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PROJECT A9: COST-EFFECTIVE MITIGATION STRATEGY DEVELOPMENT FOR BUILDING RELATED EARTHQUAKE RISK

Reporting on economic loss models
or deleted if not required

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Cover: Christchurch after 4 September 2010 Darfield Earthquake. Source: Geoscience Australia

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EXECUTIVE SUMMARY

This report forms part of the output from Project A9 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 an extensive literature review has been published to inform the best approach for assessing the costs of business interruption and the losses associated with injury and death. Frameworks have also been 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.

This report presents the trial runs for business income loss and rental income loss estimation methods undertaken. A complete work plan for health care expenditure also presented for the Greater Melbourne region (excluding Mornington Peninsula) as a case study.

Current research on the economic loss modelling is on track. This report presents the methodological development undertaken so far. Future work will describe the cordon model. It will also estimate the actual business interruption loss values for assessing precinct level economic activity disruption. The work will provide the basis for the Melbourne city CBD case study scheduled for 2019/20.

INTRODUCTION

The CRC Project A9 entitled "Cost-Effective Mitigation Strategy Development for Building Related Earthquake Risk" 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 undertook some trial runs to estimate business income loss and rental income loss and provided a complete work plan for estimating direct health care cost.

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.

This report presents the methodological progress in estimating the proprietary and wage/salary income loss due to business interruption, direct health care costs and the casualty costs to society due to injury and loss of life in the context of the forthcoming Melbourne city case study. The report corresponds with the 30 June 2019 project milestone deliverable "*Reporting on Economic Evaluation of Mitigation Strategies and Building Level*".

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 the 1930's. Ductile steel moment frames have been later 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 (in progress)
6. National assessment of retrofit needs (in progress).

Research on the fourth component draws upon international research and aligns with an 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 earthquakes 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. Similar losses of rental income for tenanted buildings are an added economic consequence.

Buildings contents 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, telecommunications 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.

ECONOMIC FRAMEWORK

The economic framework has been updated and is presented in Figure 2 below. While the framework assesses the loss for an individual earthquake event, the framework can be used for a full event set representing the range of possible earthquake scenarios to assess long term risk. It covers the full range of metrics within this research, though not all would apply for each decision maker:-

1) For individual owners and occupiers of residential properties the avoided damage to buildings and their contents would apply. Intangible losses associated with displacement from one's home, recovery from injury and perceived loss of safety are applicable.
2) For owners and operators of business premises, direct damage to premises and the contents apply. In addition, property losses and losses if parts of the premise are rented are also included.
3) For owners of businesses, direct business income loss.
4) For government, damage to public buildings and their contents apply. However this also includes health care costs and the lost economic activity to the impacted region.

Depending on the decision makers the relevant sectors can be included or excluded.

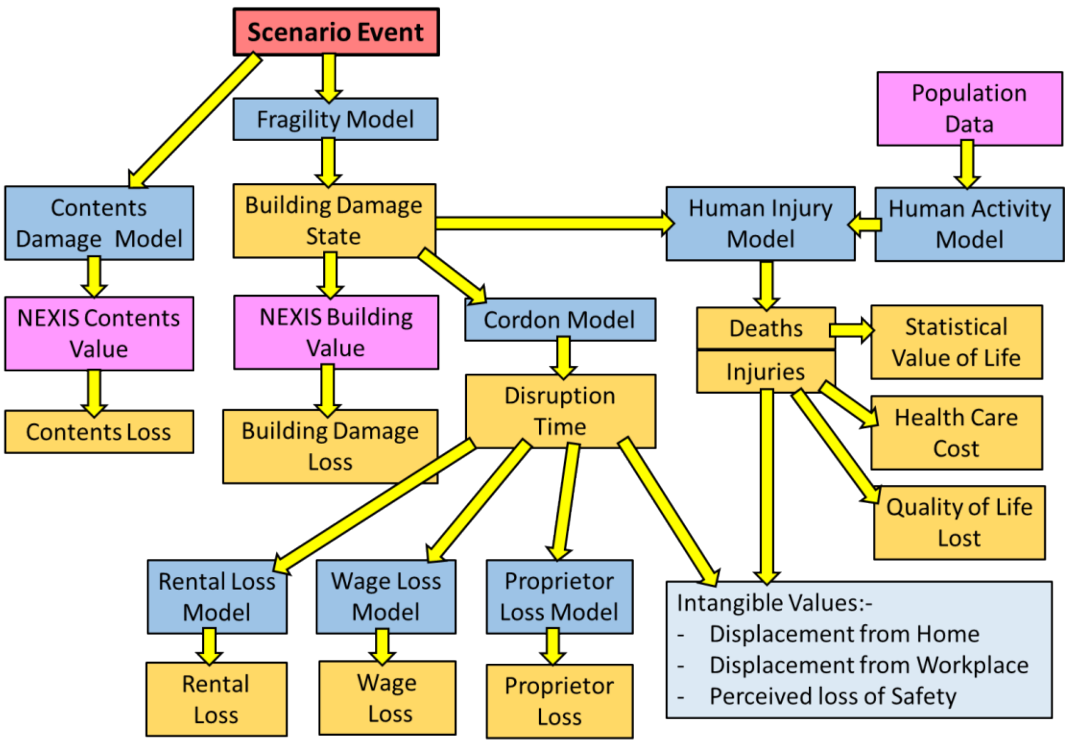

FIGURE 2 ECONOMIC FRAMEWORK FOR ASSESSING THE BROAD RANGE OF BENEFITS OF MITIGATION. SUB-SECTIONS OF THE FRAMEWORK ARE APPLICABLE TO SPECIFIC DECISION MAKERS FROM BUILDNG OWNERS TO DIFFERENT LEVELS OF GOVERNMENT. PINK BOXES RPESENT DATA INPUTS, BLUE BOXES REPRESENT MODLES AND ORANGE BOXES PREDICITED DAMAGE, INJURY AND LOSSES.

Each elements of the economic framework have been separately developed or sourced and will be integrated to assess the overall loss.

Key elements of the framework are:

1) Direct damage costs to buildings and contents as ordinarily assessed by the financial sector as part of the financial risk.
2) Costs to society due to loss of life.
3) Costs to society due to health care costs associated with injuries.
4) Indirect costs due to lost wages, rents and business profit.
5) Intangible impacts that add to the overall impact but generally not measured quantitatively.

DIRECT DAMAGE AND MITIGATION COSTS

One of the main contributors to economic loss caused by earthquake impact is direct damage to buildings. Empirical data of repair costs for direct damage is often difficult to source in Australia although attempts have been made using (a) aggregated insurance data from the Newcastle, 1989 earthquake (Maqsood et al, 2016 and Ryu et al, 2013) and (b) estimating cost of repair following post-earthquake damage survey of the Kalgoorlie, 2010 earthquake (Edwards et al, 2010).

For this project, cost estimates were required for the repair and replacement of URM building types typical of Australian towns and cities. Repair cost estimates were needed for the repair of whole buildings and individual components from damage states of varying severity. Additionally, estimates of the cost of installing retrofit measures were required to enable the assessment of benefit/cost ratios for retrofitting URM buildings to improve resilience to earthquake.

To obtain the required cost estimates a contract with quantity surveyors Turner and Townsend was tendered and commissioned (18 March 2019). This provided cost estimates for retrofit, repair and replacement of URM building types typical of the York exposure. The detailed scope of the contract is provided in Appendix A.

The cost estimates for replacement and repair contained in Turner and Townsend, 2019 are summarised in Table 1 and in Table 2 costs for parapets are presented for the longest length of parapet encountered amongst the generic building types. In establishing the repair cost for an individual building, the repair cost was adjusted for the actual length of each segment of parapet considering the segment's damage state.

