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PRELIMINARY REPORT ON ECONOMIC LOSS MODELLING

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Cover: Building damage during the 2011 Christchurch, New Zealand earthquake. Photo: John McCombe, New Zealand Fire Service

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EXECUTIVE SUMMARY

This report forms part of the output from entitled "Cost-Effective Mitigation Strategy Development for Building Related Earthquake Risk" within the Bushfire and Natural Hazards Cooperative Research Centre.

Earthquakes have the potential to cause widespread damage to Australian communities and the economic activity that occurs within them. Recent earthquake events have illustrated this, including the Newcastle Earthquake (1989) and the Kalgoorlie Earthquake (2010). This potential is largely due to the fact that much of the Australian building stock has not been designed nor constructed with adequate consideration of earthquake hazard.

Mitigation intervention is needed to reduce this risk but an evidence base is lacking to inform investment. In particular, there is a need for economic measures of the benefits of retrofit as an offset to the sometimes large costs of upgrading structures for earthquake.

This need exists in many other countries. As part of this research a literature survey of research published internationally is underway to inform the best approach for assessing the costs of business interruption and the losses associated with injury and death. The findings of this work to date are described and are informing the research program.

This preliminary report also describes the frameworks developed for a range of Australian decision makers. Decision makers include building owners, owners of both business premises and the business within, local government, state government and national government. The scale of decision making metrics range from individual building level up to business precinct level exposures and the interdependence of building performance within them. The information and models required as inputs into the framework have been identified along with how these will be met, either with outputs from this CRC project, or from other sources.

Current research on the economic loss modelling is on track. Future work will complete the literature survey and develop casualty cost modules adapted from those published for use in this project. In the succeeding year business interruption loss models will be developed and framework/methodology developed for assessing precinct level economic activity disruption.

INTRODUCTION

The "Cost-Effective Mitigation Strategy Development for Building Related Earthquake Risk" project is seeking to address the need for an evidence base to inform decision making on the mitigation of the earthquake risk posed by vulnerable Australian buildings. It aims to develop information related to more vulnerable Australian building types in the following areas:-

- retrofit strategy options for high risk buildings to reduce their vulnerability;
- the current and retrofitted performance of these buildings;
- the cost of implementing the retrofit strategies; and,
- the ability to assess the benefit of avoided societal costs through the implementation of these strategies.

This report describes progress made against the last component which is directed at economic loss modelling. The work has been guided by, and is consistent with, the project team consensus achieved at a single day workshop convened at Swinburne University on the 23rd October 2015.

The economic loss modelling approach aims to encompass the information needs of a range of decision makers. These view benefits through different "lenses" and at differing scales. For this research they include:-

- Building owners.
- Owners of both the building and business.
- Local Government for a business precinct.
- Jurisdictional and Federal Governments and their additional interest in economic loss associated with health care and lost productivity.

In this report a background will be provided on the motivations for this project. The current findings of an ongoing literature survey will be presented, and the economic modelling frameworks proposed by the project team will be described. This report corresponds with the 31 Dec 2015 project milestone deliverable "Preliminary report on economic loss modelling".

PROJECT BACKGROUND

Earthquake hazard has only been recognised in the design of Australian buildings since approximately 1995. This oversight has resulted in the presence of many buildings within communities that currently present a high risk to property, life and economic activity. These buildings also contribute 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 subject to the Christchurch Earthquake of 2011. With new building construction representing 1.8% of the building stock nationally (ABCB 2014), the legacy of high risk buildings 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. Damage to these not only leads to direct repair costs but also to injuries and disruption to economic activity. This research project is drawing upon and extends existing research and capability within both academia and government to develop information on these that will inform policy, business and private individuals on their decisions concerning mitigation. It will also draw upon New Zealand initiatives that make use of local planning as an instrument for effecting mitigation. The Wellington City Council Resilience Program is an exemplar of this that has progressively resulted in the retrofit of a large proportion of earthquake prone unreinforced masonry buildings in that city. Other New Zealand cities have retrofitted vulnerable buildings. Figure 1 is of a two storey reinforced concrete frame building with unreinforced masonry infill in Napier. The city experienced a devastating earthquake in 1931 and this building was part of the extensive rebuild of the central business district (CBD) that took place in 1930's. Ductile steel moment frames have been added to strengthen the structure in the transverse direction.

