COST-EFFECTIVE MITIGATION STRATEGY DEVELOPMENT FOR FLOOD PRONE BUILDINGS

Annual Project Report 2016-2017

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Cover: Flood mitigation strategy: elevating floor level (Geoscience Australia)

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EXECUTIVE SUMMARY

The motivation for this project arises from the experience and observations made during the 2011 and 2013 floods in Australia, which caused widespread devastation in Queensland. The flood events also resulted in significant logistics for emergency management and disruption to communities. Considerable costs were sustained by all levels of government and property owners to effect damage repair and enable community recovery.

A fundamental reason for this damage was inappropriate development in floodplains and a legacy of high risk building stock in flood prone areas. The vulnerability and associated flood risk is being reduced for newer construction by adopting new standards (ABCB, 2012), building controls and land use planning, however, the vulnerability associated with existing building stock remains. The vulnerability of existing building stock contributes disproportionally to overall flood risk in many Australian catchments.

The Bushfire and Natural Hazards Collaborative Research Centre (BNHCRC) project entitled "Cost-effective mitigation strategy development for flood prone buildings" aims to address this issue and is targeted at assessing mitigation strategies to reduce the vulnerability of existing residential building stock in Australian floodplains. The project addresses the need for an evidence base to inform decision making on the mitigation of the flood risk posed by the most vulnerable Australian houses and complements parallel BNHCRC projects for earthquake and severe wind.

To date, the project within the BNHCRC has developed a building classification schema to categorise Australian residential buildings into a range of typical storey types. Mitigation strategies developed nationally and internationally have been reviewed. Five typical storey types have been selected which represent the most common residential buildings in Australia. A floodproofing matrix has been developed to assess appropriate strategies for the selected storey types. All appropriate strategies have been costed for the selected storey types through the engagement of quantity surveying specialists.

Furthermore, selected building materials/systems have been tested to ascertain their resilience to floodwater exposure. These tests were aimed at addressing knowledge gaps in the areas of strength and durability of building materials during immersion. The results of the tests showed that flooding did not have any significant effect on the pull-out strength of the bond of the ceramic floor and wall tiles to their substrate, nor on the racking strength of the OSB and HDF wall sheet bracing. However, there was a significant reduction (~45%) in load carrying capacity of the timber joists when tested in the wet condition.

In the following years of the project vulnerability of predominant storey types will be assessed. The information on vulnerability is fundamental to evaluate mitigation strategies and to examine the opportunities for reducing the vulnerability. The research will include cost benefit analysis to find optimal mitigation strategies for selected storey types located within a range of catchment types.

This project is investigating methods for upgrading existing housing stock in floodplains to increase their resilience in future flood events. The project will provide an evidence base to inform decision making by governments and property owners to reduce flood risk. The risk mitigation achieved will decrease human suffering, improve safety and ensure amenity for communities.

END USER STATEMENT

Leesa Carson, Geoscience Australia, *ACT*

Floods cause widespread devastation, disruption and cost to communities. A key contributing factor to flood risk is the presence of buildings within flood prone areas.

This project is developing an important evidence base to assist governments and householders make informed decisions on retrofit options for existing houses to reducing the vulnerability of these buildings to flooding.

The project has achieved its scheduled tasks including the development of an initial Australian specific building classification schema and a literature review of existing mitigation strategies. A flood mitigation matrix has been developed to identify appropriate mitigation strategies. These strategies have been costed for selected building types and will provide a method to assist investment decisions. Finally, based on identified knowledge gaps in material susceptibility to floodwater, a significant experimental program has been undertaken that has provided insights into material susceptibility.

The project team is actively engaging in relevant conferences, workshops and forums to communicate the research of the project and engage with key end-users and experts. The visit by the lead researcher to Italy and Germany early in the year has been very valuable in showcasing the CRC research and seeking feedback from three separate European research groups. Further, the project team has successfully engaged with two major insurers that has informed the experimental program and its outcomes. Finally, the team has developed with the National Flood Risk Advisory Group a project utilisation project that will translate and augment the research outcomes for use by the floodplain management community.

INTRODUCTION

Globally, floods cause widespread damage with loss of life and property. An analysis of global statistics conducted by Jonkman (2005) showed that floods (including coastal flooding) caused 175,000 fatalities and affected more than 2.2 billion people between 1975 and 2002. In Australia floods cause more damage on an average annual cost basis than any other natural hazard (HNFMSC, 2006). The fundamental cause of this level of damage and the key factor contributing to flood risk, in general, is the presence of vulnerable buildings constructed within floodplains due to ineffective land use planning.

Retrospective analysis show large benefits from disaster risk reduction (DRR) in the contexts of many developed and developing countries. A study conducted by the U.S. Federal Emergency Management Agency (FEMA) found an overall benefit-cost ratio of four suggesting that DRR can be highly effective in future loss reduction (MMC, 2005). However, in spite of potentially high returns, there is limited research in Australia on assessing benefits of different mitigation strategies with consequential reduced investment made in loss reduction measures by individuals and governments. This is true not only at an individual level but also at national and international levels. According to an estimate, international donor agencies allocate 98% of their disaster management funds for relief and reconstruction activities and just 2% is allocated to reduce future losses (Mechler, 2011).

The Bushfire and Natural Hazards Collaborative Research Centre project entitled 'Cost-effective mitigation strategy development for flood prone buildings' (BNHCRC, 2017) is examining the opportunities for reducing the vulnerability of Australian residential buildings to riverine floods. It addresses the need for an evidence base to inform decision making on the mitigation of the flood risk posed by the most vulnerable Australian building types and complements parallel BNHCRC projects for earthquake and severe wind.