Generic building type	1	2	3	4	5	6
Replacement cost ($)	714,200	2,508,600	1,519,400	1,836,900	1,770,400	1,224,900

TABLE 1 GENERIC BUILDING TYPES REPLACEMENT COSTS. GENERIC BUILDING TYPES ARE DEFINED IN APPENDIX A

Component	**Component repair cost from damage state ($)**				
	Damage state1	**Damage state 2**	**Damage state 3**	**Damage state 4**	**Damage state 5**
Squat chimney	624	1,140	1,510	1,510	2,020
Medium chimney	624	1,290	1,830	1,830	4,880
Slender chimney	1,110	2,340	3,440	3,440	6,490
Short parapet	2,590	12,360	14,820	14,820	75,630
Tall parapet	4,000	24,730	29,640	29,640	90,740
Gable wall	1,480	2,060	3,220	3,220	3,220
Generic building type 1 'box'	6,660	51,490	180,140	180,140	508,900
Generic building type 2 'box'	20,300	192,900	529,600	529,600	1,859,600

TABLE 2 COMPONENT REPAIR COSTS

Component	Component repair cost from damage state ($)				
	Damage state1	Damage state 2	Damage state 3	Damage state 4	Damage state 5
Generic building type 3 'box'	16,850	143,530	422,600	422,600	1,142,120
Generic building type 4 'box'	56,595	249,240	632,370	632,370	1,316,240
Generic building type 5 'box'	29,700	139,400	446,510	446,510	1,277,130
Generic building type 6 'box'	36,390	122,590	256,260	256,260	879,720

Note that the costs in Table 2 do not include costs for access (scaffolding), preliminaries or profit. These costs were added to the sum of repair cost for a combination of component damage states to establish a total repair cost for a building whose components were in a variety of damage states. Where a building 'box' was in Damage State 5, repair costs for all other components were set to zero as their repair is, of necessity, included in the full rebuild cost. Where the building 'box' was required to be scaffolded for repair, the access cost for roof-level components was set to zero. The logic used to establish the building repair cost incorporating the above issues is summarised in Figure .

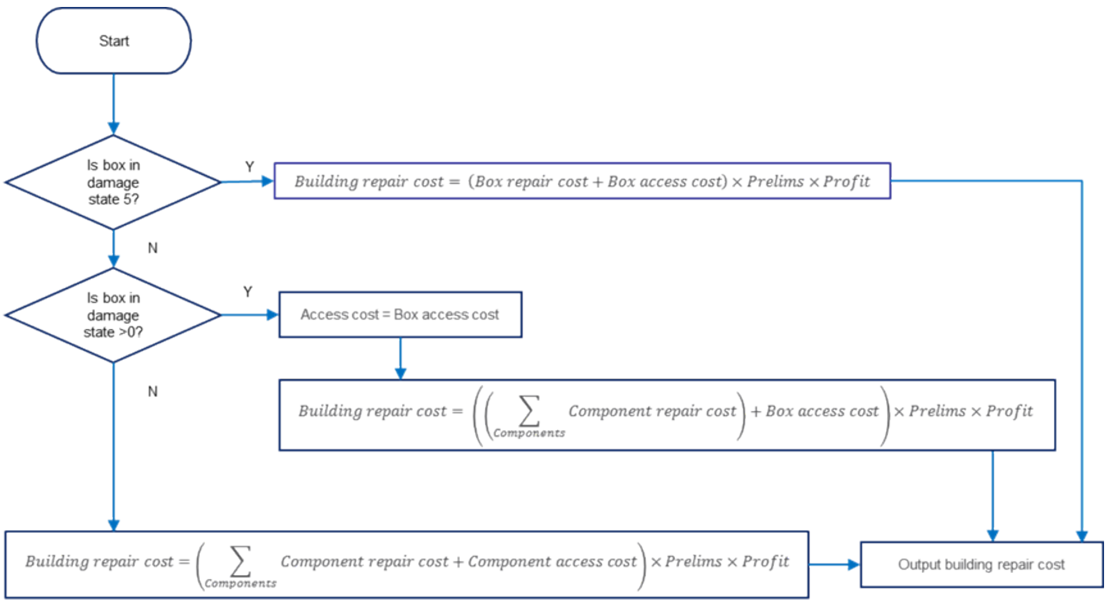

FIGURE 3 LOGIC USED TO ESTIMATE BUILDING REPAIR COST

BUSINESS INCOME LOSS

This report presents the methodological development in estimating the proprietary income loss of owner-Manager of incorporated/unincorporated enterprises, and wage/salary income loss. These would be major components of the business income loss and employee wages in the Melbourne city for an earthquake scenario event, as a case study.

Wage/salary Income loss

The wage/salary income loss will be estimated as a function of the number of employees at the building level and the average estimated income of employees by employment type and industry classification and proportion of employees affected in each business by industry classification and building damage state.

Based on the available input data sets and the Geoscience Australia earthquake impact modelling capability, the methodology for estimating wage/salary income loss in the Melbourne city will involve the steps described below.

1. Estimate the average wage/salary incomes of employed people based on their employment types comprising: full time, part time, casual or contract; and their industry of employment in the Melbourne CBD.

2. Apply these average wage/salaries in each category to the number of employees at individual building level in the Melbourne CBD

3. The GA earthquake impact modelling capability will simulate the building damage state for each building type in the CBD for earthquake severity levels.

4. The impact modelling capability will map the building damage state to the degree of impact on the businesses, which also, depends on the industry classification. This process will simulate the proportion of employees affected.

5. Based on the proportion of employees affected, the wage/salary income loss will be estimated at individual business and building level.

This report proposes to estimate the average wage/salary income loss for a week. The estimates of the business interruption periods in the event of an earthquake scenario as a function of earthquake severity level, damage state and industry classification will be simulated separately and applied to the weekly average wage/salary income loss.

The following section describes the input data and the methodology for estimating the earthquake related wage/salary income loss in a CBD precinct in the event of an earthquake scenario.

Methodology for wage/salary income loss

The first step in estimating the wage/salary income loss in Melbourne city is to source the appropriate data set that contains information on wage/salary and that can be combined with the earthquake impact and risk modelling capability. There is no census level wage/salary information available for Melbourne city at building level that can be combined with the impact modelling capability. The Census of Land Use and Employment (CLUE 2016) available for the city of Melbourne is the only data set in Australia that provides up-to-date information about land use, employment and economic activity at individual building level that can be effectively mapped to the impact modelling capability. But, CLUE does not contain information on wages/salaries of employees. Adding more to the problem, Australian Census of Population and Housing, while contains information on wages /salaries in brackets by employment type and industry classification, does not contain information at building level.

The impact modelling will simulate the building damage state for each building in the CBD by earthquake severity levels. CLUE contains information on number of employees at building level by their employment categorised such as – full time, part time, casual and contract. They are also categorised to the Australian and New Zealand Standard Industrial Classification (ANZSIC). The alternative option is to combine the CLUE data with a survey data set on Melbourne containing information on wages/salaries. To our knowledge the only survey data available in Australia that contains information on wages/salaries by CLUE employment categories and ANZSIC industry classification is the Household Income and Labour Dynamics in Australia Survey (HILDA). It also contains regional information by Greater Capital City/Rest of the State that can be applicable for Melbourne. But, HILDA does not contain wage/salary information at the building level but rather contains the same at individual/household level. Consequently, this research proposes combining the latest CLUE 2016 with the HILDA survey for the corresponding time period, Wave15 Release 2016, using statistical data matching to estimate average wage/salary by employment type and industry level. Consequently the average wage/salary values in these categories at building level will be imputed or predicted in CLUE 2016 using the matching variables and slope coefficients estimated in HILDA.

