2017 Annual Report

QuakeCoRE

NZ Centre for Earthquake Resilience

Contents

Directors' Report

QuakeCoRE is transforming the earthquake resilience of communities and societies, both in New Zealand and internationally. We achieve this through a programme focused on *research excellence, collaboration,* and *impact and education.* This Annual Report provides a diverse range of highlights achieved in the 2017 calendar year.

Our *research excellence* leverages New Zealand as a natural earthquake laboratory with world-renowned research arising from the 2010-2011 Canterbury and 2016 Kaikōura Earthquakes, among others. In this Annual Report we highlight a variety of achievements, including proprietary damping devices that enable 'low-damage' building construction and are being used both in New Zealand and internationally. Our researchers also gained a better understanding of the earthquake resilience of New Zealand's vulnerable churches, and collected evidence on human behaviour and injuries from earthquakes using unprecedented and internationally unique data.

QuakeCoRE's *collaboration* as a national network of research institutions and stakeholders, and across traditional disciplinary boundaries, is essential for developing earthquake resilience in New Zealand. Our network has provided leadership in research-driven outcomes, side-by-side with stakeholders. Following the 2016 Kaikōura Earthquake, including the development of assessment methods and guidance for earthquake-damaged multi-storey buildings in Wellington City and liquefaction of reclaimed land at CentrePort. Multi-disciplinary research collaboration is also showcased in the context of understanding the resilience of heritage precincts in Oamaru. The QuakeCoRE Annual Meeting was once again the focal point of this year's collaboration efforts, with 180 participants, full capacity at the Wairakei venue.

This report also showcases significant capability developments in *impact* and *education* during the second year of QuakeCoRE's existence. A novel web tool is enabling open-access to state-of-the-art research simulations within QuakeCoRE to facilitate multi-disciplinary research and translation to industry end-users. Another QuakeCoRE outreach programme, called *QuakeScape,* provides a new approach to develop community awareness and preparation for earthquake risks through game-play. Meanwhile, the establishment of QuakeCoRE Emerging Researcher Chapters in Auckland, Wellington, and Christchurch provides unique educational opportunities for students and early-career researchers to develop a variety of skills, engage with people from various disciplinary backgrounds, and participate in outreach activities.

Welcome to our second Annual Report!

Ken Elwood – Director

Brendon Bradley – Deputy Director

Chair's Report

The 2010-2011 Canterbury and 2016 Kaikōura Earthquakes are a reminder to all New Zealanders that significant research and technological advances are needed to address the economic (estimated at $40 billion for the Canterbury earthquakes alone), social and cultural impacts of these natural events. What motivates the QuakeCoRE Board, Leadership Team and researchers is that their work enables communities to have the capacity and resilience to recover rapidly.

In this context, 2017 has been another immense year for QuakeCoRE. Ken Elwood and Brendon Bradley continue to successfully lead and focus the research programme to ensure QuakeCoRE remains the preeminent earthquake research centre in New Zealand.

Our research programmes remain focussed on six key areas:

- Ground motion simulation and validation
- Liquefaction impacts on land and infrastructure
- Addressing earthquake-vulnerable buildings through a multidisciplinary approach
- Next-generation infrastructure: Low-damage and repairable solutions
- Pathways to improved resilience
- Spatially-distributed Infrastructure

We are committed to collaborating across projects, across institutions and across other research programmes to support a best-for-NZ approach. This integration depends on the support and collaboration of our partners and on linkages between international and New Zealand research institutions, industry, iwi and the wider community.

I thank the Board for their wisdom, guidance and leadership. We welcome Sir Mark Solomon and Professor Jan Evans-Freeman to the Board, and thank Dr Sulo Shanmuganathan, Dr Rod Carr and Nick Miller for their service as they depart.

My gratitude extends to Ken, Brendon, members of the QuakeCoRE Leadership Team, and indeed our entire research community for their passion and the difference they make.

On behalf of the Board, we are looking forward to 2018.