This project investigates methods for the upgrading of the existing residential building stock in floodplains to increase their resilience in future flood events. It aims to identify economically optimum upgrading solutions so the finite resources available can be best used to minimise losses, decrease human suffering, improve safety and ensure amenity for communities.

PROJECT BACKGROUND

Recent events in Australia (2011 and 2013) highlight the vulnerability of housing to flooding which originates from inappropriate development in floodplains. While there is now a construction standard published by the Australian Building Code Board (ABCB, 2012) for new construction in some flood prone areas, a large proportion of the existing building stock has been built in flood prone areas across Australia (HNFMSC, 2006). The Australian Government has developed a National Strategy for Disaster resilience which defines the roles of government and individuals in improving disaster resilience (NSDR, 2011). The strategy also emphases the responsibility of governments, businesses and households in assessing risk and taking action to reduce the risk by implementing mitigation plans (Productivity Commission, 2014).

An in-depth understanding of the effects of floods is required for the assessment of risk and the development of mitigation strategies, particularly in the context of limited financial resources. In this respect, reliable information about the costs and benefits of mitigation are crucial to inform decision-making and the development of policies, strategies and measures to prevent or reduce the impact of flood.

The objective of this project is to provide an evidence base for two target groups to inform their decision making process around mitigation against flood risk: government and property owners. Federal, State/Territory and local governments have an interest in the losses arising from past or future flood events and require vulnerability information to support several objectives including decision making concerning the allocation of funding and risk management. Property owners are also interested in vulnerability and mitigation assessment to know the potential risk to their properties due to floods and to make decisions on undertaking mitigation measures to reduce risk and (possibly) their insurance premiums (Meyer et al. 2012).

Therefore, this project aims to provide an evidence base to inform decision making on the mitigation of flood risk by providing information on the cost-effectiveness of a range of mitigation strategies involving alterations to existing residential buildings.

WHAT THE PROJECT HAS BEEN UP TO

The first four tasks have been completed by the end of June 2017 in line with the project schedule. A summary of the project activities is provided below:

BUILDING CLASSIFICATION SCHEMA

Within Australian communities there is a wide range of building types. These vary in many attributes that include floor area, number of storeys, age, architectural style, fit-out quality, construction material types and the level of maintenance. For mitigation research it is necessary to take this range of building types and geometrics and discretise it into building classes or categories of similar, if not identical, vulnerability.

In this project a literature review was conducted which reviewed building schemas developed nationally and internationally for a range of uses within different projects. The reviewed schemas were from HAZUS, USA (FEMA, 2007), UNGAR, Global (Maqsood et al. 2014a), Earthquake damage Analysis Center, Germany (Schwarz and Maiwald, 2008), GMMA RAP, Philippines (Pacheco et al. 2013), RiskScape, New Zealand (NIWA, 2010) and Geoscience Australia, Australia (Wehner et al. 2012).

Following the literature review a new schema was proposed which was a fundamental shift from describing the complete building as an entity to one that focuses on sub-components. The proposed schema divided each building into the sub-elements of foundations, bottom floor, upper floors (if any) and roof to describe its vulnerability (see Figure 1).

Through this approach it was made possible to assess the vulnerability of structures with different usage and/or construction material used in different floors, and also to assess the vulnerability of tall structures with basements where only basements and/or bottom floors are expected to be inundated (Maqsood et al. 2015a). The schema classified each storey type based on six attributes: construction period, fit-out quality, storey height, bottom floor, internal wall material and external wall material.

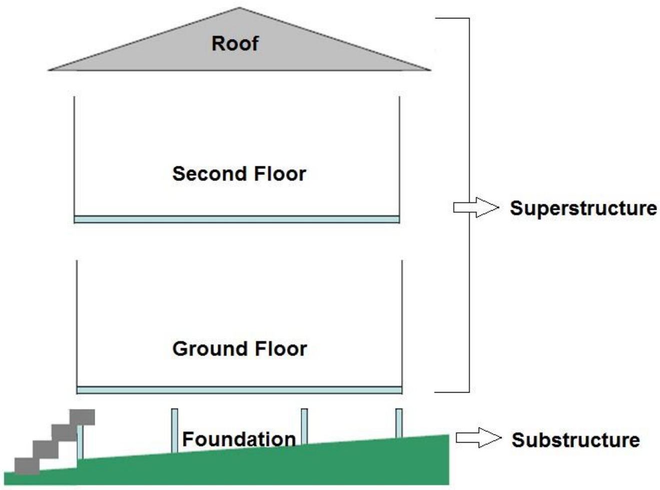


FIGURE 1: SCHEMATIC DIAGRAMS OF EACH TEST TYPE (MAQSOOD ET AL., 2015A)

LITERATURE REVIEW OF FLOOD MITIGATION STRATEGIES

The succeeding task completed in this project was the literature review of mitigation strategies developed nationally and internationally. The review helped to evaluate the strategies that suit Australian building types and typical catchment behaviours for adoption in Australia. The review considered literature available through peer-reviewed journals, international conferences and research reports.

Strategies in the international literature have been developed for different types of floods and the adoption of a particular strategy depends upon the characteristics of flood hazard and building stock along with any mitigation incentives and associated cost benefit analysis. The review discussed the commonly used strategies and summarised the advantages and disadvantages of each of them. The review categorised mitigation strategies into five categories: elevation, relocation, dry floodproofing, wet floodproofing and flood barriers (Maqsood et al. 2015b).

