CHARACTERISATION AND SCREENING OF NEW ZEALAND STOPBANK NETWORKS

Kaley Crawford-Flett (Quake Centre), Matthew Wilson (Geospatial Research Institute),
Asaad Shamseldin (University of Auckland)

Characterising the New Zealand stopbank portfolio to inform knowledge gaps, relative service and condition levels, risk exposure, management and policy needs, and long-term research.

Why are Stopbanks important to New Zealand?

Stopbank networks are a critical distributed infrastructure network, providing the primary means of flood protection for people and properties in many New Zealand communities.

The construction of flood protection stopbanks in New Zealand began in the late 1800s, well before the development of modern embankment engineering standards. From 1949 to 1969, more than 2,500 km of stopbanks were constructed in New Zealand (Ericksen, 1986). It is presently estimated that New Zealand has in excess of 3,000 km of stopbanks, protecting around 100 "flood prone" population centres (Ericksen, 1986), and managed largely by private landowners and regional and local government agencies.

Potential damage to a stopbank network is likely to have significant economic and social impacts; therefore, a clear understanding of the attributes of this system is needed to be able to assess the expected performance and impacts.

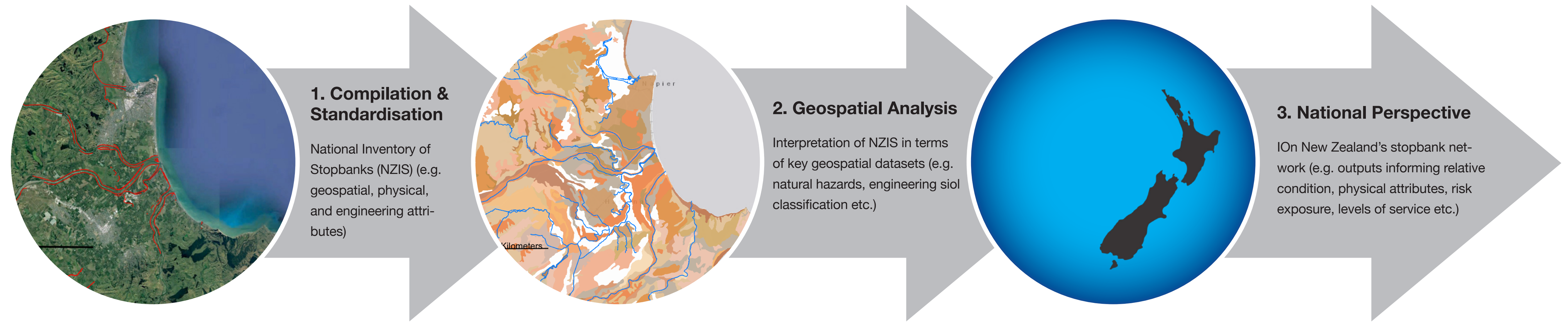
Why create a National Inventory of Stopbanks?

Activities on stopbanks and floodways are generally governed by the Resource Management Act (1991) and maintenance is governed by the Local Government Act (2002). However, the enactment of stopbank management is entirely local; guided by Regional and District Plans in response to local priorities.

Just as levels of flood protection vary locally, regionally, and nationally; the physical and engineering attributes of stopbank assets in New Zealand "vary across the country depending on past decisions, community expectations and the risk profile of each area" (MfE, 2008). Available levels of resource and expertise vary widely among the regions, resulting in inconsistent design, assessment, and maintenance standards.

Given the regional nature of stopbank and flood protection management, "direct comparison across the country is difficult". Furthermore, "There are no standardised national data sets, indicators or methodologies to assess (flood protection) risk across the country". A national flood risk management review concludes that "There are no uniform standards for the design, construction and maintenance of (flood protection) assets." (MfE, 2008).

In order to better understand the make-up of stopbank assets in New Zealand a goal of this project is to provide a single, standardised, reliable and spatially-referenced inventory in the form of the NZ Inventory of Stopbanks (NZIS). Statistical and spatial analysis of the NZIS will inform properties of the New Zealand stopbank network (e.g. height, type, geometry, location, design and service levels) and enable broad-based risk and consequence assessments across the portfolio.



What does this mean for New Zealand? Who will benefit?

Analysis of the NZIS will set the stage for improved stopbank risk management in coming decades.

Regulatory authorities (both national and regional) will gain an improved nation-wide understanding of stopbank assets to help inform appropriate and consistent risk management measures and policy.

Outputs from analysis of the NZID will inform the academic community, refine future research needs, and help identify relevant international collaborations.

The New Zealand hazard and embankment engineering communities can use the NZID to ensure that:

- Dissemination channels target the full cross-section of stopbank owners and stakeholders.
- Event response actions are appropriately prioritised.
- Future stopbank engineering needs are anticipated.

Through long-term research and governance, we hope that the New Zealand public will benefit by way of improved reliability of flood protection networks, consistent levels of service, and safer embankment networks.

The physical and engineering attributes of stopbank assets in New Zealand "vary across the country depending on past decisions, community expectations and the risk profile of each area" (MfE, 2008).

Rangataiki River stopbank breach, April 2017. Image: Sky View photography

What are the expected outcomes?

The aim of the research project is to develop an improved understanding of New Zealand's stopbank infrastructure. The project will provide an initial spatial analysis framework that can be extended to assess the impact of potential stopbank failure on other infrastructure, both in terms of flood hazard and the cascading effect of other natural hazard events

The NZIS will be used to inform a first stage assessment of the hazard exposure of the stopbank network across New Zealand using geospatial properties of the network in relation to land-use, geology, and hazard datasets. The NZIS will form the basis for future research in this area.

Ultimately, the national characterisation outputs will to help asset owners and regulators manage risk, prioritise improvement works, and improve inspections following earthquake and flood events.

"There are presently no standardised national data sets, indicators or methodologies to assess [flood protection] risk across the country." (MfE, 2008)

Acknowledgements

We wish to acknowledge the professional and financial support provided by Quake Centre, QuakeCoRE, Geospatial Research Institute (GRI). The support of regional authorities to date is greatly appreciated, in particular: Environment Canterbury, Greater Wellington Regional Council, and Hawkes Bay Regional Council.

Quake Centre — Delivering Industry Solutions
QuakeCoRE — NZ Centre for Earthquake Resilience
GRI — Geospatial Research Institute Toi Hangarau

Funded by industry to deliver solutions to industry identified needs.

[1] Ericksen, N.J. (1986). Creating flood disasters? New Zealand's need for a new approach to urban flooding. National Water and Soil Conservation Authority.
[2] Ministry for the Environment (2008). Meeting the challenges of future flooding in New Zealand. Ministry for the Environment and the Flood Risk Management and River Control Review Steering Group. August 2008. ISBN: 978-0-478-33126-4

PRECAST AND FACADES WORKING GROUPS

P Smith and Greg Preston

The earthquakes experienced in NZ over the last seven years have highlighted a number of structural engineering issues that need to be addressed. The Quake Centre, working closely with the Industry; the Technical Societies; QuakeCoRE; BRANZ and the Universities of Canterbury and Auckland are looking at ways to address a couple of these issues.

Precast floors

The 2016 Kaikoura Earthquake caused significant damage to a number of buildings in Wellington. These buildings were all characterised as having precast concrete floor systems. The floor in one building collapsed and 12 buildings have been earmarked for demolition. The fate of many more buildings is uncertain.

There are three parallel and interlinked work streams looking at the precast issues. These are:

- MBIE-led Assessment Panel looking at how to give a seismic rating under the Earthquake Prone Building Legislation
- The Quake Centre's Retrofit Working Group
- A research team led by QuakeCoRE, the Universities of Auckland and Canterbury, BRANZ. This research underpins the assessment and retrofit.

What is the problem?

There are a number of problems associated with precast flooring systems in seismic zones. These relate to the brittle nature of the floor, the floor's ability to act as a diaphragm, and the inherent inability to predict the seismic performance of the floor. These issues are further compounded when precast floors are used in conjunction with frame systems that may undergo beam elongation in an earthquake leading to insufficient seating of the floor.

The inherent uncertainty in respect to seismic performance is a major worry for property owners and tenants who do not know how safe the building is or how to remedy this situation. Engineers and researchers are currently working towards answers to the questions of life-safety and reliable retrofit solutions.

Fig 1: Damage to Precast flooring from the Christchurch earthquake. Source – Sam Corney

What is being done?

The three parallel work streams have a significant overlap in personnel all of whom are working together to address the problem. The Quake Centre is managing the process of developing retrofit guidance and ensuring that any solutions are fit-for-purpose, affordable and constructible. To this effect the working group comprises engineers, architects and contractors. The final outputs will form part of the Improvement Guide that is planned to follow the Seismic Assessment of Existing Buildings which provides the assessment component of the earthquake-prone building regulations, and the Earthquake Prone Building Methodology that came into force on 1 July 2017.

Fig 2: Damage to Precast damage. Source – Sam Corney

What are the benefits?

Benefits will be shared across a number of sectors:

1. Engineers for property owners, banks and insurers will be able to assess the earthquake risk to their buildings.
2. Property owners and architects will be able to understand the solutions and related costs in retrofitting buildings with precast floors.
3. Engineers will have consistent design approaches to seismic retrofit solutions for seismic retrofits.
4. Contractors will have constructible and well-priced solutions.

When can we expect outputs?

There are a very large number of uncertainties in respect to the assessment and retrofit of precast floor systems. The research outputs may be expected over the next two-three years. Solutions will be developed in light of these results. Interim communications on progress will begin in the first quarter of 2018.

Unreinforced masonry (URM)

URM was the cause of 44 deaths in the February 2011 Christchurch earthquake. Unreinforced Masonry (URM) parapets and facades pose one of the highest risks to life-safety in an earthquake in New Zealand. There are approximately 4,000 URM buildings around New Zealand many of which have critical structural weaknesses that could cause parapets or facades to fall in a seismic event. These need to be assessed and made secure under the Building (Earthquake-prone Buildings) Amendment Act 2016 and as per recommendations 77-81 of the Canterbury Earthquakes Royal Commission.

Additionally, as a result of the Kaikoura Earthquake, the Government has created an Order under Council which requires owners of URM buildings who are notified by their council (predominantly in Central NZ) to secure street facing facades within one year. This process needs to be completed by early 2018. Wellington City Council (WCC) and Hutt City Council (HCC) are making good progress in this area and are largely on target to meet the required date.

The good work of WCC and HCC offers an opportunity that will benefit areas of NZ that have to undertake a similar exercise under the 2016 Building Amendment Act, but over a longer time-frame. In the regions, the issue of insecure facades and parapets also has to take into account the overall earthquake-prone status of the building. However, parapets and facades are often critical structural weakness that need to be addressed. Lessons learnt from Wellington and Hutt will be invaluable in other regions.

What is being done?

The working group is in its initial stages. It plans to build on the work undertaken by Stuart Oliver from Holmes. In conjunction with a review of the retrofit solutions in Wellington and the Hutt by Dmytro Dizhur of UoA, a work plan and set of guidance documents will be developed that is based on region and risk.

What are the benefits?

There are a number of benefits:

1. Local communities
   - Lower life-safety risks associated with URM on street frontages
2. Property owners
   - Optimised standard solutions and lower costs of meeting mandatory safety levels
3. Consulting engineers
   - Ability to deliver standardised detail at a competitive and viable cost with reduced liability. This is important as many engineers are reluctant to take on these jobs because of the low fees and high liability.

When can we expect outputs?

The process is expected to start mid-2018 with outputs delivered throughout 2019.

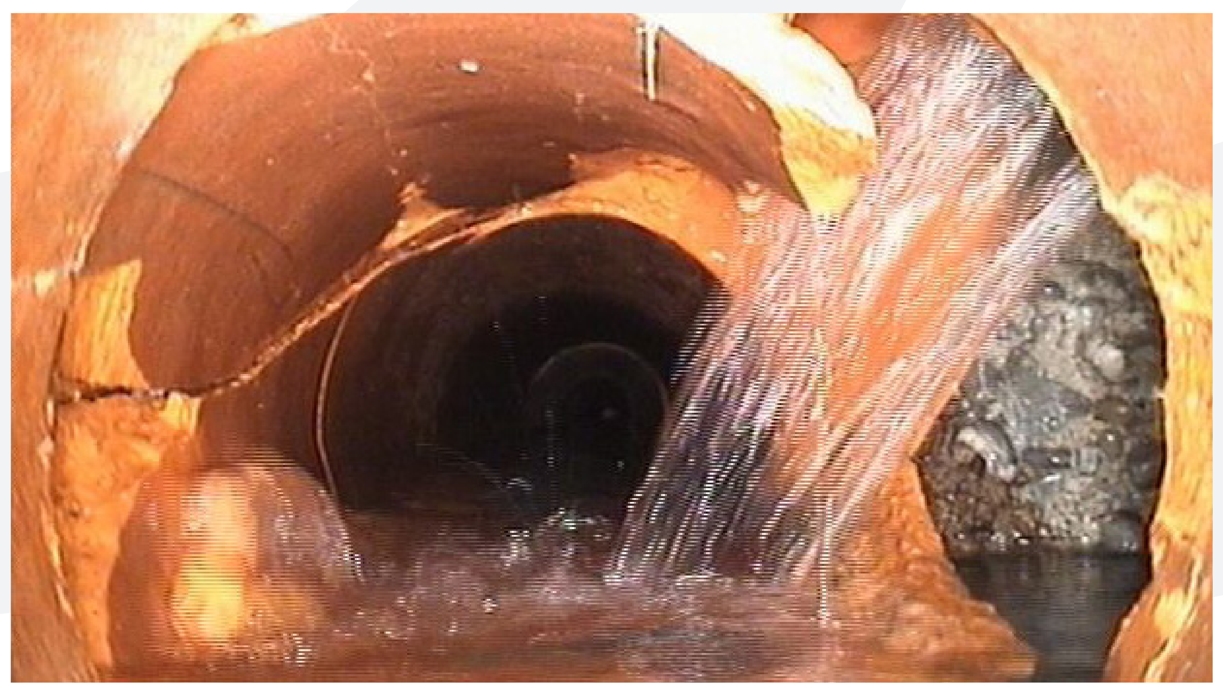
NATIONAL PIPE DATA PORTAL

Greg Preston

Learning from the SCIRT experience of the rebuild of Christchurch's Potable, Storm and Waste Water networks (3 Waters), it was realised that the only difference between business-as-usual renewals planning and recovery from a natural disaster is the scale and speed at which the planning and construction are undertaken.

This prompted the Quake Centre, in conjunction with Water New Zealand and the Institute of Public Works Engineers Australasia (IPWEA NZ) to undertake a programme of work to develop guidance that defines good practice in renewals planning for the 67 organisation around New Zealand that are responsible for the country's 3 Waters networks. This programme is called the Evidenced-based Investment Decision-making for Three Waters Networks programme (or Pipe Renewals). It is estimated that the Pipe Renewals programme will take 10 years and comprise more than 40 individual pieces of work.

Underpinning many of these pieces of work is the need for better information. This information can only be derived from more and better data. The National Pipe Data Portal is a part of the Pipe Renewals programme which aims to collate and share data on a national basis.



What is the problem?

Across NZ (and the world) the understanding of 3 Waters pipe networks is poor. This is due to the age of the infrastructure and the fact that it is underground and largely invisible. In addition, the water sector in NZ is divided across nearly 70 organisations, all working to different standards and specifications. Data is sometimes inaccurate and often incomplete and data standards are inconsistent across the country. Without good data it is difficult to make informed decisions.

Currently the estimate is that by 2022 there will be an $8 billion shortfall between the depreciation on NZ's 3 waters infrastructure and the provisions made by councils to finance the renewals needed. Unfortunately the data on which this estimate is made is very unreliable. The picture may be much better than this, or much worse. Without accurate data we cannot know.

Why a National Pipe Data Portal?

If we are able to access data on a national basis we are able to do a number of things. These include:

- Building improved models for the useful life of pipes
- Understanding the risk profile of the 3 Waters networks across the country
- Planning for resilience to natural hazards across regional boundaries
- Using virtual teams to work on problems of local and national significance
- Comparing regions with similar ground conditions to inform planning and design in areas of limited data
- Identifying opportunities for improvements in data quality
- Overlying other data sets such as the NZ Geotechnical Database and RAMM
- Working on a process to aid Digital Engineering for streamlined design, consent, construction and asset management.

NZ Metadata Standards

The draft New Zealand Metadata Standards define the data attributes for Light Industrial and Residential Property; Roads and 3 Waters. The National Pipe Data Portal is premised upon the Metadata Standards and is also an implementation path for the standards nationally.

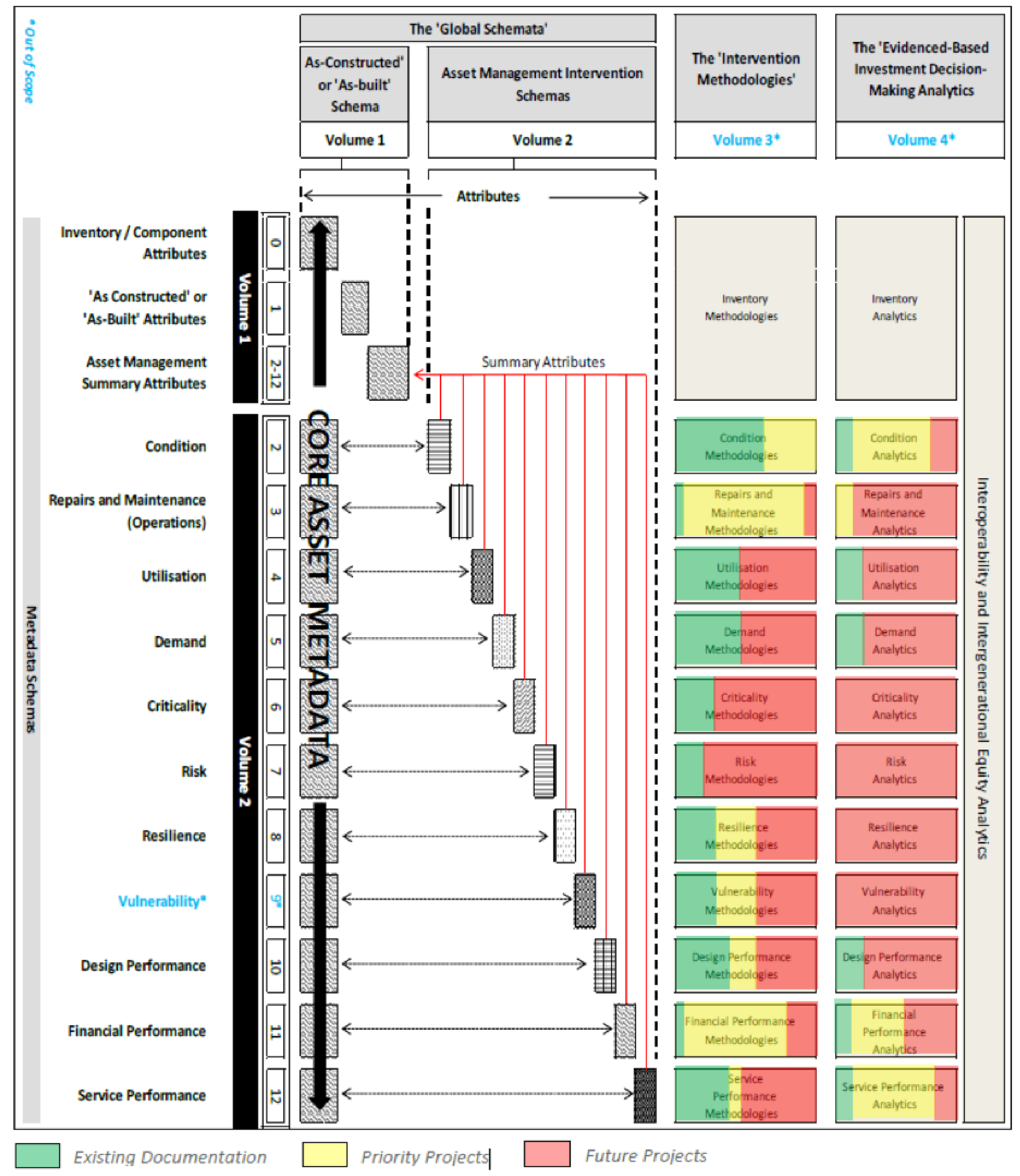


Fig 1: NZ Metadata Schema

How are we doing this?

Data is stored in many forms across the country. In addition a number of asset management systems are used. An important feature of the National Pipe Data Portal is that the data should reside with its owners and not be mirrored somewhere else in a national database. There are a number of technologies that can map data from one schema to another in real time. In addition, powerful geospatial and visualisation tools allow assessment of data quality and accuracy. Data sets will only be created for specific purposes as required. Additionally, if the data owner consents, it is also possible to write back to the source database with corrections to data. This will require clear risk management and governance processes.

The aim is to have the major cities sharing data by 2020 and 80% of the other territorial authorities on board by 2023.

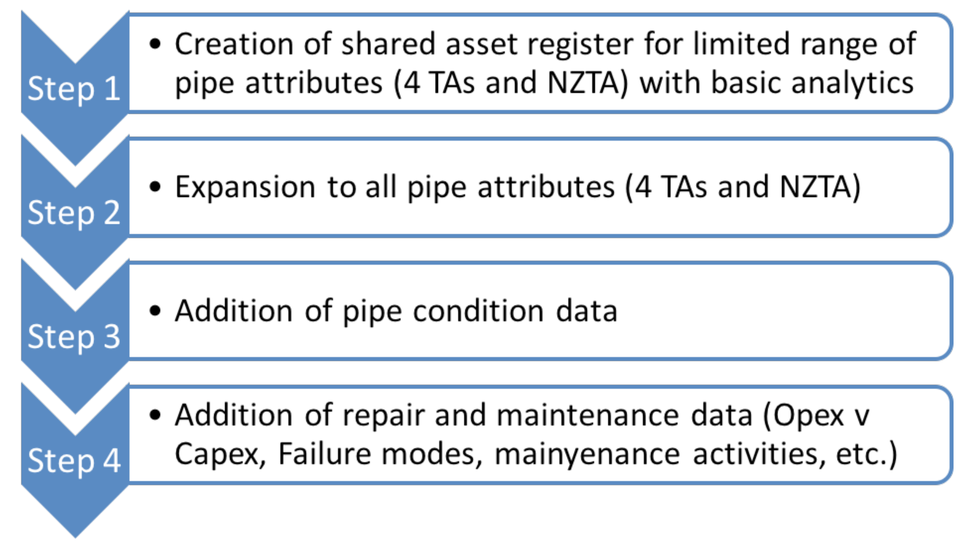


Fig 2: First four steps of agile portal development

What are the benefits?

The benefits of a National Pipe Data Portal are:

- National Government
  - Understand the contingent liabilities faced by the country in respect to natural hazards and under-investment
- Local Government
  - Better knowledge and more accurate models of the useful life of their assets
  - Better data on which to make investment decisions
  - Better knowledge of risk and insurance needs
  - Alignment with a national standard allowing benchmarking, sharing of knowledge, process efficiencies, etc.
  - Faster and more efficient consenting processes.
- Contractors and developers
  - Faster and more efficient design, consent, construction and hand-over processes.

Conclusion

The National Pipe Data portal is a long-term project which has the opportunity to transform design, consenting, construction and management of New Zealand's pipe networks by bringing together all the key players in the municipal water sector.

OUTREACH ACTIVITY AND ACHIEVEMENT

Brandy Alger

Quake Centre outreach programmes aim to improve the resilience of New Zealand through education and increased awareness. By training industry and community leaders in scenario based disaster risk reduction, Quake Centre is helping to increase risk mitigation and disaster understanding at multiple levels.

Programmes underway

QuakeScape

QuakeScape is innovative puzzle-based scenario training for communities and industry leaders. The goal is to encourage participants to think about certain risks that can be mitigated in the event of a natural disaster.

QuakeScape begins as a game, where participants are encouraged to solve five puzzles themed around natural disasters. Each puzzle completed gives the team a code which unlocks a specific lifeline. Each puzzle leads to winning five lifelines (i.e. energy, waste water, drinking water, communication and transportation.) Once all lifelines are acquired, participants are asked to place lifelines onto a gameboard containing five themes (e.g. law and order, multi-hazard awareness, governance). By connecting a lifeline to a theme, the facilitator will announce a scenario involving the two, and the group must work out the optimal solution to mitigate risks associated.

This programme encourages risk mitigation and community thinking through fun game play. It is especially important in communities surrounding the Alpine Fault, and is currently funded through the Brian Mason Trust.

Fig 1: QuakeScape contains retro themed puzzles and an engaging scenario playing board

Public seminars

Public seminars run through Quake Centre are rapid-fire style talks open to the community, aimed particularly at young professionals. The seminars are presented by six to eight speakers ranging from community project leaders to engineers and researchers, who talk about earthquake resilience. The broad range of speakers connects many industry backgrounds with earthquake resilience and encourages attendees to continue bridging the gap between research and industry experience. Quake Centre also hosts ad-hoc presentations for industry professionals.

QuakeCraft

Other outreach programmes delivered through Quake Centre include QuakeCraft, a secondary school based programme which encourages year 9 and 10 students to design, build and test model houses on a shake table. The intended outcome of this project is to encourage students to think about structural resilience as well as community resilience.

Ideally, many of these students will rethink their career pathways and pursue an education in engineering or another earthquake resilience related field. This programme is being run nationally and is funded through the Unlocking Curious Minds grant.

Fig 2: QuakeCraft is currently being run in 10 schools across the South Island

Fig 3: Brandy Alger speaking to over 1,000 attendees of Pecha Kucha Christchurch

Benefits

The biggest benefit of the outreach programmes within Quake Centre is increased awareness within the community and industry. Connecting Quake Centre research to industry leaders and community members at a national level will not only increase education in earthquake resilience, but will augment a tighter network of professionals associated with Quake Centre's vision. Training at higher levels will improve disaster risk reduction and expand risk recognition in the event of a natural disaster.

Through increased earthquake resilience education and awareness, Quake Centre outreach is striving to make a difference in improving the resilience of New Zealand.

Timeline

QuakeScape was funded in June 2017 and the pilot is being carried out until January 2018. QuakeScape will be run on a national level by June 2018, focussing on industries and communities in the path of the Alpine Fault.

Public seminars are ongoing and will be carried out on a national level throughout 2018. Most public seminars are hosted by local IPENZ Engenerate groups and have been well attended.

Acknowledgment of partners

Outreach for Quake Centre could not have been achieved without the generous financial support of Quake Centre partners along with QuakeCoRE and assistance from Fabriko Ltd.

THREE WATERS RESILIENCE GUIDELINE

Marcus Gibson & Melanie Liu (Beca Ltd)

Water supply | **Wastewater** | **Stormwater**

Supporting local authorities and the private sector to assess resilience of three waters systems in the event of extreme natural hazards

- Assess the resilience of three waters systems in the event of natural hazards, at city/district level, taking into account level of service requirement
- Improve system resilience through use of effective asset management strategies
- Standardise and embed system resilience assessment into asset planning and management as business-as-usual programme

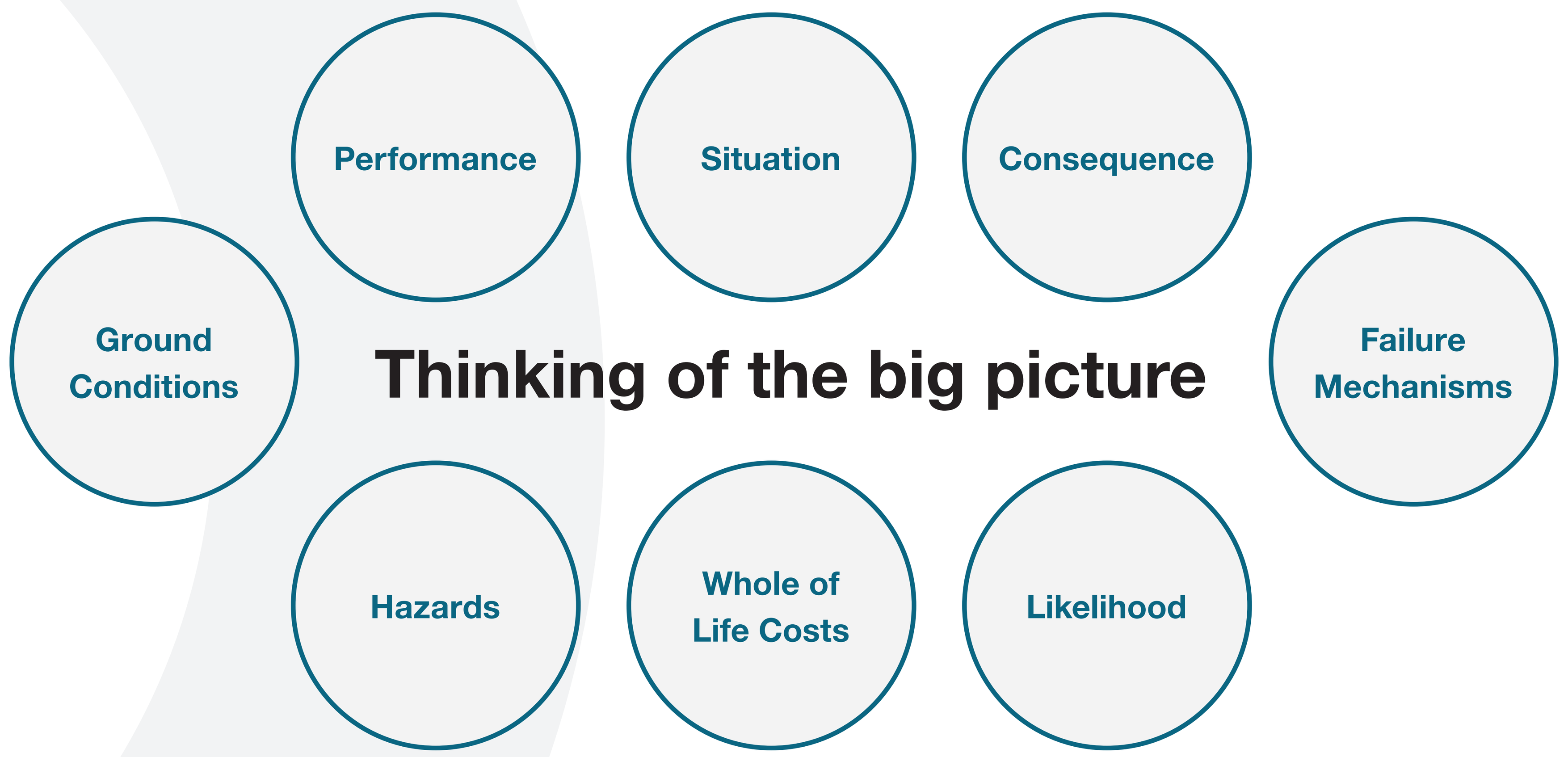


Fig 1: Assessment by both engineering judgement and analysis

Problem

- Resilience of three waters networks is an important element of the overall resilience of communities.
- Traditionally, determining infrastructure resilience is challenging due to the complexity of non-linear, interacting and highly unpredictable processes that lead to wide variety in performance outcomes.
- With limited resources available to rebuild infrastructure in New Zealand, it is important that the opportunity to improve resilience through ongoing renewals is maximised. Understanding the benefit of replacing each asset on Level of Service (LoS) can focus asset management decision making, and further differentiate and refine renewal strategies.
- There is a lack of guidance on how to conduct a resilience assessment for three waters infrastructure.
- There is variability in the approach and level of detail of assessment currently preformed in New Zealand.
- Traditionally, asset managers and engineers focus using modern materials as a proxy for improving resilience. However, resilience is the ability and speed of the network LoS to bounce back following an event. Resilience assessment needs to consider both damage and the consequence of this damage on the operation of the network, and the community effects.

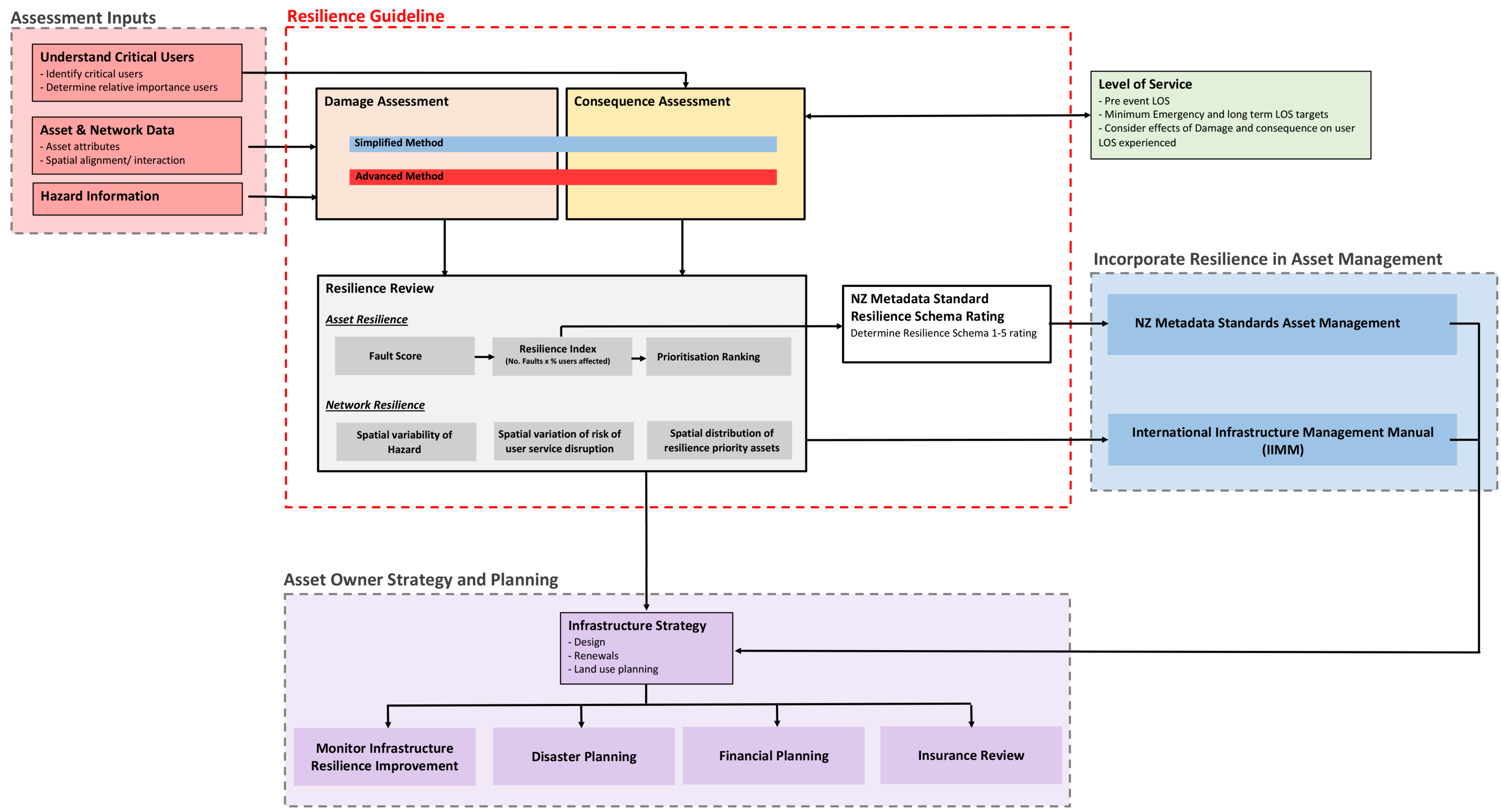


Fig 2: Summary flow diagram of guideline process and external interface

Output

The output of the project is a guidance document to:

- Identify spatial understanding of hazards, anticipated damage, and network consequence.
- Identify key facilities in the network and whether satisfactory service is anticipated.
- Provide prioritisation ranking of assets within the network to inform asset renewal selection.
- Identify network zones at risk, requiring network strategy review and physical improvement.
- Quantify and monitor network resilience over time.
- Provide New Zealand Metadata Standard Resilience Schema Rating (1-5).