Project A9 has six key elements of research that are being progressed sequentially:-

1. Australian building stock vulnerability classification (completed).
2. Review of existing retrofit options (completed).
3. Development of Australian specific retrofit options (in progress).
4. Economic loss model development (in progress).
5. Benefit versus cost analysis of retrofit options
6. National assessment of retrofit needs.

Work on the fourth element has commenced with the engagement of economist Dr Itismita Mohanty as part of the project team. Her research will draw upon international research and align with earthquake impact and risk modelling capability developed by Geoscience Australia for use in elements 5 and 6.

Figure 1: Ground floor view of retrofitted two storey retail structure of the 1930s period in Napier, New Zealand. The building is of poorly detailed reinforced concrete frame construction with unreinforced masonry infill walls. Ductile steel moment frames have been retrofitted to strengthen the structure in the transverse direction.

NATURE OF ECONOMIC LOSSES IN BUSINESS PRECINCTS

The severe ground shaking that accompanies earthquake can cause physical damage to buildings. This has an attendant repair cost or, in a very severe event or with very vulnerable buildings, may require demolition and complete reconstruction of the damaged building.

The severity of physical damage has implications for the use of the building. Minor cracks and dislodgment of non-structural elements may permit full use of the structure post-earthquake, whereas more severe damage may limit or preclude access. Where the use of the building includes business activity, the resultant disruption to turnover adds to the economic loss. This impact may extend to businesses in less damaged adjacent structures where damage cordons impact their building access.

The contents of building can also be damaged in an earthquake. In high seismic regions of developed countries restraint is often provided to contents that can topple but this is not a common practice in Australia. Floor accelerations can overturn furniture and damage fit-out. On upper floors this can be more significant as the response of the building to ground motion accentuates the floor motion. Where a building sustains partial or complete collapse, direct damage to contents will also result.

Building damage also translates into deaths and injury to occupants. It is recognised that "earthquakes don't kill people, collapsed buildings do," (https://www.unops.org/english/News/Pages/Earthquakes-dont-kill-people-collapsed-buildings-do.aspx#sthash.oLoV6vEu.dpuf). Earthquake triggered landslide deaths aside, the performance of poorly designed and/or built structures directly affects occupants. This has an insidious aspect in that it is the human contribution to our built environments that has the greatest negative influence on human safety. Medical care requirements and lost productivity caused by recovery from injury, disability or death represent a further economic cost.

Utility and supply chain issues can also affect business turnover. Loss of electricity, water, sanitation, telecommunication and gas supply can render some business premises unusable. Lack of material supply to the business or the inability to dispatch goods can also disrupt business activity and cause economic losses.

Other costs often unquantified for mitigation investment include the greater cost of emergency response, the cost to effect clean-up and Government financial assistance to a range of recipients to promote community recovery.

LITERATURE REVIEW OF BUSINESS INTERRUPTION AND CASUALTY MODELS

The literature review aims to identify and inform models of different components of building related economic costs associated with earthquake events in Australian business districts. Broadly there are two identified components of building related earthquake loss: the direct and the indirect economic cost.

Direct economic costs include the losses due to damage to buildings, their contents and the direct business interruption. Direct business interruption refers to the immediate reduction or cessation of economic production in a damaged property or a property cut off from at least one of its utility lifelines. These interruptions form part of the direct losses.

Indirect economic losses are losses due to interruption in supply chains, infrastructure, and interconnectivity of economic sectors. Indirect losses are estimated by the ripple effects associated with the supply chain or customer chain of a directly impacted business. Indirect loss calculations account for the impact of both property and infrastructure loss on the overall economy of the region by different sectors.

Thus, a further detailed classification of the economic costs includes:-

1. Direct building damage Loss
2. Direct building contents Loss
3. Direct business activity disruption due to damaged premises
4. Broader scale business activity disruption due to precinct level damage
5. Cost to society from injury and loss of life
6. Other associated earthquake disaster costs (emergency response, clean-up and other support services)

The scope of this component of the project involves building modelling capability to estimate earthquake scenario costs such as:-

1. A business interruption costs model related to broader scale business activity disruption due to Precinct level damage. The model will be tested with a Melbourne CBD case study.
2. A casualty model or cost to society from injury and loss of life

The literature review has been progressing well and has reviewed some of very significant literature in this space. One significant shift in the literature in this direction has been in the space of rapid earthquake loss estimation - the HAZUS-MH (FEMA 2003) and the OpenQuake (Silva et al. 2013) earthquake loss assessment models. Both of these applications use comprehensive and rigorous loss assessment methodologies that can be adapted to rapid earthquake loss assessment after intelligent simplifications. The HAZUS-MH Earthquake Model (FEMA 2003) is developed to provide a nationally applicable methodology for loss estimates of damage and loss to buildings, essential facilities, transportation and utility lifelines, and population based on scenario or probabilistic earthquakes. The last part of the HAZUS methodology on Direct Economic/Social Losses is relevant to this research which includes a casualty loss model. It also identifies Indirect Economic Losses which are outside of this research scope.