Elevation is traditionally considered to be an easier and effective strategy and is the one which generally results in incentives such as a reduction in insurance premiums (Bartzis, 2013). However it is difficult to implement for some construction types such as concrete slab-on-grade structures. Relocation is the surest way to eliminate flood risk by relocating outside the floodplain but, as in the case of elevation, it becomes more difficult to implement for heavier and larger structures. Dry floodproofing and flood barriers are efficient only in shallow low velocity hazard areas and are generally not practical in deep fast flowing waters. Wet floodproofing is suitable in low to moderate depths of water with inundation duration not exceeding a day.

Figure 2 presents examples of elevating ground floor and flood barriers to keep water away from the property.

(A) ELEVATING GROUND FLOOR (B) USING FLOOD BARRIERS

FIGURE 2: EXAMPLES OF MITIGATION STRATEGIES (MAQSOOD ET AL., 2015B)

DEVELOPMENT OF COSTING MODULES FOR SELECTED MITIGATION OPTIONS

A list of building materials typically used in Australian residential construction was developed. This list helped to identity predominant construction materials and storey types in Australia and also informed the development of costing modules. Five typical residential storey types were selected for the balance of the research which was a subset of the schema proposed earlier in this report. Key characteristics of these storey types are presented in Table 1.

TABLE 1: CHARACTERISTICS OF SELECTED STOREY TYPES

Storey Type	Construction period	Bottom floor system	Fit-out quality	Storey height	Internal wall material	External wall material	Photo
1	Pre-1960	Raised Timber	Low	2.7m	Timber	Weather-board	
2	Pre-1960	Raised Timber	Low	3.0m	Masonry	Cavity masonry	
3	Pre-1960	Raised Timber	Low	2.4m	Masonry	Cavity masonry	
4	Post-1960	Raised Timber	Standard	2.4m	Plasterboard	Brick veneer	
5	Post-1960	Slab-on-grade	Standard	2.4m	Plasterboard	Brick veneer	

Further, based on the characteristics of the selected storey types a floodproofing matrix was developed which excluded the mitigation options that were invalid in the Australian context (see Table 2).

TABLE 2: FLOODPROOFING MATRIX

Building Type	Elevation (Building a whole house)	Elevation (Raising the storey)	Elevation	Relocation	Flood Barriers (Permanent)	Flood Barriers (Temporary)	the walls) (Extending second	
1	N/A					N/A	N/A	N/A
2	N/A	N/A		N/A	N/A			
3		N/A	N/A		N/A	N/A	N/A	N/A
4	N/A	N/A		N/A		N/A	N/A	N/A
5	N/A							

Costing modules (see Table 3) were developed by quantity surveying specialists to estimate the cost of implementing all appropriate mitigation strategies for these five storey types (Maqsood et al., 2016a). These costing modules will be utilised to assess the vulnerability of selected storey types after mitigation in the next phase of the project. Furthermore, these costing modules will be a crucial input in the Cost Benefit Analysis (CBA) to identify optimum mitigation strategies in selected catchment types.

TABLE 3: COST OF IMPLEMENTING FLOOD MITIGATION STRATEGISES TO EXISTING BUILDINGS FOR SELECTED STOREY TYPES (MAQSOOD ET AL., 2016A)

Storey Type	Elevation-Extending the walls ($)	Elevation-Building a second storey ($)	Elevation-Raising the whole house ($)	Relocation ($)	Flood Barriers (Permanent) ($)		Flood Barriers (Temporary) ($)			Dry Flood-proofing ($)	Wet Flood-proofing ($)	
					1.0m high	1.8m high	0.9m high	1.2m high	1.8m high		Existing structure	Substantial Renovation
1	N/A	N/A	78,200		N/A	N/A	N/A	N/A	N/A	N/A	11,700	68,000
2	N/A	213,500	N/A	N/A	133,500	177,600	62,500	111,800	136,300	N/A	15,400	56,600
3	397,700	429,700	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	17,400	104,300
4	N/A	405,200	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	15,500	140,000
5	N/A	431,000	N/A	N/A	154,300	208,300	164,600	144,100	176,200	$154,320	17,400	149,800

EXPERIMENTAL TESTING OF SELECTED BUILDING MATERIALS

In this project the strength and durability implications of immersion of key structural elements and building components in conditions of slow water rise were examined to ascertain where deterioration due to wetting and subsequent drying needed to be addressed as part of repair strategies (Maqsood et al., 2017a).

This research included experimental testing of selected materials/systems to address key gaps in knowledge on resilience to floodwater exposure. The Cyclone Testing Station at James Cook University (JCU) was selected to conduct the experiments on selected building materials and structural systems to assess degradation in simulated flood events. Meetings were held at JCU in June 2016 to scope the research program and to inspect the testing facilities available for this work.

Furthermore, the experimental programme was developed in consultation with the insurance industry loss assessors and was scoped in recognition of the available budget. Two separate workshops were organised in Sydney on 13th July 2016 with the Insurance Australia Group (IAG) and the Suncorp Group. The workshops were aimed at seeking feedback from the insurance industry on proposed experimental programme. The feedback addressed the appropriateness of the testing regime, identified gaps in material testing research and prioritised the tests to be included in the experimental programme to fill the gaps. Based on the feedback, for three test types were selected. A number of samples were prepared for each test type at JCU and tested to attempt to provide some understanding of the variation of resistance.