Employment and Industry

The latest CLUE-2016 provides comprehensive information on land use, employment and economic activity across the City of Melbourne at individual building level. CLUE data includes:

• industry structure and type (ANZSIC code and numberof establishments or business locations)

• floor space type and use (office, retail, industrial, accommodation or entertainment and office vacancy rates)

• employment type (full-time, part-time, casual or contractor)

• building information (number of floors, year of construction, gross floor area and lettable area)

• spatial distribution (maps, CLUE small areas, blocks and customised regions).

The Household, Income and Labour Dynamics in Australia (HILDA) Survey is a household-based panel study that collects valuable information about economic and personal well-being, labour market dynamics and family life. The survey started in 2001and follows the lives of more than 17,000 Australians each year. It collects information on many aspects of life in Australia, including household and family relationships, income and employment, and health and education.

Industry Classification

Both CLUE and HILDA contain information on employment by the Australian and New Zealand Standard Industrial Classification (ANZSIC). In facilitating data matching between CLUE and HILDA, the ANZSIC industry divisions will be combined in this report into the three broad industry sector categories of primary, secondary and tertiary industries (for details refer Mohanty et al, 2017).

Employment Types

The CLUE Employment Type categories that are also available with HILDA include: Full-time, Part-time, Casual, Contract and Volunteer.

This report scopes to estimate loss in wage/salary income by the above described employment type and industry classification at building level. Based on the building damage state, building access and proportion of employees affected the loss in wage/salary values can be estimated at individual business and building level and aggregated at the Melbourne city level.

Proprietary Income loss

The proprietary income loss will be estimated as a function of gross proprietary income in the Melbourne city by type of industry, total floor space used by businesses by industry and the proportion of floor space affected by industry. Based on available data sets, the methodology will estimate proprietary income loss by square metre of the floor space by industry classifications, which subsequently can be applied to the proportion of the floor area in each industry affected by an earthquake scenario.

Methodology for Proprietary Income Loss

This research proposes to use latest Census of Population and Housing 2016 and CLUE 2016 for estimating the proprietary income loss by square metre of the floor space by industry classification.

As reported in Mohanty et al (2017) ABS Census of Population and Housing contains information by employment types; owner managers of incorporated enterprises and owner managers of unincorporated enterprises. Methodologically that will enable the estimation of the total number of business owners in Melbourne city by industry type. The total personal weekly income ranges in Census with their mean values are presented in Mohanty et al (2017). The mean weekly income values in each income bracket and in each industry division will be multiplied with the number of business owners and the gross weekly proprietary income will be estimated by industry.

The Census of Land Use and Employment (CLUE) on Melbourne contains information on the floor space use by businesses at building level by ANZSIC industry classification. This will enable the estimation of the total floor space used by businesses by industry classification. The estimated gross weekly proprietary income and the estimated total floor space used by industry classification will enable the estimation of the proprietary income by square metre of floor space by industry.

The GA modelling capability will simulate the effect of earthquake seismicity at building level and will produce the proportion of floor space in each industry that would be affected.

DIRECT HEALTH CARE EXPENDITURE COST

Mohanty et al (2017) presents a modelling approach to estimate direct health care costs in the immediate aftermath of an earthquake event in Australia. Further, Mohanty et al (2018) presents a work plan for estimating direct health care expenditure cost that is considered implementable.

This report will present the methodological development so far in estimating direct health care expenditure loss. The first step in this process (for details see Mohanty et al 2017 & 2018) involves mapping the earthquake related injury severity levels to established Australian Refined Diagnosis Related Groups (AR-DRG) and Urgency Related Groups (URG) and the associated streams of care services provided by the Australian health care sector to enable estimation of the direct cost.

The previous report (Mohanty et al, 2018) proposed using the HAZUS-MH (FEMA, 2003) five-point earthquake related injury classifications (dead or mortally wounded included). The more recent research in this field allows the use of a slightly refined five-point injury scale (Spence, 2007) that is presented below in Table 3. This new injury classification (Table 3) brings in the classification of earthquake related injuries by body parts.

Category (I)		Type of Injuries		AIS
1	Uninjured/lightly injured	Head or Face	Bruising/contusions, minor cuts	2
		Abdomen	Bruising, minor cuts	1
		Upper Extremities	Bruising, minor cuts, sprains	1
		Lower Extremities	Bruising, minor cuts, sprains	1
2	Moderately injured	Head or Face	Cuts into soft tissues	2-3
		Abdomen	Cuts into soft tissues	2-3
		Upper Extremities	Dislocation, Cuts into soft tissues	2-3
		Lower Extremities	Dislocation, Cuts into soft tissues	2-3
		Other	Dehydration/exposure; burns 1-2o; unconscious < 1hr	3
3	Seriously	Head or Face	Open head or facial wounds, fractures, brain concussion	3-4
		Abdomen	Pneumothorax and rib fractures, crushing > 3hrs, puncture organs	1-4
		Upper Extremities	Fractures – open, displaced or comminuted (pulverised)	3
		Lower Extremities	Fractures – open, displaced or comminuted (pulverised)	3
		Other	Uncontrolled bleeding; burns 2-3o (% of body?); unconscious > 1 hr	3-5
4	Critical	Head or Face	Internal head trauma, severe crushing, brain damage	5
		Abdomen	Spinal column injuries, internal organ failures due to crushing	5
		Upper Extremities	Traumatic amputations, arms	5
		Lower Extremities	Traumatic amputations, legs	5
		Other	Nerve injuries	5
5	Dead	Asphyxiation, burns and smoke inhalation, intracranial injuries, traumatic complications		6

TABLE 3 EARTHQUAKE INJURY CLASSIFICATION

For mapping the above defined five point earthquake injury classification to AR-DRG and URG classification requires consultation with injury classification and health care stream experts. AR-DRG and URG classification comes with respective heath care streams of care and associated unit costs.

The cost categories includes emergency department costs as well as admitted episode costs. DRGs only cover admitted episodes, whereas URG is used to classify and cost emergency department visits.

The injury categories presented in Table1 reveal it is unlikely that category 1 and 2 injuries would need any hospital admission. These injuries would rather be treated in the emergency department. Consequently, category 1 and 2 injuries need to be mapped to URGs. URGs are based on very broad diagnostic categories (known as Major Diagnostic Blocks) and therefore the URGs mapped to the above earthquake related categories (1 & 2) may include emergency department visits that had other injuries other than those listed in Table 1. Also, URG includes categories for patients with any diagnosis which met the criteria of "did not wait", "transferred to another hospital", "died in ED" and are not specific to injury diagnoses, which may be excluded from these health care cost estimations.

The AR-DRG classification has over 800 groups, so the types of injuries listed in Table 3, may group to any number of DRGs depending on the interventions that occurred during the hospital stay, whether the patient had multiple injuries or required extended hours of mechanical ventilation, there will be multiple potential DRGs for each issue. For example, a head injury that required surgical intervention will be grouped to a different DRG than a head injury that was managed conservatively (IHPA, 2019; accessed at https://www.ihpa.gov.au/what-we-do/classifications).

The AR-DRG classification also has a separate set of DRGs for multi trauma cases. So if a patient has multiple types of injuries recorded, the episode will be assigned to a multi trauma DRG rather than a DRG for the specific type of injury (IHPA, 2019; accessed at https://www.ihpa.gov.au/what-we- do/classifications).

