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COST-EFFECTIVE MITIGATION STRATEGY DEVELOPMENT FOR FLOOD PRONE BUILDINGS

Annual project report 2015-2016

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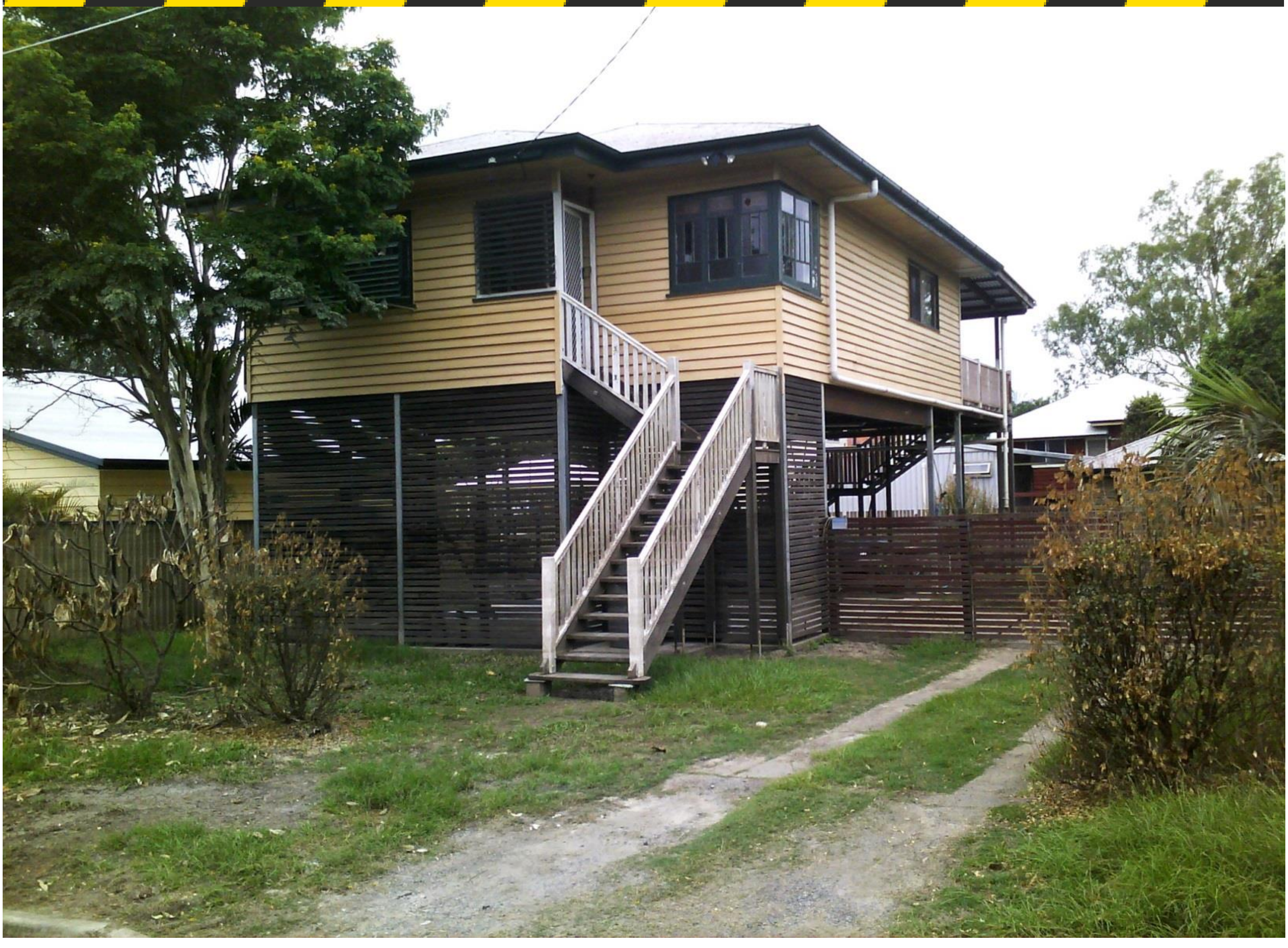