Benefits

- Standardised approach to assessment of resilience across New Zealand
- Maintaining some ability for users to mould the assessment approach to fit their requirements and the needs of the community
- Maximising the value of existing assets
- High level strategic management
- Integrating system resilience at the planning stage
- Improved understanding of network – hazards, areas of vulnerability and consequence.
- Outputs can feed into:
  - Asset management (NZ Metadata Standard, International Infrastructure Management Manual)
  - Disaster planning
  - Financial planning
  - City planning

Acknowledgements

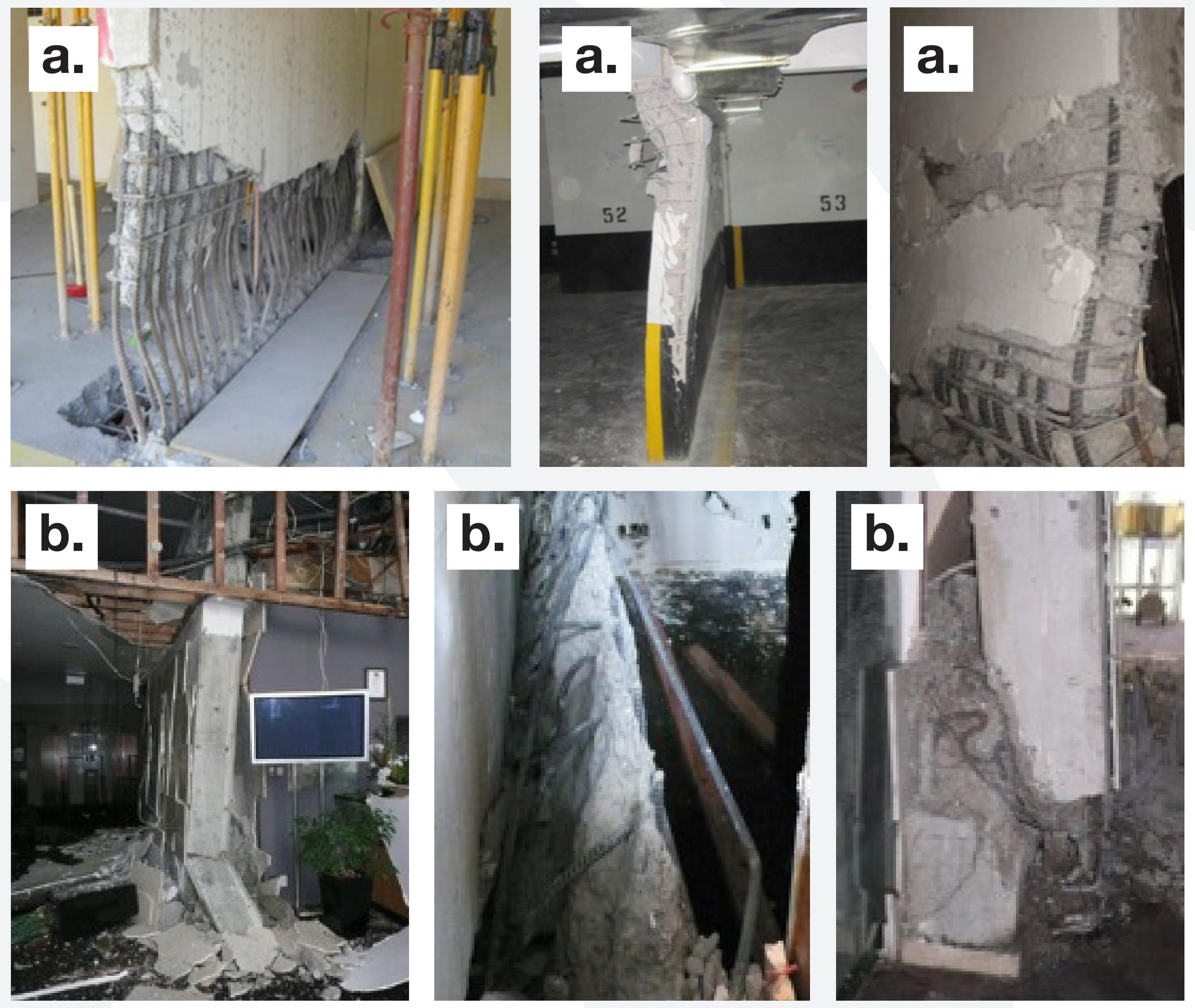
The project team wishes to acknowledge the financial support provided by the Quake Centre partners and Water NZ and IPWEA

SEISMIC BEHAVIOUR OF RECTANGULAR DOUBLY REINFORCED CONCRETE WALLS UNDER BI-DIRECTIONAL LOADING

A. Niroomandi, S. Pampanin, R. Dhakal & M. Soleymani Ashtiani
Department of Civil & Natural Resources Engineering

Statement of the problem

- Following the recent earthquakes in Chile (2010) and New Zealand (2010/2011), peculiar failure modes were observed in Reinforced Concrete (RC) walls. Some of these failure modes included out-of-plane instability and out-of-plane shear failure, which could potentially result from bi-directional excitations.



Failure modes observed in 2010/2011 New Zealand earthquake (a) Out-of-plane instability (b) out-of-plane shear

- There is a global concern on the contribution of bi-directional loading to these failure modes.
- So far the effects of bi-directional loading on the design/assessment of rectangular walls are ignored.

Purpose of research

- Identify the key parameters influencing the seismic performance of rectangular RC walls under bi-directional loading.
- Assess if bi-directional loading can change the damage/failure mode expected in uni-directionally loaded walls, and if yes, what are the likely changes.
- Investigating the effects of different loading patterns on rectangular RC walls.
- Simulating the possible failure mode(s) that can be activated in rectangular RC walls due to bi-directional loading in the laboratory.

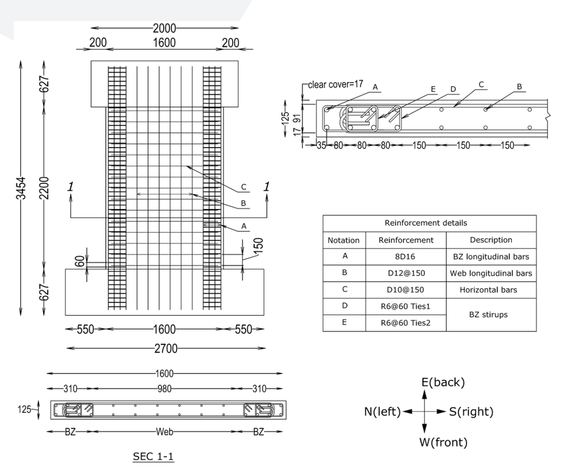
Project output

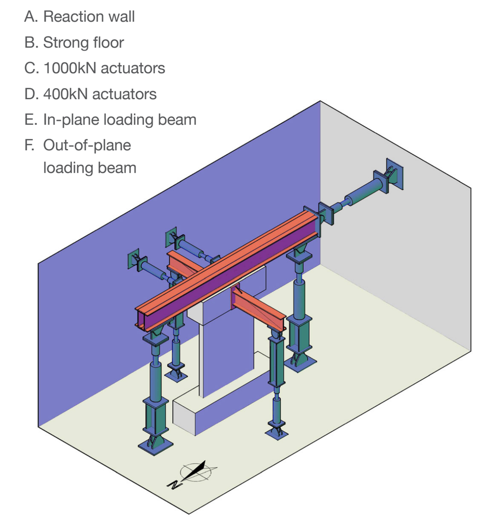
- Develop a simplified analytical method (equation/table/charts) to predict the drift capacity of rectangular RC walls taking into account the effect of bi-directional loading.
- Verify the reliability of current code-based design requirements for walls subject to more realistic cyclic loading regimes.
- Suggest recommendations/guidelines (based on experimental and analytical/numerical evidences) to improve current practice (taking into account bi-directional loading/response) for both the design of new walls and the assessment of existing ones to assist engineers in their daily practice.

Experimental campaign

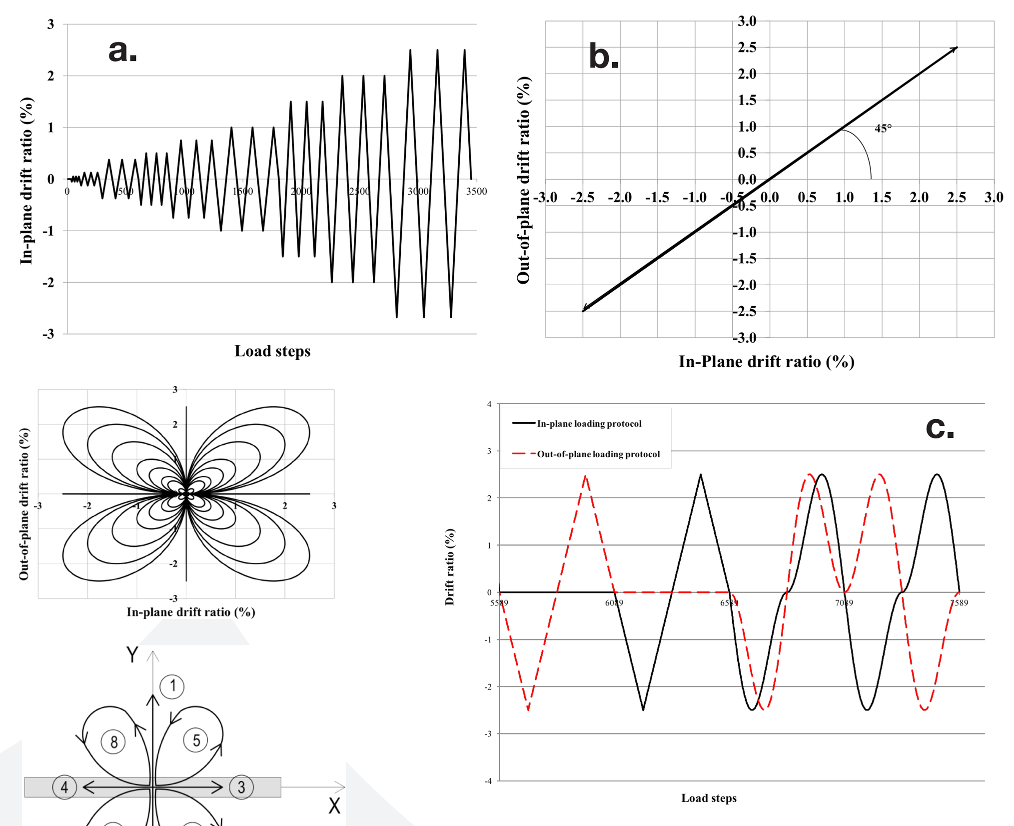
Experimental campaign includes two main phases:

1. Rectangular slender RC walls prone to out-of-plane instability under different loading regimes (presented here)
2. Rectangular slender RC walls prone to out-of-plane shear failure under bi-directional loading


Details of the section and side view of the reinforcement layouts of the first phase specimens

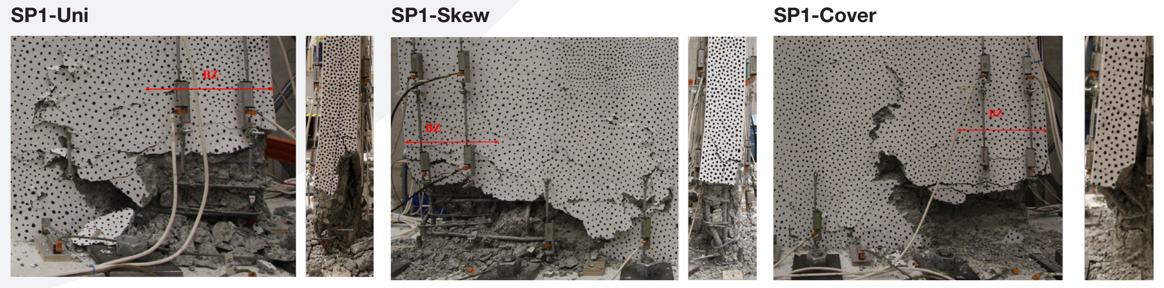


Schematic view of the test setup



Loading protocols of each specimen, (a) SP1-Uni (b) SP1-Skew (c) SP1-Clover

SP1-Uni SP1-Skew SP1-Cover

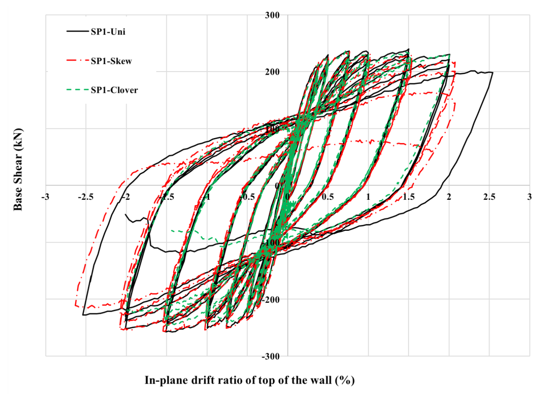


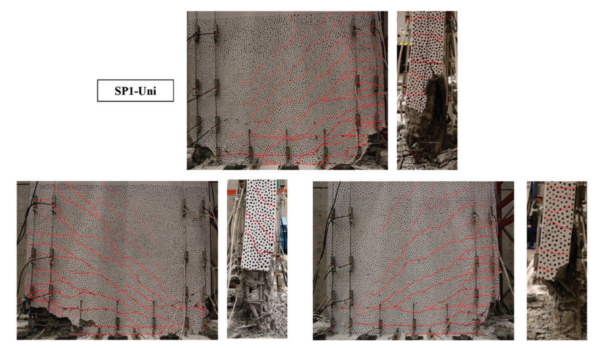
PROJECT TIMELINE — GO LIVE

MAY 2014 — OCTOBER 2018

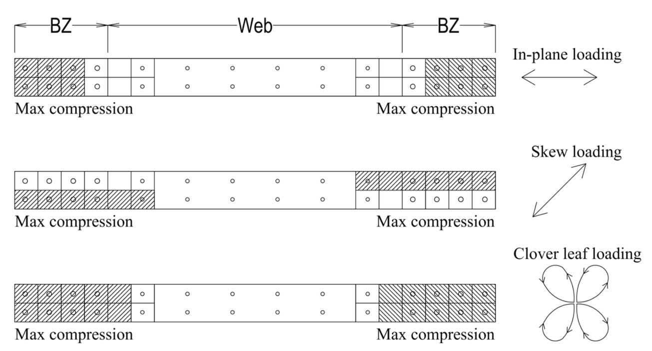
Discussion of the test results

- Significant increase of steel and concrete compressive strain. Earlier concrete cover spalling and bar buckling.
- Substantial increase in NA depth and the compression zone. Therefore, considerable concrete crushing and bar buckling in the web.
- Shear cracks in both in-plane and out-of-plane directions in the specimen under skew loading. Further development of such cracks can change the failure mode of the wall to an out-of-plane shear failure as was observed in wall D5-6 from Grand Chancellor Hotel in the 2011 Canterbury earthquake.
- The experimental results show that the confinement length and the amount of transverse reinforcements recommended by NZS3101:2006 might not be enough when the wall is under bi-directional loading. However, it supports the need to use anti buckling ties in the web as it is compulsory by the third amendment of NZS 3101:2006 for ductile walls.

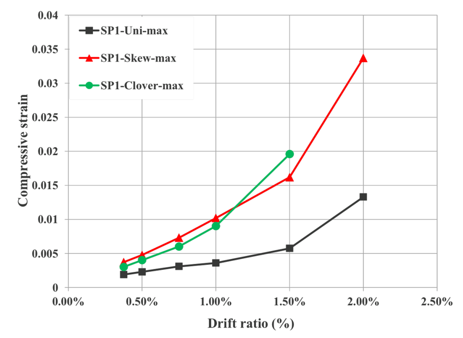

In-plane base shear - drift ratio of the three specimens

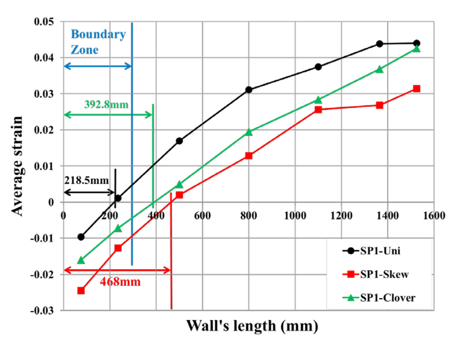


Concrete cracking in the in-plane and out-of-plane directions

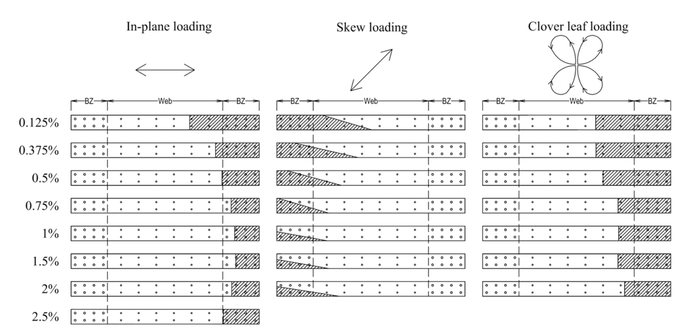


Schematic view of the effect of different loading patterns on the compressive strain of the wall


Maximum compressive strains of the specimens at each drift level



Strain profile along the wall's length at the first cycle of 2% drift

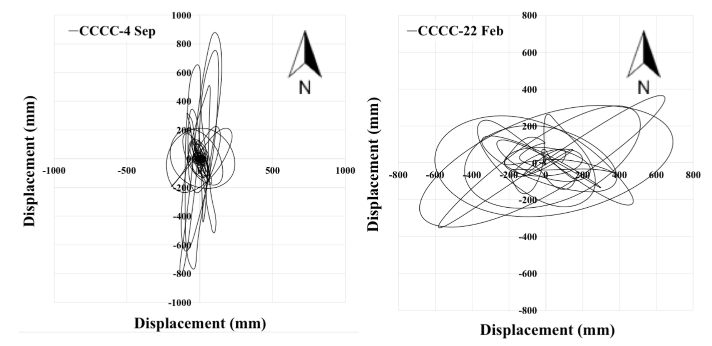


Maximum compressive strains of the specimens at each drift level

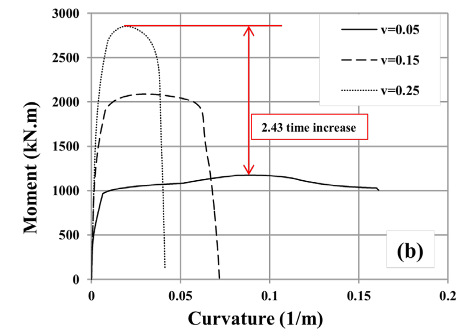
Numerical study

Numerical study includes three main phases:

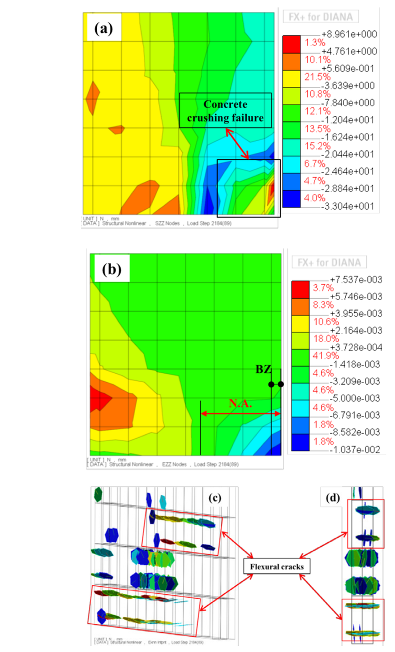
1. Numerical parametric study of squat rectangular walls under bi-directional loading
2. Finite element simulation of a case study RC wall – Wall D5-6 from Grand Chancellor Hotel, Christchurch, New Zealand (presented here)
3. Numerical parametric study of slender rectangular walls under bi-directional loading

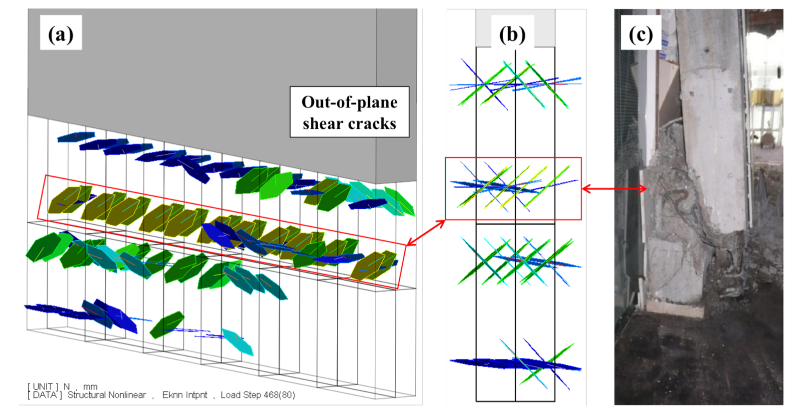


Directionality of the September 2010 and February 2011 earthquakes

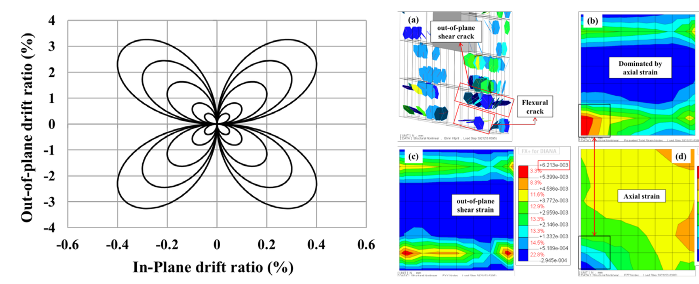


Moment-curvature diagram of wall D 5-6 in the out-of-plane direction for different axial load ratio

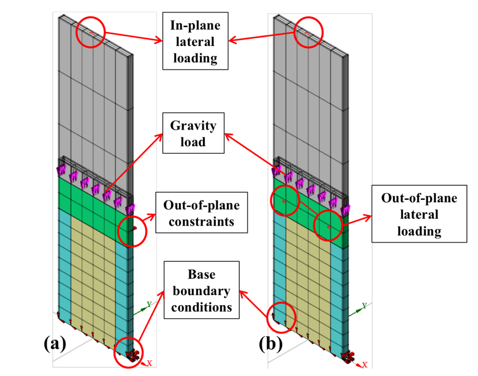

Wall D5-6 under in-plane uni-directional loading (a) axial stress, (b) axial strain and (c and d) crack pattern in the in-plane and out-of-plane directions



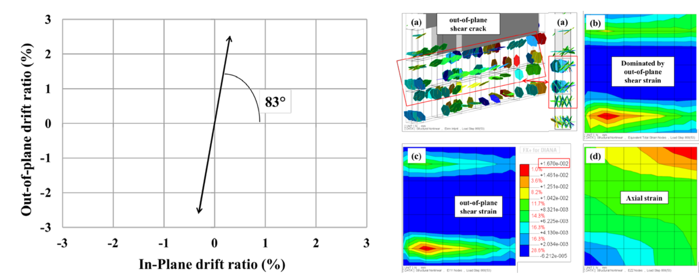
Crack pattern of wall D5-6 under out-of-plane uni-directional loading (a and b) Finite Element and (c) February 2011 earthquake



Wall D5-6 under clover leaf with 83 degree (a) Crack pattern, (b) Von Mises strain, (c) out-of-plane shear strain and (d) axial strain



Finite element model and boundary conditions for walls under (a) uni-directional and (b) bi-directional loadings



Wall D5-6 under skew loading with 83 degree (a) Crack pattern, (b) Von Mises strain, (c) out-of-plane shear strain and (d) axial strain

- Directionality of the September earthquake was along the in-plane direction of the wall D5-6 while the February earthquake was towards the out-of-plane direction.
- Shear demand of the wall was increased significantly due to the high axial load ratio of the wall.
- The numerical study showed that while the wall D5-6 was vulnerable in shear in the out-of-plane direction due to high axial load, the Christchurch 2010 February earthquake which was a skew loading towards the out-of-plane direction of the wall caused a shear failure in the out-of-plane direction.

Quake Centre — Delivering Industry Solutions

Funded by industry to deliver solutions to industry identified needs.

NZSEE GUIDELINE FOR DESIGN OF SEISMIC ISOLATION SYSTEMS FOR BUILDINGS

David Whittaker, Will Parker

Overview

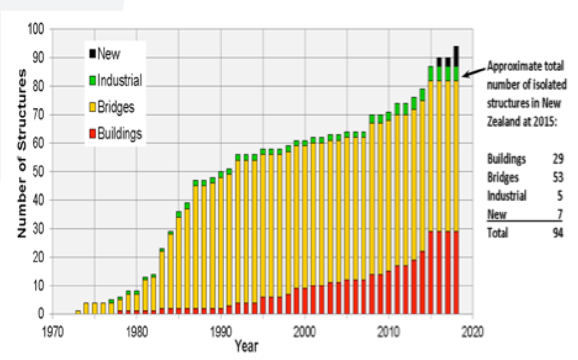
UC Quake Centre is managing the NZSEE-led project to prepare a guideline for the design of seismic isolation systems for buildings in New Zealand. The project is funded by MBIE, EQC, NZSEE, SESOC and NZCS.

Following the Canterbury Earthquakes there has been a strong market-driven interest in the use of base isolation in buildings to provide more damage resistant performance. Since 2011 around fifteen buildings have been built or retro-fitted with isolation in Christchurch alone. The Canterbury Earthquakes Royal Commission recommendations 66-69 called for MBIE to promote further knowledge and guidance around the use of low damage design technologies, of which seismic isolation is arguably the best proven.

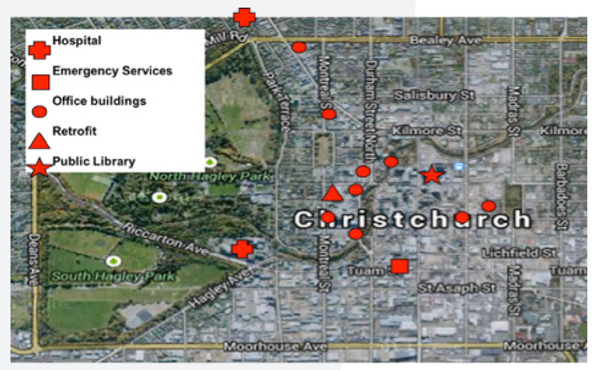
The guideline is intended to be used as part of Alternative Solution designs for compliance with the New Zealand Building Code. The guideline is written in code and commentary format compatible with NZS 1170.5. The document may eventually be cited under Section 175 of the Building Act which provides for the Chief Executive of MBIE to publish guidance documents.

The group preparing the document is drawn from the major consultancies designing base-isolated buildings.

The guideline has been drafted and is currently being edited for a first round of international peer review.



Growth in numbers of isolated structures in New Zealand



Isolated buildings in Christchurch as at 2015

Isolated building types

Four isolated building types are designated and designers must determine which type they will design for and follow the requirements and criteria for that type.

Type 1. Simple regular and low-rise superstructures. Design to remain elastic and using simple equivalent static analysis.

Type 2. Normal superstructures not meeting Type 1 requirements. Designed for nominally ductile behaviour and using at least modal response spectrum analysis methods.

Type 3. Complex superstructures and those for which some ductility may be assumed, or the isolation plane does not provide the full displacement demand on the system. Nonlinear Time History Analysis is required.

Type 4. Brittle superstructures including existing structures.

Isolator device types covered by the guideline include elastomeric (including lead rubber) bearings together with flat sliders, curved surface sliders and viscous damper devices.

Low damage performance-based design and limit states

The guideline recommends a Damage Control Limit State (DCLS) and a Collapse Avoidance Limit State (CALS) for isolated buildings. This approach requires that the overall building, including isolators and rattle space, is explicitly capable of surviving the displacement demands for the rare earthquake event referred to in NZS 1170.5.

The approach is consistent with the current Low Damage Design guideline that MBIE is developing, which includes similar performance objectives and performance assessment criteria. An important part of the low damage design approach is to not only delay the onset of damage to the building (as a whole including secondary elements and fitout) but to also consider how to make any damage repairable within targeted cost and time constraints. An important principle is to communicate the damage control objectives with the building owner and occupants through the Design Features Report.

Design seismic loadings for isolated buildings

The guideline includes change to the long period portions of the NZS 1170 design spectra, which typically govern the design of isolated buildings. The corner period at which the constant displacement part of the spectrum starts has been extended from 3 seconds to 4 or 5 seconds for some geographical locations. This has the effect of increasing displacement demands on isolation systems in those areas.

Design displacement spectra are directly provided, allowing designers to represent seismic demands in acceleration-displacement response spectra (ADRS) format. This format is convenient for designing isolated structures using simplified capacity spectrum methods for determining base shear and displacement demands and system response. ADRS demand spectra are further modified for isolated structures to account for increased (hysteretic) damping that that will be available from typical isolation systems.

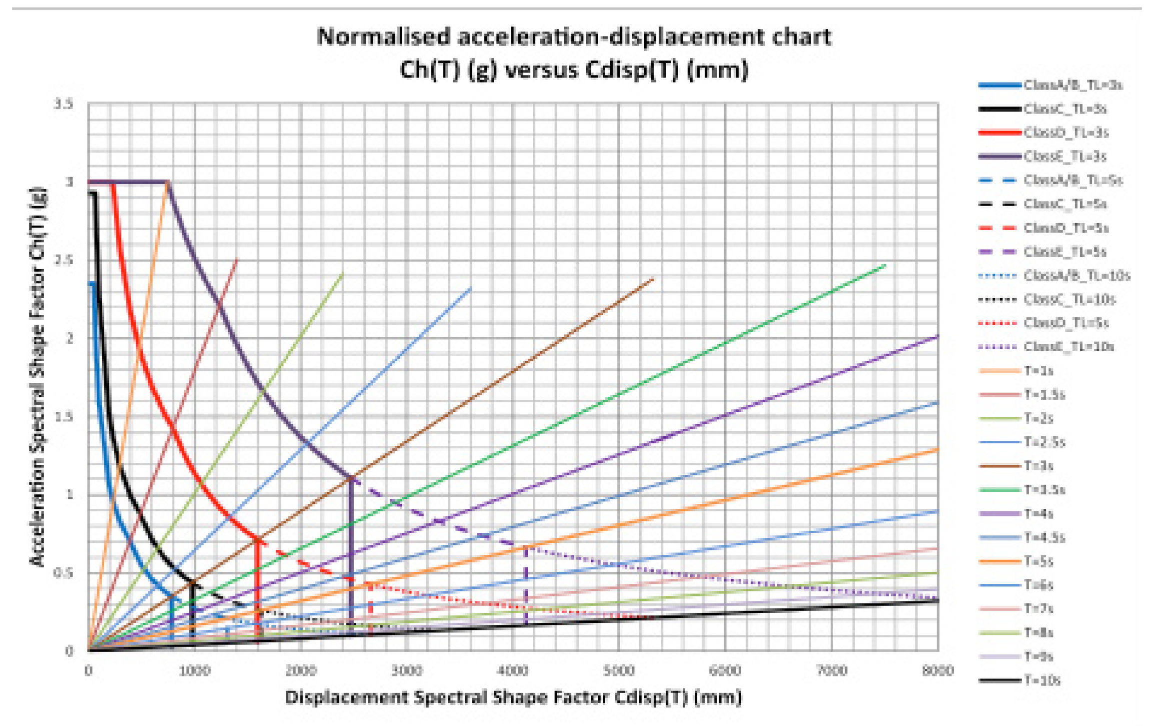
Design of isolated buildings

NZS 1170.5 design parameters, such as Structural Performance Factor Sp, design ductility factor μ (and kμ) for isolated buildings, are given for each isolated building type.

Preliminary analysis for all isolated building types would typically start with single degree of freedom analysis of a rigid building on a flexible isolation layer, followed by more detailed analysis using equivalent static, modal response spectrum or nonlinear time history analysis, depending on the type and complexity of the building.

Isolator property variability (upper and lower bound) must be considered in addition to nominal isolator system properties. Upper bound properties lead to maximum force demands on the structure, and lower bound properties lead to maximum displacement demands on the isolators.

Flow charts are provided for each building type and separately address performance design of the isolated building overall, performance at the isolators, adjacent stability structure, rattle space, substructure and superstructure.



Seismic isolation system capacity and ADRS demand curves

Guidance is provided for parameters to carry over to the materials standards for design of foundation, substructure and superstructure.

A minimum level of ductile detailing and capacity design will generally be required in the superstructure to allow for unexpected inelastic demands.