Dean Kimpton – Chair

About Us

QuakeCoRE is transforming the earthquake resilience of communities and societies, through innovative world-class research, human capability development and deep national and international collaborations. As a Centre of Research Excellence (CoRE) funded by the New Zealand Tertiary Education Commission (TEC), QuakeCoRE is a national network of leading New Zealand earthquake resilience researchers. QuakeCoRE is hosted by the University of Canterbury and has seven other formal partners.

We enhance earthquake resilience across the country and internationally, by working collaboratively on integrated, multi-disciplinary programmes of world-leading research. Our research supports the development of an earthquake-resilient New Zealand.

Our Vision

We will create an earthquake-resilient New Zealand where thriving communities have the capacity to recover rapidly after major earthquakes through mitigation and pre-disaster preparation informed by research excellence.

Our Outcomes

1

Improved Earthquake Resilience
We will contribute to a step-change improvement in the earthquake resilience of the nation's infrastructure from research-informed national and local policies, implementation standards and disaster planning.

2

Improved Economic and Commercial Outcomes
We will support New Zealand's long-term economic benefit through significantly improved seismic performance of New Zealand infrastructure, rapid business recovery after future earthquakes and the growth of engineering resilience innovation and business in the New Zealand construction sector driving international competitiveness.

3

Improved Societal Outcomes
We will enable communities to recover rapidly after major earthquakes through mitigation and pre-disaster preparation, informed by research and public outreach.

4

Highly Skilled and Diverse Workforce
Our graduates will be sought after for their knowledge of earthquake resilience and work-ready professional skills. They are taught in the very best national and international multi-disciplinary environment, combining research and industry elements. Through our graduates, we will seek a growth in under-represented groups (Māori and Pasifika) and gender equality in engineering disciplines.

5

International Recognition
We will be a focal point for international earthquake resilience, attracting the best talent and business alongside national and international research collaborations.

6

Growing Mātauranga Māori
We will contribute by building close engagement with Māori leaders who have responsibility for earthquake planning and resilience and developing opportunities for Māori capability building. The distinctive contribution of Māori indigenous knowledge of earthquake resilience will enhance social, economic and environmental outcomes for New Zealand.

Research

Research overview

QuakeCoRE continues to play an integral role in supporting and linking multi-institutional, investigator-led earthquake resilience research programmes that are internationally networked and recognised. Our research programmes are advancing the science and implementation pathways of earthquake resilience through system-level science with highly integrated collaborations coordinated across the physical, engineering and social sciences and across multiple relevant research institutions. The research is principally organised into technology platforms and flagship programmes.

Four technology platforms provide the underpinning experimental (lab and field), computational, and data infrastructure that are necessary to support our research programmes and realise QuakeCoRE's vision and mission. Our high-impact research is delivered via six flagship programmes. These programmes are advancing our research efforts to the next level through multi-institutional and multi-disciplinary research collaboration, engagement with end-users, and co-funding.

Our research programmes are supported by QuakeCoRE contestable and non-contestable funding and have strong links to end-users. Each of the flagship programmes has a named industry representative to facilitate communication at all levels between researchers and end-users.

Technology Platforms

TP1

Large-scale laboratory facilities
Leader: Ken Elwood | Deputy Leader: Alessandro Palermo
This Platform supports enhanced collaboration across domestic and international large-scale experimental facilities, innovative testing procedures, and instrumentation.

TP2

Field- testing and monitoring
Leader: Liam Wotherspoon | Deputy Leader: Quincy Ma
This Platform is building on New Zealand leadership in field testing and monitoring to focus on development of world-class testing technologies and urban system monitoring.

TP3

Multi-disciplinary community databases
Leader: Nick Horspool | Deputy Leader: Matthew Hughes
This Platform fosters the contribution to, and utilisation of, existing community databases, as well as enabling the development of new multi-disciplinary databases for transformative research.

TP4

Computational simulation and visualisation
Leader: Brendon Bradley | Deputy Leader: Christopher McGann
This Platform provides computational workflows to connect the multi-disciplinary research activities within QuakeCoRE and to provide a pipeline by which research results can be understood in terms of their wider impacts on earthquake resilience.