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Cover: Flood mitigation strategy: elevating floor level (Geoscience Australia)

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EXECUTIVE SUMMARY

The motivation for this project arises from the experience and observations made during the recent flooding in Australia in 2011 and 2013, 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 are being costed for the selected storey types through the engagement of quantity surveying specialists. Furthermore, testing of material susceptibility is being scoped to address knowledge gaps I the areas of strength and amenity.

In the following years of the project vulnerability of predominant storey types will be assessed along with the factors affecting vulnerability. The information on vulnerability is fundamental to evaluate mitigation strategies and to examine the opportunities for reducing the vulnerability. The research will include experimental testing of preferred material types to ascertain their resilience to floodwater exposure. Cost benefit analysis will be conducted to find optimal mitigation strategies for selected building 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. It is important that the latest research and economically optimum upgrading solutions are applied to existing houses to optimise the use of finite mitigation resources. 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

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 will provide 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; 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 are being 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, planning of an experimental program for testing materials and building systems is well advanced.

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. In addition, the team has developed a project utilisation plan to ensure the project outputs will be used by end users.

INTRODUCTION

White (1945) wrote that floods were acts of God but flood losses were largely acts of man. Due to major developments in floodplains, which are acts of humans, flood losses are not considered acts of God as humans have played a key role in changing the land use (Green et al. 2011). 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, 2016) 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 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 three tasks have been completed by the end of June 2016 in line with the project schedule. A summary of the two 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. This "pigeon holing" strategy makes research on impact, risk and mitigation more tractable in that vulnerabilities can be assigned to each class with the reduced variability within the class captured in the uncertainty of the model. Available exposure information can also be mapped to the schema along with building types that can particularly benefit from retrofit interventions.

In this project a literature review has been conducted which reviewed building schemas developed nationally and internationally for a range of uses within different projects. The reviewed schemas are from HAZUS, USA (FEMA, 2007a), 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 has been proposed which is a fundamental shift from describing the complete building as an enitity to one that focuses on sub-components. The proposed schema divides each building into the sub-elements of foundations, bottom floor, upper floors (if any) and roof to describe its vulnerability. Through this approach it is 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 classifies each storey type based on the following attributes:

- Construction period
- Fit-out quality
- Storey height
- Bottom floor
- Internal wall material
- External wall material

Excluding combinations that are invalid in an Australian context, the draft schema defines 60 discrete vulnerability classes for storey types based on the above mentioned attributes. Furthermore, the schema proposed 6 roof types based on material and pitch of the roof.

This proposed schema is the initial categorisation of residential structures as to vulnerability class for this project. It is expected to change and be refined as the project is taken forward and the specific building types for retrofit research are identified. The concept of "nestability" may be subsequently used where mitigation research focuses on several building types that fall within a single broader category and become sub-classes. The draft schema has been developed in recognition of the current and projected ability to define national building exposure and of the parallel BNHCRC mitigation projects examining vulnerability to earthquake and severe wind. While vulnerability schemas are hazard specific, alignment has been sought with the schemas for other hazards where possible.

LITERATURE REVIEW OF FLOOD MITIGATION STRATEGIES

The succeeding task completed in this project has been the literature review of mitigation strategies developed nationally and internationally. The review helps to evaluate the strategies that suit Australian building types and typical catchment behaviours for adoption in Australia. The review has 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 (Maqsood et al. 2015b). The review discusses the commonly used strategies and summarises the advantages and disadvantages of each of them. The review categorises mitigation strategies into the following categories:

- Elevation
- Relocation
- Dry floodproofing
- Wet floodproofing
- Flood barriers

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 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 of not more than a day.