Assistance was sought from injury classification experts for mapping the above defined five point injury classification (Table 3) to AR-DRG and URG and/or ICD-10-AM classification and respective health care streams of care. ICD-10- AM is the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD), a medical classification list by the World Health Organization (WHO). Experts from the Independent Hospital Pricing Authority (IHPA) that hosts the National Hospital Cost Data Collection in Australia (NHCDC) and has expertise in this area have helped in mapping the ICD-10-AM classifications to Earthquake injury categories. Presented in Table 4 below are the code maps used to classify ICD-10-AM classification codes into earthquake injury categories (in Table 3).

TABLE 4: CODE MAPS USED TO CLASSIFY ICD-10-AM CLASSIFICATION CODES INTO EARTHQUAKE INJURY CATEGORIES

Category (I)		**Type of Injuries**		**AIS**		**ICD10AM 10th Ed**	**Code descriptions**	**Mapping comments**
1	Uninjured/lightly injured	Head or Face	Bruising/contusions, minor cuts	2	See Possible URGs (Urgency Related Groups) - as these minor injuries are likely treated in an ED	S00.00-S00.02 S00.04-S00.22 S00.24-S00.32 S00.34-S00.42 S00.44-S00.52 S00.54-S00.82 S00.84-S00.92 S00.94-S00.98 S09.0-S09.9 T00.0	Superficial injuries head, including face, excluding insect bites Other and unspecified injuries of head Superficial injuries head with neck - multiple	Superficial injury codes are in Category 1. Open wounds have been included only in Category 2. Most other and unspecified injuries of particular body regions have been included in category 1.
		Abdomen	Bruising, minor cuts	1		S30.0-S30.82 S30.84-S30.92 S30.94-S30.98 S39.7-S39.9 T00.1 T09.00-T09.02	Superficial injury of abdomen, lower back and pelvis, excluding insect bites Other/unspecified injuries of abdomen, lower back and pelvis Superficial injuries throax with abdo, lower back and pelvis Superficial injuries trunk level unspecified, excluding insect bites	

						T09.04- T09.08		
		Upper Extremities	Bruising, minor cuts, sprains	1		S40.0- S40.82 S40.84- S40.9 S50.0- S50.82 S50.84- S50.9 S60.0- S60.82 S60.84- S60.9 S43.4-S43.7 S49.7-S49.9 S53.40- S53.48 S59 S63.50- S63.7 S69.7-S69.9 T11.00- T11.02 T11.04- T11.08 T00.2 T00.6	Superficial injury of shoulder and upper arm, excluding insect bites Superficial injury of forearm, excluding insect bite Superficial injury of wrist and hand, excluding insect bite Sprain and strain shoulder and other parts of shoulder girdle Other/unspec injuries shoulder and upper arm Sprain and strain of elbow Sprain and strain at wrist, fingers and other parts of hand Superficial injury upper limb, level unspecified Other/unspec injuries wrist and hand Superficial injury upper limb, level unspec, excluding insect bite Superficial injuries multiple regions of upper limb Superficial injuries multiple regions	

						T11.8-T11.9	upper and lower limb Other/unspec injuries upper limb	

		Lower Extremities	Bruising, minor cuts, sprains	1		S70.0- S70.82 S70.84- S70.9 S80.0- S80.82 S80.84- S80.9 S90.0- S90.82 S90.84- S90.9 S73.10- S73.18 S79.7-S79.9 S83.40- S83.7 S89.7-S89.9 S93.40- S93.6 S99.7-S99.9 T13.00- T13.02 T13.04- T13.08 T00.3	Superficial injury of hip and thigh, excluding insect bite Superficial injury lower leg, excluding insect bite Superficial injury of ankle and foot, excluding insect bite Sprain and strain of hip Other/unspec injuries hip and thigh Sprain and strain of knee, injury multiple structures of knee Other/unspec injury lower leg Sprain and strain of ankle Other/unspec injury ankle and foot Superficial injury lower limb, level unspecified Superficial injuries multiple regions of lower limb	
2	Moderately injured	Head or Face	Cuts into soft tissues	2-Mar		S01.0-S01.9 T01.0 T03.0	Open wound of head Open wounds involving head and neck Dislocations, sprains, strains head with neck	

		Abdomen	Cuts into soft tissues	2-Mar		S31.0- S31.83 S39.0-S39.6 T01.1 T03.1 T09.1	Open wound of abdomen, lower back and pelvis Injury of muscle, tendon, organs of abdo, lower back and pelvis Open wounds thorax with abdo, lower back and pelvis Dislocations, sprains, strains thorax with lower back and pelvis Open wound of trunk, level unspecified	
		Upper Extremities	Dislocation, Cuts into soft tissues	2-Mar		S41.0- S41.82 S51.0-S51.9 S61.0-S61.9 S43.00- S43.3 S53.0-S53.3 S59.7-S59.9 S63.00- S63.4 T03.2 T11.1-T11.5 T01.2 T01.6 T03.4	Open wound of shoulder and upper arm Open wound of forearm Open wound of wrist and hand Dislocation of shoulder Dislocation of elbow and rupture elbow ligament Other/unspec injuries of forearm Dislocation or rupture of ligaments of wrist or fingers Dislocations, sprains, strains multiple regions upper limb Other injuries upper limb Open wounds multiple regions of upper limb Open wounds multiple regions upper and lower limb Dislocations, sprains, strains multiple regions upper & lower limb	

		Lower Extremities	Dislocation, Cuts into soft tissues	2-Mar		S71.0-S71.82 S81.0-S81.9 S91.0-S91.82 S73.00-S73.08 S83.0-S83.18 S93.0-S93.38 T13.1-T13.5 T13.8-T13.9 T01.3 T03.3	Open wound of hip and thigh Open wound of lower leg Open wound of ankle and foot Dislocation of hip Dislocation of knee Dislocation of ankle and foot Open wound, dislocation, sprain,strain of lower limb Other/unspec injuries lower limb Open wounds multiple regions of lower limb Dislocations, sprains, strains multiple regions lower limb	

		Other	Dehydration/exposure; burns 1-2°; unconscious < 1hr	3		T73.0-T73.9 T75.8 S06.01- S06.02 T20.0-T20.2 T21.00- T21.29 T22.00- T22.22 T23.0-T23.2 T24.0-T24.2 T25.0-T25.2 T30.0-T30.2 T01.8 T01.9 T03.8 T03.9 T09.2 T09.5 T14.3-T14.6	Effects of deprivation such as thirst, exposure, other deprivation Other spec effects of external causes Loss of consciousness < 30 mins or unspecified duration Burn of head and neck, unspec thickness, 1st or 2nd degree Burn of trunk, unspec thickness, 1st or 2nd degree Burn of shoulder/upper limb, unspec thickness, 1st or 2nd degr Burn of wrist and hand, unspec thickness, 1st or 2nd degree Burn of hip and lower limb, unspec thickness, 1st or 2nd degree Burn of ankle and foot, unspec thickness, 1st or 2nd degree Burn, body region unspec, unspec thickness, 1st or 2nd degree Open wound other combos of body regions Multiple open wounds NOS Dislocations, sprains, strains multiple body regions Multiple dislocations, sprains and strains NOS Open wound, trunk Dislocation, sprain, strain trunk Injury muscle, tendon trunk Dislocation, sprain, blood vessels, muscles unspec body region Other and unspecified injuries of head	E86 Dehydration will pick up many episodes, most of which won't be verified as caused by external agent. 1516 data revealed only 6 episodes where X54 Lack of water was assigned. Burns with 4th character of .0, .1 or .2 were mapped to moderate severity. (ie first or second degree and unspec degree) ICD-10-AM doesn't have a code for *LOC< 1 hr* as per Type of injury descriptor - thus mapped best-fit (S06.01-S06.02 LOC <30 mins or unspec duration)