The scope of the tests included:

- Construction of samples for three selected test types,
- Testing the samples for strength evaluation in a dry state,
- Immersing the samples in silt or clay-laden water for a specified period of time,
- Testing some samples immediately after immersion,
- Drying the samples using natural ventilation and/or forced ventilation but not heating, and
- Testing the samples following drying.

Furthermore, a technical specialist (loss assessor) from the Insurance Australia Group (IAG) was requested to inspect the specimens visually and to assess the repair work the samples might require if they were part of a full size house. The technical specialists submitted a report on the observations made during the tests.

Each of the test specimen types is described below along with the key results obtained.

Test Type 1 (6 specimens):

Tiled surfaces within a typical brick veneer, slab-on-ground house (see Figure 3A). This test examined the bond strength of floor and wall tiles following inundation with the objective of determining the necessity or otherwise of removing and replacing all tiles following inundation (see Figure 4A).

Six specimens were constructed. Three of them replicated a bathroom assembly while the other three replicated a shower assembly. Results indicated that flooding did not have any adverse impact on the bond strength of floor and wall tiles as shown in Table 4.

TABLE 4: RESULTS OF STATIC PULL-OUT STRENGTH TESTING

Test					Wall Tile Failure Load (kN)
A1	Bathroom	No	Control Specimens	9.27	2.82
A2	Bathroom	Yes	Tested after drying	12.44	3.66
A3	Bathroom	Yes	Tested after drying	11.69	3.64
B1	Shower	No	Control Specimens	8.92	3.57
B2	Shower	Yes	Tested after drying	8.96	3.15
B3	Shower	Yes	Tested after drying	9.72	3.70

Test Type 2 (20 specimens):

Manufactured timber sheet wall bracing (see Figure 3B). This test examined the strength of engineered timber structural sheet wall bracing. This test was designed to test the structural adequacy of structural wall sheet bracing following inundation and subsequent drying (see Figure 4B). Two types of wall sheet bracing were tested for racking strength i.e. Oriental Strand Board (OSB) and High-density fiberboard (HDF).

Ten specimens were constructed for each bracing material. Five of them were tested in a dry condition without being flooded and the other five were tested after a wetting and drying cycle. Results indicated that flooding did not have any adverse impact on the racking strength of both types of bracing shown in Table 5.

TABLE 5: RESULTS OF RACKING STRENGTH TESTS

Test	Sheet	Flooded	Comment	Failure Load (kN)
A1 - A5	OSB	Yes	Tested after drying	5.47
A6 - A10	OSB	No	Control specimen	5.35
B1 - B5	HDF	Yes	Tested after drying	5.60
B6 - B10	HDF	No	Control specimen	6.23

Test Type 3 (48 specimens):

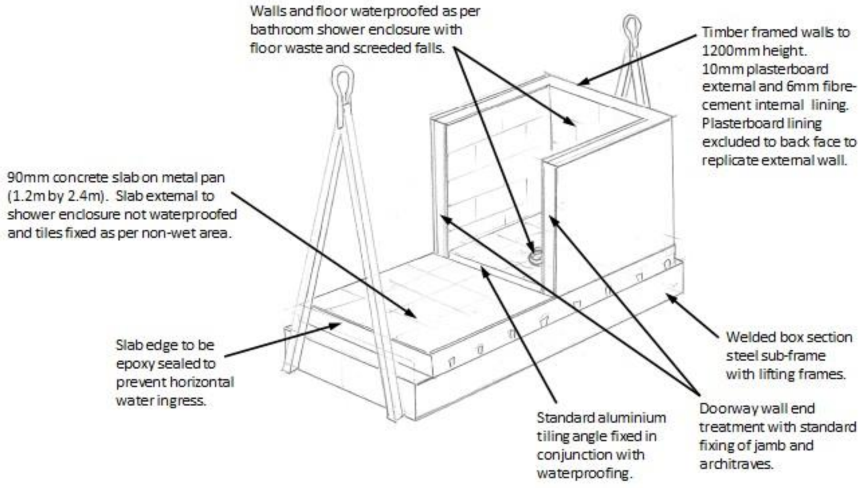
Engineered timber joists. This test examined the bending and shear strength of manufactured timbered joists (see Figure 3C). This test was designed to test the structural adequacy of manufactured timber I section joists following inundation and subsequent drying (see Figure 4C). Two types of joist were tested (H2 treated and untreated). Strength was tested at three stages: dry before immersion, wet immediately after immersion and dry after drying following immersion.

Results indicated that flooding did not have any adverse impact on the bending and shear strength of both types of bracing when tested in dried condition as shown in Table 6.

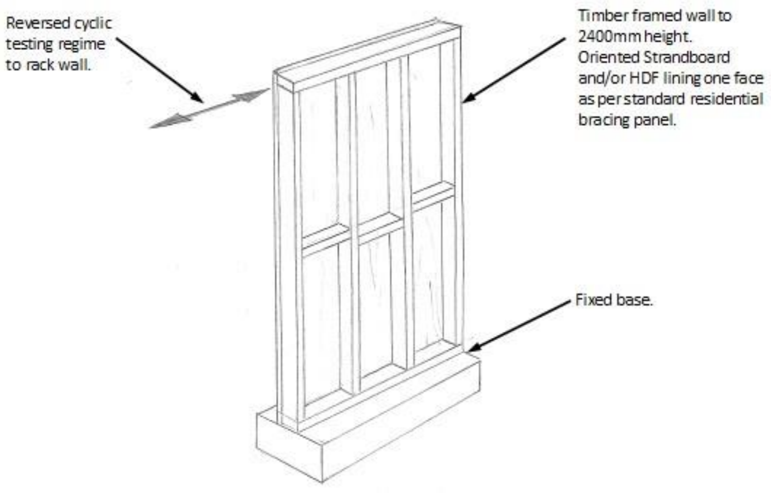
However, there was a significant reduction (~45%) in load carrying capacity of the timber joists when tested in the wet condition. Moreover, it was observed that the moisture content level after the test returned close to pre-inundation level within a week.