DEVELOPMENT OF COSTING MODULES FOR SELECTED RETROFIT OPTIONS

A list of building materials typically used in Australian residential construction has been 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 have been selected for the balance of the research which are a subset of the schema proposed earlier in this paper. 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 has been developed which excludes the mitigation options noted earlier that are invalid in the Australian context (see Table 2). Costing modules are being developed by quantity surveying specialists to estimate the cost of implementing all appropriate mitigation strategies for these five storey types. A summary of mitigation measures considered for the costing is provided below.

Elevation of a structure is one of the most common mitigation strategies which aims to raise the lowest floor of a building above the expected level of flooding. This can be achieved by (i) extending the walls of an existing structure and raising the floor level, (ii) changing the use of ground floor and constructing a new floor above the existing one, and (iii) raising the whole structure on new substructure. Figure 2 shows the three techniques to elevate a building.

Relocation of a building is the most dependable technique, however, it is generally the most expensive as well (USACE, 1993). Relocation involves moving a structure to a location that is less prone to flooding or less exposed to flood-related hazards such as erosion or scouring. Relocation normally involves placing the structure on a wheeled vehicle, then transported it to a new location and setting it on a new foundation (FEMA, 2012). In the present study it is found appropriate only for Building Type 1, which is a light-weight timber frame building with weatherboard clad exterior walls.

Dry floodproofing consists of measures to seal the portion of a structure that is below the expected flood level to make it substantially impermeable to floodwaters. Such an outcome is achieved by using sealing systems which include wall coatings, waterproofing compounds, impervious sheeting over doors and windows and a supplementary leaf of masonry (FEMA, 2012). Dry floodproofing is generally not recommended in flood depths exceeding one metre based on tests carried out by the US Army Corps of Engineers as the stability of the building becomes an issue over this threshold depth (USACE, 1988; Kreibich et al. 2005). Dry floodproofing may also be inappropriate for light timber frame structures (Building Type 1), structures with raised timber floors (Building Type 1, 3 & 4) and structures which are not in good condition and may not be able to withstand the forces exerted by the floodwater (FEMA, 2012).

Wet floodproofing includes modifying the building by (i) replacing existing building components/materials with more water-resistant materials, (ii) adapting to the flood hazard by raising key services and utilities to a higher level, and (iii) installing flood openings to equalise the hydrostatic pressure exerted by floodwaters on the interior and exterior of the building and thus reduces the chance of building failure. With this technique, as all the building components below the flood level are wetted, all construction material and fit-outs should be water-resistant and/or can be easily cleaned following a flood (USACE, 1993; FEMA, 2007b).

Flood barriers considered here are those built around a single building and are normally placed some distance away from it to avoid any structural modifications to the building. There are two kinds of barriers: permanent and temporary. An example of a permanent barrier is a floodwall which is quite effective because it requires little maintenance and can be easily constructed and inspected. Generally, it is made of reinforced masonry or concrete and has one or more passageways through it that are closed by gates. There are also several types of temporary flood barriers available in the market which can be moved, stored and reused. Flood barriers may be inappropriate for structures with raised floors (Building Type 1, 3 & 4) because of the high cost of barriers for height more than 1m.

TABLE 2: FLOODPROOFING MATRIX

Building 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	N/A				N/A	N/A	N/A	
2	N/A		N/A	N/A				
3			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		N/A	N/A				

NEXT STEPS

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

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 will be examined to ascertain where deterioration due to wetting and subsequent drying needs to be addressed as part of repair strategies. An analysis will be finalised to identify research gaps in building material susceptibility to flood water in Australia.

This research will also include experimental testing of preferred material types to address key gaps in knowledge on resilience to flood water exposure. The Cyclone Testing Station at James Cook University has been selected to conduct experiments on these 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. From this activity the testing of three specimen series has been identified as described in the Appendix. These selections will be validated with end users ahead of commencement of testing work in 2016/2017.

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.

BENEFIT VERSUS COST 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.