3	Seriously	Head or Face	Open head or facial wounds, fractures, brain concussion	3-Apr		S02.0-S02.9 S06.00 T02.00-T02.01	Fracture of skull and facial bones Concussion Fractures involving head with neck	Cannot separate severity of open wounds between category 2 & 3 - currently mapped to category 2
		Abdomen	Pneumothorax and rib fractures, crushing > 3hrs, puncture organs	1-Apr		S22.31-S22.9 S23.4 S27.0-S27.9 S36.00-S37.9 T02.1 T02.7 T79.5	Fracture of ribs and thorax Sprain and strain of ribs and sternum Injury of other and unspec intrathoracic organ Injury of intra-abdominal, urinary and pelvic organs Fractures involving thorax, lower back and pelvis Fractures thorax with lower back and pelvis with limbs Traumatic anuria	Injuries in S36.00-S37.9 vary widely in severity - range from major laceration of liver …. to Injury of vas deferens. ICD-10-AM doesn't provide a time factor (ie > 3 hrs) for crushing injuries. Crushing of abdominal organs are included here and not in Category 4.
		Upper Extremities	Fractures – open, displaced or comminuted	3		S42.00-S42.9 S52.00-S52.9 S62.0-S62.8 T02.2 T02.4 T02.6 T10.0-T10.1	Fracture of shoulder and upper arm Fracture of forearm Fracture at wrist and hand level Fractures multiple regions one upper limb Fractures multiple regions both upper limbs Fractures multiple regions upper and lower limb Fracture of upper limb, level unspecified	
			(pulverised)			S47 S57.0-S57.9 S67.0-S67.8 T04.2 T04.4	Crushing of shoulder and upper arm Crushing of forearm Crushing of wrist and hand Crushing injuries multiple regions upper limb	Note - Crushing injuries of upper limb were mapped here because of descriptor of *pulverised*

							Crushing injuries multiple regions upper with lower limbs	
		Lower Extremities	Fractures – open, displaced or comminuted	3		S72.00-S72.9 S82.0-S82.9 S92.0-S92.9 T02.3 T02.5 T12.0-T12.1	Fracture of femur Fracture of lower leg, including ankle Fracture of foot, except ankle Fractures multiple regions one lower limb Fractures multiple regions both lower limbs Fracture of lower limb, level unspecified	
			(pulverised)			S77.0-S77.2 S87.0-S87.8 S97.0-S97.8 T04.3	Crushing injury of hip and thigh Crushing injury of lower leg Crushing injury of ankle and foot Crushing injuries multiple regions lower limb	Note - Crushing injuries of lower limb were mapped here because of descriptor of *pulverised*

		Other	Uncontrolled bleeding; burns 2-3° (% of body?); unconscious > 1 hr	3- May		S06.03- S06.05 T02.8-T02.9 T20.3 T21.30- T21.39 T22.30- T22.32 T23.3 T24.3 T25.3 T26.0-T29.3 T30.3 T04.8 T04.9 T06.8-T07 T08.0-T08.1 T14.20- T14.21 T14.7	Loss of consciousness 30 mins - > 24 hrs Fractures multiple other and unspecified Burn of head and neck, 3rd degree Burn of trunk, 2nd degree Burn of shoulder and upper limb, 3rd degree Burn of wrist and hand, 3rd degree Burn of hip and lower limb, 3rd degree Burn of ankle and foot, 3rd degree Burn of eye and adnexa, resp tract, other internal organs, multiple body regions Burn, body region unspec, 3rd degree Crushing injuries other body region combinations Multiple crushing injuries NOS Other/unspec injuries multiple body regions Fracture spine level unspecified Fracture unspec body region Crushing injury/amputation unspec body region	Burn site codes with 4th character of .3 (third degree/full thickness) were mapped to serious severity.

4	Critical	Head or Face	Internal head trauma, severe crushing, brain damage	5		S07.0-S07.9 S06.20-S06.28 S06.30-S06.9 S08.0-S08.9 T04.0 T06.0	Crushing injury of head Diffuse brain injury Focal brain injury Traumatic amputation of part of head Crushing injuries involving head with neck Injuries of brain and cranial nerves with injuries of nerves and spinal cord at neck level	
		Abdomen	Spinal column injuries, internal organ failures due to crushing	5		S14.0-S14.6 S24.0-S24.77 S34.0-S34.6 S34.8 S28.0-S28.1 S38.0-S38.3 T04.1 T04.7 T06.5 T09.6	Injury of nerves and spinal cord at neck level Injury of nerves and spinal cord at thorax level Injury of nerves and lumbar spinal cord at abdo, lower back and pelvis level Crushing injury of thorax and traumatic amputation of part of thorax Crushing injury and traumatic amputation of part of abdomen, lower back and pelvis Crushing injuries thorax with abdo, lower back and pelvis Crushing injuries thorax with abdo, lower back and pelvis with limbs Injuries intrathoracic, intraabdominal and pelvic organs Traumatic amputation trunk, level unspec	Severity of nerve and spinal cord injuries are difficult to split into severity categories. Note there are broad code categories for cervical, thoracic and lumbar levels. Cannot differentiate in ICD-10-AM between traumatic and nontraumatic organ failure. Injuries to internal organs were mapped to Category 3. Crushing injuries to the abdomen were mapped to Category 4.

		Upper Extremities	Traumatic amputations, arms	5		S48.0-S48.9 S58.0-S58.9 S68.0-S68.9 T05.0-T05.2 T05.6 T11.6	Traumatic amputation of shoulder and upper arm Traumatic amputation of forearm Traumatic amputation of wrist and hand Traumatic amputation multiples upper limb Traumatic amputation upper and lower limbs Traumatic amputation upper limb, level unspec	Note not all amputations are critical in severity eg S68.1 *Amputation of single finger* but all have been mapped here in line with injury descriptor
		Lower Extremities	Traumatic amputations, legs	5		S78.0-S78.9 S88.0-S88.9 S98.0-S98.4 T05.3-T05.5 T13.6	Traumatic amputation of hip and thigh Traumatic amputation lower leg Traumatic amputation of ankle and foot Traumatic amputation multiples lower limb Traumatic amputation lower limb, level unspec	Note not all amputations are critical in severity eg S98.1 *Amputation of one toe* but all have been mapped here in line with injury descriptor
		Other	Nerve injuries	5		S04.0-S04.9 T05.8-T05.9 T06.0-T06.1	Injury of cranial nerves Traumatic amputation multiple body regions Injuries brain, cranial nerves, spinal cord multiple body regions	
5	Dead	Asphyxiation, burns and smoke inhalation, intracranial injuries, traumatic complications		6		T59.8 T71	Smoke inhalation Asphyxiation	Suggest use mode of separation = death with injuries as PD (ie S or T code)

Source: Independent Hospital Pricing Authority (IHPA), Sydney, NSW.

IHPA also enable estimation of the unit costs of health care services in each earthquake injury category. IHPA produced patient count and associated cost related to earthquake related injuries using the 2016-17 National Hospital Cost Data Collection (NHCDC) data. This is presented in Table 5 below.