Flagship Programmes

FP1

FP2

FP3

FP4

FP5

FP6

Ground motion simulation
Leader: Brendon Bradley | Deputy Leader & Industry Representative: Didier Pettinga
This Flagship aims to provide a paradigm shift in ground motion prediction via theoretical developments in physics-based simulation methods and their utilisation in engineering design and assessment.

Liquefaction impacts on infrastructure
Leader: Misko Cubrinovski | Deputy Leader & Industry Representative: Sjoerd van Ballegooy
This Flagship focuses on next-generation assessment methods and mitigation strategies for soil liquefaction, one of the principal earthquake hazards affecting land and infrastructure in New Zealand.

Heritage, safety and economics: Addressing earthquake-prone buildings
Leader: Jason Ingham | Deputy Leaders: David Johnston & Ilan Noy | Industry Representative: Bryce Davies
This Flagship addresses the risk posed by collapse-vulnerable earthquake-prone buildings through a multi-disciplinary lens.

Next-generation infrastructure: Low-damage and repairable solutions
Leader: Ken Elwood | Deputy Leader: Tim Sullivan | Industry Representative: Jared Keen
This Flagship seeks a new design paradigm where reparability and damage-control is explicitly considered in the design process of buildings and infrastructure.

Pathways to improved resilience
Leader: Erica Seville | Deputy Leader: Tracy Hatton | Industry Representative: Mike Mendonça
This Flagship focuses on determining how we decide where to invest our limited resources to most effectively improve New Zealand's resilience to earthquakes.

Spatially-distributed Infrastructure
Leader: Liam Wotherspoon | Deputy: Brendon Bradley | Industry Representative: Roger Fairclough
This Flagship is a joint research programme with the National Science Challenge 10: Resilience to Nature's Challenges. The programme is developing tools to assess the performance of spatially-distributed infrastructure networks subject to extreme natural hazards.

New damping devices help create more resilient buildings

Associate Professor Geoff Rodgers and his team have developed two new innovative damping devices that absorb energy and help protect buildings from major damage during earthquakes. The devices will be attractive to building owners, because they are less likely than other devices to need to be replaced or reset after an earthquake, resulting in both time and cost savings.

Current designs for earthquake-safe buildings feature "sacrificial structures" that will absorb energy and prevent building collapse. This type of engineering is designed to save lives, but it usually results in significant structural damage that is expensive and time-consuming to fix or replace, often leading to widespread demolition as seen after the 2010-2011 Canterbury Earthquake Sequence.

The two damping devices are uniquely designed to handle different building structures and types of ground shaking. The first design, an extrusion damper, pushes lead through a chamber to absorb and dissipate energy. Importantly, the process is completely reversible so after ground shaking, the device does not need to be reset.

The Forte Health building in Christchurch has already incorporated this device, and an ongoing project will use them in a community housing project in San Francisco. Geoff is also currently involved in a project to test the devices in a two-storey reinforced concrete rocking-wall structure. This project is a collaboration between QuakeCoRE and the International Joint Research Laboratory for Earthquake Engineering (ILEE) at Tongji University in Shanghai, funded by the Ministry of Business, Innovation and Employment (MBIE).

The second device, called Displacement and Direction Dependent Viscous Dampers (or D3 Dampers for short), uses a design with two pistons, one-way valves and a stepped cylinder wall to create different flow paths depending on which direction the building is being displaced. This response is better than previous similar devices because this D3 Damper responds automatically based on the rules of physics, rather than requiring external computation and sensors. The complex computation required with other devices and corresponding concerns about robustness has created a major barrier to their use in construction projects in the past.

Geoff and his team are also investigating how an existing high stiffness Ring-Spring technology could be used within the D3 Damper. These springs use a different type of energy dissipation to the damper, so used in combination, they could create a device that would be effective regardless of the type of ground shaking that occurs.

Geoff Rodgers with damping devices.

The team's focus is now on refining the D3 Damper design, based on the results of shake-table testing. They are also doing structural modelling to create guidelines to help practitioners use both technologies in the field.

