory Requirements for Earthquake Design:

The vulnerability and economic modelling components under development in this project have utility for developing information for the Australian building regulator, the Australian Building Codes Board (ABCB). The capabilities, once developed, can inform the future development of future earthquake design regulations for new construction, as well as retrofit of existing.

This project would use the economic modelling capability to examine the residual risk associated with current building regulations and incremental benefits of designing for rarer events. Unlike wind design, building design philosophy for earthquake under the current standard implies a greater level of damage related loss for a design level event than for the equivalent wind. This is because the building is typically designed to undergo inelastic deformation in the design level event. This damage can come as surprise to the owner of a code compliant building, as shown by the Christchurch Earthquake of 2011. With the move to reducing the cost of natural disasters and making communities more resilient, the project will develop a more holistic performance based design framework that reflects broader societal expectations and examine the incremental benefit associated with avoided costs of design for rare earthquake events.

In the second part of this project Australian life safety issues associated with collapse prevention will be examined. Australian intraplate seismicity results in greater increases in hazard with decreasing likelihood than found in tectonic plate boundary countries. While the design processes for building in plate boundary countries provide adequate assurance of collapse prevention in rare events, that this is achieved in Australia is not clear. One facet of this project is to examine how effectively current building regulation in Australia prevents total building collapse and gross loss of life, such as seen in Christchurch. Further, it will examine options for future regulatory development to averting this outcome.

Rapid Visual Screening (RVS) Procedure

This project outcome will be of the interest of State governments and Emergency Management Australia. The project will provide a checklist for a rapid, first-tier, seismic assessment of buildings. The project start is the first quarter of 2017-18 with a literature review of existing national and international methods. It is likely that State Government have existing procedures that are not nationally available. The main milestones of the project is to identify general weaknesses of the buildings and develop a simple scoring system that correlates to an expected outcome of preliminary seismic assessment.

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NOTE - only those published between 1 July 2016 & 30 June 2017 are listed.

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