TABLE 6: FOUR POINT BENDING STRENGTH TESTING RESULTS

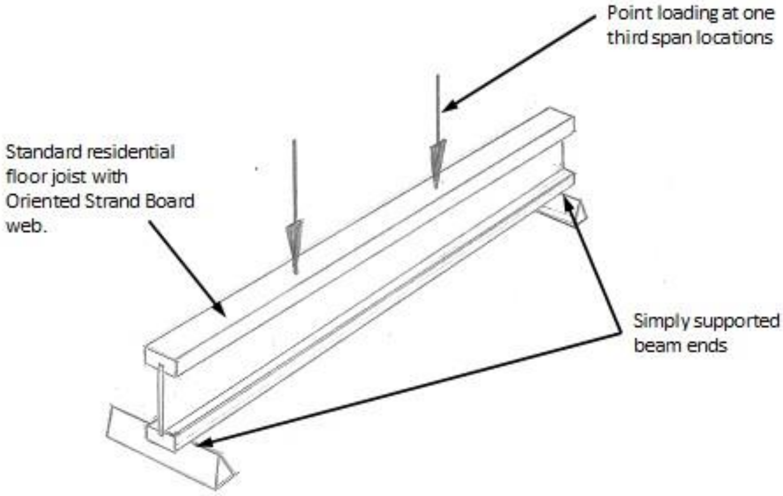
Test	Treated	Flooded	Comment	Failure Load (kN)
A1 –A8	H2	YES	Tested after drying	16.53
A9 –A16	H2	NO	Control Specimens	17.21
A17 –A24	H2	YES	Tested wet	9.23
B1 –B8	NIL	YES	Tested after drying	16.21
B9 –B16	NIL	NO	Control Specimens	18.64
B17 –B24	NIL	YES	Tested wet	9.30



(A) TILED SURFACES WITHIN A TYPICAL BRICK VENEER, SLAB-ON-GROUND HOUSE



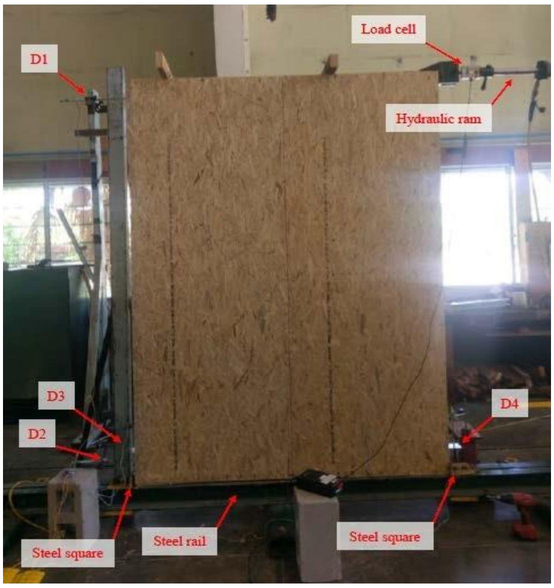
(B) MANUFACTURED SHEET WALL BRACING



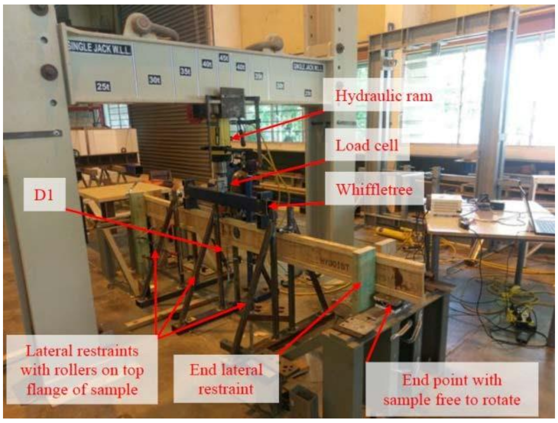
(C) ENGINEERED TIMBER JOISTS

FIGURE 3: SCHEMATIC DIAGRAMS OF EACH TEST TYPE

(A) TILED SURFACES WITHIN A TYPICAL BRICK VENEER, SLAB-ON-GROUND HOUSE



(B) MANUFACTURED SHEET WALL BRACING



(C) ENGINEERED TIMBER JOISTS

FIGURE 4: TESTING ARRANGEMENTS

NEXT STEPS

The tasks for the balance of the project are summarised below:

VULNERABILITY ASSESSMENT FOR CURRENT AND RETROFITTED BUILDING TYPES

The vulnerability of selected building types to a wide range of inundation depths will be assessed and supplemented by both a significant body of flood vulnerability research by Geoscience Australia and a body of damage and socio-economic survey activity in Australia.

The outputs of this research will be suitable for use in other CRC research concerning risk assessment and impact forecasting in the immediate aftermath of an actual event.