BUSINESS INTERRUPTION COST MODELLING

In the space of business interruption cost a number of other international studies have been reviewed, such as : Erdik et al (2014); Pan et al (2015); Rose et al (2011); Cho et al (1999); Rose (2009); Rose (2007) and Jain and Guin (2009).

Rose et al (2011) highlighted that input-output (I-O) analysis is the most widely used tool of regional impact analysis in the United States and throughout the world. Moreover, it has been used extensively to analyze the economic impacts of earthquakes and other natural hazards (e.g., ATC 1991, Shinozuka et al. 1998, Rose and Lim 2002, and Gordon et al 2007). It is especially adept at estimating ripple, or multiplier, effects. I-O analysis can be defined as a static, linear model of all purchases and sales between sectors of an economy, based on the technological relationships of production. Essentially, this is a detailed, comprehensive, double-entry bookkeeping record of all production activity. Practically every country in the world has constructed an input-output table, usually through an exhaustive census or at least an extensive survey, and there is a rich literature on ways to use non-survey data-reduction, or "downscaling" methods to generate tables for political jurisdictions at various subnational levels.

I-O analysis provides more than a modelling capability. The basic I-O table of common transactions on which the model is based serves as a valuable framework for organizing an extensive amount of data on a regional economy. The data and analytical tools, such as impact multipliers, derived from it provide insight into the structure, interdependence, and vulnerability of the regional economy (e.g., Miller and Blair 2009). In an I-O analysis, it is important to distinguish two types of second-order effects. The first is "indirect" effects, which represent the interaction between producing sectors. The second is "induced" effects, which represent the interaction between households and producing sectors; production generates income paid to households, who in turn spend a major portion of this income on produced goods and services, thereby generating additional multiplier effects.

Pan et al (2015) highlighted that there are several alternatives to input-output analysis, for example, the CGE (computable general equilibrium) models that are very popular. These can accommodate important price-substitution effects. Input-output models, on the other hand, assume fixed reduction coefficients.

CASUALTY COST MODELLING

In the space of casualty cost modelling a number of international studies have been reviewed including: Erdik et al (2014); Daniell (2014); Porter et al. (2008a, b); Jaiswal and Wald (2013); Jaiswal and Wald (2011); Jaiswal and Wald (2010); Jaiswal et al. (2009).

Erdik et al (2014) summarize the work done over last decades regarding the development of new approaches and setting up of new applications for earthquake rapid response systems that function to estimate earthquake losses in quasi real time after an earthquake. In modelling the spatial distribution of casualties they have summarized some of very significant developments in the literature as follows:-

1. The HAZUS-MH (FEMA 2003) casualty module describes and develops the methodology for the estimation of casualties. The methodology is based on the assumption that there is a strong correlation between building damage (both structural and nonstructural) and the number and severity of casualties. This model estimates casualties directly caused by structural or nonstructural damage under four severity levels to categorize injuries, ranging from light injuries (Severity Level 1) to death (Severity Level 4). The model provides casualty rates for different structural types and damage states. Relevant issues in casualty estimation such as occupancy potential, collapse and non-collapse vulnerability of the building stock, time of the earthquake occurrence, and spatial distribution of the damage, are included in the methodology. Casualties caused by a postulated earthquake can be modelled by developing a tree of events leading to their occurrence.

2. Daniell (2014) has developed an approach to rapidly calculate fatalities and economic losses from earthquakes using the input of intensity based map and historical earthquakes as a proxy over multiple temporal and spatial scales. The population and its social and economic status for each earthquake were compared to the detailed socio-economic data in CATDAT (a worldwide catalogue of damaging earthquakes and secondary effects database (Daniell et al. 2011, 2012)) to produce the functions. Temporal relationships of socio-economic losses were explored in order to calibrate loss functions.