OTHER ACTIVITIES

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 (26 November 2015). An overview of project activities and deliverables was provided to Duncan who gave positive feedback and constructive suggestion for upcoming research activities.
- Engagement with Insurance Council Australia (Karl Sullivan) who has recently joined the BNHCRC Board (21 December 2015). An overview of project activities and deliverables was provided to Karl, and more specifically, upcoming experimental work program on material testing was discussed. Karl provided his suggestions on project activities and encouraged close interaction. Karl demonstrated the ICA's resilience tool which covers eight hazards in its scope. Karl provided his suggestion to organise a loss assessor workshop to validate the mitigation strategies proposed within this project.
- Engagement with Suncorp Insurance (Sean West and Jon Harwood). An overview of project activities and deliverables was provided to Suncorp's representatives. Suncorp was interested in the project outcomes and expressed interest in becoming an end-user of the project. Suncorp was interested in attending the next cluster and end-user meeting. Suncorp offered assistance to this flood project by performing an extraction of flood prone property types in their policy database so the project can assess the level of coverage of predominant types by currently proposed mitigation option/building type selections. Suncorp also offered to provide contact details of the builders who were engaged in reconstruction activities after the 2011 Queensland flooding.
- 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 expressed IAG's interest in becoming an end-user of the project.
- Participating in the workshop organised by Insurance Australia Group (Nick Bartzis) to consult IAG's flood loss assessors and engineers to seek their feedback on the proposed flood mitigation and repair strategies.
- Engagement with South Australian Government: Advice and review of Flood Resilience Scorecards for Aged Care facilities. A project of the Government of South Australia.
- Engagement with other BNHCRC projects: Flood vulnerability models developed by Geoscience Australia were provided to Prof Holger Maier who is leading a project which aims to develop a multi-hazard decision support tool. Further assistance is being provided to incorporate the vulnerability models into the tool and to run selected scenarios.
- 2015 Dungog flood survey report. Dungog, located in the Hunter Valley, NSW, was impacted by flash flooding on 21 April 2015 resulting in 4 deaths, 4 houses washed away and damage to 46 houses and 5 businesses. Two

officers from Geoscience Australia undertook a damage survey to gather data about the affect of high velocity water flow on lightweight timber frame structures. During the survey building damage, building attributes and field measurements to document flood depth and flow velocity were recorded. The primary objective was to record sufficient information such that an estimate could be made of the water velocity at the site of the washed-away houses. The secondary objective was to record damage caused by the flood water along with water level information.

- Attendance and poster presentation at the 2015 AFAC & BNHCRC Conference, Adelaide (1-3 September 2015).
- Participation in BNHCRC workshop: Presenting with impact, Adelaide (31 August 2015).
- Full length paper submitted to the 5th International Conference on Flood Risk Management and Response, Venice, Italy (29 June – 1 July 2016).
- Extended abstract submitted to the 2016 AFAC & BNHCRC Conference, Brisbane. The abstract has been accepted for oral presentation. A full length paper has also been submitted in June 2016.
- Attendance and oral presentation at the BNHCRC Research Advisory Forum, Brisbane (17-18 November 2015). 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. A draft project utilisation map was also prepared during the forum.