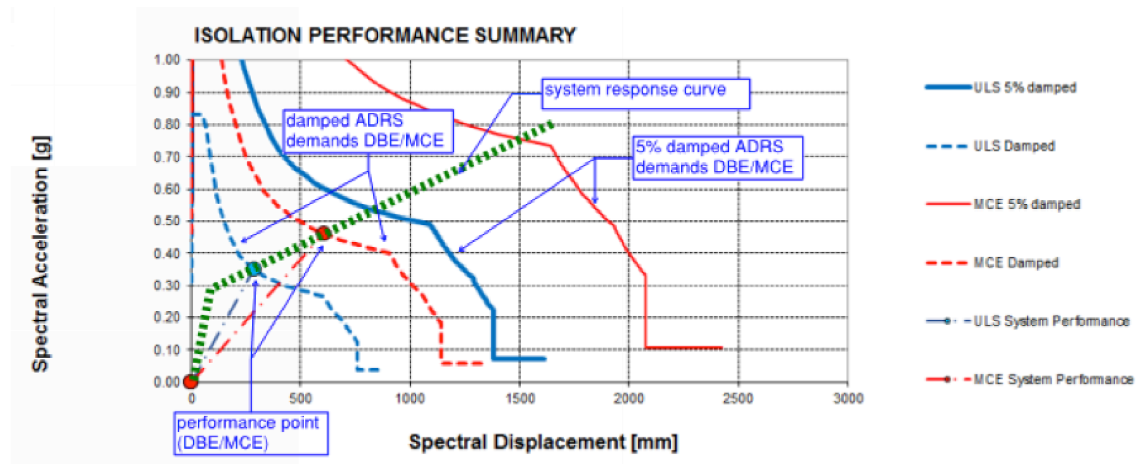
Procurement of isolators

Guidance is provided for performance-based specification of the isolation system and isolator devices based on international standards from the US (ASCE) and Europe (EN 15129). A sample specification is also provided. Designers are recommended to select the type and number of isolators to be provided and to prepare a performance-based specification giving the combinations of design forces and displacements that isolators are to be supplied for. It is strongly recommended that actual design of the isolators is left to the supplier in accordance with an approved international standard. Qualification, prototype and production testing sequences and acceptance criteria are to be specified. Full-scale testing of isolators or similar prototypes is generally required.

International peer review

Three international peer reviewers (from USA, Europe and Japan) have been approached to review the document.

Progress



Seismic isolation system capacity and ADRS demand curves

As at November 2016, all sections of the guideline have been drafted and technical editing is proceeding. The document will now be sent to international peer reviewers for a first review, before being finalised by the project team and reviewed again. Industry trialling and review will also be sought. A working guideline is expected to be available in early 2017.

Project management

The project has a Governance Group comprising representatives of the Funders, UCQC and the project leaders. UCQC is providing the project management.

Guideline authors

Will Parker (Opus) co-leader

David Whittaker (Beca) co-leader

Graeme McVerry (GNS)

Alastair Cattanach (Dunning Thornton)

Didier Pettinga (Holmes Consulting)

Kam Weng Yuen (Beca)

Dario Pietra (Holmes Consulting)

Andrew Charleson (Victoria University)

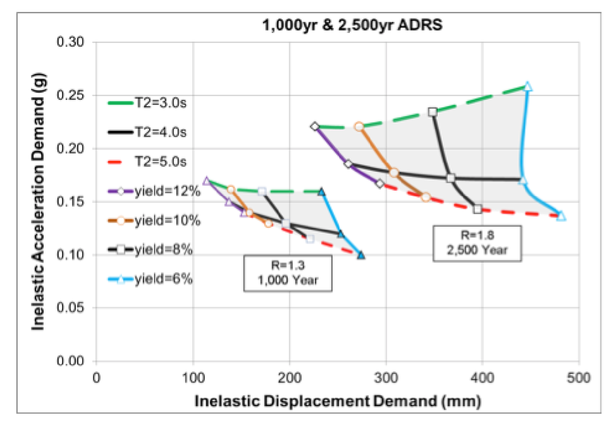
Acknowledgements

The financial support of the funders is gratefully acknowledged.

Awly– new isolated building in Christchurch

Christchurch Art Gallery – retrofitted with isolation

Transmission Gully Bridges to be isolated



Inelastic demand Acceleration and Displacement Spectra for Christchurch to NZS 1170.5 (Whittaker and Jones 2014)

Quake Centre
Delivering Industry Solutions

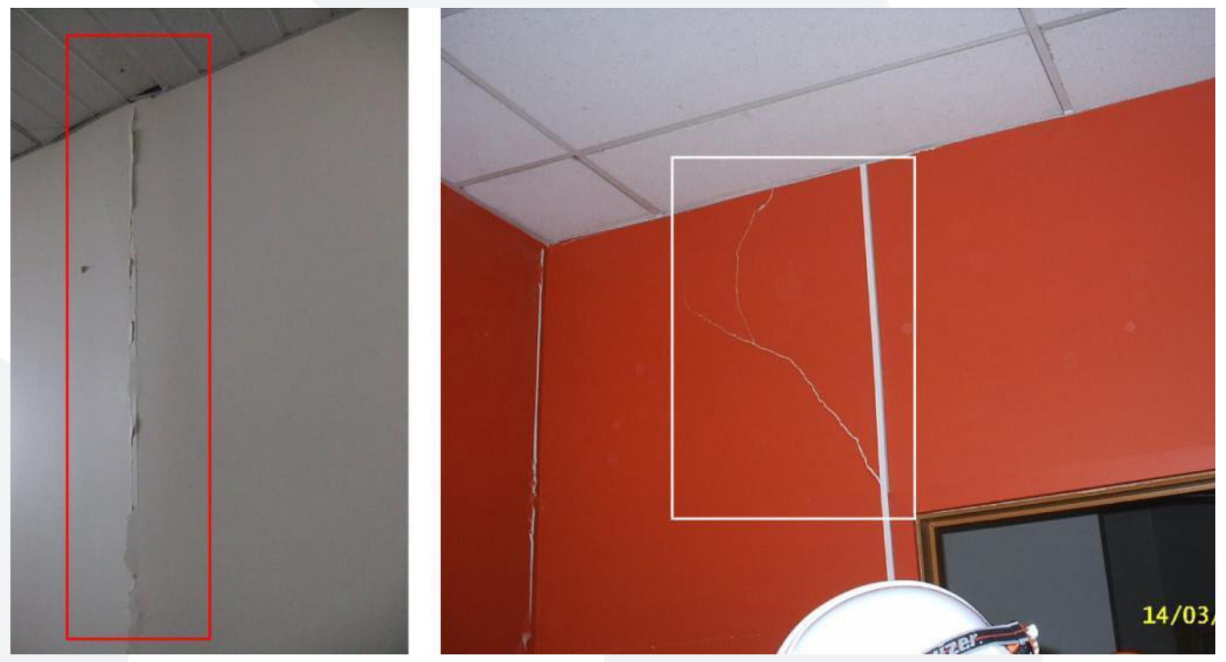
Funded by industry to deliver solutions to industry identified needs.

LOW DAMAGE NON-STRUCTURAL DRYWALLS FOR COMMERCIAL MULTI-STOREY STRUCTURES

Dr. Ali Sahin Tasligedik, UC Quake Centre, sahin.tasligedik@canterbury.ac.nz

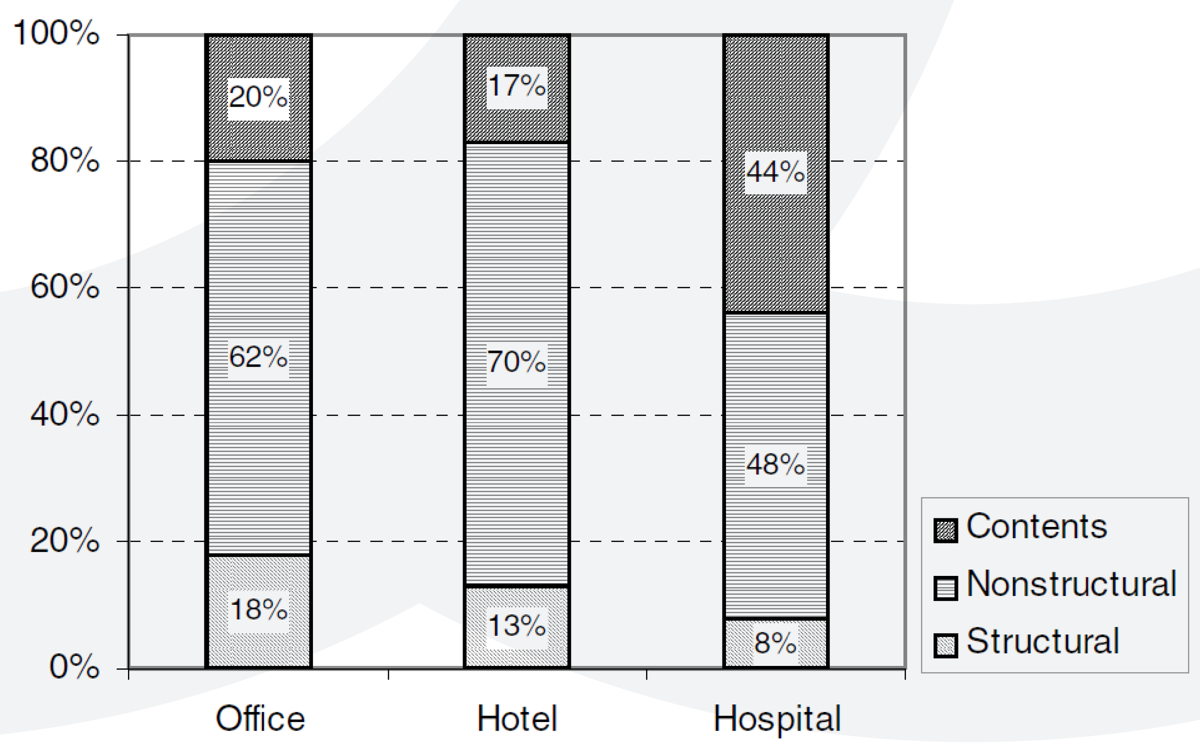
Introduction and statement of the problem

Modern structural systems are generally able to perform well in accordance with the life safety and serviceability limitations defined by the seismic standards. On the other hand, the existing non-structural partition systems are not on par with these structural systems, resulting in a non-uniform serviceability expectation within structures. This usually manifests itself as low or moderate damage to the structural system under a serviceability limit state earthquake while severe non-structural damage can be expected from the non-structural drywall partition systems. Serviceability loss and the resulting downtime of structurally intact buildings was a common occurrence after the Christchurch earthquake in Feb 2011.



Example drywall damage

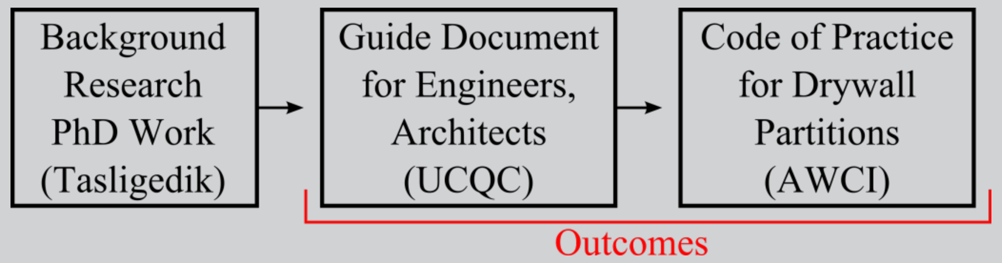
Considering the cost breakdown of non-structural elements within buildings, damage to such components places a large burden on economy. Therefore, seismically resilient drywall partition systems are a must for the general earthquake resilience of New Zealand.



Cost breakdown of structural and non-structural components (Miranda 2003)

Project outputs

The background and the theory of this work is based on the past PhD research carried out by Ali Sahin Tasligedik. The output of this project will be a design guide for low damage non-structural drywall partitions aimed at structural engineers, architects and the contractors (to an extent). The outputs of this work will be implemented in the upcoming AWCI Code of Practice for drywall partitions.

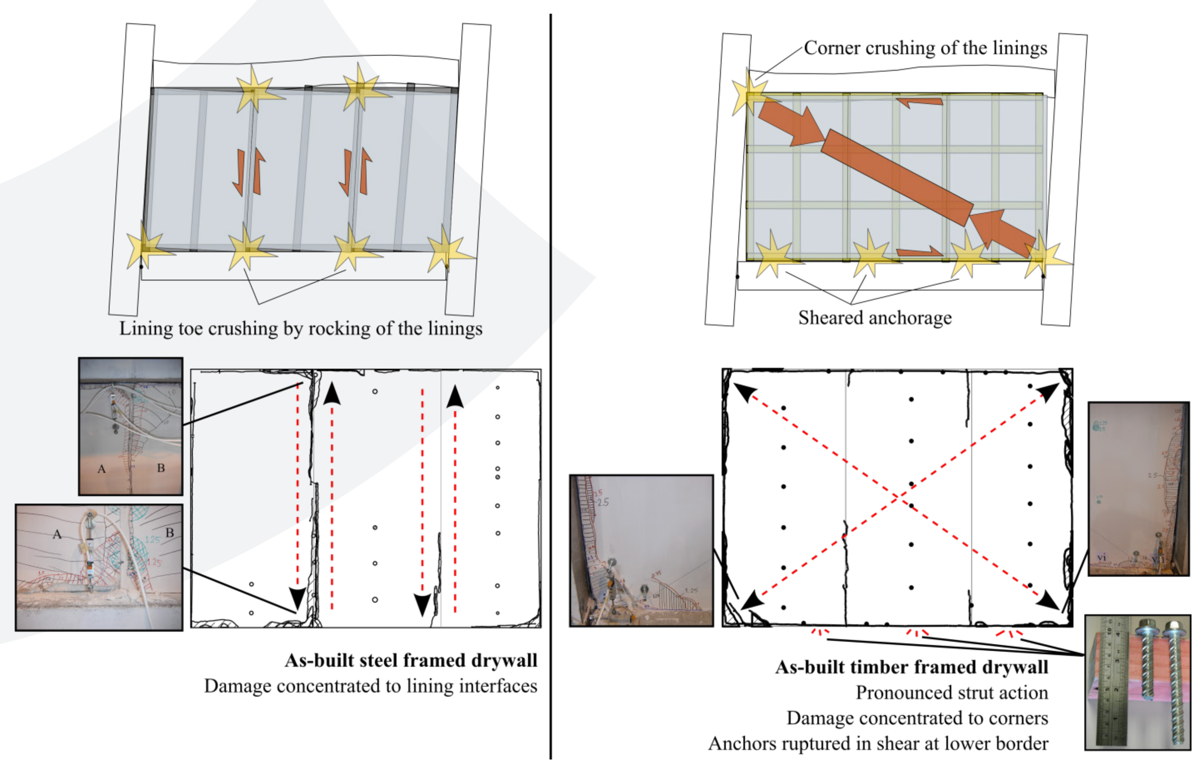


Benefits of a low damage drywall partition

- Significant economic burden can be lifted from the economy after moderate earthquakes.
- Low damage drywalls can be designed for any seismic deflections using any required design drift level.
- There will be no downtime caused by damage to non-structural partition system since the partition will remain operable after moderate seismic events (or even larger earthquakes).

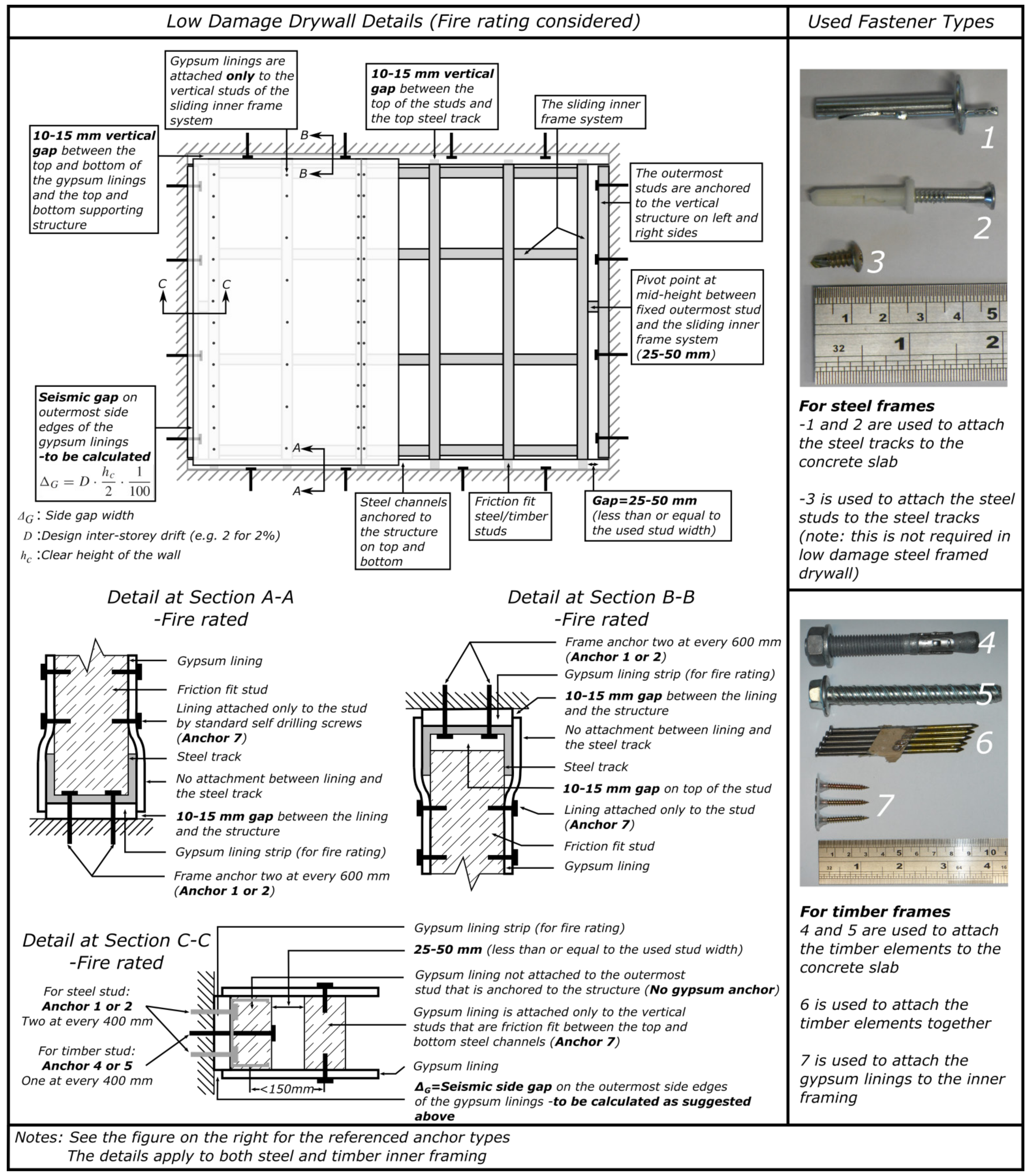
Seismic damage to existing drywall partitions

Existing drywalls have very low displacement capability and undergo seismic damage at very small inter-storey drift levels. Steel framed drywalls suffer damage at 0.3% drift level while timber framed drywalls suffer damage at 0.75% drift level (based on the past experiments).



Seismic drywall details for low damage

The conceptual summary and details of the developed low damage drywalls are shown in the figure below. It should be emphasized that these solutions are referred as low damage solutions and some damage is expected under extreme deflections since the damaging drift level is under complete control of the engineer. However, such damage has been experimentally shown to be very minor plaster damage occurring at extremely high drift levels where the structural damage is expected to be more dominant than the non-structural wall damage.



Low damage drywall detailing

Example application from practice

There are example applications of these low damage drywalls in the construction industry:

1. Novotel, Christchurch, New Zealand (Completed construction)

Low damage drywall application at Novotel, Christchurch (courtesy of Frank Kang, Winstone Wallboards)

2. New Christchurch City Library (Design stage at Architectus and Lewis Bradford)

Concluding remarks

Considering the cost breakdown of structural and non-structural systems over the total cost of a structure, economic burden resulting from the damage to the non-structural systems is evident. In addition, modern seismic design dictates low serviceability displacement levels in order to protect these elements, which is likely to be exceeded in moderate seismic events. The developed low damage drywall details are very efficient in reducing seismic damage to these components as well as increasing the resilience of drywall partition systems generally. UC Quake Centre is in close collaboration with AWCI to include these details and design methods in the upcoming code of practice for drywall partition construction in New Zealand.

Acknowledgements

We would like to express our gratitude to UC Quake Centre for funding this project. We are also very grateful for the collaboration with Frank Kang (Winstone wallboards), Hans Gerlich and Denis Prout (AWCI). For these system to be adopted in real applications, close industry collaboration is crucial and any communication we are having is greatly appreciated.

DESIGN OF FRP STRENGTHENED RC BEAM-COLUMN JOINTS USING STRENGTH HIERARCHY ASSESSMENT METHOD

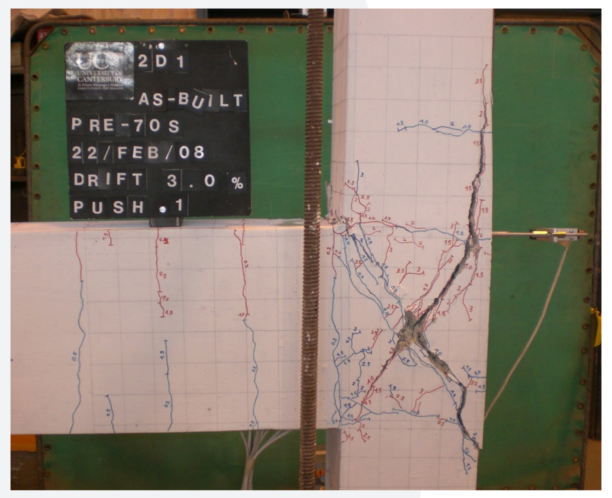
Dr. Ali Sahin Tasligedik, UC Quake Centre, sahin.tasligedik@canterbury.ac.nz

Introduction and statement of the problem

In practice, there are not many options to strengthen vulnerable reinforced concrete beam column joints. Moreover, their design is usually time consuming and complicated. In this work, the Fiber Reinforced Polymer (FRP) beam-column joint strengthening layout adopted by the researchers at the University of Canterbury (UC) has been studied and improved for practical adoption by structural engineers.

A simplified analysis and design procedure is proposed that can be used to quantify the provided capacity. This work aims to provide the New Zealand Structural Engineering community with a practical and accurate FRP strengthening design approach. The proposed procedure can facilitate the use of this strengthening scheme in real life engineering applications. The developed methods are based on the utilization of strength hierarchy assessment, which was improved previously within the scope of this project.

Joint shear failure (Amuri Courts, Christchurch Earthquake February 2011)



Joint shear failure of vulnerable reinforced concrete beam column joints (courtesy of Dr. Umut Akguzel)

Project Outputs for Structural Engineers

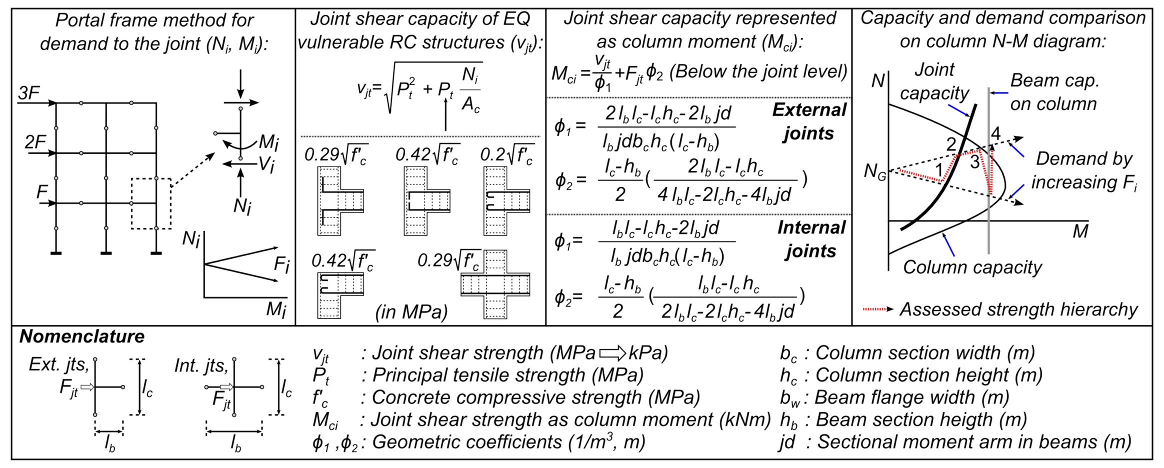
Guidance documents for structural engineers	←	Reinforced concrete beam column joints (UC research)	→	Strength hierarchy and global capacity -Peer reviewed &published in JEE Final draft guide and online course in progress
			→	Strengthening by fiber reinforced polymers (Late 2016) -To be presented in WCEE

Benefits of the method

- Application can be done in a matter of hours.
- The engineer understands the structural behaviour and its parameters unlike computer analyses (black box).
- Manual calculations, a spread sheet software and basic reinforced concrete knowledge is required.
- After the application of the strength hierarchy assessment method, FRP design of a vulnerable beam column joint can be immediately carried out.
- An immediate observation can be made to determine if FRP strengthening is the most effective option for a given RC beam column joint, making the retrofit decision faster.

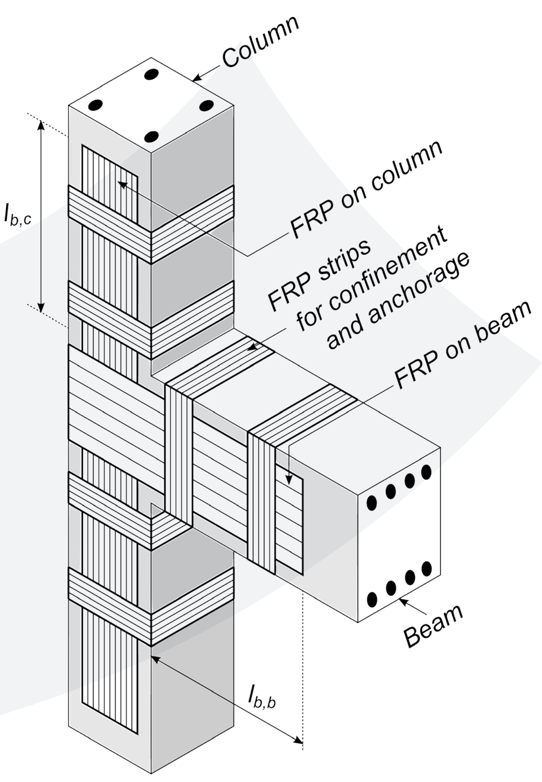
Summary of the strength hierarchy assessment method

Strength hierarchy assessment was previously improved and presented as the basis of the approaches in this project. It is used in order to quantify the capacity of an existing RC frame structure as well as the design of the joint strengthening. RC beam column joint strengthening by FRPs can be directly implemented in this assessment method.

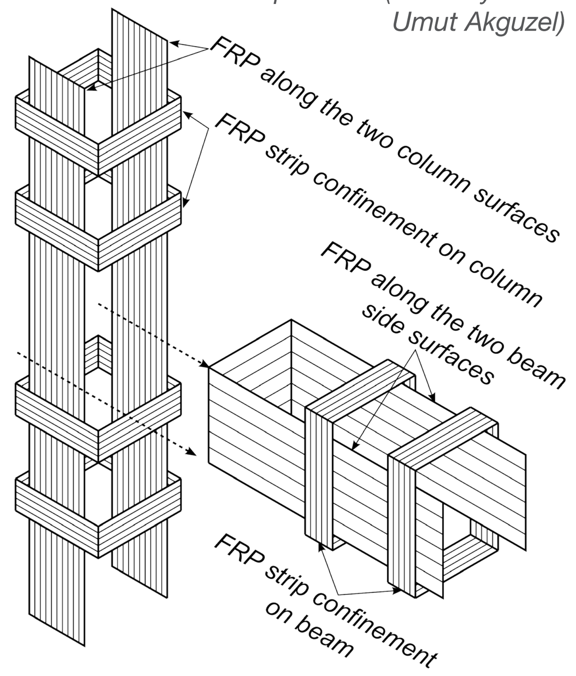


FRP Strengthening Scheme for the RC Beam Column Joints

FRP application on a test specimen (courtesy of Dr. Umut Akguzel)



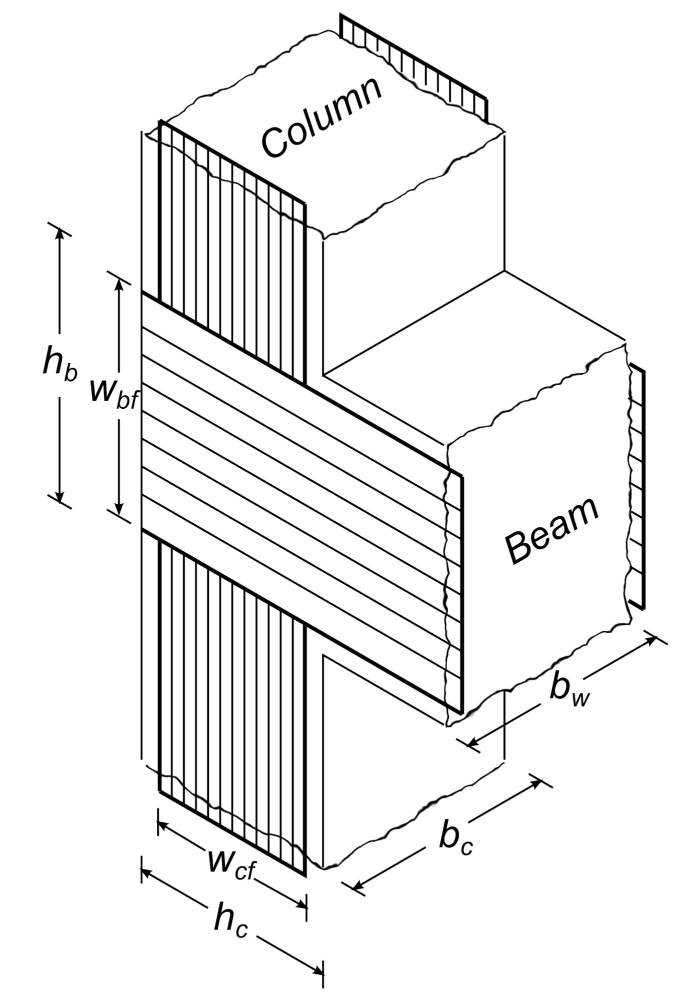
$l_{b,b}$, $l_{b,c}$: FRP bond length along beam and column



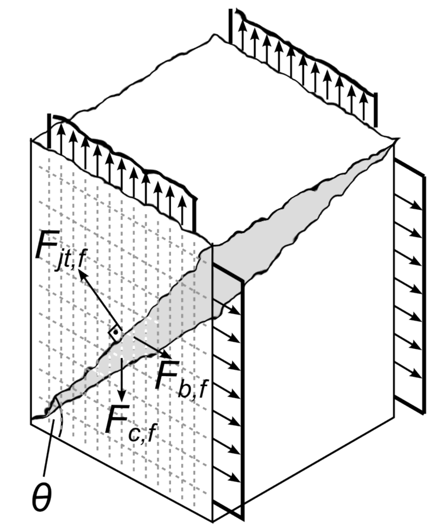
FRP scheme for joint strengthening used in past UC research

Capacity of FRP strengthened RC beam column joints

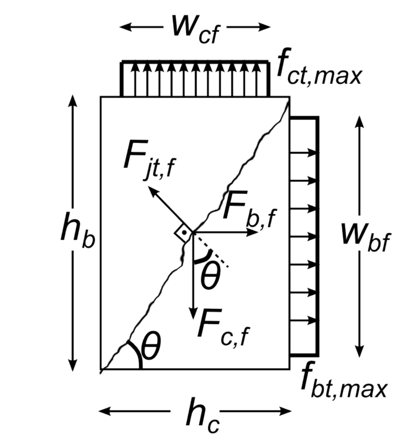
The joint shear capacity provided by the adopted FRP scheme can be approximately quantified for use in strength hierarchy assessment as follows.



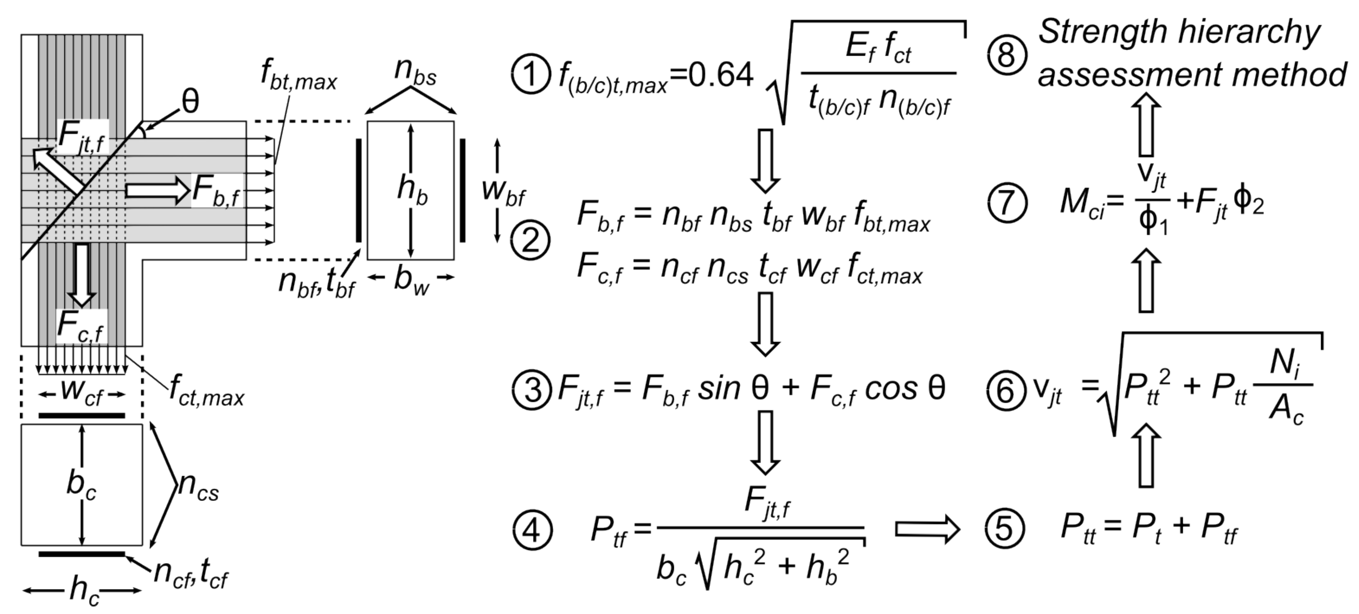
-Joint panel zone-

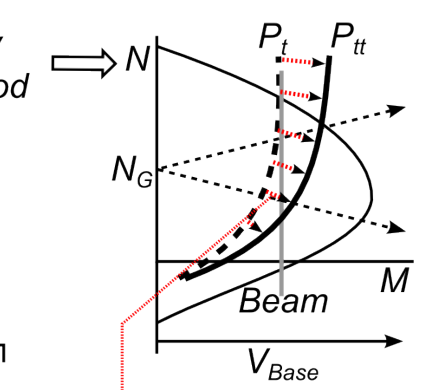


-Front view of the joint-panel zone



θ: Diagonal cracking plane averaged from corner to corner





Increased joint shear capacity/base shear
Note: FRP retrofit has diminishing returns for added capacity

Concluding remarks

The procedure is confirmed and reported for the quantification and assessment of the provided capacity as a result of the given FRP joint shear strengthening layout. The procedure does not require complicated computer models and can be conveniently implemented by the practitioner engineers using only a spreadsheet software and fundamental knowledge of reinforced concrete structures with accuracy and efficiency.