3. Porter et al. (2008a, b), Jaiswal et al. (2009) and Jaiswal and Wald (2010) have concentrated on the key parameters of intensity as the hazard metric versus fatality to population ratios or the death rate in collapsed buildings, using expert opinion related collapse ratios and historical data. They have estimated the earthquake fatality rates as total killed divided by total population exposed at specific shaking intensity level. The total fatalities for a given earthquake are estimated by multiplying the number of people exposed at each shaking intensity level by the fatality rates for that level and then summing them at all relevant shaking intensities. The fatality rate is expressed in terms of a two-parameter lognormal cumulative distribution function of shaking intensity.

PROPOSED LOSS AND BUILDING TYPE SCOPE

The literature survey has identified a broad range of direct and indirect losses associated with severe earthquake events. Some, such a business disruption losses, have proven to be very significant in historical earthquakes. The inherent lack of warning for earthquakes (as distinct from bushfire, flood and tropical cyclones) also contributes to significant injuries and deaths. Potential losses due to heath care costs and lost productivity are correspondingly higher. The proposed loss model scope includes the following:-

- Direct building damage related loss.
- Direct building contents loss.
- Direct business activity disruption due to damaged premises
- Broader scale business activity disruption due to precinct level damage
- Cost to society from injury and loss of life

Precinct level damage implication will capture the effects encountered in the Christchurch Earthquake where cordons were in place for up the 12 months in some areas with implications for business activity (Elwood *et al*, 2015)

The building stock within business districts varies as to age, structural form and use. The timing and scale of urban growth has had a bearing on the current building stock profile within communities. For example, the Victoria gold rush of the late 1800s resulted in the construction of many large prestigious masonry buildings for public and commercial use that are present today in the cities of Bendigo, Ballarat and Melbourne. For the purposes of this research two principal structural types have been sellected that are considered to contribute the most to the earthquake risk of Australian communities and the larger CBD's of Australian cities:-

- Unreinforced masonry that is inherently brittle and poorly tied together structurally.
- Poorly detailed and configured reinforced concrete frame and shearwall construction. Buildings of this type have poor ductility, are often torsionally irregular and can exhibit "soft storey" behavior.

Excluded are losses associated with interruption of supply chains or utility supply disruption. In addition, the costs incurred for emergency response and clean-up are also excluded.

PROPOSED FRAMEWORK AND APPROACH

This research aims to develop an economic loss modelling framework that is implementable while capturing the range of economic measures included in the scope of work. This has required a pragmatic framework and approach for which the information requirements are tractable. The proposed framework is described in detail below.

FRAMEWORK

The frameworks proposed for each of the range of decision makers are similar to one another, but have been adjusted to reflect the measures used by the respective decision maker. In Figure 2 the framework for decision making at an individual property level is described (for mitigated building case). As a single asset is under consideration the hazard input is the severity of ground shaking for a range of likelihoods for the building site with the effects of site soil response included. The horizontal dashed line reflects the limit of interest in avoided costs incurred for a building owner deciding on retrofit options. The added loss measures below the line are considered applicable to occupants who own both the business premises and the business. Finally, the correlations of contents damage and business disruption with building damage are captured.