PUBLICATIONS LIST

- Project Management Plan. Submitted to BNHCRC. 31 March 2014.
- First Quarterly report of FY2013-14. Submitted to BNHCRC. 31 March 2014.
- Second Quarterly report of FY2013-14. Submitted to BNHCRC. 30 June 2014.
- Report on building classification schema (Maqsood et al. 2014b). Submitted to BNHCRC. 25 June 2014.
- Annual report of FY2013-14. Submitted to BNHCRC. 30 June 2014.
- Cost-Effective Mitigation Strategy Development for Flood Prone Buildings (Maqsood et al. 2014c). 2014 AFAC & BNHCRC Conference, Wellington, New Zealand. Poster presentation.
- First Quarterly report of FY2014-15. Submitted to BNHCRC. 30 September 2014.
- Second Quarterly report of FY2014-15. Submitted to BNHCRC. 24 December 2014.
- A schema to categories residential buildings in Australian floodplains (Maqsood et al. 2015a). 2015 Floodplain Management Association National Conference, Brisbane, Australia. Full length paper. 16 March 2015.
- Third Quarterly report of FY2014-15. Submitted to BNHCRC. 31 March 2015.
- A schema to categories residential buildings in Australian floodplains. 2015 Floodplain Management Association National Conference, Brisbane, Australia. Oral presentation. 20 May 2015.
- Report on literature review of flood mitigation strategies (Maqsood et al. 2015b). Submitted to BNHCRC. 29 June 2015.
- Annual report of FY2014-15. Submitted to BNHCRC. 30 June 2015.
- Cost-Effective Mitigation Strategy Development for Flood Prone Buildings (Maqsood et al. 2015b). 2015 AFAC & BNHCRC Conference, Adelaide, Australia. Poster presentation.
- Report on 2015 Dungog Floods, NSW. Submitted to BNHCRC. 30 September 2015.
- First Quarterly report of FY2015-16. Submitted to BNHCRC. 30 September 2015.
- Second Quarterly report of FY2015-16. Submitted to BNHCRC. 24 December 2015.
- Third Quarterly report of FY2015-16. Submitted to BNHCRC. 31 March 2016.
- Cost-effective mitigation strategies for residential buildings in Australian floodplains (Maqsood et al. 2016a). 5th International Conference on Flood Risk Management and Response, Venice, Italy. Full length paper. 16 March 2016.

- Cost-effective mitigation strategies for residential buildings in Australian floodplains. 5th International Conference on Flood Risk Management and Response, Venice, Italy. Oral presentation. 30 June 2016.
- Cost-effective mitigation strategies for residential buildings in Australian floodplains (Maqsood et al. 2016b). International Journal of Safety and Security Engineering.
- Development of flood mitigation strategies for Australian residential buildings (Maqsood et al. 2016c). 2016 AFAC & BNHCRC Conference, Brisbane, Australia. Extended abstract. 3 March 2016.
- Report on developing costing modules for implementing flood mitigation strategies (Maqsood et al. 2016d). Submitted to BNHCRC. 25 June 2016.
- Annual report of FY2015-16 (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 twelve years Dr Maqsood has focused his research on vulnerability and risk assessment of built environment from natural hazards. In 2011, Dr Maqsood conducted a flood impact assessment case study in the Alexandra canal catchment in Sydney and highlighted the importance of modelling rigor required for risk/impact assessment. In March 2012 Dr Maqsood organised an international flood vulnerability workshop convened in Brisbane attended by over 25 recognised experts from Australia and regional countries that served to validate GA flood research and derive directions for future research. He has also been a part of several international initiatives, such as the Global Earthquake Model, the Greater Metro Manila Risk Assessment (flood), the UNISDR Global Assessment Report and the Earthquake Risk Assessment in Pakistan. He has published several papers in international refereed conferences and reputed journals.