Acknowledgements

The author would like to express his gratitude to UC Quake Centre for funding this project.

The author is grateful for the background information, sources and comments provided by Umut Akguzel (Ramboll UK Ltd).

OUT-OF-PLANE INSTABILITY IN RECTANGULAR RC STRUCTURAL WALLS SUBJECT TO IN-PLANE LOADING

Farhad Dashti, Research Engineer – UC Quake Centre

Rajesh P. Dhakal (Professor), Stefano Pampanin (Professor), University of Canterbury, New Zealand

Out-of-plane instability refers to the buckling of a portion of a wall section out-of-plane, as a result of in-plane actions.

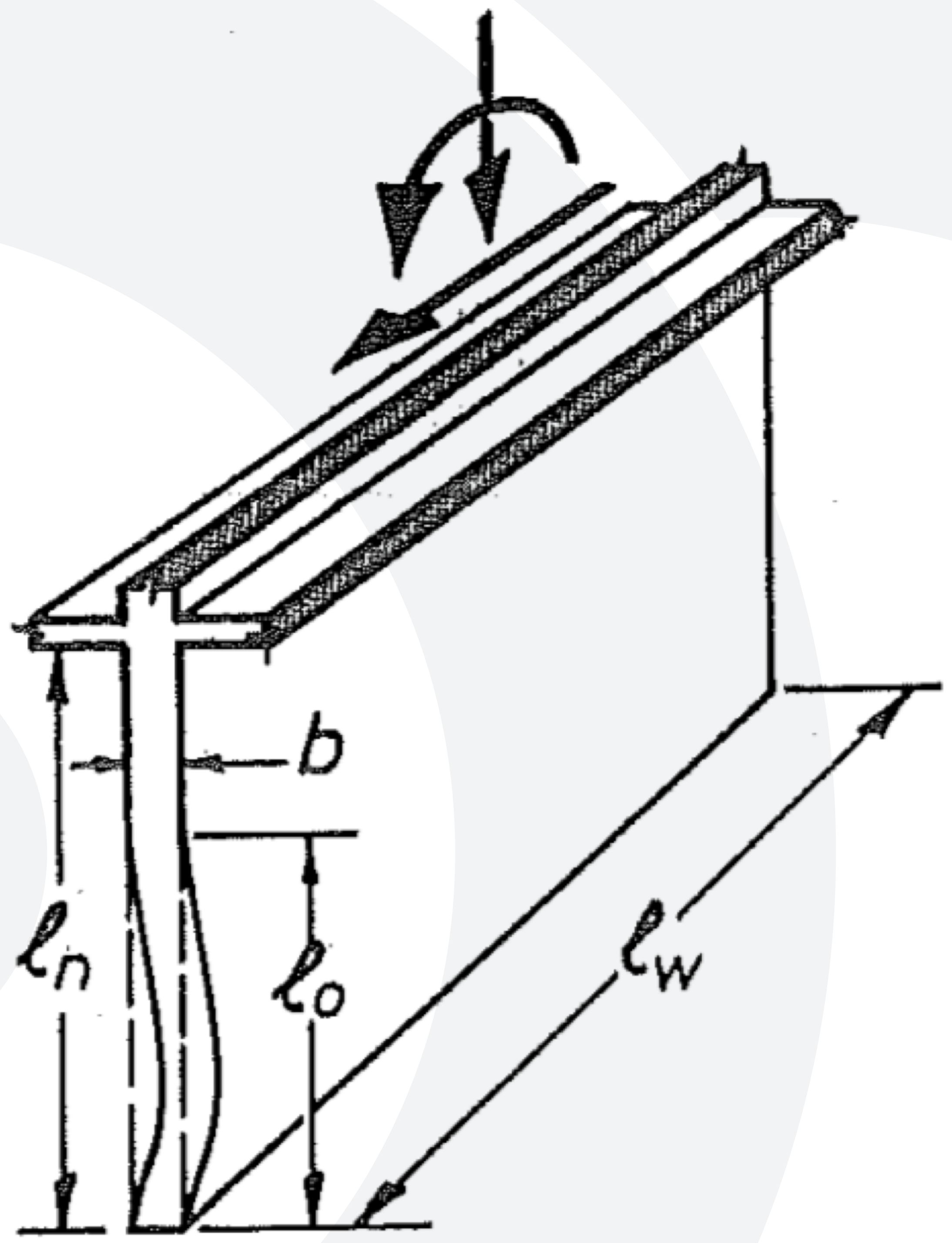


Fig 1: Out-of-plane instability (Paulay and Priestley 1993)

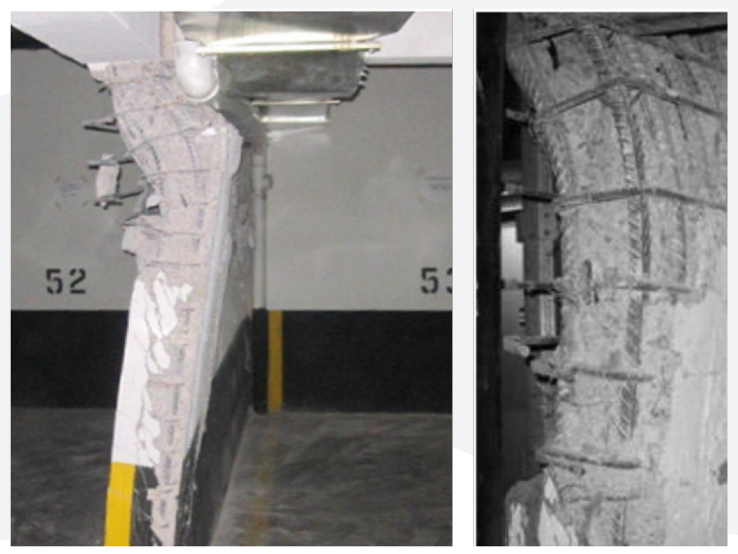


Fig 2: 2010 Chile earthquake (Wallace 2012)

Fig 3: 2011 Christchurch (Elwood 2013)

This mode of failure has been observed in several modern buildings in the 2010 Chile and 2011 Christchurch earthquakes causing concerns over the existing design provisions of walls.

The parameters controlling this mode of failure need to be identified and scrutinised, resulting in design provisions that can prevent out-of-plane deformations of rectangular walls.

Research methodology

- Simulation of the common failure patterns of structural walls using finite element modelling (FEM) approach
- Verification of the FEM model against experimental observations of out-of-plane instability

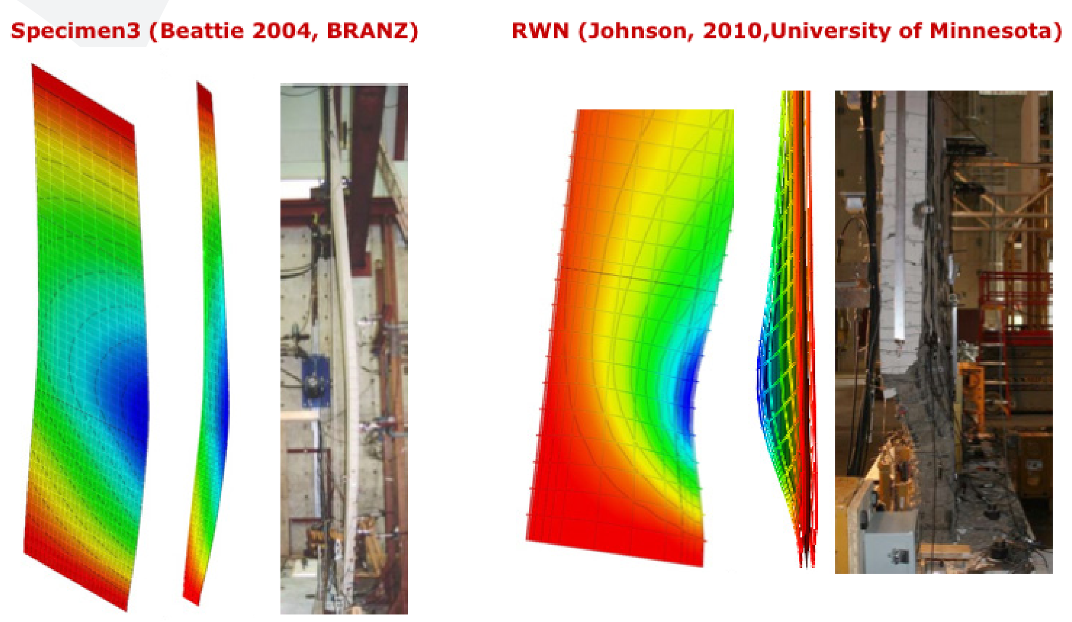


Fig 4: Numerical simulation of the out-of-plane instability observed in wall experiments

- Blind-prediction of a wall test in which out-of-plane instability had occurred
- Identification of the parameters controlling out-of-plane instability of rectangular walls using the verified model and parametric studies
- Experimental investigation of the parameters
- Comprehensive parametric analysis based on numerical simulations and experimental observations.

Fig 5: Test setup and out-of-plane instability of one of the specimens

Research outcomes

- Design provisions limiting the parameters that are known to be most influential on out-of-plane instability of rectangular walls
- Assessment charts proposing the probability of out-of-plane instability for a set of parameters.

How will these outcomes be used?

New design

Some changes will be proposed to apply in the next revision of the NZS 3101 following a comprehensive parametric study using the verified numerical model and considering the experimental observations. According to the revised version of the NZS 3101, the structural walls will need to satisfy specific limitations to be able to resist against out-of-plane instability failure.Existing buildings

Using the proposed assessment charts, the probability of out-of-plane instability in rectangular walls of the existing New Zealand buildings can be evaluated.

Benefits

The structures with instability failure in walls are hardly repairable as a very abrupt loss of lateral load resistance is induced to the building by this mode of failure which can cause instability of the whole building.

The findings of this research will help prevent observations of out-of-plane instability in rectangular structural walls in future earthquakes and facilitate repairability of damaged wall buildings.Publications

Journal papers

1. F. Dashti, R.P. Dhakal, S. Pampanin (2017) "Evaluation of Existing Understanding on Evolution of Out-of-plane Deformation and Subsequent Instability in Rectangular RC Walls under In-plane Cyclic Loading" Earthquake Engineering and Structural Dynamics, EQE-17-0078. R1 (Revised manuscript under review)
2. F. Dashti, R.P. Dhakal, S. Pampanin (2017) "Validation of a Numerical Model for Prediction of Out-of-plane Instability in Ductile Structural Walls under Concentric In-plane Cyclic Loading " Journal of Structural Engineering, DOI 10.1061/(ASCE)ST.1943-541X.0002013
3. F. Dashti, R.P. Dhakal, S. Pampanin (2017) "Tests on slender ductile structural walls designed according to New Zealand standard", Bulletin of the New Zealand Society for Earthquake Engineering 50(4):504-516 • December 2017
4. F. Dashti, R.P. Dhakal, S. Pampanin (2017) "Blind prediction of in-plane and out-of-plane responses for a thin singly reinforced concrete flanged wall specimen" Bulletin of Earthquake Engineering, DOI 10.1007/s10518-017-0211-x
5. F. Dashti, R.P. Dhakal, S. Pampanin (2017) "Numerical Modeling of Rectangular Reinforced Concrete Structural Walls" Journal of Structural Engineering 143 (6), DOI 10.1061/(ASCE)ST.1943-541X.0001729
6. F. Dashti, R.P. Dhakal, S. Pampanin (2014) "Comparative in-plane pushover response of a typical RC rectangular wall designed by different standards", Earthq. Struct 7 (5), 667-689

Conference papers

1. F. Dashti, R.P. Dhakal , S. Pampanin "An Experimental Study on Out-of-plane Deformations of Rectangular Structural Walls Subject to In-plane Loading" 16th World Conference on Earthquake Engineering, 9-13 January 2017, Santiago, Chile
2. F. Dashti, R.P. Dhakal , S. Pampanin "Evaluation of New Zealand code requirements related to instability failure of structural walls" The 2017 New Zealand Society for Earthquake Engineering Conference, 2017, Wellington, New Zealand
3. M. Tripathi, R.P. Dhakal, F. Dashti "Effect of Reinforcement Compression Capacity on In-Plane Flexural Behaviour of Slender RC Walls" The 2017 New Zealand Society for Earthquake Engineering Conference, 2017, Wellington, New Zealand (Best Student Paper Award)
4. F. Dashti, R.P. Dhakal , S. Pampanin "Out-of-plane instability of a rectangular wall specimen subject to in-plane cyclic loading" The New Zealand Concrete Industry Conference 2016, Auckland, New Zealand
5. F. Dashti, R.P. Dhakal , S. Pampanin "Development of out-of-plane instability in rectangular RC structural walls" The 2015 New Zealand Society for Earthquake Engineering Conference, 2015, Rotorua, New Zealand
6. F. Dashti, R.P. Dhakal , S. Pampanin "Seismic Performance of Existing New Zealand Shear Wall Structures" The New Zealand Concrete Industry Conference 2015, Rotorua, New Zealand
7. F. Dashti, R.P. Dhakal , S. Pampanin "Simulation of out-of-plane instability in rectangular RC structural walls" Second European Conference on Earthquake Engineering and Seismology, 25-29 August, 2014, Istanbul, Turkey
8. F. Dashti, R.P. Dhakal , S. Pampanin "Numerical simulation of shear wall failure mechanisms" The 2014 New Zealand Society for Earthquake Engineering Conference, 21-23 March, 2014, Auckland, New Zealand
9. F. Dashti, R. P. Dhakal "Comparative performance of RC shear walls designed by different standards" The 2013 World Congress on Advances in Structural Engineering and Mechanics (ASEM13), 8-12 September, 2013, Jeju, Korea

Acknowledgments

This project is part of a programme of work funded by MBIE. The programme aims to address a number of recommendations identified by the Canterbury Earthquakes Royal Commission.

BUCKLING OF REINFORCING BARS AND ITS EFFECTS ON SEISMIC PERFORMANCE OF SLENDER REINFORCED CONCRETE WALLS

Mayank Tripathi, PhD – Candidate, Professor Rajesh P. Dhakal, Farhad Dashti (Research Engineer) – UC Quake Centre
Associate Professor Leonardo Massone – University of Chile, University of Canterbury, New Zealand

In a well detailed reinforced concrete (RC) wall subjected to lateral loading, bar buckling is one of the critical and common modes of failure, contributing to premature concrete crushing and failure of the wall.

Fig 1: Bar buckling observed in the test (Dashti et al 2017)

This mode of failure has been observed in several modern buildings in the 2010 Chile and 2011 Christchurch earthquakes causing concerns over the existing design provisions of walls.

Fig 2: 2010 Chile earthquake (Wallace 2012)

Fig 3: 2011 Christchurch earthquake (NZRC 2012)

The parameters controlling this mode of failure need to be identified and scrutinised, resulting in design provisions that can prevent premature bar buckling in RC walls.

Research methodology

- Numerical investigation on the effect of reduction in compression stress capacity of reinforcement on the overall in-plane behaviour of flexurally dominated RC shear walls
- Tests on the effects of slenderness ratio, grade of steel and loading history on buckling and low-cycle fatigue behavior of reinforcing bars
- Tests on rectangular concrete columns representing boundary zones of rectangular structural walls to identify the effects of different configurations of transverse reinforcement on buckling of the longitudinal bars
- Tests on structural walls to identify the effects of different configurations of transverse reinforcement on buckling of the longitudinal bars and consequently overall response of structural walls
- Numerical predictions of the experimental test specimens
- Identification of the parameters controlling buckling of reinforcing bars using the verified model and parametric studies.

Research outcomes

Design provisions limiting the parameters that are known to be most influential on buckling of longitudinal bars in structural walls.

How will these outcomes be used?

Changes will be proposed to apply in the next revision of the NZS 3101 following a comprehensive parametric study using the verified numerical model and considering the experimental observations. According to the revised version of the NZS 3101, the structural walls will need to satisfy specific limitations to be able to resist against premature buckling of reinforcing bars.

Benefits

The findings of this research will help prevent observations of premature bar buckling and subsequent bar fracture in rectangular structural walls in future earthquakes.

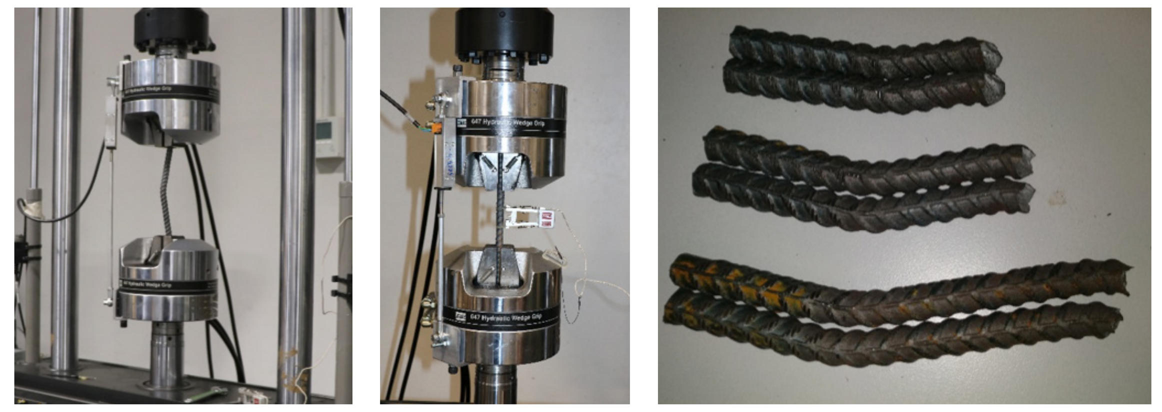


Fig 4: Experimental test setup and fracture of buckled rebars

Publications

Journal papers (in preparation)

1. M. Tripathi, R.P. Dhakal, F. Dashti , L. Massone “Evaluation of low cycle fatigue life of grade 300E and 500E reinforcing bars including the effects of inelastic buckling of reinforcement” (under preparation).

Conference papers

1. M. Tripathi, R.P. Dhakal, F. Dashti “Effect of Reinforcement Compression Capacity on In-Plane Flexural Behaviour of Slender RC Walls” The 2017 New Zealand Society for Earthquake Engineering Conference, 2017, Wellington, New Zealand (Best Student Paper Award).
2. M. Tripathi, R.P. Dhakal, F. Dashti , L. Massone “Evaluation of Low-Cycle Fatigue Life of Reinforcing Bars:Test Results” 11th National Conference on Earthquake Engineering, 2018, Los Angeles, California (To be submitted).
3. M. Tripathi, R.P. Dhakal, F. Dashti , L. Massone “Experimental Investigation on Low-Cycle Fatigue Life of New Zealand Reinforcing Bars” The 2017 New Zealand Society for Earthquake Engineering Conference, 2018, Auckland, New Zealand (Abstract submitted).

Acknowledgments

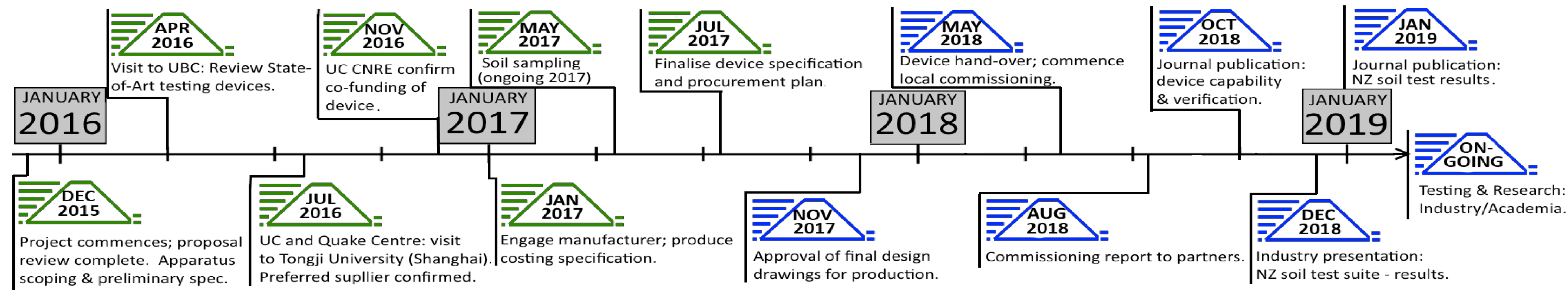
This project is part of a programme of work funded by MBIE. The programme aims to address a number of recommendations identified by the Canterbury Earthquakes Royal Commission.

THE UC TRIAXIAL PERMEAMETER: A NOVEL GEOTECHNICAL TESTING APPARATUS FOR NEW ZEALAND EARTH DAM MATERIALS

Dr. Kaley Crawford-Flett and Dr. Jennifer Haskell
Industry Representative: Peter Amos (Damwatch)


1. NEW ZEALAND EARTH DAM

Design of a laboratory testing facility to address the impact of seismic events on the performance of earth dam materials.



Why earth dams?

Over 75% of dams in New Zealand are earth embankment dams, many of which were designed from the 1920s through to the 1980s to enable hydroelectric power generation and agricultural development, and to provide reliable water storage. New Zealand has around 150 large dams (over 15 metres in height, or retaining a volume of more than 1 x 10^6 m^3) which primarily serve the hydroelectric, agricultural and reticulated water supply sectors.

The Quake Centre Earth Structures research project was initiated to address an industry need for improved guidance on the evaluation of embankment dams subject to seismic loads.

What concerns do we face?

Many of the world's large earth dams were constructed before the evolution of current engineering design standards. A number of recent international sinkhole and erosion incidents suggest that some mechanisms of dam failure could take many decades to manifest at a visible scale. All over the world, the dam engineering community is calling for an improved science-based understanding of long-term earth dam performance.

Laboratory seepage testing is often recommended for soils used in critical embankment applications. To date, very few experimental studies have addressed the seepage performance of New Zealand soils, and appropriate testing equipment is not currently available in New Zealand. Specifically:

- New Zealand presently lacks geotechnical testing facilities capable of testing for particle migration and hydro-mechanical response in local earth dam materials.

Compounding these long-term performance uncertainties is New Zealand's highly seismic environment.

- There exists considerable uncertainty surrounding the behaviour of filter and transition soils during, and following, seismic loading.
- We possess a limited understanding of the response of earth embankments to successive periods of ground shaking – that is, the cumulative effects of earthquake events occurring throughout the entire life of the dam.

How will the UC Triaxial Permeameter address these concerns?

This project comprises the development, design, construction and commissioning of a 'dynamic' Triaxial Permeameter device. The device will be capable of state-of-art seepage testing for internal instability and filter compatibility, and will also incorporate a novel dynamic (simulated seismic) loading capability.

The UC Triaxial Permeameter will provide a local, specialized seepage testing facility in New Zealand, designed to accommodate challenging New Zealand earth dam materials. Specifically, the device will feature:

- Monotonic and cyclic (simulated seismic) testing capability.
- Large (300 mm) diameter test specimens: a scale sufficient to accommodate gravelly materials.
- Conventional permeameter (seepage) capability with triaxial stress control.
- Conventional triaxial testing capability, with or without seepage flow.
- A double-walled cell configuration to permit volume change measurements in unsaturated or transient flow conditions.

What are the expected outcomes?

The commissioning of a specialized seepage testing facility in New Zealand will develop expertise in the performance of soils subject to seepage and seismic loading, and provide local support to assist with the management of critical dam infrastructure.

Following fabrication and commissioning, the UC Triaxial permeameter will be made available for further specific research and contract testing of New Zealand dam soils.

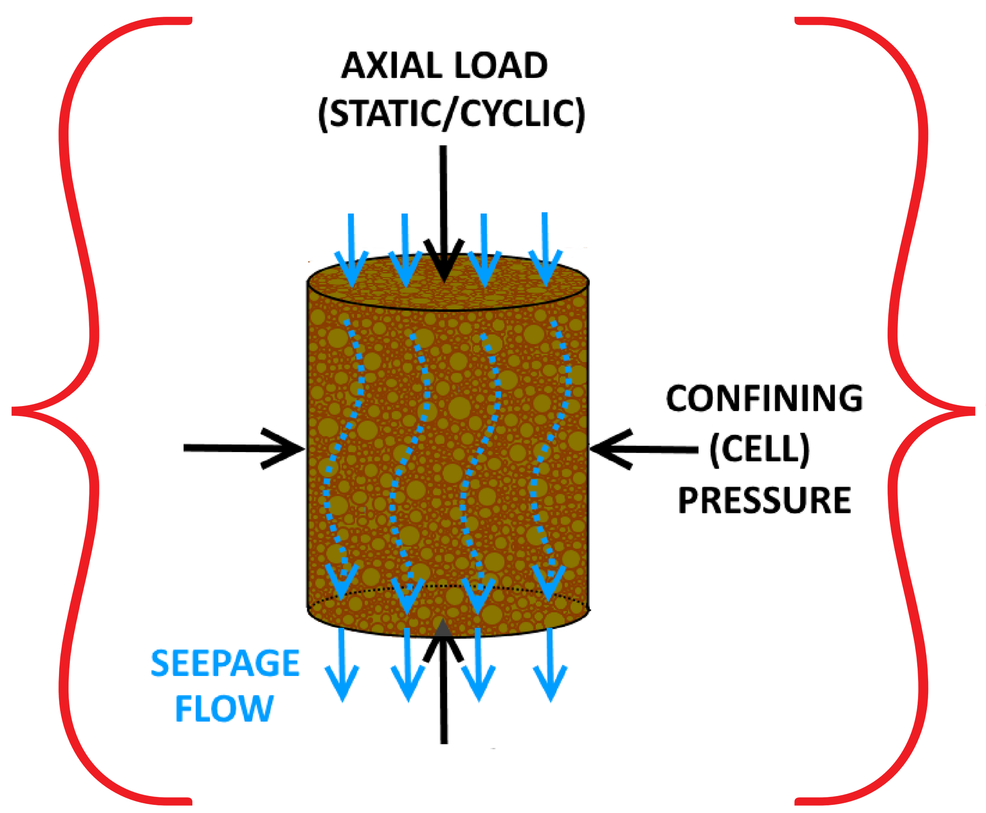
The project will grow dam engineering capability in New Zealand, both within industry and research faculty, and develop internationally-recognized expertise.

Who will benefit?

Research outcomes will set the stage for improved dam risk management across New Zealand in coming decades.

- **Asset owners** will benefit from reduced uncertainty in the assessment of earth dam performance, and will gain access to world-class local testing facilities for high-priority projects.
- The **academic community** will benefit from the concentrated investment of resources and expertise in the field of geotechnical dam engineering. Research collaborations will provide enduring links to the international dam engineering research community.
- The **New Zealand dam engineering community** will benefit from research outcomes and the development of local, world-class, capability in the field of geotechnical dam engineering.
- The **New Zealand public** will benefit by way of improved reliability of power and water supply, and safer dams.


2. WIDELY GRADED SOIL



3A. SPECIMEN SCHEMATIC


3B. LARGE SCALE SEVICE
(Example Load Frame)

Acknowledgements

We wish to acknowledge the professional and financial support provided by the Quake Centre partners, particularly Genesis Energy, Meridian Energy, Mercury and Trustpower.

Quake Centre
Delivering Industry Solutions

Funded by industry to deliver solutions to industry identified needs.

IMPLEMENTATION FRAMEWORK FOR IMPROVED RENEWALS PLANNING

Pulith Kapugama, Phillip McFarlane, James Thorne

Many wastewater pipelines are nearing the end of their design lives and might need to be replaced in the next couple of decades.

There is a disconnect between predicted renewals expenditure and the amount that local authorities are depreciating. The Auditor General (2014) identified that during the period 2007 to 2013, local authorities consistently spent less than they intended on capital works, including asset renewals. If actual spending trends continue to match those forecast, the Auditor General estimates that by 2022, the gap between asset renewals expenditure and depreciation for the local government sector could be between $6 and $7 billion (Controller and Auditor General, 2014).

This raises the question, are New Zealand communities going to be faced with significant liabilities in the future to renew assets? Or, is too much money being allowed for depreciation of water assets, diverting funds away from other productive uses?

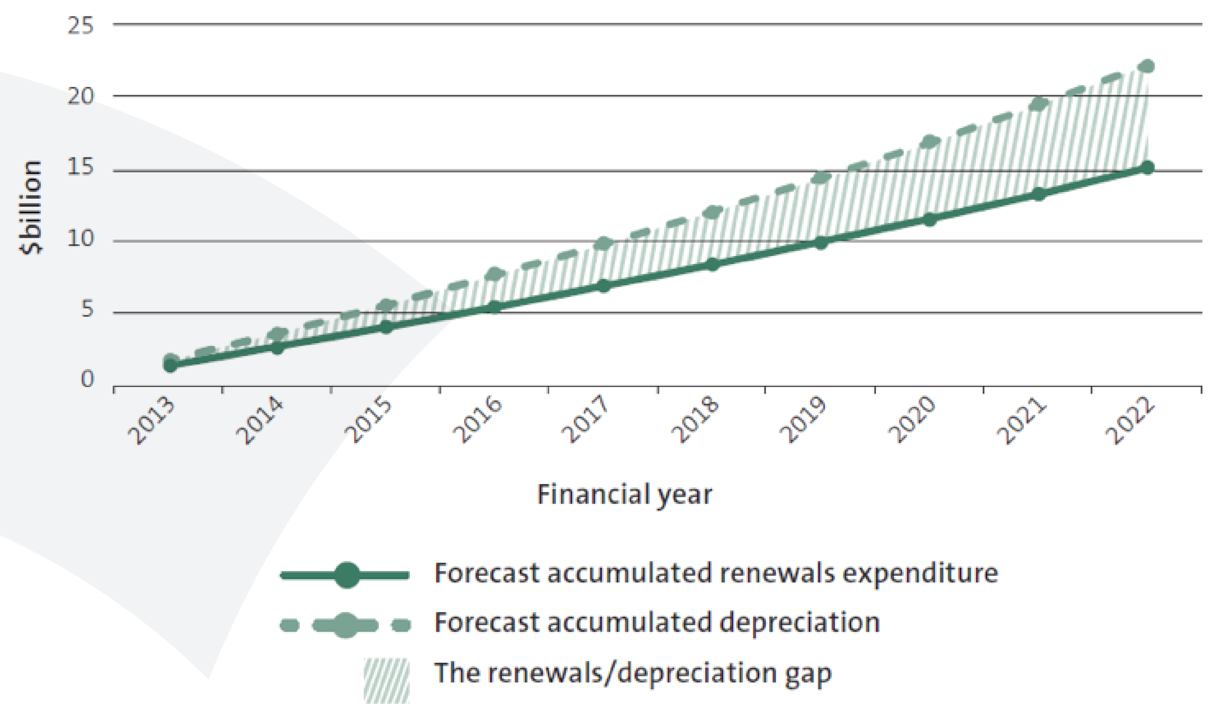


Fig 1: Forecast accumulated renewals expenditure and depreciation

How is the problem addressed?

This project develops a renewals framework in the form of a guidance document to improve pipeline renewals planning for gravity wastewater pipelines through evidence-based decision making.

- The renewals planning framework is to be scalable in terms of both network size and maturity of data management practices.
- The framework shall identify areas where further research is required, identifying those areas that have the greatest impact on decision-making.
- The framework allows provision for incorporating future data improvements and planning processes.
- While the framework focusses on gravity wastewater pipelines, it is envisaged that there will be significant overlap with other pipelines.

How was the framework developed?

A literature search was undertaken which found that there are several documents available to guide renewals. However, the application of these documents to renewals planning is not always clear. The Framework provides clarity around how these existing documents, including the IIMM and New Zealand Asset Metadata Standards, can be applied in a consistent manner.

A Technical Working Group was formed to gather feedback throughout the development of the Framework. Members of the group represented the spectrum of organisation size, funding availability, network characteristics and asset management sophistication.