TABLE 5: PATIENT COUNT AND ASSOCIATED COST RELATED TO EARTHQUAKE RELATED INJURIES

Category	**Admitted Acute**		**Admitted Subacute**		**Emergency Department**	
	Number of patients	**NEP in-scope cost ($)**	**Number of patients**	**NEP in-scope cost ($)**	**Number of patients**	**NEP in-scope cost ($)**
Category 1: Head or face	26,860	40,266,400	224	2,834,000	64,240	35,824,800
Category 1: Abdomen	10,090	23,925,900	224	2,916,600	6,810	5,238,800
Category 1: Upper extremities	7,950	18,784,400	116	1,496,100	130,020	55,554,600
Category 1: Lower extremities	18,660	73,758,700	784	10,121,200	157,800	71,549,600
Category 2: Head or face	23,590	49,982,000	180	2,185,900	78,810	35,807,300
Category 2: Abdomen	2,630	10,002,100	24	340,100	5,990	3,631,900
Category 2: Upper extremities	29,633	87,700,000	218	2,840,000	122,100	55,794,600
Category 2: Lower extremities	17,490	80,394,100	352	4,635,500	61,550	29,553,900
Category 2: Other	12,560	49,550,000	97	1,544,800	36,770	20,415,300
Category 3: Head or face	18,270	82,335,000	251	3,917,300	23,840	16,625,300
Category 3: Abdomen	15,140	142,181,300	845	11,320,700	19,760	19,006,100
Category 3: Upper extremities	68,220	355,879,000	2,175	35,924,400	146,300	82,906,700

Category 3: Lower extremities	55,570	715,498,200	12,208	212,520,300	75,800	54,865,300
Category 3: Other	2,290	51,124,850	98	3,173,300	15,800	20,283,600
Category 4: Head or face	10,640	189,433,900	2,503	61,767,900	13,200	13,272,700
Category 4: Abdomen	1,110	33,512,700	364	24,946,300	1,640	1,424,200
Category 4: Upper extremities	2,800	17,231,200	4	39,935	1,920	1,262,500
Category 4: Lower extremities	161	2,814,600	33	298,300	188	130,700
Category 4: Other	96	685,400	1	2,900	178	124,700
Category 5: Asphyxiation, burns and smoke inhalation, intracranial injuries, traumatic complications	1,002	7,920,000	6	808,200	1,524	1,343,700

Source: Independent Hospital Pricing Authority, 2016-17 National Hospital Cost Data Collection (NHCDC) data was used.

Note: 1. The care type included in the Admitted Acute stream includes acute care, newborn with qualified days and mental health care. The care type included in the Admitted Subacute stream includes rehabilitation care, palliative care, geriatric evaluation and management, psychogeriatric care and maintenance care.

2. National Efficient Price (NEP) in-scope cost includes ward medical direct cost, ward medical overhead code, ward supplies direct cost, ward supplies overhead cost, ward nursing direct cost, ward nursing overhead cost, non-clinical salaries direct cost, non-clinical salaries overhead cost, pathology direct cost, pathology overhead cost, imaging direct cost, imaging overhead cost, allied health direct cost, allied health overhead cost, pharmacy direct cost, pharmacy overhead cost, critical care direct cost, critical care indirect cost, open room direct cost, open room overhead cost, emergency department

direct cost, emergency department overhead cost, supplies and ward direct cost, supplies and ward overhead cost, prostheses direct cost, prostheses overhead cost, on-cost direct cost, on-cost overhead cost, hotel direct cost and hotel overhead cost.

The impact modelling capability will simulate potential number of injuries at different earthquake injury severity levels that can be applied to unit costs of health care services for estimation of direct health care cost in the Melbourne city case study, while the methodology can be adopted for any other regions in Australia.

CASUALTY COST ESTIMATION FROM INJURY AND LOSS OF LIFE

Mohanty et al (2017) presents a modelling approach to estimate casualty cost to society from injury and loss of life. This report will present the methodological development so far in estimating the casualty costs from injury and loss of life. The first step in this process (for details see Mohanty et al 2017) involves mapping the earthquake related injury severity levels (presented in Table 3) to the recent version of ICD-10-AM classification. However, for obtaining more relevant country specific disease and injury classification for Australia, the ICD- 10-AM classification further needs to be mapped to Australian Burden of Disease Study (ABDS) nature of injury classification. This calls for rather specialized expertise in the area and experts from Australian Burden of Disease expert group at Australian Institute of Health and Welfare (AIHW) that routinely publishes the Australian Burden of Disease Study (AIHW, 2016) have helped in mapping earthquake related injury categories with ICD-10-AM and the ABDS injury classifications.

This mapping exercise presented in Table 6, aligns the five point earthquake injury classification to ICD-10-AM and ABDS injury classification. This will allow us to estimate the burden of earthquake related injuries as the Disability Adjusted Life Years (DALYs), Years of Life Lost (YLL) and/or Years of Life Disabled for non-fatal and fatal cases of injury based on Australian Burden of Disease Study (AIHW 2019) and ICD-10-AM injuries (for details see Mohanty et al, 2017). The DALY for injury causes by ABDS are presented in Table 7.

TABLE 6: EARTHQUAKE INJURY CATEGORIES MAPPED TO ABDS AND ICD10 CODE

Injury category	Body part injured	Type of Injuries	AIS	ABDS injury cause or sequela	ICD10 code
Uninjured/lightly injured	Head or Face	Bruising/contusions, minor cuts	2	Injury to eyes	S05, T15
Uninjured/lightly injured	Abdomen	Bruising, minor cuts	1	Superficial injuries	S00, S10, S20, S30, S40, S50, S60, S70, S80, S90, T00, T090, T110, T130, T140
Uninjured/lightly injured	Upper Extremities	Bruising, minor cuts, sprains	1	Open wound	S01, S08, S111–S119, S15, S21, S31, S399, S41, S51, S55, S61, S65, S71, S75, S81, S85, S91, S95, T01, T091, T111, T114, T131, T134, T141
Uninjured/lightly injured	Lower Extremities	Bruising, minor cuts, sprains	1	All other injuries	S09, S19, S298, S299, S45, S598, S599, S698, S699, S89, S99, T058, T059, T063, T068, T07, T096, T098, T099, T118, T119, T138, T139, T145, T148, T149, T16, T17, T18, T19, T33, T34, T35, T66, T67, T68, T69, T70, T71, T73, T74, T75 (excluding T75.1), T79, T80, T81, T88
				Soft tissue injuries	S130, S46, S832–S837,S860, S932, S934, S96,S134, S230, S233, S235, S290, S335–S337, S434-S437, S498-S499, S034, S035, S135–S136, S234, S390, S532–S534, S56, S633–S637, S66, S731, S76, S861–S869, S935–S936, T064, T095, T115, T135, T146,S16, S330, S334
Moderately injured	Head or Face	Cuts into soft tissues	2-3	Open wound	S01, S08, S111–S119, S15, S21, S31, S399, S41, S51, S55, S61, S65, S71, S75, S81, S85, S91, S95, T01, T091, T111, T114, T131, T134, T141
Moderately injured	Abdomen	Cuts into soft tissues	2-3	Split open wound by body part	
Moderately injured	Upper Extremities	Dislocation, Cuts into soft tissues	2-3	Dislocation - shoulder joint	S430–S433
				Dislocation - shoulder other	S530–S531

				Dislocations - other	S131–S133, S231–S232, S331–S333, S630, S631, S632, S930, S933, S930, S933, S030–S033, S931, T03, T092, T112, T132, T143
Moderately injured	Lower Extremities	Dislocation, Cuts into soft tissues	2-3	Dislocation - hip	S730
Moderately injured	Other	Dehydration/exposure; burns 1-2o; unconscious < 1hr	3	Dislocation - knee	S830, S831
Seriously	Head or Face	Open head or facial wounds, fractures, brain concussion	3-4	Skull fracture	S020, S021, S027, S029
				Traumatic brain injury including concussion	S06
				Fracture - face bone	S022–S026, S028
Seriously	Abdomen	Pneumothorax and rib fractures, crushing > 3hrs, puncture organs	1-4	Fracture - pelvis	S321, S323–S328, T021
				Fracture - pelvis (coccyx)	S322
				Fracture - radius or ulna	S52, S597, T10
				Fracture - sternum / ribs	S222, S223
				Fracture - vertebral column	S12, S220–S221, S320, T08
Seriously	Upper Extremities	Fractures – open, displaced or comminuted (pulverised)	3	Fracture - humerus	S422, S423, S424, S427
				Fracture - patella	S820
				Fracture - clavicle or scapula	S228, S229, S420, S421, S428, S429, S497
				Fracture - hand bone	S620–S624, S625–S627, S628, S697
Seriously	Lower Extremities	Fractures – open, displaced or comminuted (pulverised)	3	Fracture - foot bone	S92