Showcasing the importance of this work, in 2017 Geoff was awarded the Kiwi Innovation Network (KiwiNet) Norman FB Barry Foundation's Emerging Innovator Award, as well as the Royal Society Te Apārangi Early Career Research Excellence Award for Technology, Applied Science and Engineering. These awards recognise the significant impact of Geoff's work in the field of earthquake engineering, especially in the design and engineering of earthquake-resilient structures.

Understanding human behaviour during earthquakes to prevent injury

To reduce earthquake casualties and injuries, we need to understand how human behaviour, during and immediately following earthquake shaking, exposes people to increased risk of injury. To date little research has systematically analysed the immediate human responses to earthquake shaking, mostly due to data constraints and ethical considerations.

QuakeCoRE scientist Professor David Johnston at GNS Science and Massey University has developed a programme of work to fill this gap in order to better understand who gets injured during earthquakes and why. The research has investigated what people do during and immediately after shaking, as well as what actions individuals could take to better protect themselves.

To answer these questions, David and his colleagues have examined over 7,500 ACC injury claims from the 2010-2011 Canterbury Earthquake Sequence to determine the types of injuries people sustained and how they were hurt. The researchers then followed up with a questionnaire asking people what they did when the earthquake started, and triangulated these two sources of data with CCTV footage showing what people actually did.

The results show that there were two general ways people were injured during the 2010-2011 Canterbury Earthquakes: either people were hit by objects (passive injuries) or they did an action such as running that led to tripping or falling (active injuries). Passive injuries were proportionally more common during earthquakes that occurred at day, whereas active injuries were proportionally more common during the night.

This data highlights two ways to better protect people during earthquakes. First, we need to prevent objects from falling and hitting people, which has been the focus of many previous safety campaigns. Second, we need to help people understand that their actions may have unintended and dangerous consequences. In other words, trying to move during shaking increases the risk of sustaining injuries during an earthquake.

This finding has led David to suggest changing the adage “drop, cover and hold” to “stop, cover and hold”. He says that the data show people can best protect themselves by stopping first to assess their surroundings before making a decision about what to do next.

From this work, the team has begun asking whether it’s possible to train people to behave in certain ways. Anecdotal evidence indicates that children are more likely to act in appropriate ways during an earthquake than adults, which suggests that child-based learning is important and school-based educational efforts have been effective. The researchers are now focusing on collecting data to validate the effectiveness of school safety campaigns in changing behaviour.

The group is also focusing on the increasingly abundant data from CCTV footage to understand the range and sequencing of human behaviours during and immediately after earthquakes. Objective observation of earthquake video data can provide a useful quantitative measure of human behaviour, and enable researchers to look more closely at the social and physical contexts associated with injury risk during and immediately following earthquake shaking. The group is developing protocols for using CCTV footage that will address privacy and ethical concerns and enable researchers to effectively analyse footage after future events.

Benchmarking the resilience of New Zealand's earthquake-prone churches

The 2010/11 Canterbury earthquakes demonstrated that churches, particularly unreinforced masonry (URM), are highly vulnerable to earthquakes. PhD scholar Shannon Abeling is working with the Anglican diocese of Waikato and Taranaki to develop a framework for assessing the earthquake risk to the regions' churches.

The project will help limit the further destruction of heritage church architecture in New Zealand, as part of Flagship Programme 3, which aims to develop methods for improving earthquake-vulnerable buildings such as URM. Shannon and her supervisor, Professor Jason Ingham, have developed a screening framework that identifies vulnerability factors for churches to determine which structures would likely be damaged in a future earthquake. Shannon hopes that eventually this framework can be applied to churches nationwide.

One goal of the research is to develop procedures to better assess, prioritise and retrofit church buildings. A cost-effective way to analyse existing buildings is to create a methodology for practicing engineers to predict possible failure mechanisms and vulnerabilities. Shannon's research will help develop such a methodology by assigning a vulnerability rating that can be used by the stakeholders to prioritise seismic strengthening interventions.