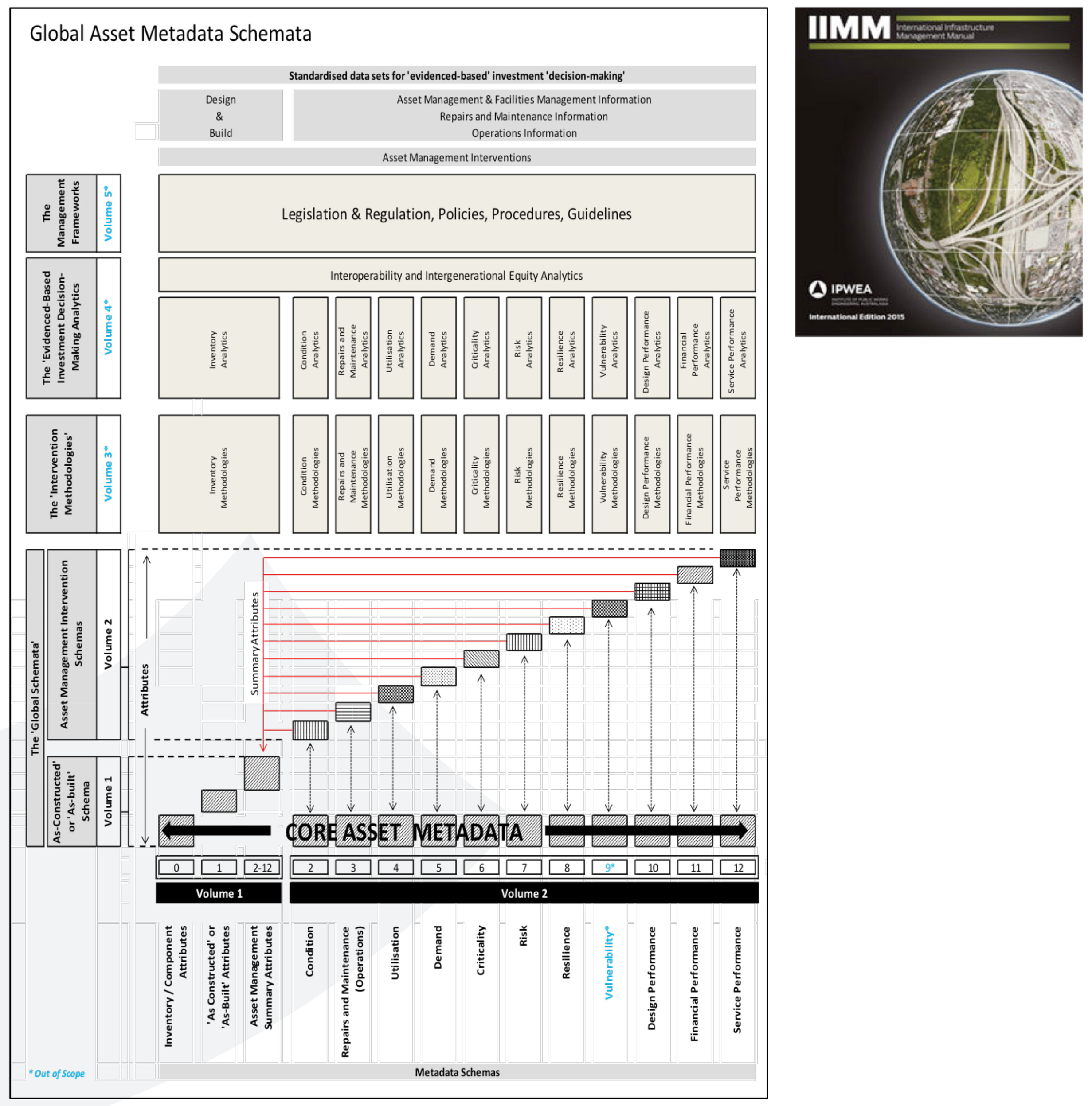


Fig 2: The NZ Metadata Schema and the International Infrastructure Management Manual

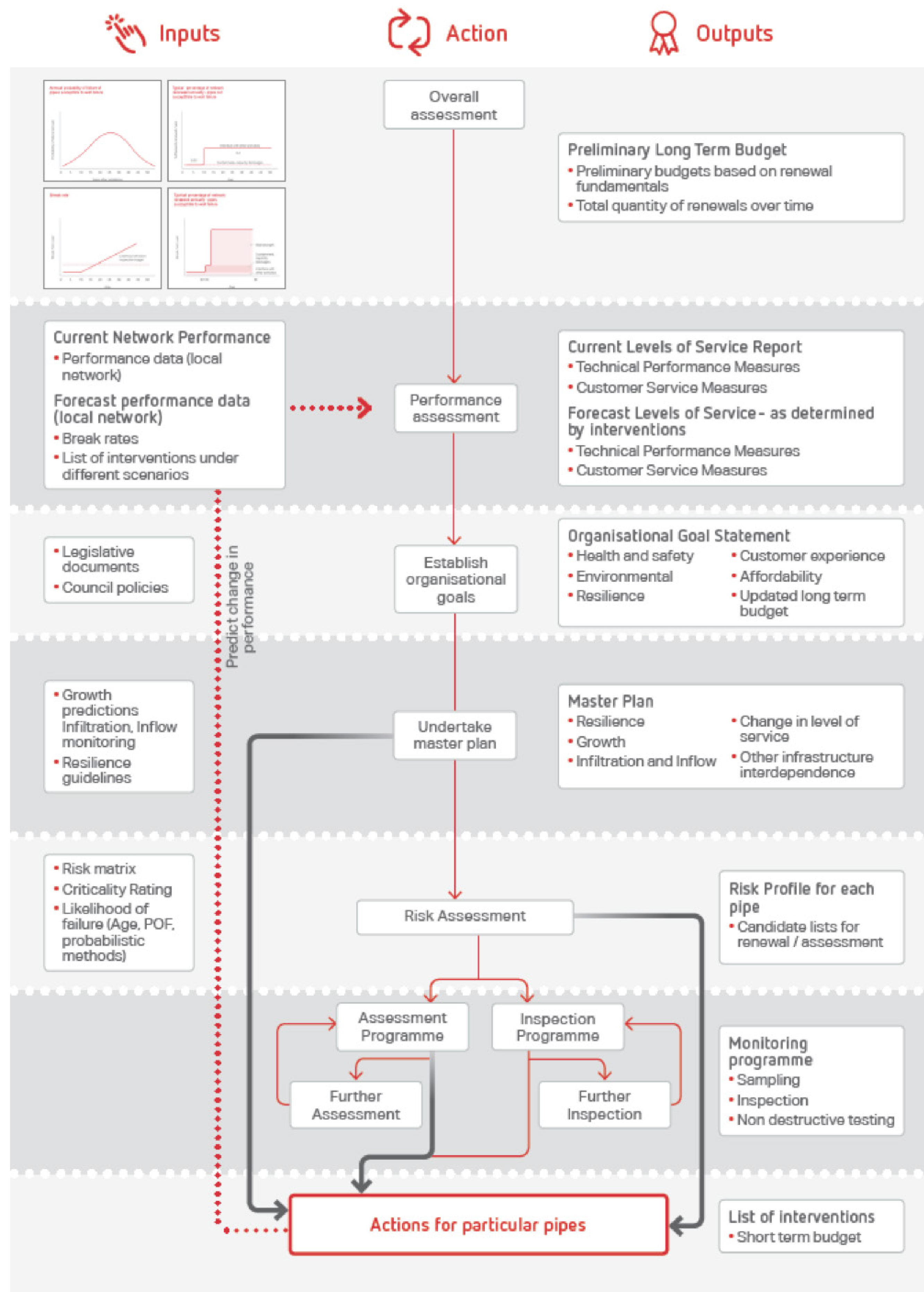


Fig3: The renewals planning framework

Conclusion

This project helps organisations improve pipeline renewals planning with evidence-based decision making so that pipelines deliver the intended service in an economical manner without creating liabilities for future generations.

The framework identifies the different phases of renewal planning and presents logical steps for applying evidence at each. Renewal decisions can be integrated with customer outcomes, organisational goals and network master planning to optimise spending and outcomes.

Who benefits and how?

Asset Managers

- Provides a basis for establishing long-term renewals budgets and short-term pipeline specific interventions
- Allows comparison of actual performance against target performance of pipelines
- Improves risk management to prioritise renewals for pipelines with high risk of failure
- Allows selection of appropriate interventions to balance levels of service, risk management and cost of interventions
- Aligns renewals decisions with wider organisational goals and master planning
- Simplifies communication between asset managers and key stakeholders by providing a consistent and documented basis for decision making
- Identifies gaps in industry knowledge related to renewals planning.

Rate-payers

- Helps ensure value for money 3 Waters services to local communities.

National Government

- Improves the allocation and spend of funds for depreciation and renewal, thereby reducing future liability
- Improves consistency of renewals planning between organisations across the country.

Acknowledgements

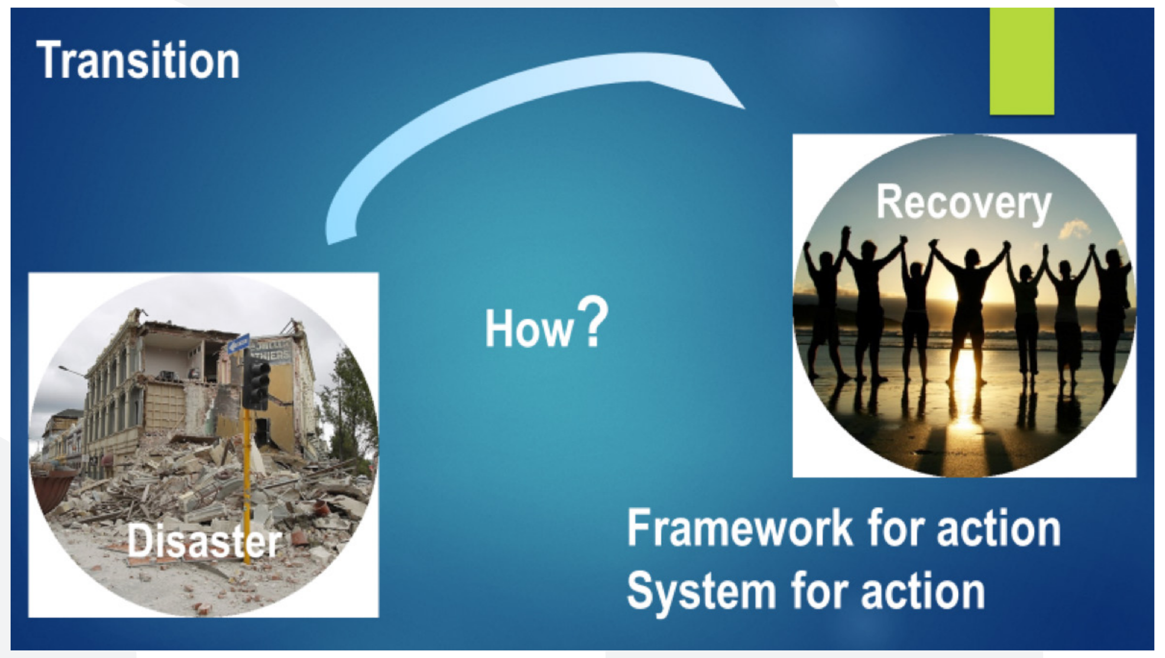
The project team wishes to acknowledge the financial support provided by Watercare Services Limited as well as the input from the members of the technical working group.

FRAMEWORK FOR ACTION AND SYSTEM FOR ACTION

Duncan Gibb, Matt Thomas and Rod Cameron

Post-disaster rebuild and recovery

When a disaster strikes, how are you going to achieve timely and effective rebuild that will enable speedy and satisfying recovery?



Lessons from the Canterbury and Kaikoura earthquakes will be used to build a comprehensive framework for rebuild, and system for action supporting it.

Project outputs

Deliverables

The deliverable will be a thorough description of the concepts, in sufficient detail for engagement with government and local government, to enable transformation of the way New Zealand prepares for and rebuilds following a disaster.

The primary medium will be a condensed book, setting out an explanation of the framework for action and system for action.

But, what is the framework for action?

The framework for action is a post-disaster rebuild model, recommending relationships, structures, systems and processes, to create a rebuild entity and steer its creation, planning and activities.

It presents principles and practical steps to bring all stakeholders together through unique collaborative approaches to achieve prompt and effective rebuild, enabling recovery.

It describes what needs to be addressed and done, for best rebuild outcomes. It complements high-level guides already available for disaster preparation organisations by adding practical experience and an outcome focused 'how to' approach, from the New Zealand perspective.

Since many of the features can be put in place before a disaster strikes, the framework will enable disaster preparedness.

Key features of the framework include:

The benefits

Enabling rebuild to support recovery

Implementing the framework will enable multi-party collaboration and create a high-performing rebuild organisation, with immediate and lasting benefits to the community, by supporting its recovery and rebuilding that which has most relevance and use.

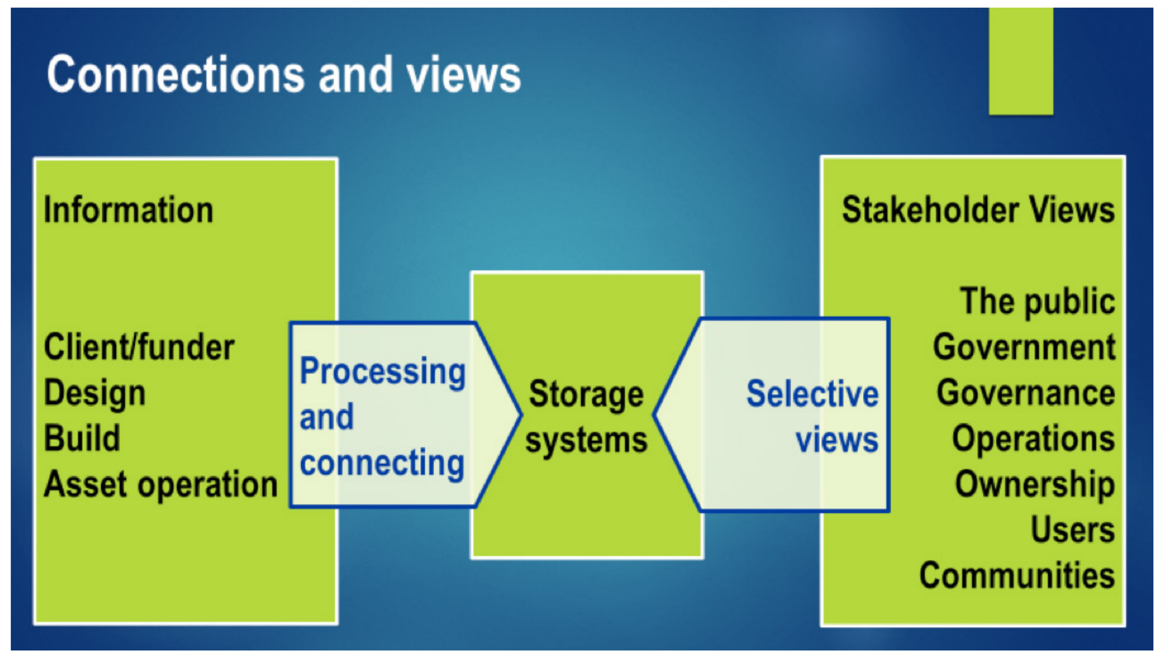
A secondary benefit arises for the people involved, who will be proud of their achievements.

The framework will generate a planned, clear, rapid, engaged rebuild with reliable outcomes for a single community or a region, for various event scales.

The framework has application where disaster has struck or can be expected, used as a template to initiate, develop and carry out rebuild as part of a recovery plan. It will therefore be highly relevant to governments, territorial local authorities, large enterprises and professional bodies, and to purpose-built disaster rebuild agencies and organisations.

And what is the system for action?

The enterprise that rebuilt the pipes and roads following the Canterbury earthquakes developed an integrated set of tools for business and geographic data to support all functions of the organisation. This is known as the 'system for action' and is an integral part of the framework for action.



Leading edge

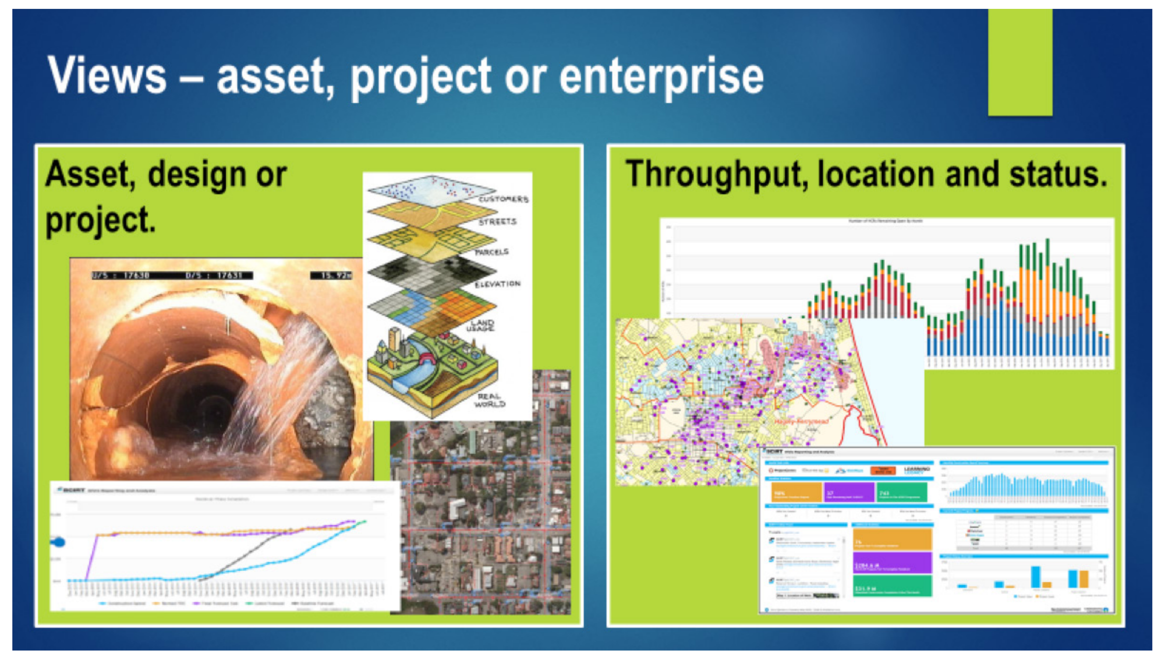
The leading-edge business practice has a wide range of practical applications for infrastructure in preparing for disaster and for response and rebuild afterwards – as well as in monitoring of assets or systems and for any design, construction and management of projects that arise.

The system for action output can be summarised by its vision and primary objective:

The project has a vision: to provide enduring digital capability that facilitates and supports disaster recovery.

It also has a primary objective of providing the backbone for the framework for action, as an integrating platform that connects, channels and enables damage measurement, design, construction and asset management, capturing all costs, accessible for all needs.

Its key attribute is the provision of evidence-based decision-making views.



Project timeline

A 35-page booklet describing the model is planned for circulation as first draft late in March 2018. This will then become a vehicle for initial engagement with government and local government agencies to bring the framework to a must-do status by June 2018.

How the project will benefit the improved resilience of NZ

Benefits

The framework will be beneficial to resilience in New Zealand in many ways.

Firstly, the fundamentals of the framework can be set up before a disaster and will create alignment of purpose, which in turn will enable faster rebuild. When a community suffering from a disaster sees rebuild progress happening, there is a lift in spirits, substantially increasing community resilience.

With the framework in place, successful rebuild outcomes will result, in the form of getting work done promptly, in volume, in a prioritised schedule, to consistent standards, whilst containing costs.

Probably the most significant benefit will come from the rebuild enabling and supporting wider recovery.

Regulation and education

The authors believe that the framework will need the support of regulation or legislation to ensure that it is in place before a disaster and will be used immediately following.

The concepts and processes involved depart from normal industry approaches and therefore it is expected that educational tools and training will need to be established to ensure sufficient understanding by stakeholders and operators to allow effective adoption.

Wider application

It seems clear to the authors that the framework for action has application to the normal business of building and construction. If applied more widely to creating built infrastructure, it can reasonably be expected to lift performance.

This will therefore be investigated during framework definition, as a second focus following post-disaster rebuild.

Acknowledgments

It is expected that several government departments will be engaged with the process of generating the framework by contributing feedback and subsequently by ensuring that it is enshrined in regulation and legislation. Similarly, industry has a strong interest in best preparedness for disaster and rebuild, supporting recovery.

The project wishes to acknowledge the financial support of the Quake Centre Industry Partners.

Quake Centre
Delivering Industry Solutions

PERFORMANCE OF REINFORCED CONCRETE WALLS DESIGNED FOR DUCTILITY

Alex Shegay, Chris Motter, Rick Henry, Ken Elwood

Reinforced concrete (RC) walls exhibited unexpected failures in the 2011 Christchurch Earthquake

The series of earthquakes hitting the Canterbury region between 2010 and 2011 resulted in unexpected failure of several RC walls as pictured below.

Following the earthquakes, SESOC and CERC recommended several changes to the design provisions in the New Zealand Concrete Structures Standard (NZS 3101:2006) that have been published under the third amendment in August 2017. Some of these provisions were based on professional judgement, and had limited literature and experimental validation.

Fig 1: Crushing and global instability

Fig 2: Web and end region crushing failures

Fig 3: Axial crushing failure

Fig 4: Web crushing failures

NZS 3101:2006 amendments of interest

A. Axial load limitation on walls

B. Increased confinement length used in the end region

C. Anti-buckling cross-ties required in the web region

The objective

This project will validate and further develop the improved detailing provisions in NZS 3101:2006 for ductile RC walls such that the severe failures presented in fig 1-4 are minimised in future earthquake events.

The objective can be broken down into the following deliverables:

1. Compile a database of tests comprising ductile RC wall tests from around the world [complete]
2. Identify gaps in testing data and ductile wall performance understanding [complete]
3. Identify the typical New Zealand design and construction practice used in walls [complete]
4. Develop and conduct a test programme to address the gaps [complete]
5. Propose a set of recommendations to NZS 3101:2006 relating to the above amendments [complete]

The benefits

1. Research-backed facts and guidance to aid informed decision making by the NZS 3101:2006 committee
2. Improved codified design methodology for RC walls to be used by practicing engineers
3. Predictable performance of RC walls to guarantee life safety in new buildings
4. Increased global understanding on performance of ductile walls and wall buildings in earthquakes.

As this topic is of international interest, the findings from this project will be shared internationally to be considered for implementation into other major standards such as the United States, Japanese and Chilean building codes.

Improved wall resilience

The research outputs from this project are geared towards improving wall design such that the building not only guarantees life safety but sustains minimal structural damage, making it safe to reoccupy soon after a seismic event.

Large-scale testing of ductile RC walls

Four half-scale test specimens shown in Fig 5 have been tested at the University of Auckland. They were designed with typical detailing and geometry expected for an 8-storey idealised prototype building located in Wellington, New Zealand. The testing set up is shown in Fig 6. These are the largest wall tests conducted in New Zealand.

Test results

Fig 7 shows the final state of each wall at failure and Fig 8 shows the force-displacement curves for the four tests. At low axial loads the walls exhibited excellent ductility characteristics while at high axial loads the failure mode is more brittle. Fig 9 and 10 compare the curvature ductility and plastic rotations achieved in the test with the limits specified in NZS 3101:2006. Fig 10 shows that the NZS 3101:2006 curvature ductility limits require adjustment to account for a reduction in deformation capacity as axial load increases.

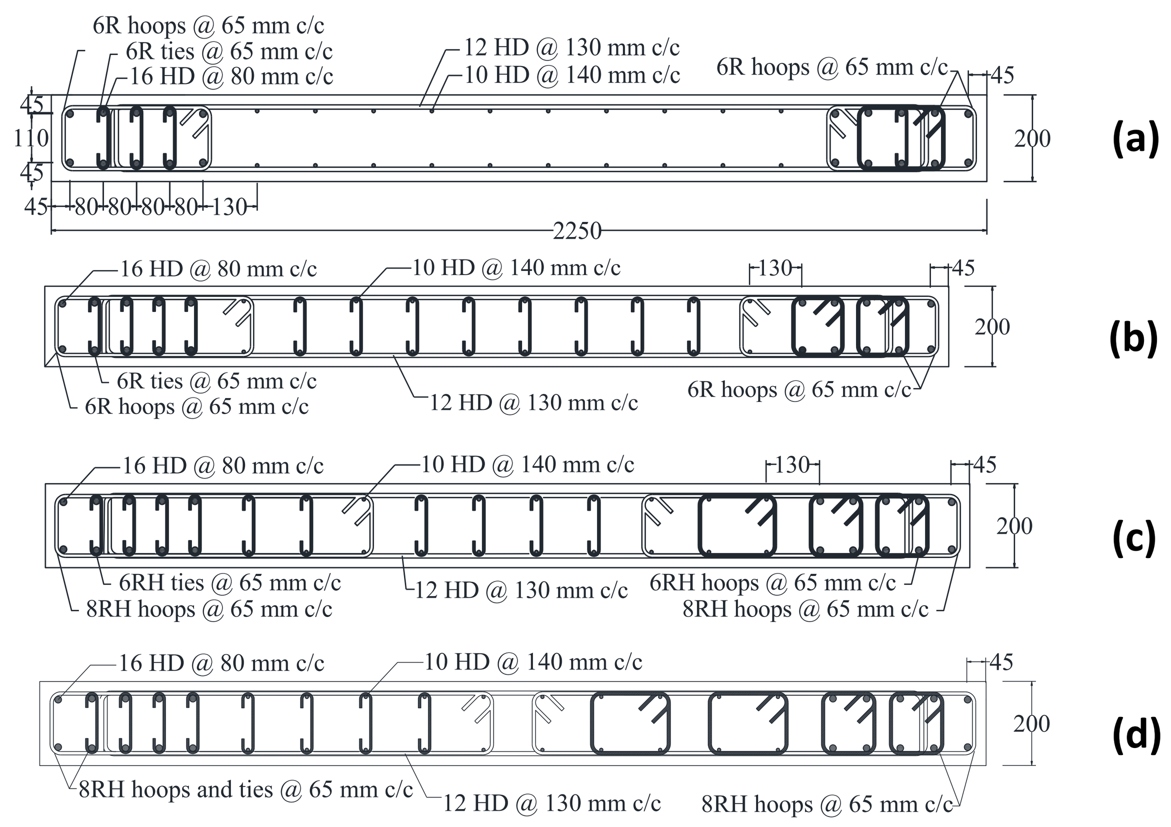


Fig 5: Test wall cross-sections (a) C10 (b) A10 (c) A14 and (d) A20

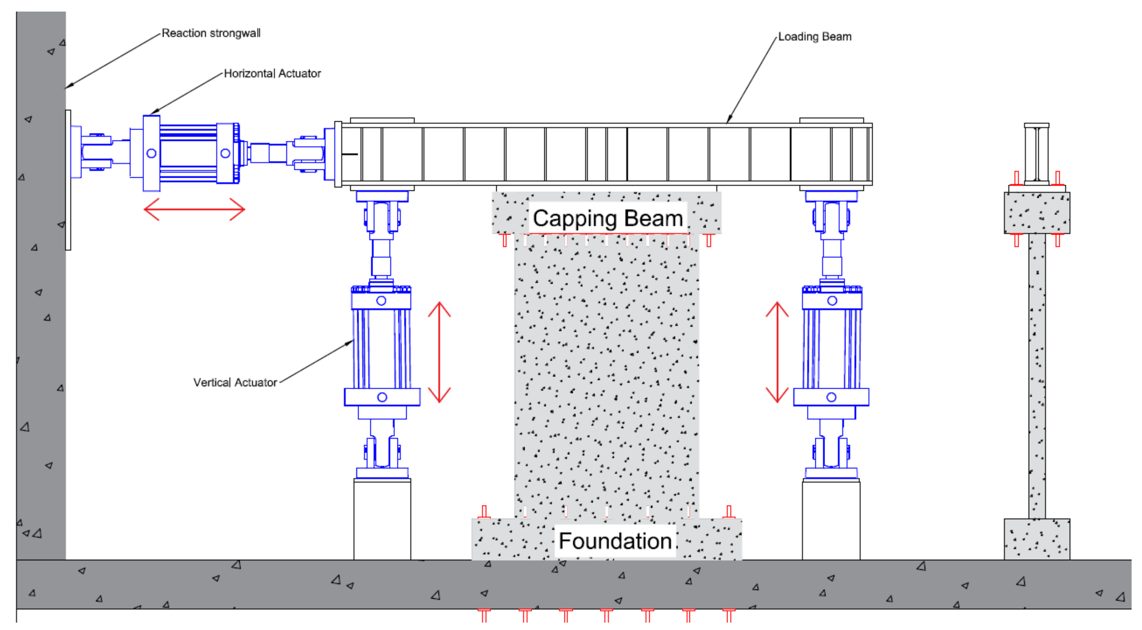


Fig 6: Experimental set up used for testing each wall

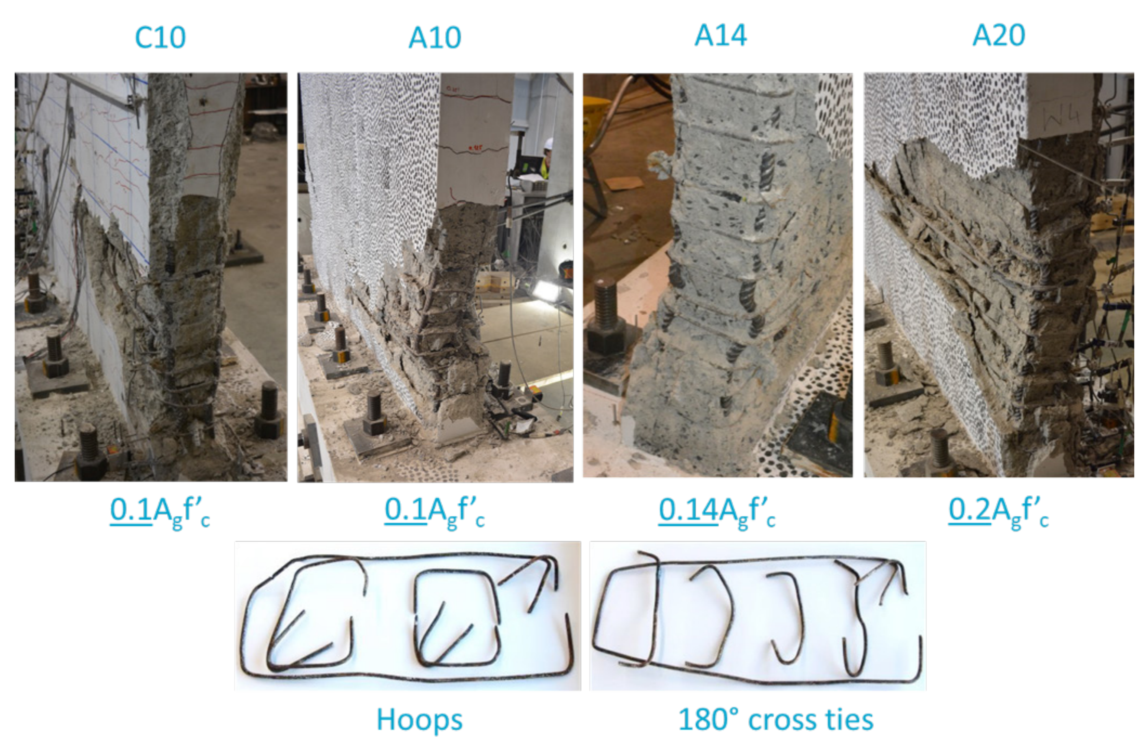


Fig 7: Final damage states of each wall after failure (top) and typical failure of transverse reinforcement (bottom).

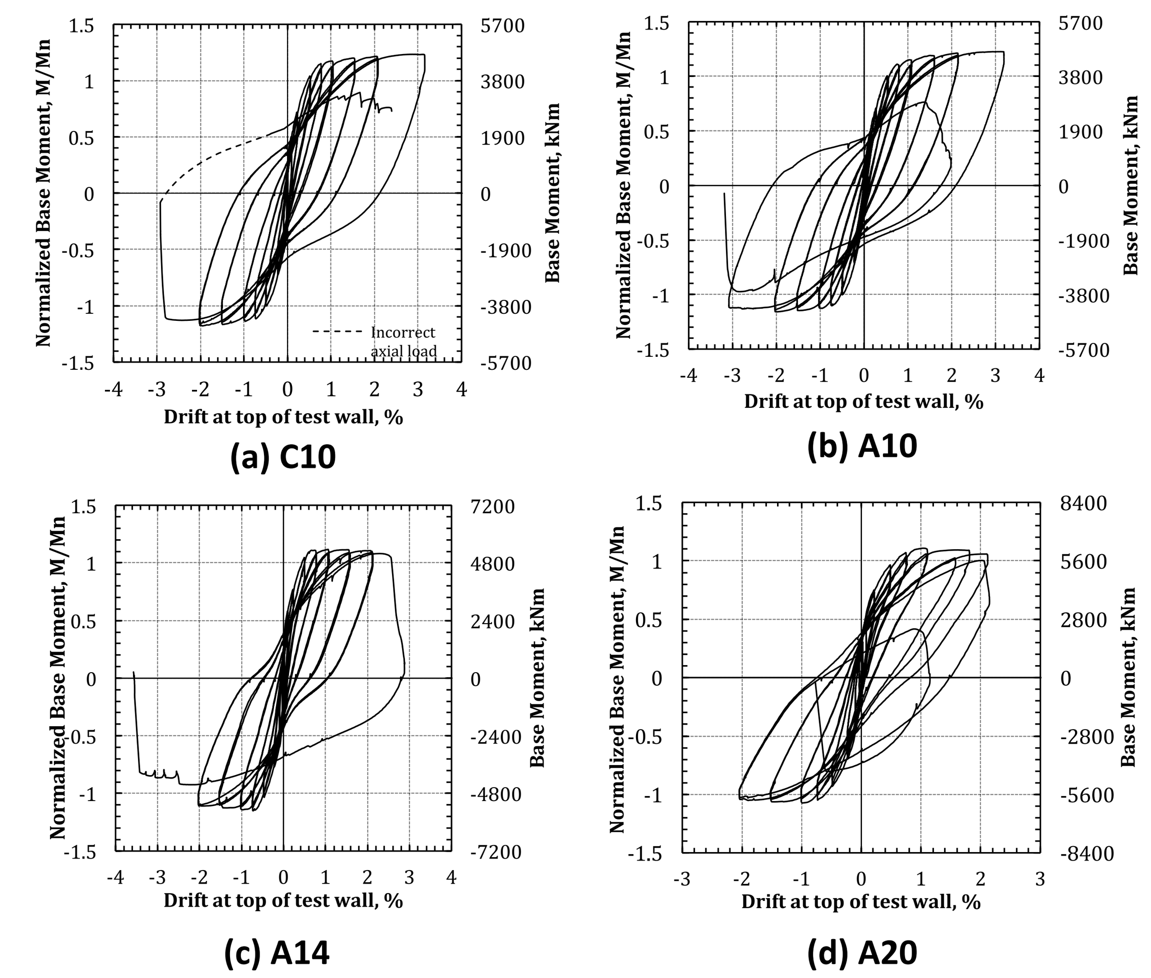


Fig 8: Results of the four half-scale tests

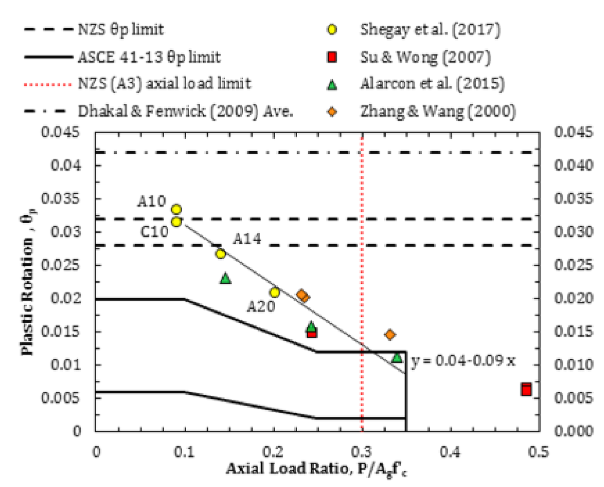


Fig 9: Plastic rotation capacity vs axial load ratio with NZS 3101 limits.