COST BENEFIT ANALYSIS

Retrofit options entail an investment that will realise a benefit over future years through reduced average annualised loss due to severe flood exposure. Decisions to invest in reducing building vulnerability, either through asset owner initiatives or the provision by government or the insurance industry incentives, will depend upon the benefit versus cost of the retrofit.

In this exercise all retrofit options will be assessed through a consideration of a range of severity and likelihood of flood hazard covering a selection of catchment types. The work will provide information on the optimal retrofit types and design levels in the context of Australian construction costs and catchment behaviours.

DISSEMINATION

The work will provide information on the retrofit types suitable for Australian building types and associated cost-benefit analysis. The output will be an evidence-base to inform decision making on the mitigation of the community risk posed by Australian residential buildings located in flood plain environments.

The outcomes will be communicated to stakeholders through workshops, reports and conference/journal publications. Using the outcomes of the stakeholder workshop and the research, tailored retrofit information will be developed to inform decision making by governments and property owners to reduce flood risk.

LAUNCESTON FLOOD RISK MITIGATION ASSESSMENT PROJECT

INTRODUCTION

Launceston is floodprone and located within the Tamar River floodplain at the confluence of the Tamar, North Esk and South Esk Rivers in Tasmania. To replace the existing deteriorated levees a new flood mitigation initiative was commenced in 2010 to provide Launceston with reliable flood protection up to the 200 year Annual Recurrence Interval (ARI) event (Fullard, 2013). The initial project cost estimate was assessed to be $22 million in 2006 (Frontiers, 2006). However, the final project cost was exacerbated to $58 million (in 2016 dollars) due to increases in cost of construction and land acquisition. The project was funded by the Federal, State and Local Governments. The completed work comprises a levee and flood gate system which includes 12 kilometers of earth levee, 700 metres of concrete levee and 16 floodgates (National Precast Concrete Association, 2015).

Geoscience Australia (GA) was awarded a project as a variation to its current project within the BNHCRC to conduct a CBA of the Launceston flood mitigation initiative described above. The project stakeholders included the BNHCRC, Tasmanian Department of Premier and Cabinet, Tasmanian State Emergency Service, Launceston City Council (LCC), Launceston Flood Authority and Northern Midlands Council.

AIMS AND OBJECTIVES

The study aimed to assess:

- The avoided damage cost to Launceston in the June 2016 floods as a result of the new mitigation works.
- The number of people displaced due to inundation of homes for flood events ranging from the 20 year ARI up to the Probable Maximum Flood (PMF) and the expected time for them to return before and after the new mitigation works.
- Avoided residential and non-residential building loss for flood events ranging from the 20 year ARI up to the PMF due to the new mitigation works.
- The long term cost to Launceston from flood hazard prior to the new mitigation works.
- The long term cost to Launceston from flood hazard following the new mitigation works.
- A CBA of the new flood mitigation investment.

SCOPE OF STUDY

To accomplish these aims the study followed the traditional concept of risk (the combination of hazard, exposure and vulnerability) and conducted a CBA by assessing risk before and after mitigation at the building level (mirco-scale study). This study utilised data from a number of sources for each component of the research. Table 7 presents the range of components for which direct losses were estimated in 2016 dollar values for the residential and non-residential sectors.

TABLE 7: ESTIMATED LOSS FOR THE RESIDENTIAL AND NON-RESIDENTIAL SECTORS

Residential Sector	Non-residential Sector
Building repair/rebuild cost	Building repair/rebuild cost
Contents damage cost	Clean-up cost
Loss of rental income	Loss of Inventory/equipment
Clean-up cost	Loss of stock
Loss due to fatalities	Loss of income: proprietor's income
	Loss of income: turnover
	Loss of income: wage/salary

RESULTS

The results indicated that during the 2016 June flood in Launceston (a 50 year ARI event based on LCC, 2016) the reconstruction of the levee system resulted in avoiding losses of about $216 million should the pre-existing levees have failed. The resulting avoided losses would be approximately four times the investment in new levee system.

For the assessment of direct losses before and after the new mitigation initiative, conditional probabilities of failure with increasing flood depth were used to replicate the deteriorated condition of pre-existing levees. The assessed likelihood of failure in overtopping of the new levee system if subjected to extreme flood loads was also considered.

Table 8 presents the number of affected people before and after mitigation work that would be displaced due to inundation of homes for selected ARIs. The new levee system would be able to protect the community up to the 200 ARI event and it was assumed that the community will not be affected for this flood severity. Furthermore, it was estimated that there is a 90% chance of protection during the 500 year ARI event based on the freeboard provided on top of the 200 ARI peak flood level.

TABLE 8: ESTIMATED AFFECTED NUMBER OF PEOPLE IN THE RESIDENTIAL SECTOR

ARI (Year)	Annual Probability of Exceedance	Number of affected residential properties	Number of Affected People Before Mitigation	Number of Affected People After Mitigation
100,000	0.00001	1,853	4,262	4,262
1,000	0.001	989	2,275	2,275
500	0.002	864	1,987	199
200	0.005	786	1,356	0
100	0.01	707	650	0
50	0.02	627	72	0
20	0.05	551	1	0

Table 9 presents the estimated direct flood losses to the residential and non-residential sectors before and after construction of the new levee system for the components listed in the Table 7. Using these, the Average Annual Loss (AAL) was calculated for both before and after mitigation. There was a reduction of $2.9 million in the AAL which reflected the savings made by the investment in mitigation.