Another project Shannon is working on uses data from more than 600 URM buildings damaged during the 2010-2011 Canterbury Earthquake Sequence to provide insight into the building damage, casualty, and economic impacts of earthquakes on URM buildings. By examining aerial photos and images taken from the ground days after the 22 February 2011 Christchurch earthquake, Shannon determines whether the debris fell inside or outside of a building, and if it fell outside the building, how far the debris travelled.

Shannon's work is part of a larger QuakeCoRE project looking at the potential impacts of a magnitude 8 Alpine Fault earthquake. Using her data alongside surveys of URM buildings around the South Island and Professor Brendon Bradley's projected ground motion models, the researchers are developing detailed models to predict building vulnerabilities and probable damage from such an event. The work is also intended to inform emergency response planning by predicting the likely damage that will occur and what responses are likely to be most effective.

Collaboration to Impact

Collaboration helps Wellington assess quake damage to multi-storey buildings

A national collaborative effort stemming from the 2016 Kaikōura Earthquake has led to further cooperation amongst QuakeCoRE, Kestrel Group, and the Wellington City Council (WCC) in 2017 to confirm the structural integrity of multi-storey buildings. The goal of the project was to provide confidence to building owners, occupants and the community that appropriate engineering investigations of buildings most affected by the Kaikōura Earthquake are being carried out, and that where necessary, the appropriate repairs and remediation are being completed.

The WCC's Targeted Assessment Programme focused on buildings considered most likely to have been damaged in the Kaikōura Earthquake: concrete, 6-15 storey structures located on soft soils. The project was particularly concerned with damage to precast concrete floors, which are likely present in over 80% of Wellington's commercial building stock.

The collaboration included QuakeCoRE researchers Professor Ken Elwood, Dr Rick Henry and Dr Dmytro Dizhur, as well as Kestrel Group Ltd engineers led by Dave Brunsdon. The team analysed the WCC data to identify trends and make recommendations on how various agencies and building owners can improve the resilience of CBD buildings.

One of the group's key recommendations is that the WCC should better understand their building inventory, identify key vulnerabilities, and develop monitoring programmes that use 'indicator' buildings to more rapidly identify damage after a future event.

A second key recommendation is for the development of guidelines on the seismic assessment of buildings with precast floors. Based on research at the University of Canterbury, engineers have recognised for many years that earthquakes could damage precast floors in a way that could lead to building collapse. However, the guidance for building assessment has until now been complex and therefore not frequently used in practice.

This recommendation, along with MBIE investigation into the partial collapse of precast floors in Statistics House, led MBIE to form a working group, chaired by Ken Elwood, to guide the further assessment of buildings with precast floors. The working group's goal is to use research on precast floors to provide clearer guidance for engineers doing seismic assessments. Going forward, engineers will be required to include a more comprehensive assessment of precast floors in their investigation of buildings. Ken says that, "This effort has led to the development of new procedures for the seismic assessment of buildings with precast floors, the first of their kind in the world."

Alongside the development of assessment guidelines, QuakeCoRE researchers have also been conducting research on precast floors to determine if damage from the Kaikōura Earthquake has impacted their residual capacity, making them more vulnerable in future earthquakes. Dr Tim Sullivan is using the proposed assessment guidelines to develop fragility curves for buildings with precast floors, giving probabilities of failure for different levels of ground shaking, a key missing component from seismic loss studies worldwide.

This close relationship with WCC has in turn led to collaboration with WCC on QuakeCoRE's Smart Seismic Cities (SSC) project. Led by Ken and Nick Horspool, this project is creating a suite of structural models for all buildings in the CBD more than five storeys tall. These models are then linked with information from instrumented buildings throughout the city to enhance situational awareness and to identify likely locations of damage immediately following earthquakes.

SSC will also help Wellington City evaluate the efficacy of future seismic mitigation policies through scenario studies. As part of the SSC project, and to enhance our understanding of the performance of Wellington CBD buildings during earthquakes, QuakeCoRE is collaborating with the University of Tokyo in the installation of accelerometers in the Wellington Central Library.