				Fracture - neck of femur	S720, S721, S722
				Fracture - other than neck of femur	S723–S729, S79
				Fracture - tibia or fibula	S821, S822, S823, S827, S824, S828, S829
				Fracture - ankle	S825, S826
				Fracture - other	T020, T022–T029, T12, T142
Seriously	Other	Uncontrolled bleeding; burns 2-3o (% of body?); unconscious > 1 hr	3-5	%TBSA can be expanded from the Burns ICD codes	
Critical	Head or Face	Internal head trauma, severe crushing, brain damage	5	Crush injury	S07, S17, S18, S47, S380, S57, S67, S77, S87, S97, T04, T147, S382, S383
Critical	Abdomen	Spinal column injuries, internal organ failures due to crushing	5	Spinal cord injury	S240, S241, S247, S340, S341, S347, T061, T093
				Spinal cord injury	S140, S147, T060 S1410, S141
				Internal and crush injury (abdominal /pelvic injuries)	S35–S37, S381, S396, S397, S398, T065
				Internal and crush injury (chest injury)	S110, S224, S225, S25, S26, S27, S28, S297
Critical	Upper Extremities	Traumatic amputations, arms	5	Amputation of finger/s excl thumb	S681, S682
				Amputation of thumb	S680
				Amputation of both arms	T050–T052
				Amputation of one arm	S48, S58, S683, S684, S688, S689, T116
Critical	Lower Extremities	Traumatic amputations, legs	5	Amputation of toe	S981, S982
				Amputation of one leg	S78, S88, S980, S983, S984, T136, T056
				Amputation of both legs	T053–T055
Critical	Other	Nerve injuries	5	Injured nerves	S04, S142–S146, S242–S246, S342–S346, S348, S44, S54, S64, S74, S84, S94, T062, T113, T133, T144, T094

Dead	Asphyxiation, burns and smoke inhalation, intracranial injuries, traumatic complications		6	Burn	T20-T31
				All injury deaths	

Note: The classification format of ICD codes is CNN.[NN]. That is, a decimal point separates the first 3 code characters from the remaining optional codes. The decimal point is not shown here. An example is S430–S433 shown above is actually S43.0-S43.3.

Used in ABDS injury classification, but not allocated above

Poisoning

Drowning and Submersion injuries

Source: Australian Burden of Disease Study, AIHW (2019)

TABLE 7: DALY (NUMBER AND RATES), INJURY CAUSES, BY AGE GROUPS AND SEX, 2011

	Males										**Females**								
Injury cause	**0–4**	**5–14**	**15–24**	**25–34**	**35–44**	**45–54**	**55–64**	**65+**	**Total (all ages)**		**0–4**	**5–14**	**15–24**	**25–34**	**35–44**	**45–54**	**55–64**	**65+**	**Total (all ages)**
	DALY (number)										**DALY (number)**								
Traumatic brain injury	396.2	1,093.2	4,385.3	6,773.9	8,340.3	9,467.0	8,793.1	12,338.9	51,587.8		394.5	684.7	1,563.7	1,676.2	2,217.1	2,821.1	2,808.1	8,437.1	20,602.5
Spinal cord injury	4.6	41.5	349.4	665.4	956.8	1,289.6	1,256.4	1,291.4	5,855.0		1.2	24.5	103.3	162.6	221.0	332.6	308.8	423.1	1,577.2
Internal and crush injury	215.0	93.0	1,447.9	1,195.2	1,088.4	751.1	553.3	661.9	6,005.9		89.8	8.2	360.6	220.5	192.8	205.6	125.4	447.0	1,650.1
Poisoning	5.1	320.2	5,902.8	17,686.2	15,266.7	11,159.9	4,371.1	2,268.2	56,980.3		4.3	161.1	2,117.5	5,323.0	6,186.6	5,973.6	3,210.5	2,006.3	24,982.9
Drowning and	1,610.0	983.6	2,094.4	2,143.5	1,479.8	1,479.1	1,105.7	862.8	11,758.9		622.3	330.6	418.2	675.4	517.5	479.7	532.5	372.3	3,948.6

submersion injuries																			
Hip fracture	9.6	22.3	99.9	30.5	37.5	131.5	136.5	2,415.0	2,882.7		7.6	10.4	15.9	14.0	18.0	30.3	62.9	3,935.6	4,094.7
Tibia and ankle fracture	13.8	57.2	58.6	31.7	32.5	20.7	18.0	14.7	247.2		7.8	18.6	14.1	17.3	21.4	32.2	33.2	29.0	173.6
Humerus fracture	9.5	20.2	6.3	3.3	3.2	5.1	5.2	7.5	60.2		10.3	19.8	2.3	1.5	2.5	4.6	9.7	30.9	81.5
Other fractures	39.9	242.9	697.0	967.2	974.4	1,066.1	879.2	1,962.5	6,829.2		31.1	140.2	242.0	329.1	266.2	338.6	326.7	1,859.1	3,533.1
Dislocations	4.5	8.5	42.6	22.2	12.7	6.3	4.3	3.2	104.3		3.5	20.9	15.7	6.6	4.1	2.7	2.6	5.9	62.0
Soft tissue injuries	2.7	21.9	67.6	35.3	24.1	16.7	10.1	3.9	182.3		2.6	17.5	19.1	13.1	14.1	10.0	6.0	3.7	86.2
Burn injuries	318.2	234.8	801.5	1,001.5	982.5	1,328.7	917.4	923.1	6,507.6		114.0	503.9	314.6	398.1	442.0	420.7	390.9	471.9	3,056.1
Other injuries	2,859.1	2,962.0	30,550.7	29,225.0	25,935.4	18,778.2	12,077.9	11,838.4	134,226.6		3,002.6	2,132.2	11,589.3	7,271.6	7,774.0	5,077.7	3,526.6	7,003.7	47,377.8
	DALY (crude rates per 1,000)								**ASR (per 1,000)**		**DALY (crude rates per 1,000)**								**ASR (per 1,000)**
Traumatic brain injury	0.5	0.8	2.8	4.2	5.3	6.3	6.9	8.7	4.6		0.6	0.5	1.0	1.1	1.4	1.8	2.2	5.1	1.7
Spinal cord injury	0.0	0.0	0.2	0.4	0.6	0.9	1.0	0.9	0.5		0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.1
Internal and crush injury	0.3	0.1	0.9	0.7	0.7	0.5	0.4	0.5	0.5		0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.3	0.1
Poisoning	0.0	0.2	3.8	11.0	9.7	7.4	3.4	1.6	5.2		0.0	0.1	1.4	3.4	3.9	3.9	2.5	1.2	2.2
Drowning and submersion injuries	2.2	0.7	1.3	1.3	0.9	1.0	0.9	0.6	1.1		0.9	0.2	0.3	0.4	0.3	0.3	0.4	0.2	0.4
Hip fracture	0.0	0.0	0.1	0.0	0.0	0.1	0.1	1.7	0.3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.3

Tibia and ankle fracture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Humerus fracture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other fractures	0.1	0.2	0.4	0.6	0.6	0.7	0.7	1.4	0.6		0.0	0.1	0.2	0.2	0.2	0.2	0.3	1.1	0.3
Dislocatio ns	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soft tissue injuries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Burn injuries	0.4	0.2	0.5	0.6	0.6	0.9	0.7	0.7	0.6		0.2	0.4	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Other injuries	3.8	2.1	19.5	18.1	16.5	12.5	9.5	8.3	12.0		4.2	1.6	7.8	4.6	4.9	3.3	2.7	4.2	4.2

Note: ASR (per 1,000) = age-standardised rate, they were age-standardised to the 2001 Australian Standard Population and are expressed per 1,000 persons. Source: Australian Burden of Disease Study, AIHW (2019)

SUMMARY

This report presents the methodological developments for the modelling approach developed in Mohanty et al (2017) for some components of the economic costs such as the business income loss, direct health care and casualty cost. These are put in the context of an updated economic framework that encompasses the metrics applicable to a range of decision makers. Significantly it also included the intangible values place on a range of avoided impacts that can form part of a more holistic risk assessment. Finally, the report describes the work completed in developing cost models for retrofit and damage repair to enable the benefit versus cost of building retrofit to be assessed.