TABLE 9: ESTIMATED LOSSES ($) BEFORE AND AFTER MITIGATION

ARI (Year)	Annual Probability of Exceedance	Potential Loss ($ M)	Conditional Loss – Before Mitigation ($ M)	Conditional Loss – After Mitigation ($ M)	Average Annual Loss – Before Mitigation ($ M)	Average Annual Loss – After Mitigation ($ M)
100,000	0.00001	972.2	972.2	972.2		
1,000	0.001	476.5	476.5	476.5		
500	0.002	430.2	430.2	43.0		
200	0.005	324.8	256.4	0	3.95	1.04
100	0.01	278.4	111.2	0		
50	0.02	232.4	11.9	0		
20	0.05	165.8	0.08	0		

For the assessment of Benefit Cost Ratio (BCR) the project life was considered to be 80 years and five annual discount rates (3% to 7%) were used to assess the sensitivity of the results to investment capital cost. The actual investment cost of the project comprised an initial construction and land acquisition cost of $58 million in 2016 dollars.

The CBA showed that the BCR remained less than 1.0 for the discounted rates of 5% to 7% (see Table 10). However, the BCR improved greatly if the original estimated cost of the project utilised for decision making was used. This was assessed to be $22 million in 2006 ($28 million in 2016 dollars) by Frontiers (2006) but was later inflated due to increases in the cost of construction and land acquisition (Fullard, 2016). The original estimated cost yielded BCR greater than 1.0 for all discount rates (see Table 10).

TABLE 10: COST BENEFIT ANALYSIS FOR SELECTED DISCOUNT RATES

Investment (2016 $ M)	Avoided Losses (2016 $ M)					Benefit Cost Ratio (BCR)				
	3%	4%	5%	6%	7%	3%	4%	5%	6%	7%
58.4	88.0	69.7	57.1	48.1	41.4	1.51	1.19	0.98	0.82	0.71
27.9	88.0	69.7	57.1	48.1	41.4	3.15	2.49	2.04	1.72	1.48

DISCUSSION

CBA is a tool that is commonly used to estimate the efficiency of a given project by comprehending the costs and benefits of an investment. Not all forms of impact can be practically quantified and incorporated into a CBA. This study has focused on assessing the direct tangible impacts of floods of varying severity to the residential and non-residential sector at building level. The BCR would be increased by taking into account other direct costs to infrastructure, storm water and sewage systems, and damage to vehicles.

Furthermore, indirect costs such as the cost of emergency services response, loss of utility of services and intangible costs (stress, trauma, depression, loss of living environments or social contacts or relationships) could also be included to make this analysis more comprehensive (White and Rorick, 2010).

However, lack of data and difficulty in assigning monetary values to intangibles have limited the ability to include these costs into the analysis.

FINDINGS

The key findings of the project are summarised below.

- The losses that would be experienced during the June 2016 floods should the old levee have failed would be approximately four times the total investment in the new levee system.
- The investment in building the new flood levee system in Launceston was found to be a sound economic decision based on the estimated costs at the time of decision making and improved estimates of benefits from this study.
- Actual benefits of the mitigation works to the community are greater than could be assessed economically and would further support the investment in mitigation.
- It is found that sea level rise scenarios have only a limited impact on building losses. However, the combined impact of sea level rise and increased rainfall intensity due to climate change on the total losses may be significantly greater and could be further investigated.

OTHER ACTIVITIES DURING THE FY 2016-17

Other activities during this financial year include:

- Engagement with NSW Office of Environment and Heritage (Duncan McLukie) who is a key end user of the project. An overview of project activities and deliverables was provided to Duncan who gave positive feedback and constructive suggestion for upcoming research activities. Duncan also provided input into the scoping of an end user focussed utilisation project to develop flood vulnerability models that can become part of best practice floodplain management guidelines.
- Engagement with Insurance Council Australia (Karl Sullivan) and Edge Environment Pty Ltd (Tom Davies). An overview of project activities and deliverables was provided to Karl, and more specifically, the outcomes of the experimental work program on material testing were discussed. The outcomes of the tests could be included in the ICA's resilience tool and would enhance the Building Resilience Knowledge Database. It would also provide Australian specific benchmarks to rate the resilience of selected building materials. Tom acknowledged this input and also demonstrated the ICA's resilience tool.
- Engagement with Insurance Australia Group (Nick Bartzis). An overview of project activities and deliverables was provided to Nick. He was very much interested in the project activities and agreed to provide input in the selection of case studies for the next phase of the project.
- The costing modules developed within this project were provided to the University of Adelaide to support the development of Decision Support System within the BNHCRC. These modules will help to run a case study with the project end-users to quantify benefit/costs.
- The Project Management Plan for the second phase of the project was submitted to the BNHCRC. One utilisation project was proposed to be included in the second phase which will utilise the research outcomes of the current phase of this project. The project has strong end-user support and got feedback to shape the activities, outcomes and utilisation.
- The Research Utilisation Roadmaps for the current project were submitted to the BNHCRC and also for the proposed utilisation project.
- Attendance and poster presentation at the 2016 AFAC & BNHCRC Conference, Adelaide, Australia.
- Attendance and oral presentation at the BNHCRC Research Advisory Forum, Canberra (17-18 November 2016). Delivery of a presentation providing details of the project activities and completed tasks. The forum was attended by researchers, senior partner representatives and end- user representatives within the BNHCRC. The attendance and presentation helped to engage with end users and to inform them about project goals and achievements.