Photo: Phillip Capper (CC Images)

Interdisciplinary project addresses earthquake resilience in Oamaru Heritage Precinct

The Oamaru Heritage Precinct is the most unique, intact Victorian precinct in New Zealand. The precinct has become a focus of heritage tourism activity, and is helping to grow the tourism industry in the Waitaki district, which is important for regional development in rural New Zealand.

Oamaru lies 260km from the Alpine Fault, which has the potential to produce a magnitude 8 earthquake that could affect many parts of the South Island, including Oamaru. Heritage buildings are often earthquake-prone and pose a potential risk to public safety. Recent building and casualty models suggest Oamaru could expect some building damage and potentially some loss of life in the event of a magnitude 8 earthquake on the Alpine Fault.

The architectural practice Forrester & Lemon designed the Oamaru precinct in the 1880s during a boom in pastoral farming, and the buildings were constructed from locally quarried blocks of stone. For many decades after the subsequent 'bust', the buildings lay empty and fell into disrepair. A community-led effort to preserve the buildings began in the late 1980s, with the establishment of the Whitestone Civic Trust and subsequent purchase of sixteen properties over the next two decades. These buildings now comprise Oamaru's 'Victorian Precinct'.

The almost complete streetscapes that remain today present both unique opportunities and challenges. The QuakeCoRE project in Oamaru combines social science and engineering to identify the challenges and potential ways of addressing the tensions amongst heritage conservation, public safety, seismic risk, tourism and regional development.

The engineering portion of the project, led by Professor Jason Ingham at the University of Auckland, has used drones to create the first aerial map of the precinct. Doctoral students Francisco Galvez (Engineering) and Stacy Vallis (Architecture) have focused on several case studies of notable buildings, investigating their structural integrity along with engineering assessment of the completed retrofit/conservation schemes in recent years.

The social science portion of the project, led by Dr Caroline Orchiston and supported by her research assistant Will Stovall at the Centre for Sustainability at the University of Otago, has involved interviewing 22 stakeholders in the precinct, including local government officials, tenants and members of the Whitestone Civic Trust. These interviews have investigated local stakeholder perceptions of tourism growth, perceptions of seismic risk and future options for investing in the built infrastructure alongside other investment decisions such as tourism development.

The interviews have illustrated some tensions for the town in preserving its architectural heritage, while ensuring public safety. Caroline describes the project as "a baseline study of a town with a beautiful and unique heritage resource, but with some challenges around engineering, tourism perceptions and economic growth alongside the risk of future earthquakes." The team will hold a workshop to help stakeholders address these challenges using decision-support tools in February 2018.

CentrePort collaboration yields insights into liquefaction on reclaimed land

The 2016 Kaikōura Earthquake caused significant liquefaction at the port of Wellington (CentrePort), which caused wharf and building damage and temporary loss of operations. This damage resulted in CentrePort seeking to develop a close collaboration with QuakeCoRE researchers, led by Professor Misko Cubrinovski, to inspect the damage and aid in planning and recovery. The project also involved significant international collaboration with North American researchers, headed by Professor Jonathan Bray from the University of California, Berkeley.

The damage at CentrePort is not unexpected given its location on reclaimed land, which was created 50-100 years ago when there was little available information on the effects of earthquakes and liquefaction. As a result, most reclaimed land has not been engineered or constructed to handle earthquakes and is therefore at significant risk from liquefaction and displacement.

The results of this project therefore provide invaluable evidence and insights for the engineering evaluation and treatment of reclaimed land and structures not only at CentrePort but also in the wider waterfront zone of Wellington. The area approximately 200-500 m from the present CBD coastline is reclaimed land composed of similar soils and constructed with the same techniques as those used for the CentrePort reclamations.

In addition, geotechnical engineers internationally are interested in two aspects of the liquefaction at CentrePort that will help them understand the relationship between soils and the impacts of earthquakes. First, little is known about the seismic performance of reclaimed land in general, and more specifically the liquefaction of gravelly fills. Gravels are known to have higher liquefaction resistance than sands, but when gravels are mixed with sand and silt, the mixture may behave either as a gravel, a sand, or somewhere in-between depending on the proportion of gravel and sand size particles in the mix.