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 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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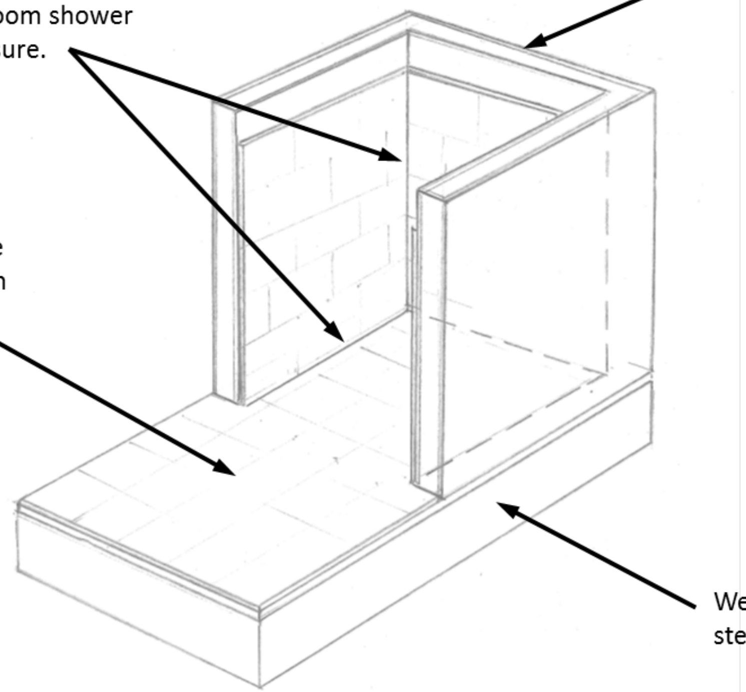
APPENDIX -