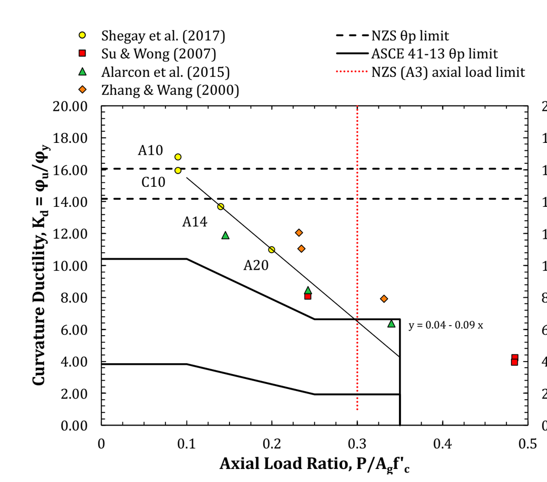


Fig 10: Curvature ductility vs axial load ratio with NZS 3101 limits

Conclusions

- Current NZS 3101 detailing requirements are satisfactory – walls are achieving drifts in excess of 2.5% drift at low-moderate axial load level.
- Hoops and ties exhibit different local failure modes but this does not affect global wall performance.
- Increasing axial load directly related to reduction in plastic rotation capacity/curvature ductility
- Current NZS 3101:2006 curvature ductility limits do not account for axial load
- Available curvature ductility is far below permitted for design in NZS 3101:2006

Acknowledgements

The project team wishes to acknowledge the financial support provided by the Quake Centre partners, and the MBIE Building Performance Branch for enabling the project to proceed.

LIGHTLY REINFORCED CONCRETE WALLS

Rick Henry, Ken Elwood, Jason Ingham, Lucas Hogan
Students: Yiqiu Lu, Pouya Seifi, Tongyue Zhang, Signy Crowe
Industry representatives: Des Bull, Rod Fulford, Ashley Smith

Introduction

A number of concerns were raised regarding the design and construction of reinforced concrete (RC) walls following the 2010/2011 Canterbury earthquakes. A lack of distributed cracking was observed in several modern lightly RC walls, such as the Gallery Apartments. The potential issues with lightly reinforced panels combined with examples of poor detailing and panel fixings also lead to renewed concerns around the seismic response of precast concrete wall buildings. Lastly, the potential non-ductile response of older lightly reinforced concrete walls was also a contributing factor to the collapse of the PGC building.

Objectives

A series of experimental tests and numerical modelling will be used to verify the behaviour of existing wall designs, as well as to investigate improved design procedures and details.

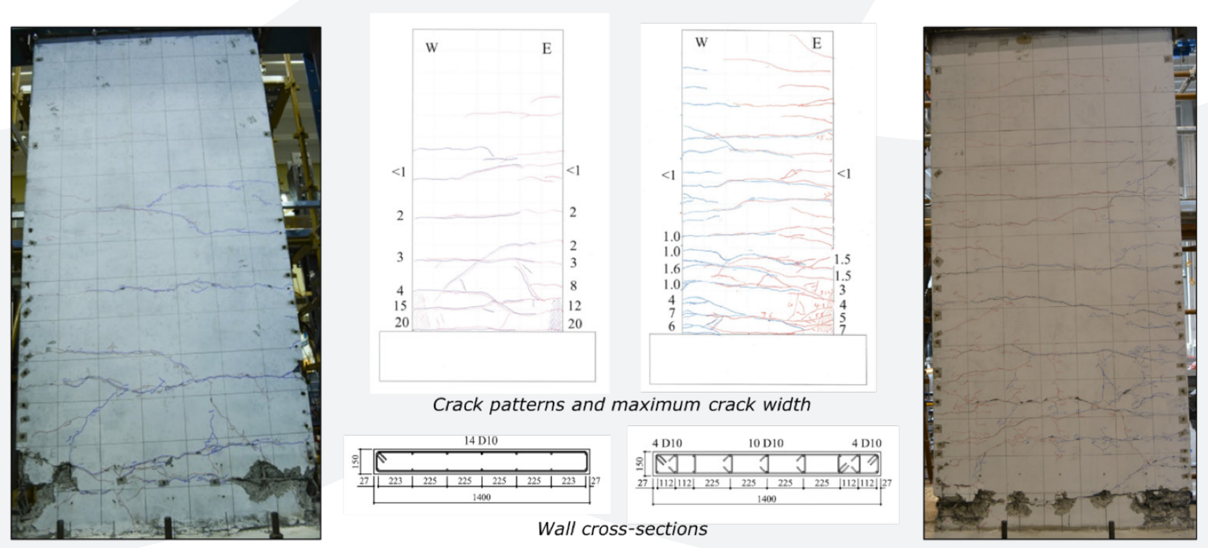
The detailed research objectives are:

- Determine minimum reinforcement requirements and deformation capacity of for lightly reinforced walls
- Determine the deformation capacity of older singly reinforced walls
- Evaluate the capacity of precast walls with grouted connections and identify improved connection details
- Evaluate out-of-plane deformation capacity of base connections for singly-reinforced walls, including bi-directional loading.

Minimum reinforcement limits

A total of 11 half scaled test walls were tested to verify minimum reinforcing requirements for new RC walls, resulting in the following key findings:

- Phase I test walls designed in accordance with NZS 3101:2006 (A2) was controlled by 1-3 large flexural cracks at the wall base. The experimental results confirmed that current minimum vertical reinforcing limits in NZS 3101:2006 (A2) are insufficient to ensure that a large number of secondary cracks form and are only suitable for walls designed for low ductility demands.
- Phase II test walls designed in accordance with NZS 3101:2006 (A3) were controlled by a large number of primary and secondary cracks over the wall height that allowed the reinforcement strains to be more evenly distributed over the plastic hinge region. The additional vertical reinforcement limits proposed for the end region of ductile walls in NZS 3101:2006 (A3) were found to be adequate to ensure the secondary cracks occurred in the plastic hinge region.



Wall designed to NZS 3101:2006 (A2) *Wall designed to NZS 3101:2006 (A3)*

Fig 1: Results from lightly reinforced wall tests

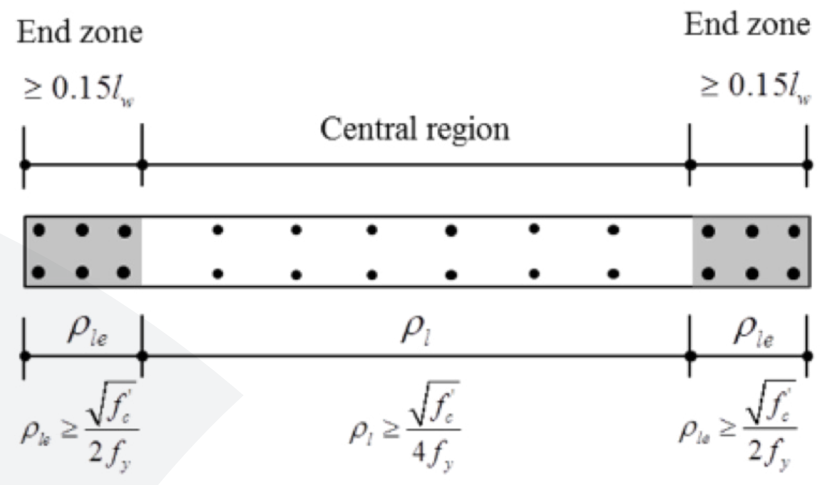


Fig 2: Proposed requirements in NZS 3101:2006 (A3)

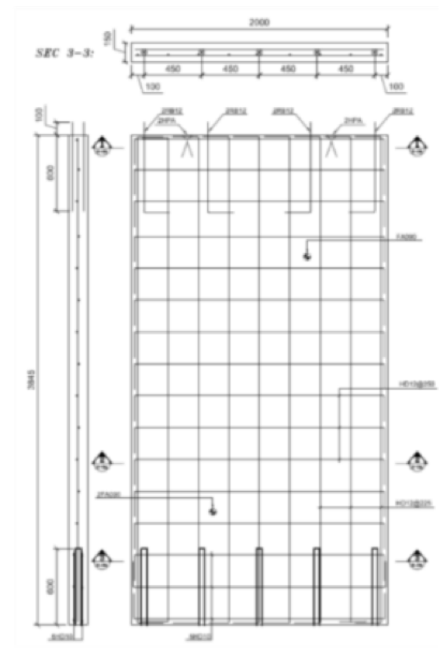
Output

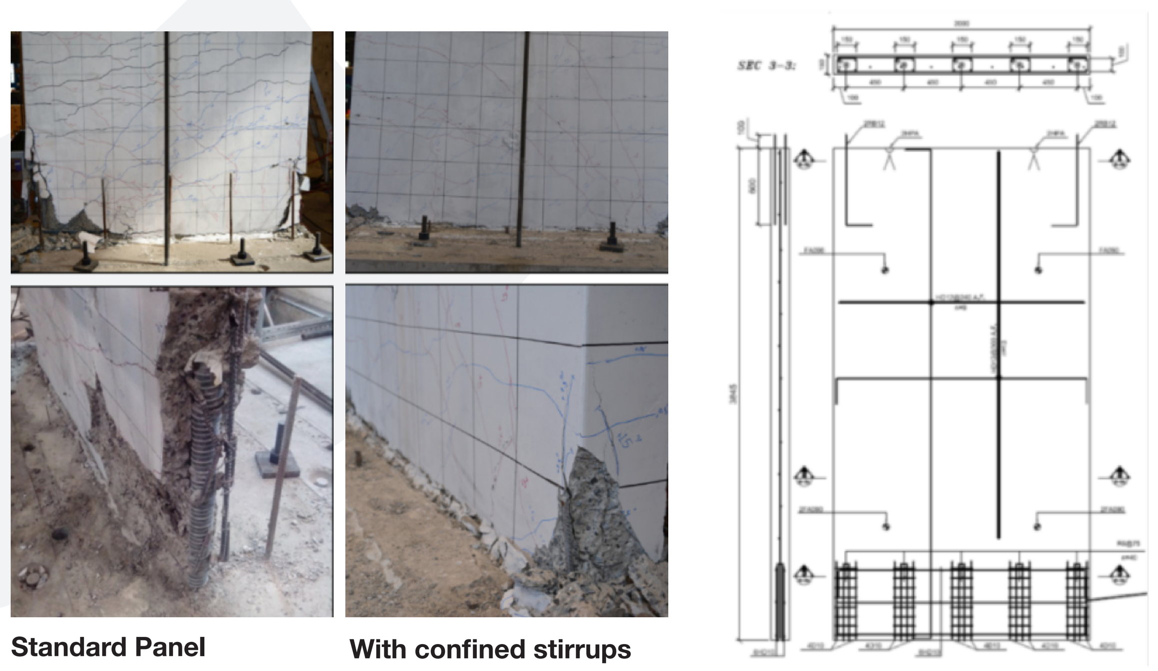
Proposed changes to minimum reinforcement requirements were implemented in NZS 3101:2006 Amendment 3. A change proposal with the same requirements has also been approved for ACI 318:19.

Precast wall connections

Tests have been performed on precast concrete panels connected to the foundation using grouted connections (including drossbach ducts and grout sleeves), resulting in the following key findings:

- Singly reinforced panels without connection confinement fail due to duct pull out (splice failure) when axial loads are sufficient to cause spalling in the corner of the walls.
- Transverse confinement reinforcement around the splice, as recommended in the SESOC interim design guidance, prevents excessing spalling and splice failure. However, the additional reinforcement resulted in a jointed panel behavior which resulted in strain concentrations in the connection reinforcement and bar fracture at modest drifts.





Standard Panel **With confined stirrups**

Fig 3: Results from in-plane tests on grouted panel connections

Out-of-plane tests of dowel type panel-to-foundation connections have highlighted the deficiencies of common detailing using shallow embedded inserts. Further testing has verified alternative connection detailing that provides sufficient load paths to avoid joint damage and allow the panel to reach its flexural capacity.

Test setup *Connection details* *Poor connection performance* *Good connection performance*

Fig 4: Results from out-of-plane tests on dowel connections

Bi-directional tests on both grouted and dowel connections were performed at the MAST lab in Swinburne University in early 2017. The tests highlighted the vulnerabilities of existing detailing and the superior performance of proposed alternative detailing.

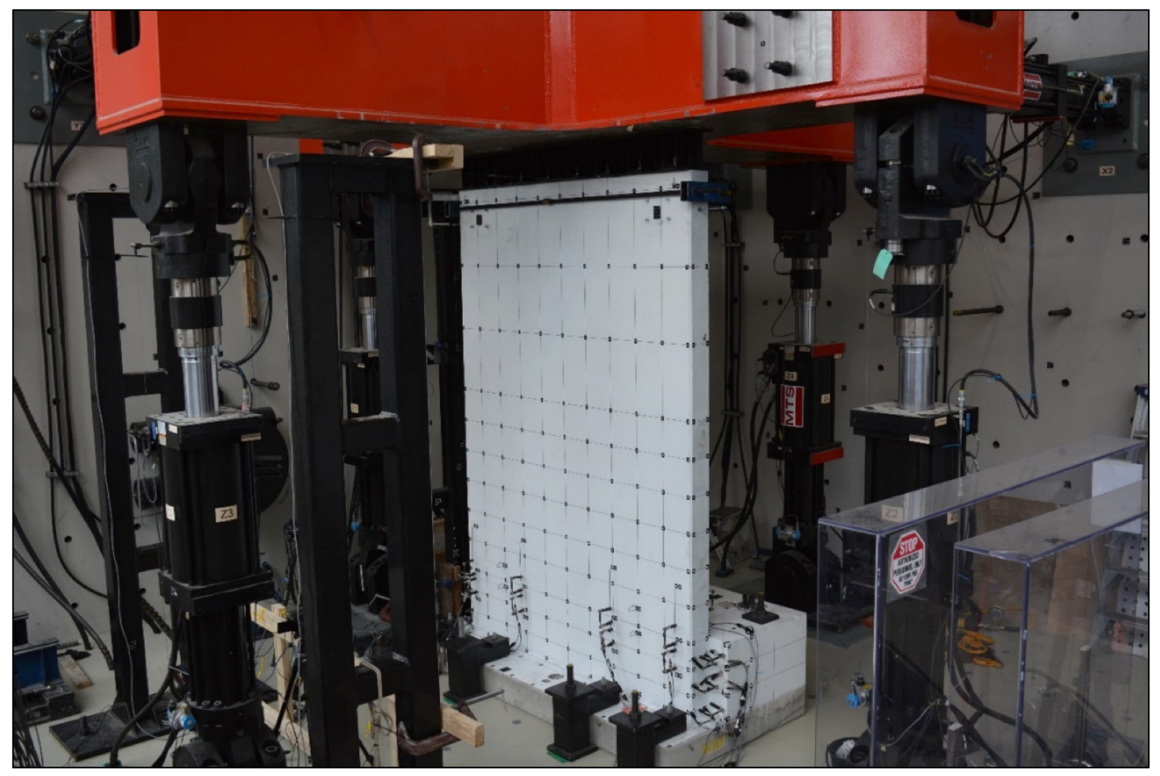


Fig 5: Bi-directional tests on precast panel connections in the MAST facility

Output

Draft guidance on low-rise precast wall panel connection detailing will be published in the SESOC journal in April 2018. A working group is expected to be established by ConcreteNZ to further develop guidance on low-rise precast panel design.

Assessment of existing walls

Older concrete walls often have vertical and horizontal reinforcement that is less than the minimum required by current design standards. In addition, the single layer of reinforcement makes them particularly vulnerable to non-ductile failure modes, such as that observed in the PGC building.

A database of 38 older reinforced concrete walls was collated and used to assess the current assessment procedures in C5 of the seismic assessment guidelines.

- For walls with a shear span ratio below 2, the C5 procedures were found to be overly conservative and it is proposed to adopt ASCE 41 limits instead.
- For walls with a shear span ratio greater than 2, a new curvature ductility limits is proposed that accounts for both detailing and axial load.

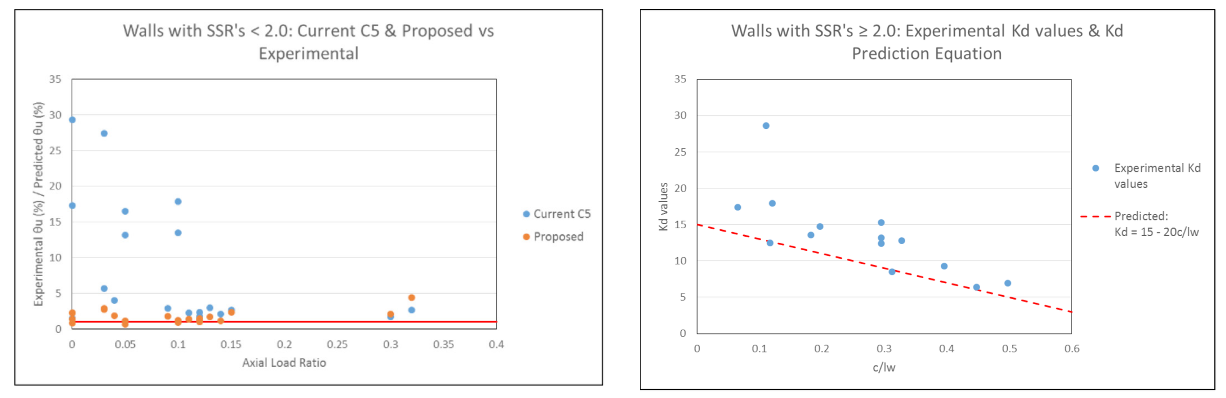


Fig 6: Deformation capacity of existing concrete walls

Experimental testing and modelling is also underway to identify failure modes and to refine seismic assessment procedures for older singly reinforced concrete walls in multi-storey buildings. These tests are intended to fill gaps in the existing tests database, in particular flexural dominate walls with thickness compression failures.

Fig 7: Testing of singly reinforced concrete wall

Output

Recommendations to NZSEE assessment guidelines for existing concrete walls (by Dec 2017).

Acknowledgements

The project team wishes to acknowledge the financial support provided by the Quake Centre partners and project funding from the Building System Performance Branch of MBIE.

OPEN SLAT FOR SEISMIC RESILIENCE EVALUATION OF BUILDINGS

Masoud Moghaddasi, Michael Gauland

Designing buildings for seismic resilience

Modern building codes, including New Zealand codes, focus heavily on safety (the important need to preserve life), discounting expected repair costs, repair time, fatalities and injuries after a disaster. However, following the Canterbury Earthquakes, the population at large and building owners in particular have begun to realise that modern designed buildings might not give the economic protection needed in the event of an earthquake. Consequently, the engineering community has begun thinking of a new design and assessment approach which can be used to deliver credible information on the expected safety, damage and recovery of the buildings. This knowledge is essential to pre-disaster planning for both new construction and the existing built environment in order to reduce the immediate and long-term impact of a disaster.

FEMA P-58 methodology for building-specific performance assessment

FEMA P-58 is a probabilistic performance assessment methodology that has been developed to predict the building damage that contributes to the reduced social and economic resilience of our communities. This has required $12M+ investment over 10+ years. FEMA P-58 output results in: (1) repair costs, (2) repair time, and (3) safety in terms of fatalities & injuries. These outputs can be used by designers to communicate seismic risk to building owners in a way they can understand, using metrics related to risk of injury, risks of the cost of damage, and risks pertaining to the duration of any repairs. This allows owners, developers, financers and insurers to assess the costs and benefits of design changes.

OpenSLAT – software for application of FEMA P-58

FEMA P-58 is a comprehensive procedure and it may take an enormous time to perform a building-specific risk assessment. Therefore, it might not be feasible or justified for all projects. However, tailor-made software can facilitate this procedure at a rapid pace and enable widespread and mainstream use of FEMA P-58.

OpenSLAT is a software that has been developed at Quake Centre to leverage the knowledge from FEMA P-58 to help engineers anticipate how much seismic shaking will cost over the life of the structure.

How does OpenSLAT work?

OpenSLAT uses a Seismic Hazard Curve to model how often the structure will be subject to different levels of shaking. This curve is generated from the rules in NZS 1170, based on location and soil class.

The way the structure responds to seismic activity is described by a set of Demand Curves. These depend on the design, and are produced as part of a structural analysis. OpenSLAT is interested in Drift (how far each floor sways side to side), and Acceleration (how rapidly each floor changes direction during the event).

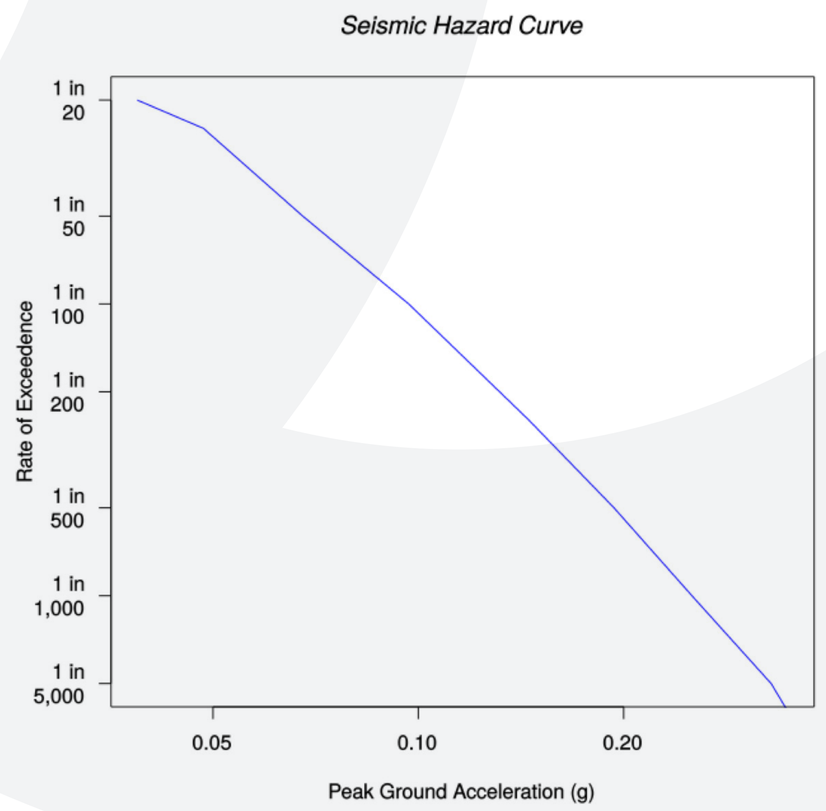


Fig 1: Example Seismic Hazard Curve

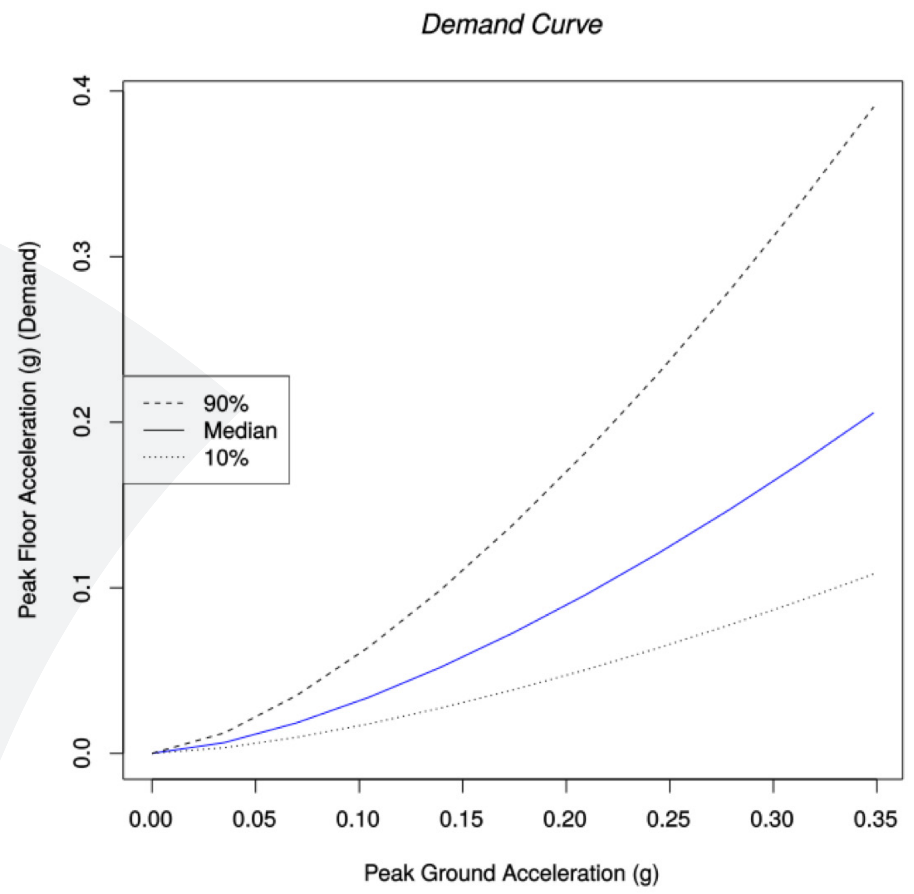


Fig 2: Example Demand Curve

OpenSLAT can apply the Seismic Hazard Curve to a Demand Curve to determine how frequently that demand will exceed specific values.

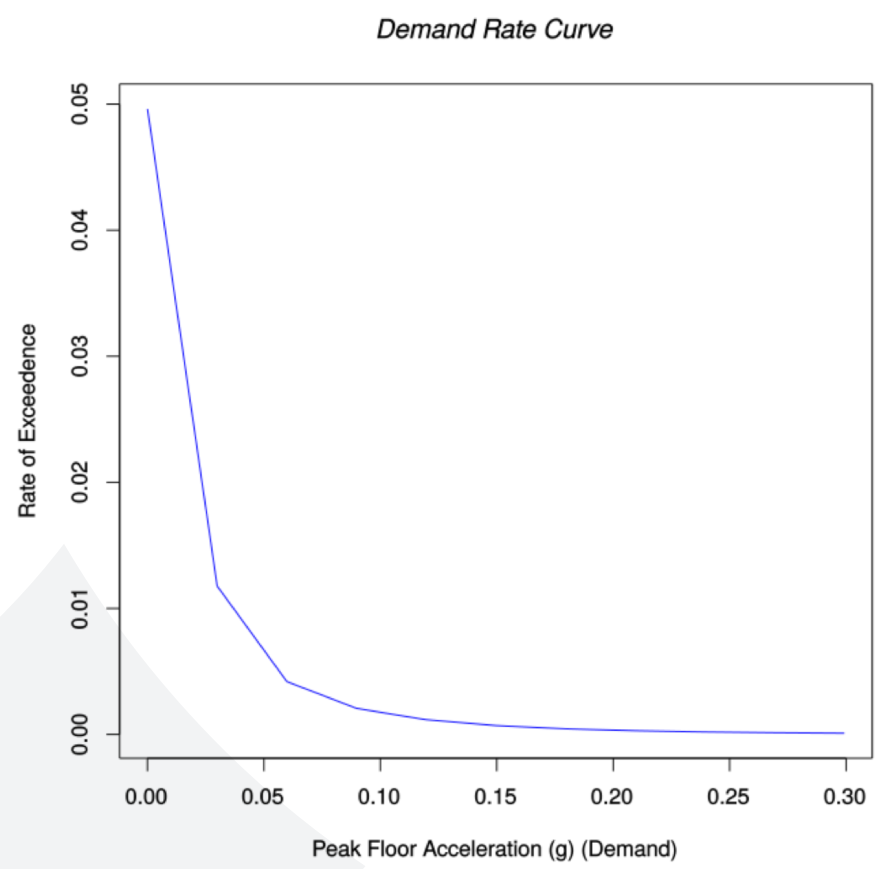


Fig 3: Demand Rate Curve to determine how often the demand exceeds specified limits

OpenSLAT also needs an inventory of the components in the building. These include the beams, columns, joints and so on in the building itself, as well as the building contents. The forces a component will be subjected to depend upon on its location. For example, a partition on the seventh floor will experience different forces from an identical partition on the third floor.

The way a component responds to forces is described by a set of Damage States (e.g., 'Slight Damage', 'Moderate Damage', 'Severe Damage'), and the average force which will result in that amount of damage. This is known as the Fragility of the component. By applying the appropriate demand curve, OpenSLAT determines how likely it is that a component will suffer each level of damage.

Each component type also has a Cost Function, which describes the cost of remedying each damage state by repairing or replacing the component. By applying the results above to the Cost Function, OpenSLAT estimates how much we should expect to spend on that component as a result of seismic activity.

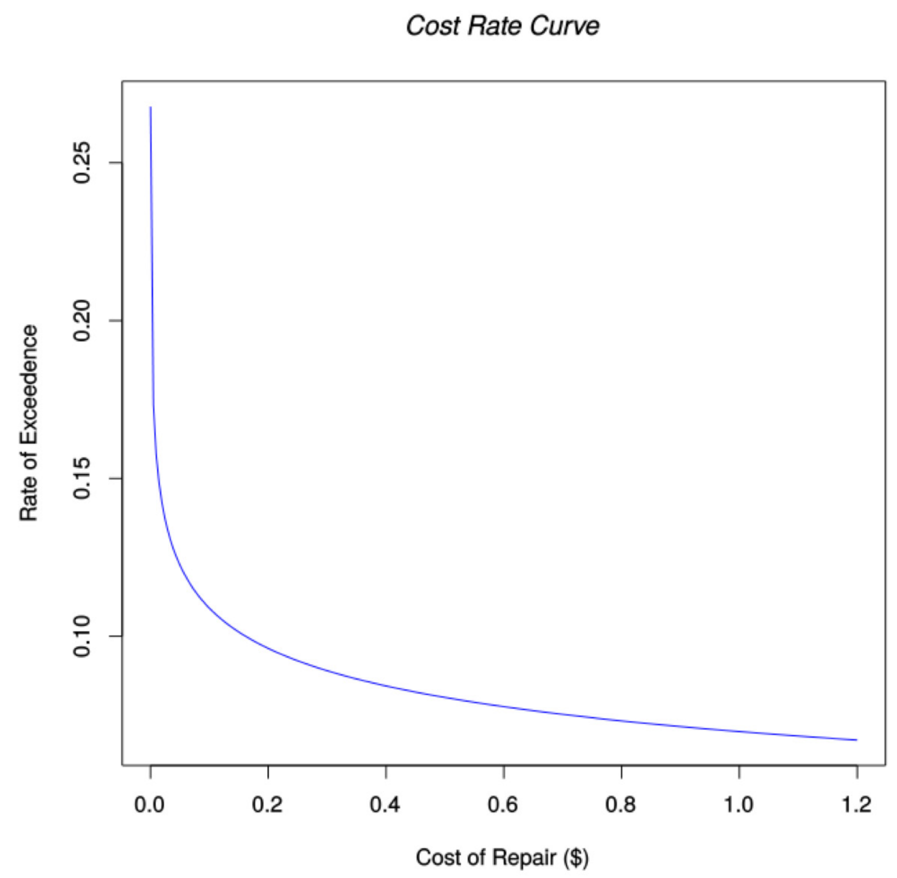


Fig 4: Curve to estimate the likely repair costs

Once this has been done for all the components, OpenSLAT provides an estimate of the total cost, allowing engineers, insurers, owners and others to make better-informed decisions.

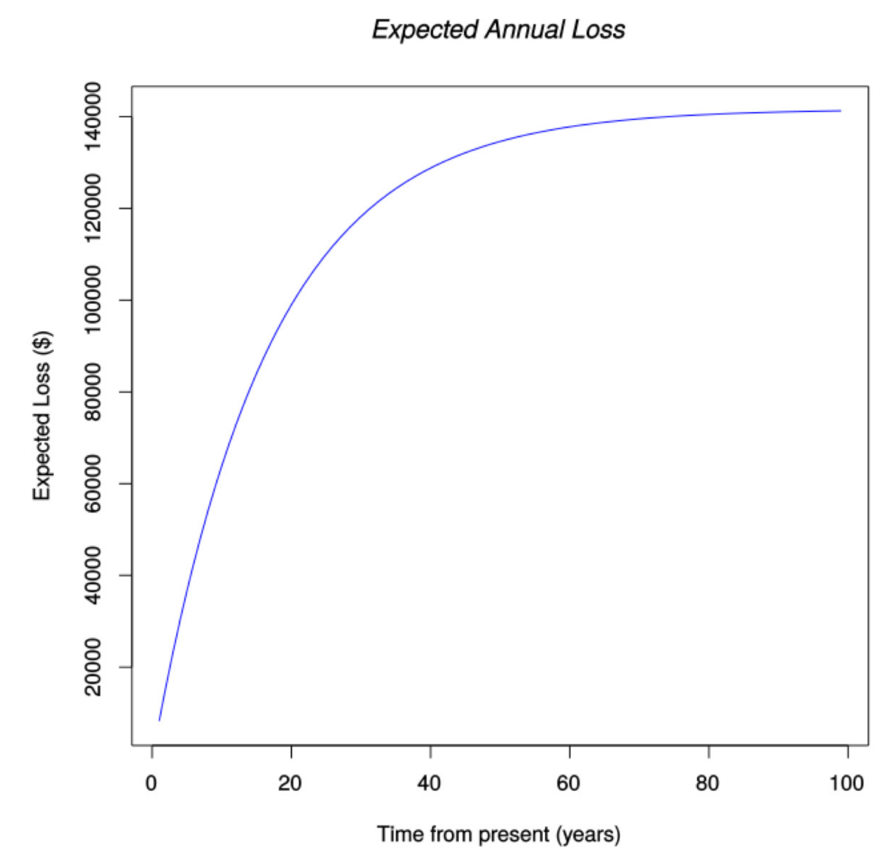


Fig 5: Estimating the annualised seismic losses for a building

The losses can also be broken down in different ways, such as by floor or component type, facilitating more detailed analyses.