It was therefore important for the QuakeCoRE researchers to understand the composition of the soils that liquefied at CentrePort. PhD scholar Christopher de la Torre managed comprehensive field investigations, which independently verified laboratory tests that showed soils that liquefied were 30-40% silt and sand, and that their particles controlled the behaviour of the gravel-sand-silt mixture. In other words, liquefaction occurred in soils with as much as 60-70% gravels.

The second goal of the study was to quantify the ground distortion and impacts of the Kaikōura Earthquake on CentrePort structures. The project provided important evidence on the impacts of soil liquefaction on the seismic performance of characteristic port structures. Liquefaction and lateral spreading radically change the foundation environment and earthquake-loading conditions for wharves and buildings, and for many structures these phenomena may impose extreme seismic loading conditions. Hence, understanding the characteristics of soil liquefaction is essential for the quantification of its effects on engineering structures.

This collaborative project was funded by the Ministry for Business, Innovation and Employment (MBIE), the National Science Foundation (USA) and CentrePort Ltd. Misko calls the collaboration with CentrePort “exceptional” and the port continues to receive immediate access to data and findings from the QuakeCoRE research to use in their recovery and planning.

Capability Development

New web tool helps industry access QuakeCoRE ground motion data

QuakeCoRE researchers have developed a new open-source web application called SeisFinder to enable other researchers and practitioners to easily use highly innovative, but difficult to produce, ground motion data. Created by Flagship Programme 1 (Ground Motion Simulation and Validation), the data is produced by a new modelling technique to create improved predictions of ground shaking. The approach is extremely valuable but difficult for others to replicate because of the computational power and skills required.

SeisFinder has been developed under Technology Platform 4 (Computational Visualisation and Simulation) to eliminate the need for other researchers and practitioners to produce their own data and instead enable them to access the QuakeCoRE data directly. Professor Brendon Bradley says, "SeisFinder provides a collaborative connection between multiple researchers across QuakeCoRE that use these results in downstream calculations, as well as external researchers and earthquake engineers in both research and the private sector."

Users of SeisFinder select historical or potential future earthquake events and then can retrieve the strength of horizontal and vertical ground shaking for specific geographical locations. Engineers can download this data and use it in models to predict the effects of ground shaking on buildings, or to understand why existing buildings have been damaged in certain ways in past earthquakes. The website provides instructions and codes to help users manipulate the data, and future functionality includes models of liquefaction and landslides, as well as impacts on the built environment.

The project illustrates the emphasis that QuakeCoRE has placed on ensuring their research has a strong impact on engineering practice in New Zealand. No equivalent tool has been developed anywhere else in the world, which has international researchers interested in how they might create similar models in their own countries.

The Technology Platform 4 team completed a proof of concept this year, and interest has been so great that the team is now working on a new and improved second version, which will be available around mid-2018.

The response of early adopters has not only indicated a strong need for the tool but also suggests that it has significant commercial viability, which is currently being explored through various avenues.

Novel gameplay helps rural community leaders prepare for earthquake risks

QuakeScape is a new interactive activity developed by QuakeCoRE researchers and students to help rural communities understand the science behind earthquakes, as well as the real-world risks for their towns and the best opportunities for risk mitigation. The 2016 Kaikōura Earthquake illustrated how a lack of rural community understanding of and planning for natural disasters can lead to an inadequate response. QuakeScape helps address the importance and urgency of helping communities understand the science behind natural disasters so they can work together to mitigate the associated risks for their towns.

Through QuakeScape, community leaders are encouraged to play, learn, and talk about natural disasters and then facilitate conversations on how to mitigate risks for their community. QuakeCoRE PhD students have been heavily involved in the project, designing many of the puzzles and helping to facilitate the workshops. This encourages students to engage with communities, as well as creating direct links between the QuakeCoRE research community and the New Zealand public.