PROPOSED MATERIAL FLOOD SUSCEPTIBILITY TESTING

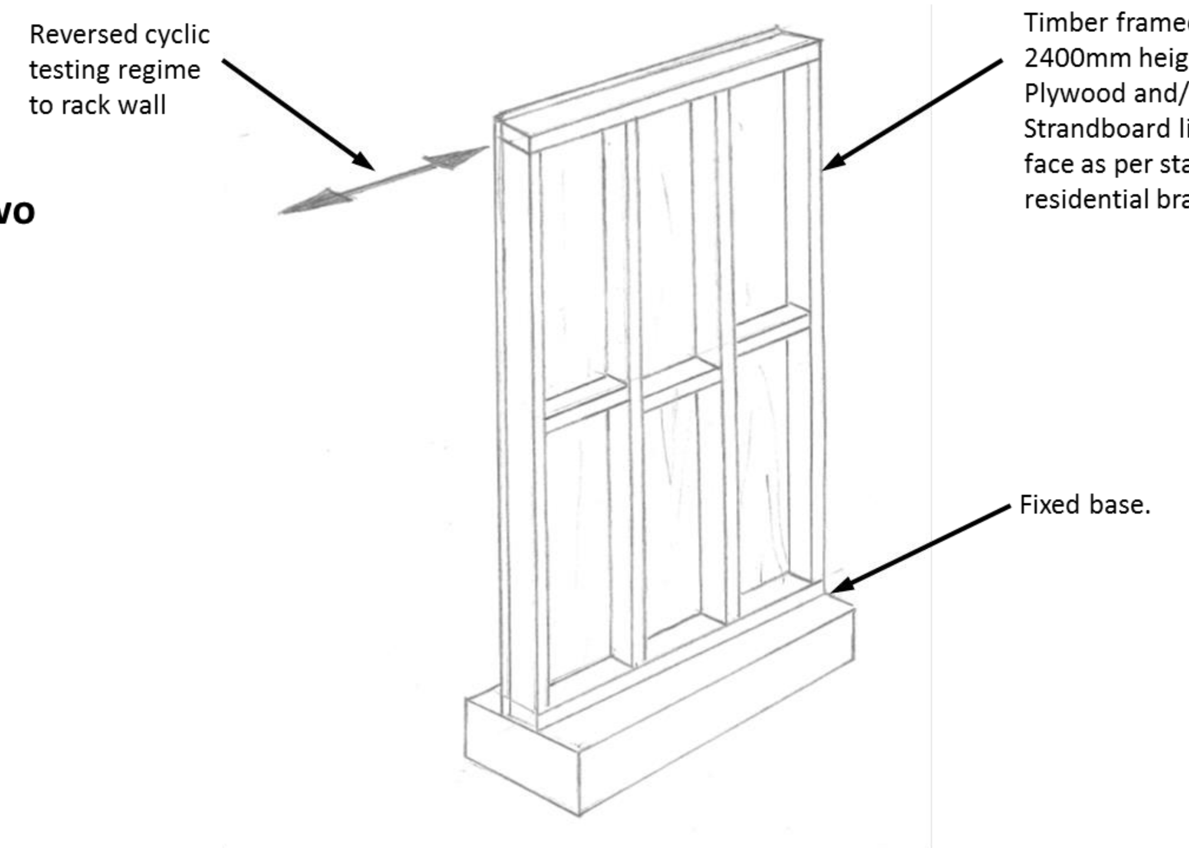
Specimen Series One



Notes:-

1) Nominally 5 specimens
2) Specimens soaked for 4 days to 0.6m depth above tiles and then dried. Drying entails removal of external plasterboard wall lining and washing our wall cavity.
3) Post-flood waterproofing check requires temporary gate across “U” sealed to wall ends and floor and flooded to 0.3m depth.
4) Tile delamination to be testing with selected in-situ tile pull-off testing.
5) Moisture consent samples to be taken prior to wetting, after wetting and after drying.

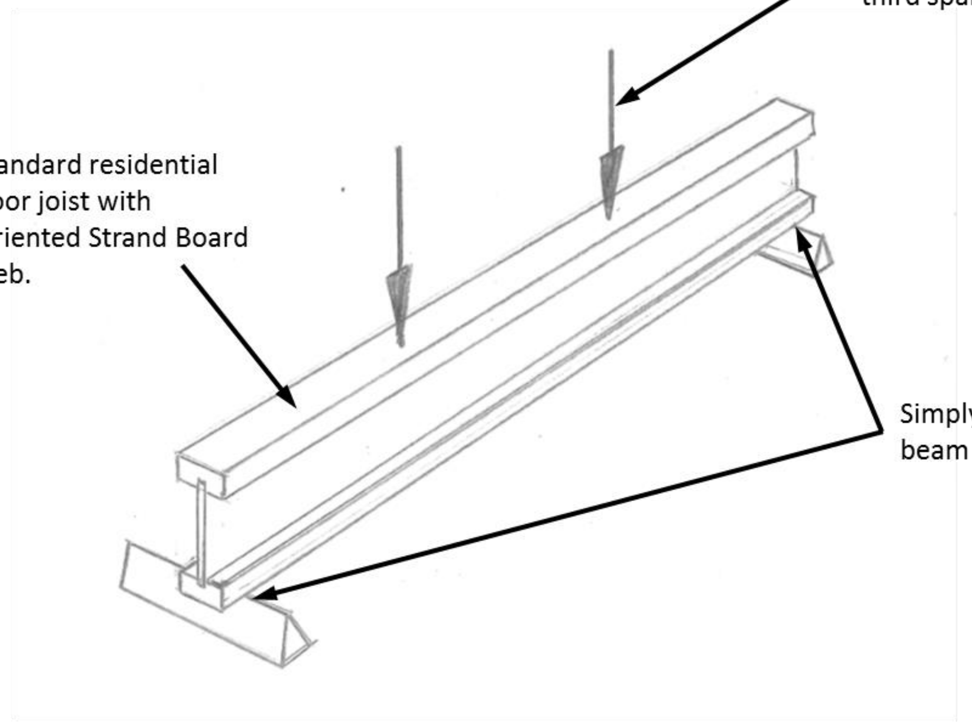
Specimen Series Two



Notes:-

1) Nominally 10 specimens tested dry and 10 specimens tested wet.
2) Specimens fully soaked for 4 days and then dried.
3) Testing regime to follow standard wall racking test protocol for plasterboard lined residential framed walls.
4) Moisture consent samples (3) to be taken prior to wetting, after wetting and after drying.

Specimen Series Three



Notes:-

1) Nominally 10 specimens tested dry and 10 specimens tested wet.
2) Specimens fully soaked for 4 days and then dried.
3) Testing regime to follow standard monotonic loading to failure process. End restraint conditions to be resolved.
4) Moisture consent samples (3) to be taken prior to wetting, after wetting and after drying of both flange and web elements.