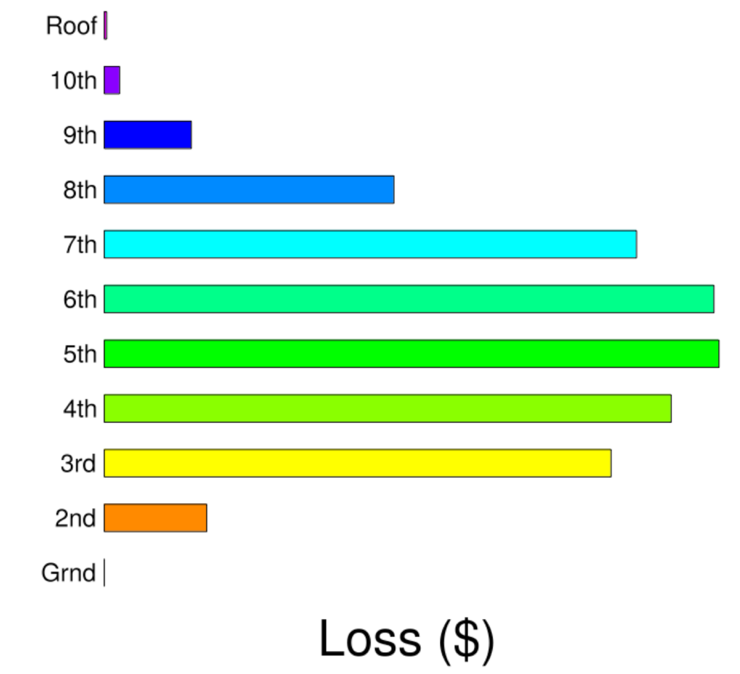


Fig 6: Estimating losses by storey

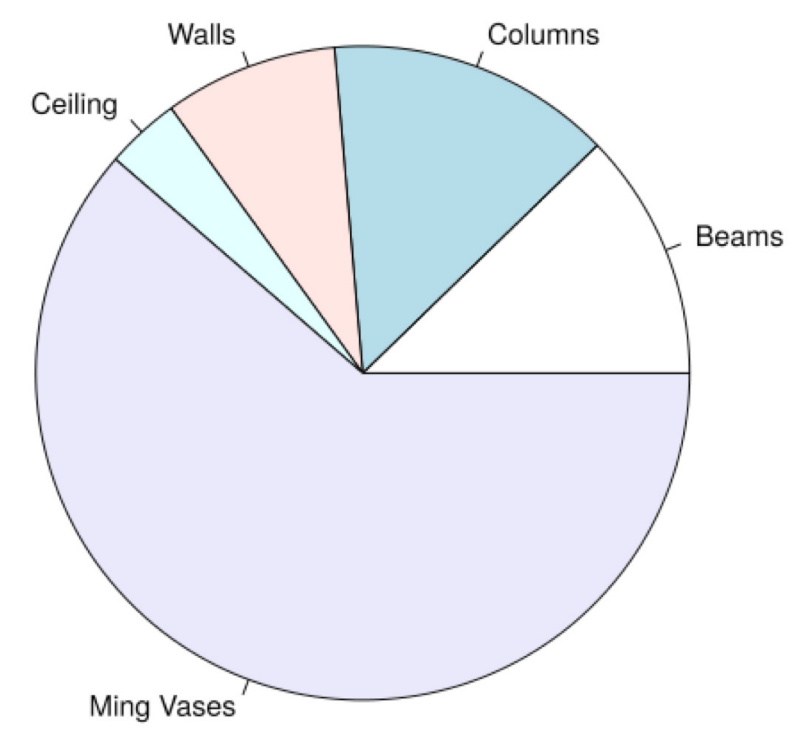


Fig 7: Breakdown of losses by component type

Who will benefit?

OpenSLAT is a tool for designers in conceptual and final design assessment. It can also be used to assess existing buildings. This could be used as a basis for a universal seismic rating system such as QuakeStar being proposed by Davin Hopkins or the US Resiliency Council's Building Rating System. The ultimate beneficiaries will be building owners, tenants and the general public through improved seismic performance of buildings.

Acknowledgements

The project team wishes to acknowledge the financial support provided by the Quake Centre partners and the great technical support provided by Professor B. Bradley (University of Canterbury) and Professor K. Elwood (University of Auckland) in enabling the project to proceed.

Quake Centre
Delivering Industry Solutions

Funded by industry to deliver solutions to industry identified needs.

"SO, YOU'VE GOT AN EARTHQUAKE PRONE BUILDING?" – A GUIDELINE BOOKLET

Warren Batchelar

The Building (Earthquake-prone Buildings) Amendment Act 2016 (the Amendment Act) came into effect on 1 July 2017. Its purpose is to target those buildings that pose the highest risk to life-safety in the event of an earthquake.

Project objectives

This project is to develop a user-friendly Guideline in booklet format for building owners, occupants/tenants and Territorial Authorities - putting the technical stuff into clear and simple to understand language for the general public. It explains the process of assessing whether a building is earthquake prone and what you might do if your building is determined to be so.

The Amendment Act applies to non-residential buildings, and also some residential buildings if they are:

- two storeys or more and have three or more household units, or
- two storeys or more and used as a hostel, boarding house, or other specialised accommodation.

The Amendment Act specifically excludes single tenancy residential dwellings (i.e. typical family homes). Other exclusions include farm buildings, retaining walls, fences, certain monuments, wharves, bridges, tunnels and storage tanks.

The Amendment Act places obligation on the owners of older buildings to have their buildings assessed and upgraded in a timely manner. While it may appear yet another obligation on building owners, the legislation is fundamentally directed to save lives through improving the performance and resilience of the New Zealand building stock.

The Guideline booklet is specifically targeted to remove the hype and separate the fact from the fiction so those affected by the new legislation can readily find out how it affects them and what they need to do. An extensive list of FAQs is included.

Timeframe

The Guideline was scheduled for delivery by the end of 2017 however it looks likely to slip into early 2018.

Acknowledgements

We acknowledge the support of the team at the Quake Centre and also the financial support from EQC.

Fig 1: Overview of the Amendment Act

IMPROVING THE SEISMIC STRUCTURAL REDUNDANCY OF LOW DAMAGE POST-TENSIONED ROCKING BRIDGE PIERS

PhD Student: Royce Liu

Supervisory Team: Prof Alessandro Palermo & Dr Robert Finch

Introduction

What is a post-tensioned rocking structural system?

The post-tensioned rocking structural system consists of having structural members (columns, beams, and walls) as separate bodies to the rest of the structure and for these members to be clamped together by unbonded post-tensioning. In such a configuration, rocking can occur at the member-member joints and easily replaceable energy absorbing devices are installed across those joints. This structural system is also called dissipative controlled rocking, DCR.

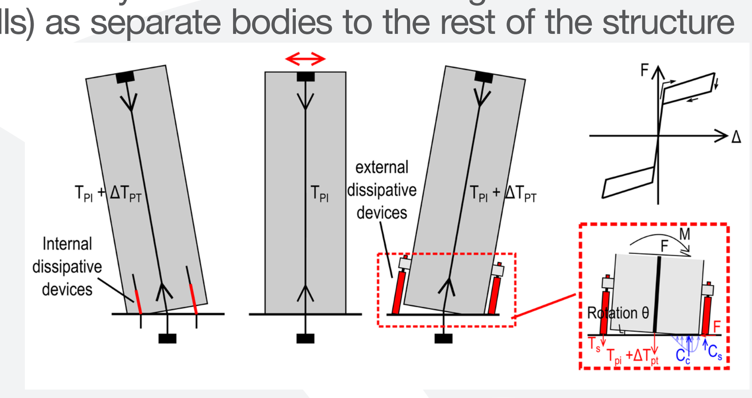


Fig 1: Hybrid PRESSS / Dissipative Controlled Rocking DCR

What is the point of Dissipative Controlled Rocking, DCR?

DCR was developed as a low seismic damage alternative to traditional R.C construction in order to aid immediate post-earthquake functionality and reduce both direct and indirect costs related to seismic structural damage. The unbonded post-tensioning ensures minimised residual drifts, whilst damage is confined to the replaceable energy absorbing devices.

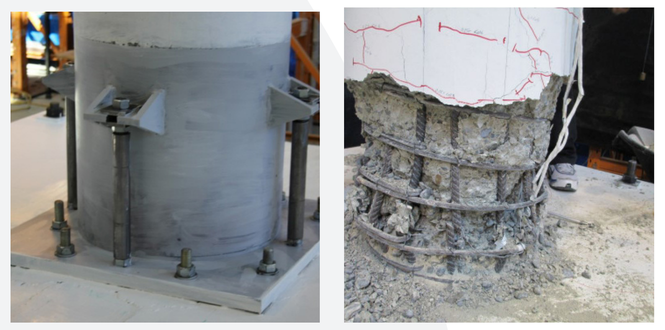


Fig 2: Difference in damage between conventional R.C (White, 2014) and DCR (Mashal, 2015)

How is the post-tensioned rocking structural system implemented in the context of bridges?

Bridges (especially in NZ) have either single or two column pier bents. Where a pier bent, consists of a column(s) with cap beam on top. In the single column bent, the rocking interface is inserted at the base of the column; the unbonded-post-tensioning is anchored in the foundation and at the top of the cap beam; and dissipative devices are installed across the rocking interface. In two column pier bents, DCR is implemented in a similar manner except that each column has an extra rocking interface and set of dissipative devices at the top of each column.

What has already been investigated about DCR implementation to bridges?

Research on this topic began around 1995 and focussed on assessing the performance of this system to simulated seismic loading compared to conventional R.C. construction and developing methods of structural analysis, modelling, and design. One of the key outputs from previous research on DCR in general was the development of the PRESSS Design Handbook which is a practitioner oriented document describing the design of buildings using DCR.

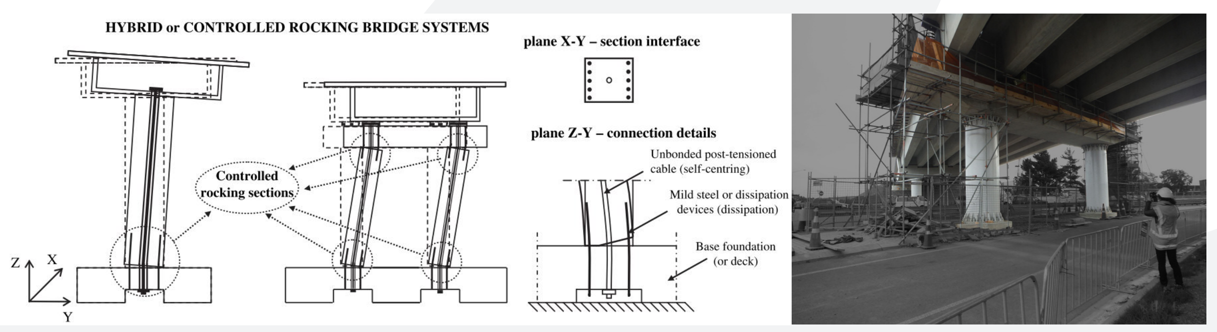
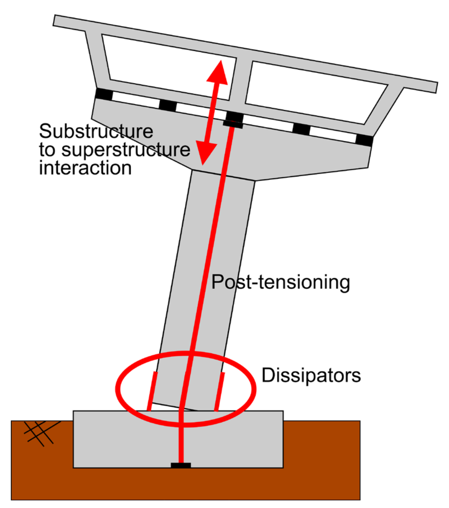


Fig 3: Implementation of DCR into bridge piers, concept left (Palermo & Pampanin, 2008) and right, real use in Wigram Magdala Bridge

What are potential seismic design issues with DCR and its implementation to bridges?



Dissipative controlled rocking depends on the dissipative devices and the post-tensioning for resisting seismic actions and preventing collapse of the overall structure. The dissipators have a limited cyclic load life and stretch capacity, whilst, the post-tensioning just has a limited stretch capacity before its capacity to self-centre the structure is compromised. Currently, all the dissipators are designed to activate at a set level of earthquake loading and all have the same ultimate capacities. Hence, currently the robustness of DCR is purely provided by the sheer number of dissipators and post-tensioning bars or tendons. Once rupture of a few dissipators and yielding of the post-tensioning occurs, the pier would lose significant stiffness and would be prone to P-Δ effects which would eventuate in collapse of the structure.

Another issue, with the implementation of DCR to bridges is the possibility of deformation incompatibility between the pier and the rest of the bridge. This is especially true for single column piers as the mode of deformation of the pier is primarily rotational about its base whilst the deck will tend purely translate in the horizontal plane when the bridge is seismically loaded.

Research question

This research looks to extend the design strategy of dissipative controlled rocking so that it is more resilient to the unknown characteristics of an earthquake (meaning more structural redundancy and robustness) and so that losses associated with dissipative controlled rocking are reduced. It looks to achieve this aim by answering the questions: "How can the seismic structural redundancy of DCR single column piers be improved?" and "Could having multiple sets of dissipative devices or rocking interfaces designed to activate at different levels of displacement of the structure be a way of achieving improved seismic structural redundancy?"

Scope

In this research, the idea of having multiple sets of dissipative devices or rocking interfaces designed to activate at different levels of displacement of the structure is investigated as a way of achieving improved seismic structural redundancy. Three structural schemes using this idea are investigated: having two sets of dissipators across one rocking interface, having a segmented column with dissipators across each joint, and combining a DCR pier with a rocking foundation. The bridge piers being developed in this research are called "multi-performance dissipative controlled rocking bridge piers" or MDCR piers. The term "multi-performance" is used to describe the piers developed in this research, because, the piers capacity is discretised by the hierarchical activation, meaning that it will have multiple performance levels.

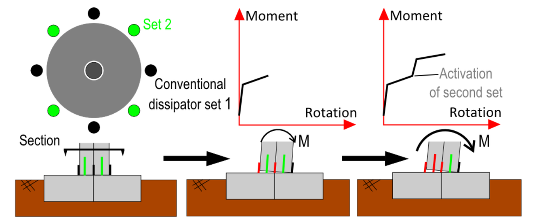


Fig 4: Multiple sets of dissipators across one rocking joint

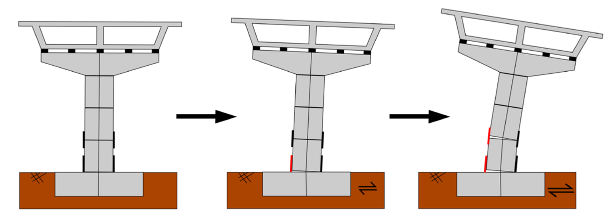


Fig 5: Dissipators across multiple rocking interfaces

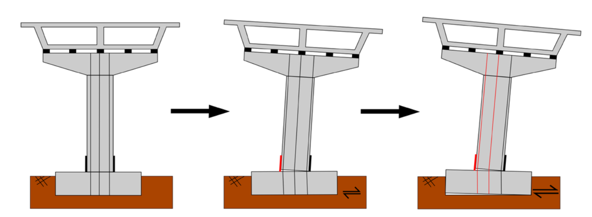


Fig 6: Combining pile cap rocking and DCR

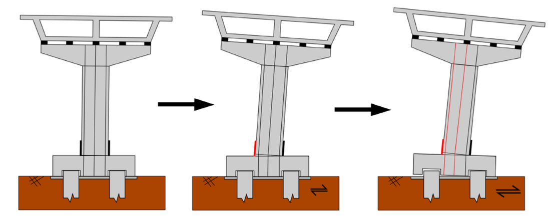


Fig 7: Combining shallow foundation rocking and DCR

Methodology

The project is being conducted in the following manner:

1. State of the art review
2. Phase I of experimental work
3. Phase II of experimental work
4. Numerical analysis and modelling
5. Design procedures and tools

Phase I of experimental work involved testing of a 1/3 scale bridge specimen and MDCR Pier.

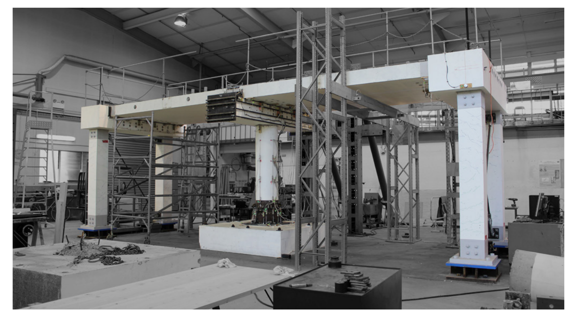


Fig 8: 1/3 scale bridge test specimen

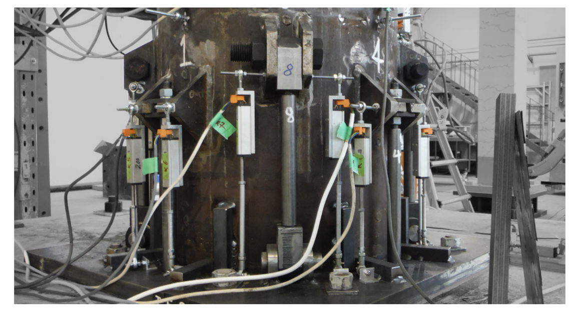


Fig 9: Close up of pier base and two sets of dissiators

Phase II of experimental work involved testing of a 2/3 scale MDCR Pier.

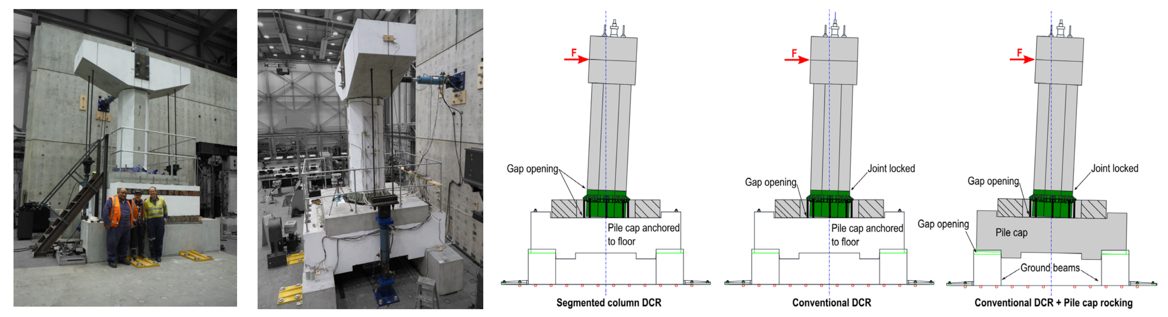


Fig 10: Implementation of DCR into bridge piers, concept left (Palermo & Pampanin, 2008) and right, real use in Wigram Magdala Bridge

Key outputs

The key outputs of this research are the following:

- Completion and submission of a research thesis in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Civil Engineering.
- Design guidelines for the groove type dissipator
- Design guidelines for MDCR piers
- Experimental evidence as proof
- Dissemination of knowledge to academics and industry through conference and journal papers.

Below is a list of publications written to date

Liu, R., & Palermo, A. (2015). Low Damage Design and Seismic Isolation : What's the difference ? In 2015 NZSEE Conference. Rotorua, New Zealand.

Liu, R., & Palermo, A. (2016a). Controlled rocking, dissipative controlled rocking and multi-hierarchical activation: numerical analysis and experimental testing. In ECCOMAS Congress 2016: 7th European Congress on Computational Methods in Applied Sciences and Engineering (pp. 5–10). http://doi.org/10.7712/100016.2160.8334

Liu, R., & Palermo, A. (2016b). Large scale testing of a low damage substructure connection in a precast concrete bridge. In The New Zealand Concrete Industry Conference 2016. Auckland, N.Z.: The New Zealand Concrete Industry.

Liu, R., & Palermo, A. (2016c). Pier to deck interaction and robustness of PRESSS hybrid rocking : issues affecting hammerhead pier bridges. In 2016 NZSEE Conference (pp. 1–9). Christchurch, N.Z.

Liu, R., & Palermo, A. (2017). Quasi-static testing of a 1/3 scale precast concrete bridge utilising a post-tensioned dissipative controlled rocking pier. In 16th World Conference on Earthquake Engineering (pp. 1–12). Santiago, Chile.

Liu, R., & Palmero, A. (2017). Experimental testing of the next generation of low damage rocking bridge piers. In The New Zealand Concrete Industry Conference 2017. Wellington, New Zealand.

Project benefits

The benefits of this project are: creation of knowledge and experimental evidence which will contribute to the implementation of DCR to bridges in New Zealand; creation of new opportunities for the precast concrete industry; and advancing the use of concrete in bridge structures.

The construction industry sector will find the outputs of this research useful. More specifically, design consultants and contractors will be able to use the knowledge developed in this research to better implement DCR to bridges.

Another benefit of this project, is the improved resilience of New Zealand through this work contributing to New Zealand's future transportation network to be significantly less impacted by earthquake damaged bridges.

References

Mashal, M. (2015). Post-tensioned earthquake damage resistant technologies for Accelerated Bridge Construction. University of Canterbury.

Palermo, A., & Pampanin, S. (2008). Enhanced seismic performance of hybrid bridge systems: Comparison with traditional monolithic solutions. Journal of Earthquake Engineering, 12(8), 1267–1295. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-57649223986&partnerID=40&md5=e24752ace4cba9921aaf958241c7f3be

White, S. (2014). Controlled damage rocking systems for accelerated bridge construction. University of Canterbury.

Fig 11: Specimen construction at Bradfords

Fig 12: Damage from the 2016 Kaikoura Earthquake

Start
March 2014

Progress - year 1, March 2014 - March 2015
- Developed aim and scope of research
- Worked on the design of phase 1 of experiments and test specimen
- Developed a DCR section analysis program in MATLAB

Progress - year 2, March 2015 - March 2016
- Attended the NZSEE conference and presented my research ideas
- Undertook Phase I experiments in the Structures Wing Extension Laboratory
- Data analysis of results from Phase I experiments

Progress - year 3, March 2016 - March 2017
- Presented Phase I of experimental work at 2 domestic and 2 international conferences.
- Worked on the design of Phase II experiments and test specimen
- Supervised construction of the Phase II specimen
- Awarded the 2016 NZCS Concrete Prize

Progress - year 4, March 2017 - March 2018
- Attended the World Conference of Earthquake Engineering in addition to 2 domestic conferences and presented a mix of phase 1 and phase 2 of my experimental work.
- Awarded the Sandy Cormack Award at the 2017 New Zealand Concrete Conference for best paper and presentation.
- Undertook Phase II experiments in the newly built Structural Engineering Laboratory
- Currently writing my thesis.
- Further outputs: Journal papers and design report (expected mid 2018)

Expected finish
March 2018

Acknowledgements

The project team wishes to acknowledge the financial support provided by the Quake Centre and the Natural Hazards Research Platform for enabling the project to proceed

QuakeCentre
Delivering Industry Solutions

Funded by industry to deliver solutions to industry identified needs.

For more information contact Royce Liu: royce.liu@pg.canterbury.ac.nz

Department of Civil and Natural Resources Engineering, University of Canterbury Private Bag 4800 Christchurch 8140 New Zealand

HYDRAULIC FRACTURE PROPAGATION THROUGH INHOMOGENEOUS DAM CORE MATERIAL

Master of Engineering Thesis – University of Canterbury

Student: Ross Waters   Senior Supervisor: Dr Jennifer Haskell   Co-Supervisor: Dr Kaley Crawford-Flett
Co-Supervisor: Dr Mark Stringer   Associate Supervisor: Dr Robert Finch

Hydraulic fracturing of dam core material can cause excessive seepage and internal erosion, and lead to the total failure of large earth dams. Failure investigations of the Teton Dam in the United States, the Hyttejuvet Dam in Norway, and the Matahina Dam in New Zealand identified hydraulic fracturing as a possible trigger.

Although hydraulic fracturing in rock formations has been researched extensively by the oil and gas industry, studies through soils and dam fill materials are scarce. Further, much of the previous geotechnical research focuses on fracture initiation in homogeneous soil samples. Homogeneous samples do not account for defects in dam core material that can occur in the field (e.g. layered soils/segregation, construction defects, shear planes, areas of post-seismic displacement, differential settlement or closed hydraulic fracture cracks). Since hydraulic fracturing is understood as a weakest link phenomenon (Jaworski, Duncan, & Seed, 1981), defects could increase an embankment's susceptibility to hydraulic fracturing.

This research will investigate how defects within earth dams influence the hydraulic fracture process, with a specific focus on materials and stress conditions found in New Zealand.

Hydraulic fracturing in embankment dams

A hydraulic fracture is a thin physical separation of material by a fluid. This process is commonly used in the oil and gas industry, where rock formations are deliberately fractured to increase well yields of hydrocarbons (Murdoch, 1993a). However, in civil engineering applications, hydraulic fracturing is often problematic. In embankment dams, hydraulic fracturing can occur when an applied fluid pressure is greater than the minor principal stress within the embankment (Reclaimation, 1995).

The fluid pressure – be it from pressurised drill fluid in a borehole or from the hydrostatic pressure of the reservoir – causes a thin, physical separation of the dam material that results in a concentrated seepage path through the dam (Sherard, 1986). If flow velocity through this seepage path is sufficiently high to cause the movement of dam fill to unfiltered exits, then catastrophic internal erosion (piping) failures can occur (Reclaimation, 1995). Internal erosion and excessive seepage accounted for 38% of dam failures between 1900 and 1975 (Lo & Kaniaru, 1990).

Research objectives

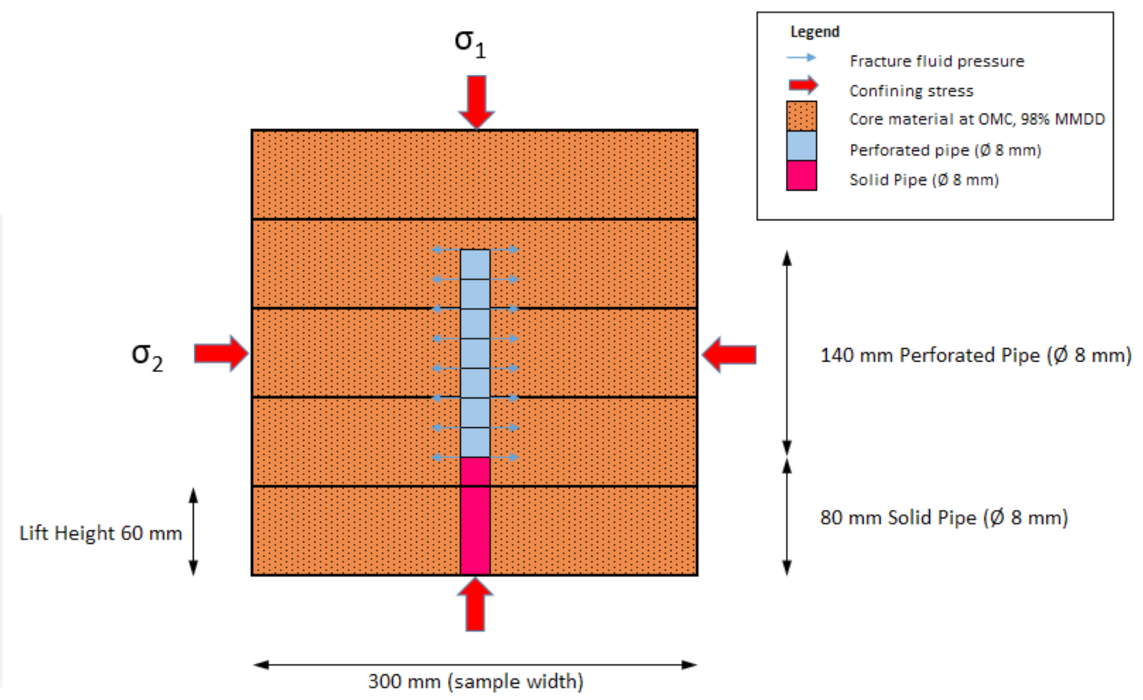
1. Design and build laboratory equipment capable of testing hydraulic fracture initiation and propagation.
2. Conduct hydraulic fracture testing on homogeneous dam core material from New Zealand. The testing will focus on the effects of Particle Size Distribution (PSD) on the hydraulic fracture process. The resulting hydraulic fracture initiation pressures and propagation mechanism will be compared to previous studies on similar material (e.g. Jaworski 1981, Lo 1990, Murdoch 1993).
3. Expand on the previous body of knowledge by investigating the effects of geotechnical defects (e.g. pre-existing cracks, wet seams, overly dry layers) on the hydraulic fracture process.

Experimental set-up

The 300 mm cubical specimen will be built up inside the fracture cell in five layers of 60 mm. Each layer will be compacted to 98% of Maximum Dry Density (MDD) at optimum moisture content (OMC) by using a compaction hammer to apply a known and repeatable amount of energy (similar procedure to ASTM D1557 – Modified Proctor).

Once the sample is compacted in-place, the major, intermediate and minor stresses will be applied to the sample. All stresses will be applied at once at the same loading rate (i.e. all principal directions will first be loaded to the value of the minor principal stress, then the intermediate and major stresses will be increased to their respective values). When the confining stresses are all at their target values, the positive displacement pump will begin injecting fracture fluid at a constant rate.

The fluid pressure will be monitored, with the expectation that a change in pressure rate will indicate the onset of hydraulic fracture. The assumed testing time (once sample preparation is complete) is approximately 1 hour.

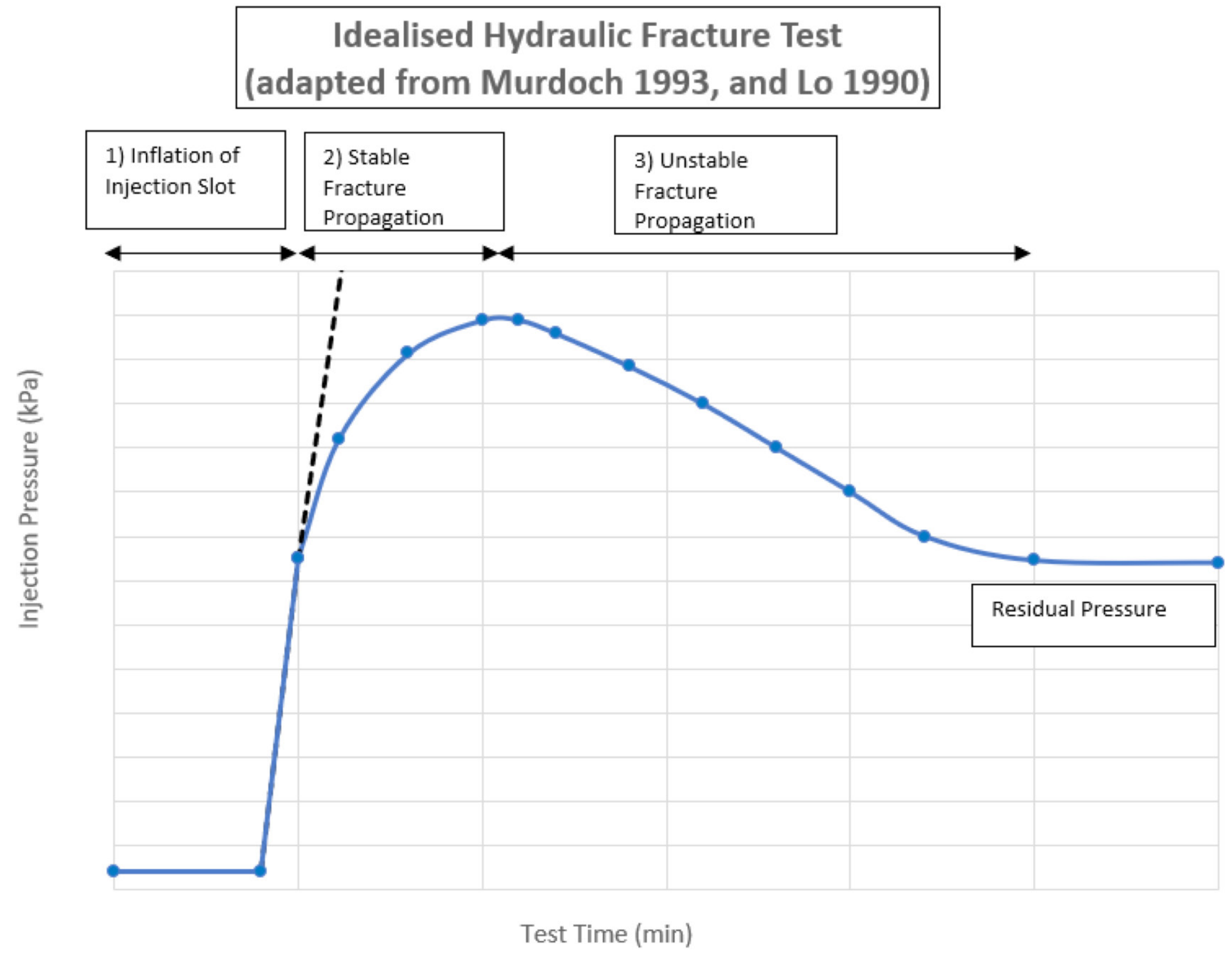


Outputs

The principal recorded outputs for each test will be fluid injection pressure vs. time. After testing is complete, the sample will be carefully broken apart until traces of the dyed injection fluid are found. The shape, initiation point and orientation of the fracture will be visually mapped and recorded.