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APPENDIX A: QUANTITY SURVEYOR SCOPE FOR DIRECT DAMAGE AND MITIGATION COSTS

BNHCRC Earthquake Mitigation of WA Regional Towns

Provision of Cost Estimates for Retrofit and Repair of Unreinforced Masonry Buildings

Quantity Surveyor Scope of Work

Background

The Shire of York (WA) is partnering with the WA Department of Fire and Emergency Services (DFES), the University of Adelaide and Geoscience Australia in a collaborative project that will examine the opportunities for reducing the vulnerability of the township of York to a major earthquake. The project forms part of the Bushfire and Natural Hazards Collaborative Research Centre project "Cost-effective Mitigation Strategy Development for Building related Earthquake Risk".

Western Australia's oldest inland town is located in one of Australia's most active earthquake regions and has a number of valuable historical unreinforced masonry buildings that are vulnerable to damage in a large earthquake. This project will examine practical approaches for retrofitting six generic types of older buildings in York. It will use technology to virtually apply various retrofits to York historical buildings to understand what modifications are most effective to reducing the damage from a large earthquake.

As part of the assessment of the benefit of retrofit, it is necessary to assess the cost of installation of retrofit and also the cost of repair of earthquake damaged buildings with and with-out the installation of retrofit measures. Following the 2010 Kalgoorlie earthquake, Turner and Townsend developed cost estimates for replacement and repair of earthquake damaged unreinforced masonry (URM) buildings (Turner and Townsend, 2012). This contract seeks to extend this work to cover the installation of retrofit works, the repair of building components from specific damage states and revisit the cost of building services.

The project will assess the repair cost of an earthquake damaged building by assessing the repair cost of each component of the building. The damage state of a particular component in a particular building is established by numerical modelling. In this project the term 'component' refers to a large element of a building such as a chimney, parapet, gable wall or the building 'box'. The building 'box' comprises walls, floors and roof but excludes those vulnerable above-eaves level elements such as chimneys, parapets, etc.

Objectives

To obtain costs for:

1. Installation of retrofit works to unreinforced masonry buildings
2. The replacement value for building services in six building types typical of country town main streets.
3. The repair of particular building components of unreinforced masonry buildings damaged by earthquake.

Cost estimates shall assume the buildings are located in Perth and be in 2019 dollars. The estimates shall assume builders are repairing a single building.

Scope

The contract's scope is divided into three sections.

1. Installation of retrofit works

Retrofit works are works undertaken to existing buildings to enhance their resilience to earthquake. For each of the retrofit types detailed in Attachment A and for each of the nominal extents of work specified in Attachment A provide a cost estimate to install the retrofit work.

2. Replacement cost for building services

The installed building services can comprise a significant portion of a building's replacement cost. Older buildings in rural towns may be less heavily serviced than more modern capital city buildings. Previously, cost estimates for building services (cost per square meter depending on building usage) were provided in Turner and Townsend, 2012. The project team wishes to confirm the currency of the 2012 estimates for the six generic building types of interest listed in Table

1. Further details are provided in Attachment B and geometrical details of the six generic building types are provided in Attachment C in the form of sketch plans.

For each generic building type, provide a cost estimate ($/m2) for replacement of electrical, hydraulic, mechanical and fire protection services.

TABLE 1 GENERIC BUILDING TYPES

Type	Description	Usage	Example photo
1	Single storey URM	Residential	
2	Two storey URM with bedrooms and bathrooms on the upper storey, kitchen, bar, dining room and bathrooms	Pub	

Type	Description	Usage	Example photo
	on ground floor		
3	Single storey URM split into 5 tenancies	Commercial	
4	Two storey URM with apartments on the upper floor and two commercial tenancies on ground floor	Commercial	
5	Two storey institutional URM with apartment on upper floor	Post Office	
6	Two storey URM with small rooms	Bank	

3. Repair from earthquake damage

3.1 Component repair

The project team requires cost estimates to repair various components of URM buildings from different levels of earthquake damage (called damage states).

For each component type and for each damage state listed in Attachment D review the repair strategy and provide a cost estimate to undertake the nominated repair work. The components to be considered are: chimneys, parapets, gable walls and the building 'box' (i.e. all the building excepting chimneys, parapets and gable walls) for the six generic building types. The cost estimate for repair work shall exclude external scaffolding to eaves level for access and builder's preliminaries as these are covered separately at item 3.2.

3.2 Project overheads

It is proposed that Builder's Preliminaries and costs associated with general access to the building such as scaffolding external walls are provided separately as the required quantity will depend on the number of components requiring repair for an individual building.

- Provide a percentage rate, or range of rates, for builder's Preliminaries
- Provide cost estimates to install and remove the access options set out in Table 2.

TABLE 2 ACCESS OPTIONS

Item	Description	Indicative quantity
1	External scaffolding to access eaves level, 4m above ground, of a single storey building	One wall, 14m total length
2	External scaffolding to access eaves level, 4m above ground, of a single storey building	Two walls, 41m total length
3	External scaffolding to access eaves level, 4m above ground, of a single storey building	Three walls, 66m total length
4	External scaffolding to access eaves level, 4m above ground, of a single storey building	Four walls, 82m total length
5	External scaffolding to access eaves level, 8m above ground, of a two storey building	One wall, 14m total length
6	External scaffolding to access eaves level, 8m above ground, of a two storey building	Two walls, 36m total length
7	External scaffolding to access eaves level, 8m above ground, of a two storey building	Three walls, 60m total length
8	External scaffolding to access eaves level, 8m above ground, of a two storey building	Four walls, 80m total length
9	Internal scaffolding to access 3.7m high ceiling	22 m2
10	Internal scaffolding to access 4.0m high ceiling	35 m2

11	External scaffolding to access roof level from ground level of a single storey building, 4m above ground level. Scaffold approx. 1.8 x 3.6m in plan.	1 location
12	External scaffolding to access roof level from ground level of a two storey building, 8m above ground level. Scaffold approx. 1.8 x 3.6m in plan.	1 location

Reporting

Prepare a report in pdf format that includes:

- a summary of the cost estimating activities undertaken,
- references of sources of cost information,
- exclusions,
- cost estimates for the installation of each nominated type and extent of retrofit work,
- cost estimates ($/m2 of floor area) for each of the four types of building services for each of six generic building types,
- summary tables of repair costs for each component from each damage state,
- cost estimates for the installation and removal of each type and extent of access,
- estimates of rates for builder's preliminaries.

Prepare an Excel file or similar containing all the repair quantities, rates and sums for the repair of each component from each damage state.

Reference

Earthquake Damage Cost Module Development, Turner and Townsend, June 2012