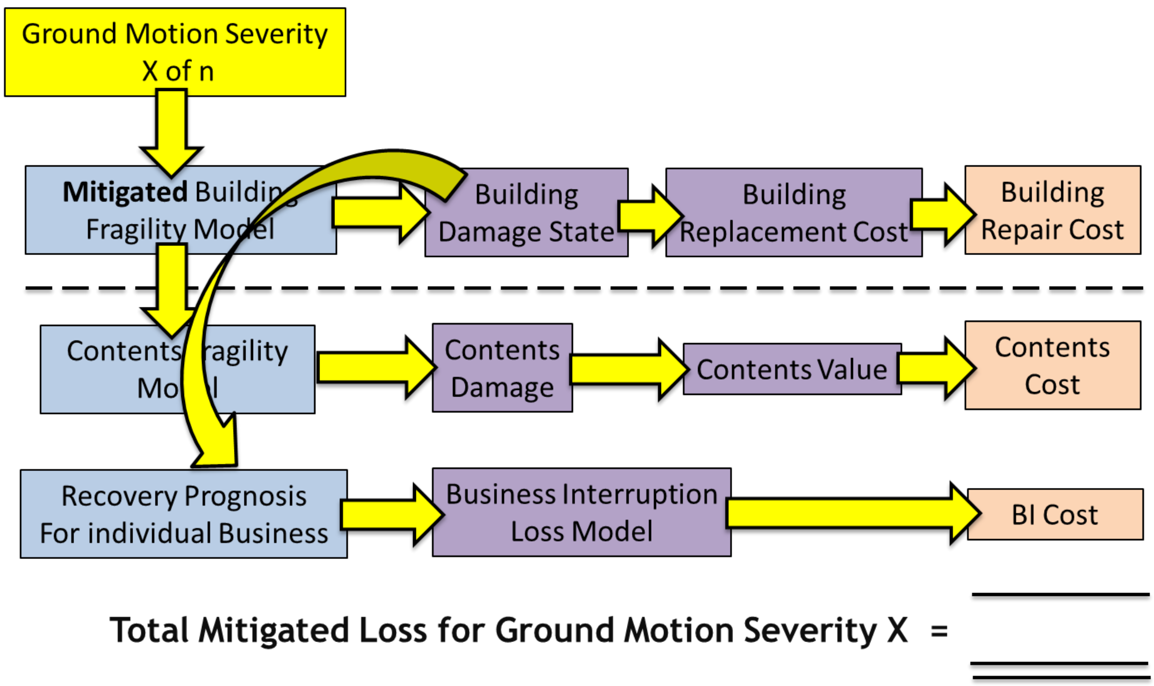

Figure 2: Economic loss modeling framework for an individual building. The mitigated case is shown and the limit of measures of interest to a building owner versus owner of both building and business is indicated by the dashed horizontal line.

For a population of buildings in a business district the spatial distribution of the ground shaking needs to be considered. The framework for this incorporates a set of earthquake scenario events that capture the range of locations and magnitude levels that need to be considered. This is illustrated in Figure 3 below. The correlation between building damage severity and injury is shown. Further, a community recovery prognosis model is incorporated that captures the relationship between severity of precinct damage, expected recovery and associated disruption to business activity while this is effected.

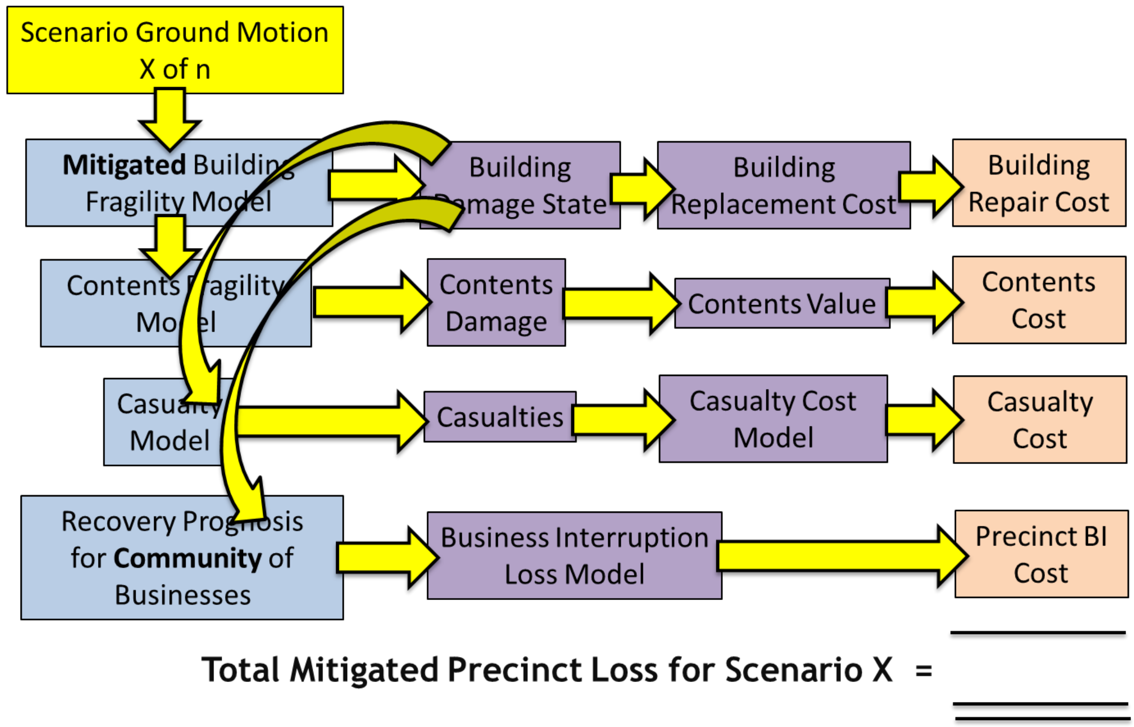

Figure 3: Economic loss modeling framework for a business precinct. The mitigated case is shown with casualties and associated costs included as of Interest to government.