A typical hydraulic fracturing test result from existing literature is reproduced below:

1. Nearly constant positive slope - pre-hydraulic fracturing
2. Change in slope - onset of stable hydraulic fracture (A stable hydraulic fracture would be held open but would not propagate if the injection pressure were held constant)
3. Negative slope - unstable hydraulic fracture (An unstable hydraulic fracture would continue to propagate at constant injection pressure)



Benefits

This research builds on the existing body of hydraulic fracture research in geotechnical materials. It will be useful to dam owners for providing guidance on proper construction controls for new structures and will provide a greater understanding of the risks geotechnical defects pose to an existing structure. This research will be particularly important for conducting risk assessments of structures without adequate filters, meaning there is little protection against a concentrated leak from a hydraulic fracture from becoming internal erosion.

Experimental testing will start early 2018 and results will be available in May.

Acknowledgements

The project team wishes to acknowledge the financial support provided by the Quake Centre partners for enabling the project to proceed.

References

Jaworski, G., Duncan, J. M., & Seed, H. B. (1981). Laboratory Study of Hydraulic Fracturing. Journal of the Geotechnical Engineering Division, 107(GT6).

Lo, K. Y., & Kaniaru, K. (1990). Hydraulic fracture in earth and rock-fill dams. Canadian Geotechnical Journal, 27(4), 496-506. doi:10.1139/t90-064

Murdoch, L. C. (1993a). Hydraulic fracturing of soil during laboratory experiments Part 1. Methods and observations. Géotechnique, 43(2), 255-265. doi:10.1680/geot.1993.43.2.255

Murdoch, L. C. (1993b). Hydraulic fracturing of soil during laboratory experiments Part 2. Propagation. Géotechnique, 43(2), 267-276. doi:10.1680/geot.1993.43.2.267

Reclaimation, U. S. D. o. t. I.-B. o. (1995). Safety Evaluation of Existing Dams.

Sherard, J. L. (1963). Earth and earth-rock dams: engineering problems of design and construction. New York : Wiley, 1963.

NUMERICAL INVESTIGATION ON SEISMIC RESPONSE OF RETAINING STRUCTURES

Arman Kamalzadeh, PhD Candidate, The University of Auckland
Supervised by: Professor Michael J. Pender
Co-supervisor: Dr Liam Wotherspoon

Infrastructure facilities are the major poles of development. In the case of geological and environmental hazards, such as earthquakes and landslides, retaining structures can protect against threats and shield roadways, rail facilities, commercial buildings and residential properties from ground movement and debris.

Designers acknowledge that the pressures exerted on basement walls during earthquake loading need better definition. New Zealand is prone to several natural hazards, which can put the resilience of its infrastructures at stake causing serious economic losses and possible casualties. These hazards range from earthquake induced slope instability and liquefaction, to heavy precipitation leading to loss of strength in soils. Therefore, a thorough investigation of NZ's retaining structures contributes to making our infrastructure more resilient.

The current design approach for retaining structures subject to earthquake can be traced back to observations from 1g shaking table tests performed in Japan in the 1920s. Recent research has shed light on scaling problems associated with 1g tests and centrifuge testing has been used to clarify these issues. Some centrifuge tests conclude that present design approaches for retaining walls may result in overdesign and in rare cases under-design. This over-conservative approach can lead to an economic burden as severe as future catastrophic failures.

By localising the study for New Zealand conditions (typical retaining structures, soil type and seismic zones) this research seeks to investigate the integrity of the previous works with the hope of understanding the factors in this possible overestimation and its extent.

What we seek

Current practitioners' design approach is mainly based on small-scale 1g shaking table test results which suffer from scaling problems especially in case of cohesionless backfills (Ortiz et al., 1983). Consequently, these scaling problems are reflected in practitioners' design methods.

- In small-scale 1g shaking table tests, the wall is usually mounted on the base of the table, representative of constructing the wall on a bedrock.
- In small-scale 1g shaking table tests, the wall height cannot be representative of deep walls.
- Because of cohesionless soils, shear modulus dependency on effective stress and the uncertainties in this relationship, choosing a shear modulus especially for medium/dense sand is impossible.

In this research, we are trying to address these deficiencies using OpenSees finite element analyses (FEM) and stepping forward to set the classical debates around this issue to rest. In addition, Clough & Fragaszy (1977) and Seed & Whitman (1970) observed well-constructed retaining walls designed only for static loads could withstand PGAs up to 0.4g. The main sources of this overestimation are identified as:

- Misplacing the location of earth pressure seismic thrust

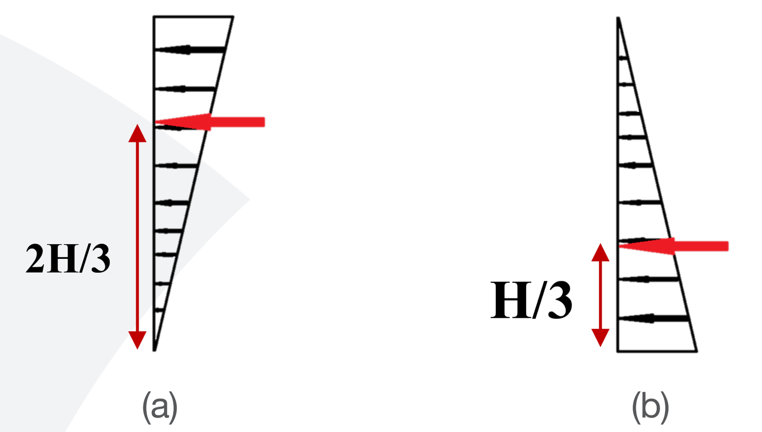
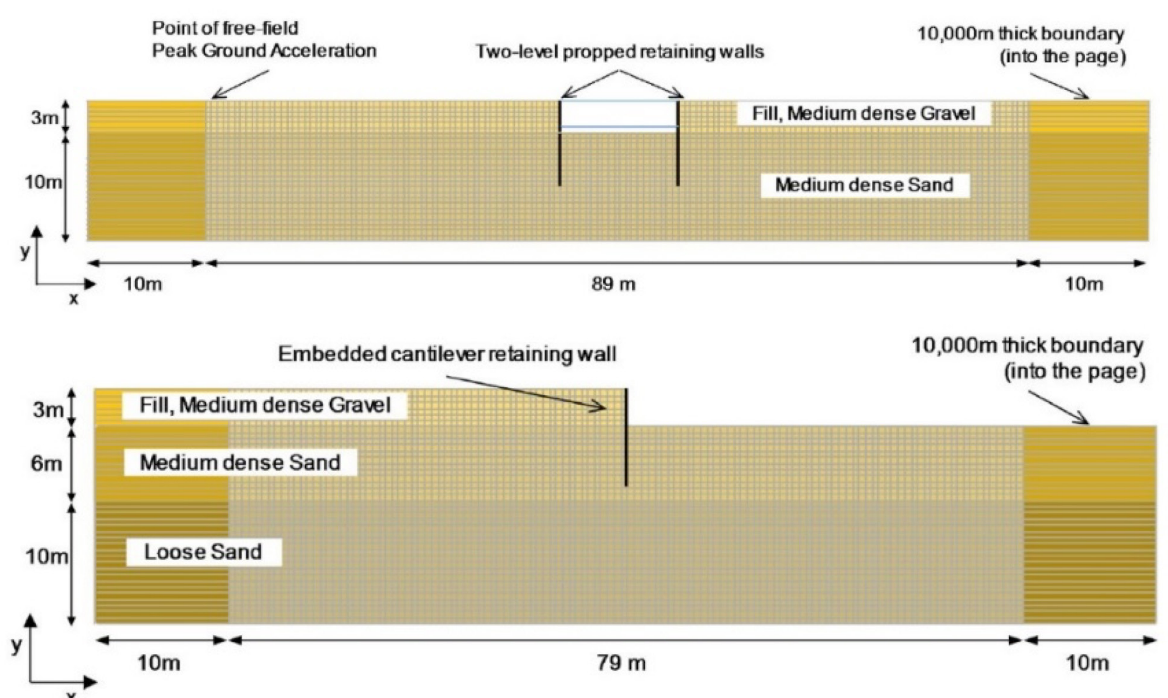


Fig 1: Earth pressure distribution utilised in (a) conventional design and (b) recent findings

- Pseudo Static Analysis: This assumes the PGA and the wall inertia force occur simultaneously. Although this deficiency exists in pseudo static analysis, due to its simplicity and the complexity of alternative approaches it is advised to use a fraction of PGA in pseudo static solutions.

Chin, Kayser and Pender (2016) compared the pseudo static responses of rigid, stiff and flexible retaining walls with OpenSees FEM analysis for New Zealand soil types and seismic regions. This study seeks to overcome small-scale 1g shaking table test cons, investigate on the state of current design approach overestimation and, push the boundaries of Chin et al. (2016) work utilising OpenSees FEM analysis. As for pre/post-processing this study benefits from GiD, Matlab and Mathcad software.

Fig 2: Numerical models of retaining walls (Chin, Kayser, & Pender, 2016)



What we have done so far

Unlike other FEM programs, OpenSees offers a variety of materials which use nested yield surfaces and can take into account dilation and non-flow liquefaction behaviour of soils. For comprehensive understanding of these materials, as the first step, we investigated drained triaxial tests results. The materials exist in the OpenSees database with the mentioned behaviour are Pressure Dependant Multi-Yield (PDMY) for cohesionless, Pressure Independent Multi-Yield (PIMY) for cohesive and Manzari Dafalias (MD) material for cohesionless soils.

Since our first objective is investigating seismic response of gravity retaining walls, we sought to model a simpler but important part of these walls, the foundation. We modelled different dimensions of soil models for a 4m foundation at centre of soil medium surface.

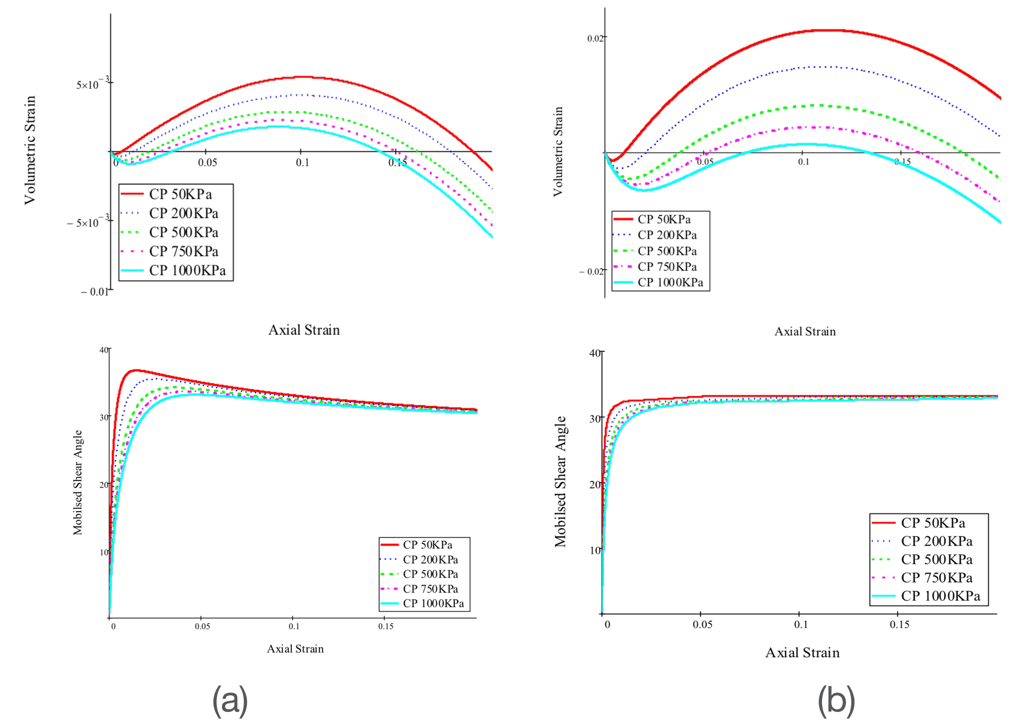


Fig 3: Drained triaxial test model results for (a) PDMY Medium Sand proposed by Yang, Lu, and Elgamal (2008) and, (b) M-D Nevada Sand with eo=0.7 proposed by Shahir et al. (2012)

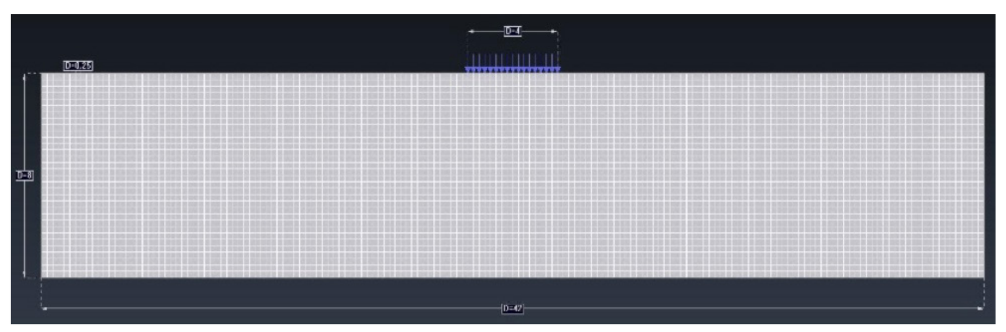


Fig 4: A 2D mesh configuration of a foundation model

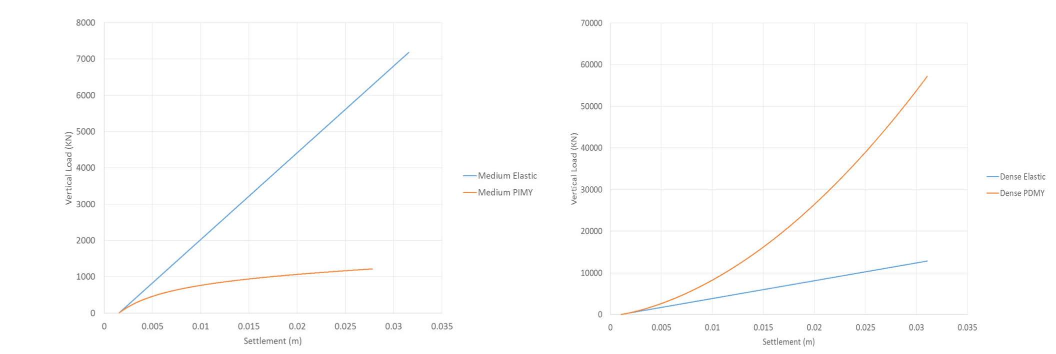


Fig 5: Comparison of elastic soil with (a) PIMY medium clay and, (b) PDMY dense sand

As the overturning moment is a crucial factor in designing gravity retaining structures, the rocking behaviour of the foundation was investigated. As the first step, a fraction of theoretical bearing capacity (Vu) of the foundation was subjected to the middle node of the foundation. Then, an incremental moment was applied at the same node. As expected, the higher the applied vertical load at the centre of the foundation, the higher moment capacity. In addition, as the moment increased in each case, more soil-foundation interfaces detached and the moment capacity reached a plateau at the end.

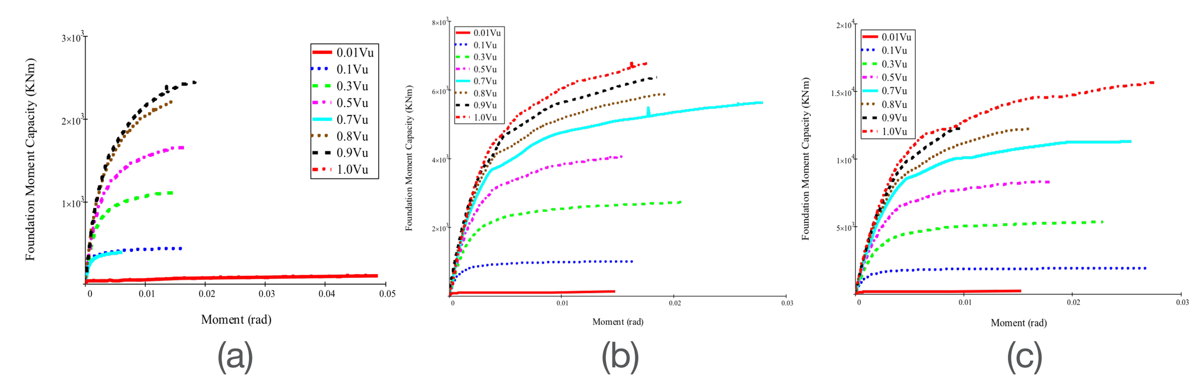


Fig 6: Moment capacity under different applied vertical loads for PDMY (a) loose, (b) medium and, (c) dense sand

More recently, we have attempted to model a 3D squared foundation (4x4 m2) on a dense sand medium (12x12x10 m3) using Manzari-Daflias material. The centre block of the soil medium consists of 0.4m elements. However, outside the central block, the element sizes increase toward the boundaries. Due to high computational demand of these kinds of models, the analyses are done utilising parallel processing and OpenSeesSP.

The bearing strength of the foundation is calculated and compared to the theoretical bearing strength presented in Eurocode 7. As can be seen, the foundation can bear greater vertical loads than Eurocode 7 suggests. The reasons for this are currently under investigation and will be discussed in further publications.

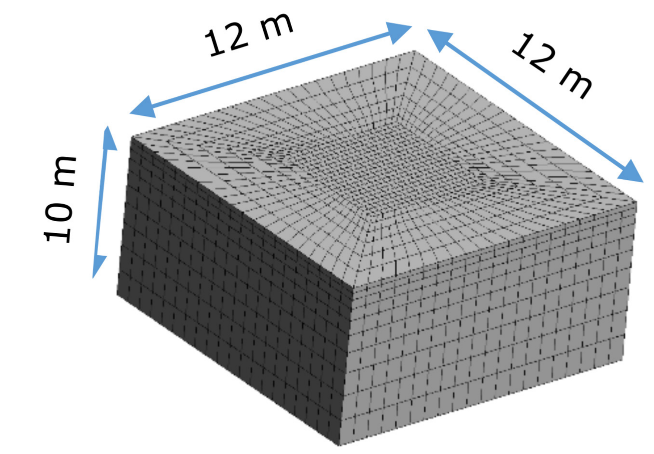


Fig 7: Mesh configuration of a 3D foundation on a dense MD Tayoura sand

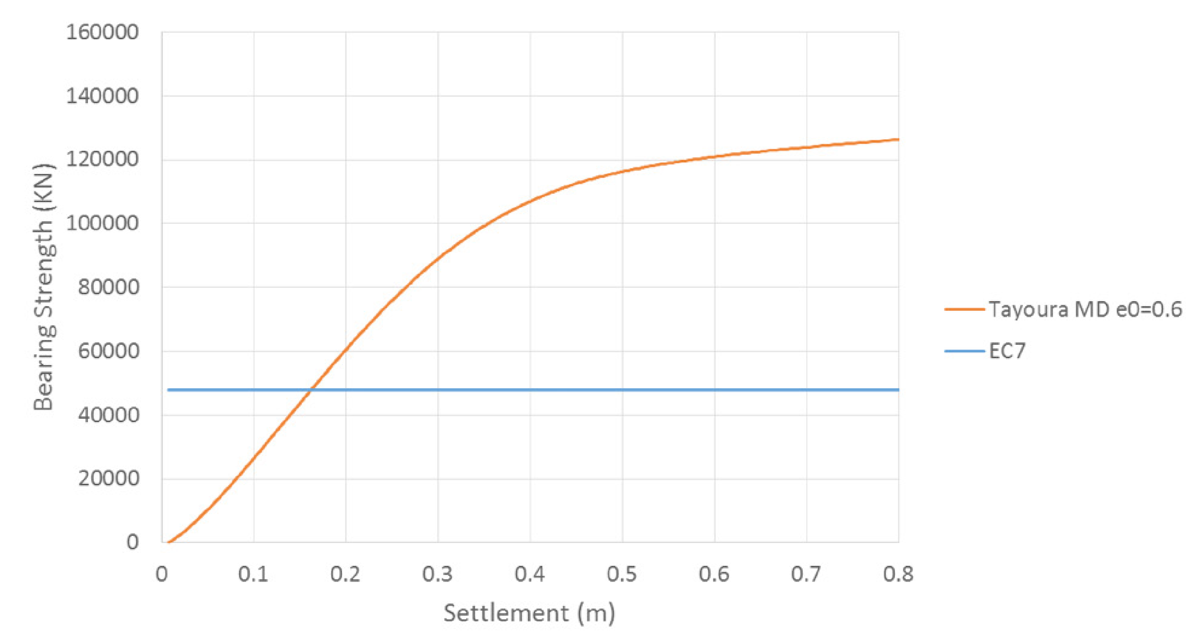


Fig 8: Comparison of dense MD Tayoura sand and Eurocode7 bearing strength

We anticipate the outcomes of our research will be ready to be presented to academic and engineering communities in multiple publications by the end of 2019.

How this research can benefit the NZ and engineering community

Since the scope of this research can be of interest of the government, civil engineering firms and research institutes, it could attract funds for experimental studies, empowering the New Zealand research community with centrifuge test facilities and appeal scholarships, with the aim of modified standards and guidelines leading to more resilient and cost effective infrastructures and buildings around New Zealand.

Even though the research will emphasise retaining wall practice in New Zealand, our practices are similar to those in many other parts of the world, so the outputs will be of wide interest beyond New Zealand. The New Zealand earthquake engineering consulting profession is successful in the international marketplace. The international reputation of earthquake engineering related research work done in NZ contributes to this success.

Acknowledgments

We wish to acknowledge the financial support provided by the Quake Centre partners in enabling the project to proceed.

Quake Centre
Delivering Industry Solutions

Make the box outline transparent

Funded by industry to deliver solutions to industry identified needs.

DEVELOPMENT AND DESIGN OF PRECAST CONCRETE BRIDGE PIERS IN SEISMIC REGIONS

B. McHaffie, P. Routledge, M.Cowan, A. Palermo, A. Sarkis

Dissipative Controlled Rocking (DCR)

Dissipative Controlled Rocking (DCR) is a system that can be used in place of traditional plastic hinges. It incorporates post-tensioning (PT) to provide re-entering, mild steel dissipaters to provide energy dissipation and steel armouring at the interface to prevent concrete degradation. This combination of PT and dissipaters leads to a flag-type hysteresis as illustrated in the figure below. The behaviour limits residual displacement after an earthquake provided the PT and axial load moment contribution (re-centring) is larger than the moment contribution of the mild steel. The major advantage of these connections is that after a design level event the connections can be repaired to 100% of the original capacity by replacing the removeable external dissipaters.

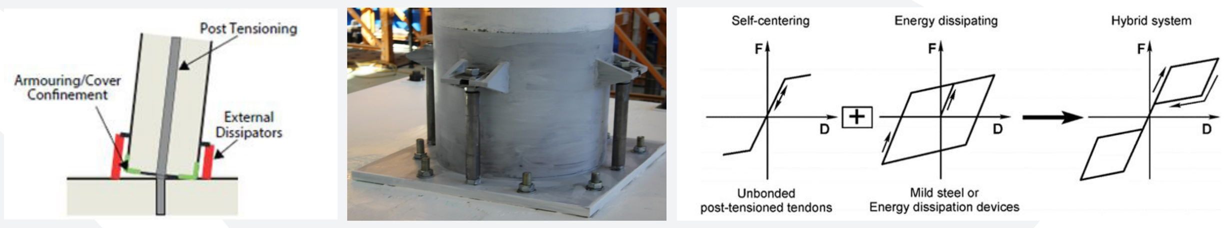


Fig 1: Left: General layout of DCR connection. Right: Idealised hysteresis behavior of DCR connection.

How does this compare to a monolithic pier?

Low damage technologies on bridges facilitate repair and inspection by incorporating external replaceable dissipaters that can be unbolted and reinserted without any need for temporary supports or restraints. Since the extent of damage is significantly limited, no significant cracking away from the main rocking interface is expected even after a collapse avoidance limit state event and no significant spalling is expected at or near the rocking interfaces. Additionally, unlike plastic hinge design, low damage systems prevent residual drifts due to its self-centring nature. Finally, control over damage leads to a minimized traffic disruption after an earthquake reducing indirect costs due to downtime all around the transportation network.

Problem

Recent seismic activity, particularly around New Zealand has highlighted complexities associated with repairing damaged structures. The result has been, in many cases, to demolish and rebuild the structure. This has lead to a shift in seismic design strategy toward minimizing post-earthquake repair. A promising strategy for doing this is the use of DCR. However, to facilitate the broader use of this technology the cost of these connections needs to be reduced to ensure they are comparative with traditional monolithic connections. In addition, while the connection itself can be easily and accurately designed the impact on other parts of the structure needs further investigation to ensure all seismic design principals are met.

Key areas where advancement could provide cost benefits:

- Efficiency in design – Can we use different design levels for DCR connections?
- Material efficiency – How can the dissipation devices be improved to reduce costs?

Key areas where advancement provides important design inputs:

- What are the correct Over-strength factors DCR connections?
- Does the current DBD methodology for MDOF systems correctly capture the response of DCR systems?
- What learnings can we take from recent earthquakes to improve bridge design for monolithic and DCR connections in the future?

Kaikoura earthquake learnings

The Kaikoura earthquake provided the perfect opportunity to learn about design issues and potential improvements that can be made to the design of bridges for both monolithic and DCR designs. Five of the most damaged structures built to recent design codes were investigated to determine failure modes and possible methods to prevent these.

Benefits and outcomes

Details of potential issues with current bridge design and possible improvements that should be considered during design.

Fig 2: Left and Centre: Damage to river road bridge piers. Right: Displacement time history of the top of the pier at River Road bridge during Kaikoura earthquake.

Completed Year 1

1. Complete research proposal.
2. Investigation of the potential to design for higher ductility's when using DCR connections through case studies.
3. Investigation into potential dissipation devices applicable to DCR in bridge piers.

Outputs

Wigram-Magdala Link Bridge – Low-Damage Details for a more efficient seismic design philosophy

Authors: P Routledge, B. McHaffie, M.Cowan & A. Palermo

Completed Year 2

1. Parametric analysis of typical monolithic and DCR piers. Design tables completed. Over-strength factor to be determined.
2. Further in-depth analysis on the impacts of designing for more frequent return periods for DCR connections.
3. Design and testing of dissipation devices.
4. Investigation of structures damaged in the Kaikoura earthquake including NLTH analysis of structures.
5. Input into footbridge design bid for CBD.

Outputs

Impact of post-earthquake reparability for low damage rocking bridge on the design framework

Authors: B.McHaffie & A.Palermo

Resilience-based design and damage-resistant technologies for an enhanced seismic performance of bridges

Authors: A.Sarkis, B. McHaffie & A. Palermo

Projected Year 3

1. Complete experimental testing (Dec)
2. Complete parametric analysis and determine over-strength factors to be used for DCR connections.
3. Begin MDOF structures modelling.

Outputs

Journal Paper: Parametric analysis and design of DCR connections

Conference paper: Comparison of DCR and Monolithic connections and their performance in the Kaikoura Earthquake

Conference paper: Experimental testing results.

Projected Year 4

1. Complete all objectives.
2. Publish thesis.

Design levels for DCR connections

In conventional forced-based seismic design, the displacement ductility factor (μ) provides a means by which, a structure can be designed for lower seismic loads on the basis of accepting more damage in a particular Damage Control Limit State event. For this reason, the NZTA Bridge Manual (NZTA, 2016) places a limit on the acceptable displacement ductility factor. As shown in the figure below the acceptable level of ductility is largely based on the accessibility and hence reparability of the plastic hinge regions. This provision strongly influences the ease of access for inspection and repair.

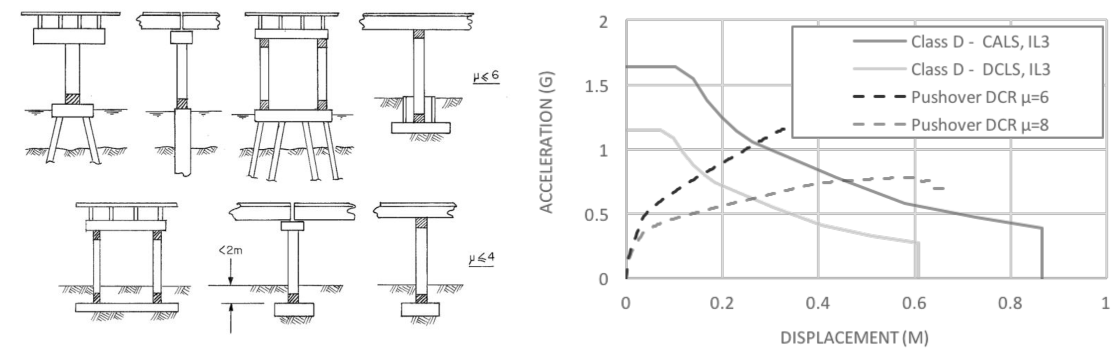


Fig 3: Left: Ductility levels outlined in the NZTA bridge manual. Right: Pushover comparison of the difference between ductility 6 and 9

Building on the notion that accessibility, and hence reparability, influences ductility an alternative seismic design philosophy is proposed. This is based on the premise that as long as the appropriate CALS (which ensures life safety) is satisfied for a particular IL structure, it would be justifiable to allow higher ductility's or lower return periods based on the economic and social impacts of the expected damage and speed of repair.

Benefits and outcomes

- Connections can be designed to sustain more displacement and less force resulting in smaller piers, foundations and pier caps.
- Reduce the cost associated DCR connections
- Reduced demands would provide an incentive for designers to consider the system, especially in challenging ground conditions.

Dissipation devices

Testing of 3 different dissipater devices is being carried out on a bridge specimen.

Dissipater types being tested include :

- Lead extrusion damper.
- Axial dissipater, non-grooved with necked area at 60% of threaded area.
- Axial dissipater, non-grooved with necked area at 80% of threaded area.

Benefits and outcomes

- Lead Extrusion dampers tested which are capable of dissipating energy with no damage essentially extending DCR to a "no damage" solution.
- Axial dissipaters have been developed which are cheaper to machine (performance to be determined).
- Ratio of threaded area to necked area may be increased (depending on performance) reducing number of dissipaters required and hence cost.

Over-strength factors for DCR systems

The over-strength factor applied to capacity protected parts of the structure not intended to yield has been well researched for monolithic connections. However, this does not capture the post yielding stiffness of DCR connections which can be much larger than for a monolithic connection due to the presence of PT.

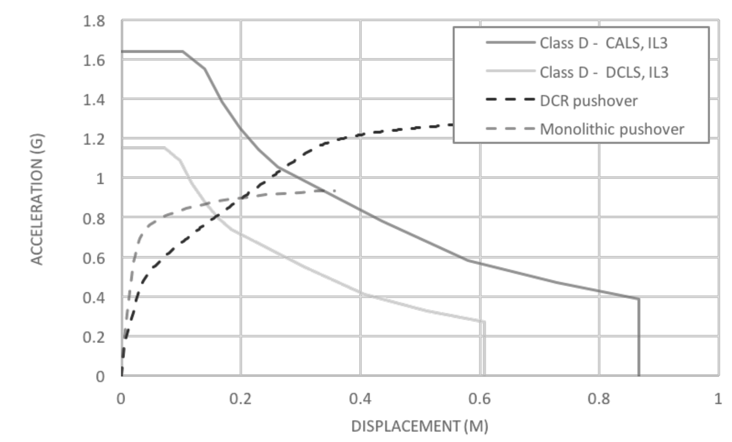


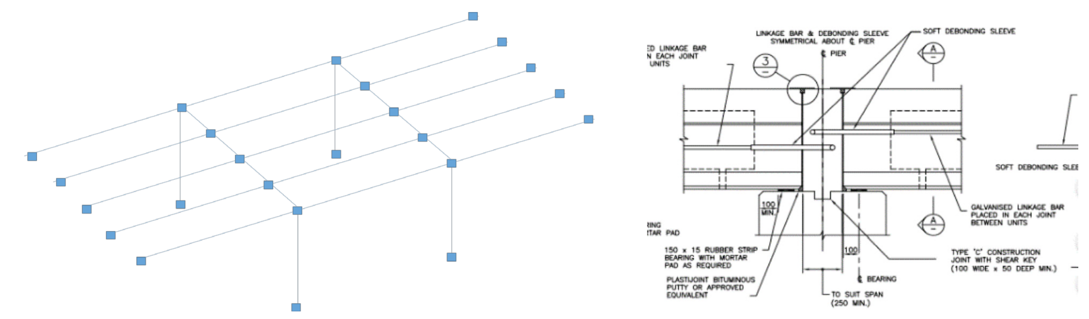
Fig 4: Pushover comparison between a DCR and monolithic connection

To carry out this objective a parametric study on monolithic and DCR connections has been completed. In addition to the over-strength factor, a range of design tables will be published which will provide a starting point for design and highlight the parameters which have the larges effect on the connections efficiency, displacement capacity and strength.

Benefits and outcomes

- Ensure that capacity design principals are met.
- Developed design tables for easier and more efficient connection design.

DBD for MDOF DCR Systems



		Traditional PH		DCR	
		Short Bridge (SB)	Long Bridge (LB)	Short Bridge (SB)	Long Bridge (LB)
Simply Supported	Short Span (SS)	SS, SB, T, SS	SS, LB, T, SS	SS, SB, DCR, SS	SS, LB, DCR, SS
	Long Span (LS)	LS, SB, T, SS	LS, LB, T, SS	LS, SB, DCR, SS	LS, LB, DCR, SS
Fixed	Short Span (SS)	SS, SB, T, F	SS, LB, T, F	SS, SB, DCR, F	SS, LB, DCR, F
	Long Span (LS)	LS, SB, T, F	LS, LB, T, F	LS, SB, DCR, F	LS, LB, DCR, F

Short Bridge – 30m	Short Span – 15m Single Hollow Core	2 Lane Bridge - (7m wide)
Long Bridge – 180m	Long Span – 30m Super T	4 Lane Bridge - (18m wide)

Non-linear time history analysis will be carried out on a range of bridges selected to represent bridges typically used in NZ. These structures will be used to investigate the effects of span, length and width on the overall performance of the structure. These will be compared to traditional FBD and DBD design methods to ensure they reasonably predict the response of DCR connections.

Benefits and outcomes

Currently a simplistic and conservative approach is taken to seismic design. This research would help improve the accuracy of these approaches by taking into account deck stiffness, connection detailing and span length resulting in more efficient designs for monolithic and DCR connections.

Acknowledgments

The project team wishes to acknowledge the financial support provided by the Quake Centre partners and other funders including the Civil and Natural resources Department at the University of Canterbury and OPUS International Consultants for enabling the project to proceed.