- Attendance at the 5th International Conference on Flood Risk Management and Response, Venice, Italy. A full length paper was published at the conference and the Project Leader delivered an oral presentation. The paper was selected for publication in the International Journal of Safety and Security Engineering. The attendance at the conference enabled the work being undertaken in the BNHCRC to be exposed to international experts.
- Engagement with the University of Potsdam, Germany: The Project Leader met with Prof Annegret Thieken who is the Chairwoman of the Scientific Advisory Board of the German Committee for Disaster Risk Reduction and a Professor of Geography and Natural Risks Research. She provided an overview of her research in flood damage assessment and especially the outcomes of surveys conducted after the 2002 floods of the Elbe and Danube rivers. Other important topics of discussion were related to the investigations of 2013 Elbe floods, assessing cost of floods and measuring damage reduction due to private precautionary measures (mitigation strategies). The Project Leader also delivered a lecture on flood vulnerability and mitigation to the students of the Master program at the University of Potsdam.
- Engagement with the German Research Centre for Geosciences (GFZ) Potsdam, Germany: The Project Leader met with Dr Heidi Kreibich who is the Head of Flood Risks and Climate Adaptation Working Group. The Project Leader delivered a presentation to her research group. The outcomes of a number of projects aiming at assessing flood risk, development of flood loss estimation models in Germany and assessing the effectiveness of flood mitigation strategies were discussed. Another important learning relevant to the BNHCRC flood project was the development of effective communication strategies to disseminate the outcomes of flood mitigation research to stakeholders.
- Engagement with the Bauhaus University Weimar, Germany: The Project Leader met with Dr Jochen Schwarz who is the Head of Earthquake Damage Analysis Centre and Dr Holger Maiwald who is Senior Lecturer of Flood Management. During the meeting the development of flood vulnerability models for typical building types and extending the application of European Macroseismic Scale to flood hazard were discussed. The Project Leader also delivered a lecture on flood vulnerability and mitigation to the students of the Master program (Natural Hazards and Risk Engineering) at the Bauhaus University Weimar.

PUBLICATIONS LIST

- Maqsood et al. 2016a. Report on developing costing modules for implementing flood mitigation strategies. Submitted to BNHCRC. 25 June 2016.
- Maqsood et al. 2016b. Cost-effective mitigation strategies for residential buildings in Australian floodplains. 5th International Conference on Flood Risk Management and Response, Venice, Italy. Full length paper. 16 March 2016.
- Maqsood et al. 2016c. Development of flood mitigation strategies for Australian residential buildings. Full length paper published in 2016 AFAC & BNHCRC Conference, Brisbane, Australia.
- Maqsood et al. 2016d. Cost-Effective Mitigation Strategies for Residential Buildings in Australian Floodplains. Paper published in International Journal of Safety and Security Engineering, Volume 6, No. 3, 550-559.
- Maqsood et al. 2017a. Testing of simulated flood effect on the bond strength of ceramic tiles, bending strength of timber joists and racking strength of structural sheet wall bracing. Bushfire and Natural Hazards CRC, Melbourne, Australia.
- Maqsood et al. 2017b. Launceston Flood Risk Mitigation Assessment Project Summary report. Submitted to BNHCRC. 21 February 2017.
- Annual report of FY2016-17 (This report). Submitted to BNHCRC. June 2016.

CURRENT TEAM MEMBERS

DR TARIQ MAQSOOD

Dr Maqsood is a structural engineer at Geoscience Australia. He is a member of Civil College of Engineers Australia and also a member of the Australian Earthquake Engineering Society (AEES). During the last 14 years Dr Maqsood has focused his research on vulnerability and risk assessment of built environment from natural hazards (earthquakes, floods, tsunami and volcanic ash). He has also been a part of several international initiatives, such as the Global Earthquake Model, the Greater Metro Manila Risk Assessment, the UNISDR Global Assessment Report and the Earthquake Risk Assessment in Pakistan. He has conducted numerous post-disaster surveys after damaging events (earthquakes, floods, cyclones, storm surges) in several countries. He has published several papers in international refereed conferences and reputed journals. Currently he is leading a flood mitigation strategies development project within the Bushfire and Natural Hazards CRC.

MR MARTIN WEHNER

Mr Wehner is a structural engineer at Geoscience Australia. He has 22 years of experience as a practising structural engineer designing buildings of all sizes and types both in Australia and internationally. Since joining Geoscience Australia in 2009 his research work has centred on the vulnerability of structures to flood, wind and earthquake. He has participated in post-disaster damage surveys to Padang (Earthquake), Brisbane (Flood), Kalgoorlie (Earthquake) and Christchurch (Earthquake). In each case he has led the post-survey data analysis to develop vulnerability relationships and calibrate existing relationships. He has led the development of Geoscience Australia's suite of flood and storm surge vulnerability curves. He is a Member of Engineers Australia and IABSE.

DR KEN DALE

Dr Dale is a structural engineer at Geoscience Australia who obtained his Bachelor Degree (1994) and PhD (2001) at Monash University. Undertook Post-Doctoral research in Japan related to the earthquake behaviour of steel beam-to-column connections (2001-2003) before joining Geoscience Australia in 2003. Research interests include the behaviour of structures and other infrastructure under extreme loads (blast, flood, tsunami, and earthquake). Research in the flood area has included modifying damage curves that incorporate flood height and velocity to suit Australian construction, and the development of stage-damage curves for a small suite of residential structures. Flood experience also includes leading teams on post-event damage surveys in Melbourne (2004) and Brisbane (2011).

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