MITIGATION IMPLEMENTATION PROGNOSIS

Mitigation measures for individual buildings can be effected in a relatively short period of time following the investment decision to do so. In contrast, the mitigation action within a population of buildings will necessarily be implemented over a period of time – even decades. Business district mitigation translates into a gradual investment and a corresponding progressive realisation of the benefits derived into the future. The research approach will consider a range of retrofit uptake rates for the building types in the scope. These rates will be influenced, and potentially incentivised, by insurance premium discounts and government initiatives to promote the action. The rates of uptake may also be influenced by local scale variations in earthquake hazard, where properties located on softer soils have higher earthquake hazard than properties underlain by stiffer soils within the same precinct, thereby realising greater returns on mitigation investment.

LOSS ESTIMATION APPROACH

The loss estimation approach utilises the aggregated losses for each severity of site shaking or scenario earthquake considered using the framework describes previously. The key steps in the approach are described below.

Annualised Long Term Loss for Hazard Exposure

The long term losses for earthquake hazard exposure will be evaluated for both the non-mitigated (as is) and mitigated building or precinct exposure cases. The event losses for all local hazard likelihoods or scenarios will be converted into a Probable Maximum Loss (PML) curve that will be subsequently integrated to obtain the annualised loss without mitigation and for the range of mitigation uptake scenarios considered. As the mitigation action for a precinct will not typically be a step function in any year, but a progressive implementation and loss reduction, the annualised loss will be assessed in stages that reflect the status of the retrofit in the business district at each time step.

Annual Benefit of Mitigation

The average annual economic benefit of each building mitigation strategy will be evaluated by subtracting the annualised mitigated case loss from the unmitigated value. For the precinct level assessment the annual benefit will be assessed at each of the retrofit uptake stages considered.

Benefit Versus Investment Cost of Mitigation:-

The future benefits of mitigation resulting from the status of retrofit will be converted to present value using standard economic discounting techniques. In this process several discount rates will be explored to assess the effect of a range of costs for capital investment. In a similar manner, for precinct level the progressive investment cost in retrofit will be discounted to present value

For individual buildings the present value of annual savings in hazard exposure cost for several bedrock hazard and site soil classes will be divided by the investment cost for each retrofit strategy considered. In a similar manner the present value of annual savings for each precinct level retrofit strategy/uptake rate/cost of capital combination will also be used to divide the present value of annual savings with the present value of the investment cost. The resultant benefit versus cost ratios (B/C) will permit comparison for optimal strategy selection in economic terms.

INFORMATION AND MODEL REQUIREMENTS

The key information and model requirements for the proposed framework and approach are:-

Hazard and Impact

National scale Australian probabilistic hazard assessment.

Seismic source zones and recurrence rates for precinct study location(s).

Surface soil (regolith) characterization for the precinct study location(s).

Seismic impact assessment software tools that integrate hazard, building exposure and vulnerability for precinct scenario modelling.

Exposure

Detailed information of building stock in study precinct(s).

Building replacement cost.

Building contents value (range of business uses).

Human activity model that places people spatially in probabilistic terms.

Vulnerability

Building retrofit strategy options

Building retrofit option costs

Building fragility curves retrofitted

Building fragility curves non-retrofitted.

Building contents loss models.

- Building repair times for reoccupation covering the full range of damage states.
- Casualty models that define the probability of injury severity for building type and damage state.
- Business interruption models (isolated business).
- Business interruption models (precinct).
- Cost model for death and injury.

The project team has identified how all of these requirements can be met either from outputs from the CRC project, or from other external sources.

FUTURE WORK

Future work will include:-

- Completion of the literature survey on casualty and business interruption loss models.
- Development/adaptation of casualty cost models for injury associated with building damage in earthquakes.
- Development of business interruption models for various business types.
- Development of proposed framework/methodology and tools for assessing precinct level economic activity disruption. This is expected to include utilization of research undertaken in NZ on the recovery following the 2011 Christchurch Earthquake (Elwood *et al*, 2015)

SUMMARY

Research staff resources in the economics area have been engaged for the project and work on the central economic loss modelling approach is underway. The interim findings of the literature review presently underway as part of this project are presented in this report and have helped to shape the scope. Frameworks for quantifying and integrating a range of economic costs associated with earthquake events have been developed which will have application to a range of decision makers. The information requirements for this framework have also been identified and strategies for sourcing these developed. This research will progressively advance in parallel to the other physical testing and vulnerability assessment work enabling the project outputs to be brought together to obtain the metrics required for decision making.

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