The workshop helps participants understand the physics-based models of earthquakes developed by Professor Brendon Bradley, and how these models predict that their own towns would be affected by a future earthquake. In working through the puzzles, the community leaders are encouraged to think about risk mitigation in their own towns, and to continue to engage with novel research being produced by QuakeCoRE researchers.

QuakeCoRE, in collaboration with the UC Quake Centre, funded the initial development of the QuakeScape programme, which was piloted on various groups in 2017 in Christchurch. A grant from the Brian Mason Trust is enabling the project to expand to 14 rural communities in Canterbury and Westland currently. Canterbury and Westland are widely known for natural disasters, both in the past and potentially in the immediate future (e.g. Alpine Fault), and many communities are in dire need of basic scientific understanding of potential disasters and risk mitigation.

QuakeScape can be modified to specific communities, and the team will work with local iwi to consider how to effectively introduce the programme into Māori communities, ensuring the programme is tailored to their needs, protocols and customs.

QuakeCoRE Outreach Coordinator Brandy Alger says, “This novel programme could help communities lower the damage and hazards associated with imminent future natural disasters as well as inspire them to take the lead in understanding the science behind natural disasters in their region and take action in risk mitigation. QuakeScape’s goal is promotion of teaching, demonstration, and the promotion of public interest in scientific and technical subjects.”

Emerging Researcher Chapters promote career development and collaboration

The QuakeCoRE Emerging Researcher Chapters (QERC) aim to stimulate networking, collaboration, and knowledge sharing between members of the earthquake resilience community, including (but not restricted to) the sociology, economics, and engineering fields. QERC's intention is to support human capability development, foster personal development of its members, and to spread knowledge beyond the academic world through the organisation of outreach activities. The Chapters also organise events for members to promote both internal and external sharing of research, and to encourage members to network.

QERC is focused on post-graduate students and post-doctoral researchers, but is also open to fourth-year undergraduate students and young professionals. The QuakeCoRE Outreach Coordinator, Brandy Alger, acts as a facilitator for the Chapters, and each Chapter is supported and guided by an Academic Mentor from each QERC Executive Team's respective university.

Professor David Johnston, Academic Mentor for the Wellington region, says, "Emerging Researcher Chapters have been extremely helpful for providing additional peer-support for our graduate students."

Emerging researchers established three Chapters in Auckland, Wellington and Christchurch in early 2017. The first year has focused on pulling together the emerging research community and initiating events that will provide a unique experience for students and new researchers aligned with QuakeCoRE. These events include meetings for students to present their research, skills building workshops, "lightning talk" competitions, and outreach events.

The Chair of the Auckland Chapter, Shannon Abeling, says the group is an important networking tool for PhD students. "We don't get the opportunity often to find out what other students are doing and to get feedback on our own research," she says.

Wellington Chapter Chair and PhD student Marion Tan agrees and says, "I personally have gained insights from regularly meeting the other students, learning from their experiences and getting ideas on my data gathering methods."

Shannon says that the Auckland chapter's outreach activities have been particularly successful. Auckland QERC outreach events, attracting over 500 participants, have included the Auckland Heritage Festival, the MOTAT Science Street Fair, the Incredible Science Day, and the "Enginuity Day," which is an opportunity for Year 13 high school girls to learn more about engineering. All these events included hands-on experiments and demonstrations to teach community members about earthquake engineering and to encourage young people to consider careers in engineering.

Another highlight for members of all three chapters was the "Disastrous Doctorate" conference, which was jointly organized with the Joint Centre for Disaster Research. The two-day event gathered doctoral students from engineering, geography, psychology, law, business, and emergency management backgrounds to learn about each other's research and to develop linkages across the disaster-research field.

Award highlights

Geoff Rodgers

In 2017, Associate Professor Geoff Rodgers was the recipient of two significant awards: the Norman F.B. Barry Foundation Emerging Innovator Award and the Royal Society Te Apārangi Early Career Research Excellence (Cooper) Award for Technology, Applied Sciences and Engineering.

The Norman F.B. Barry Foundation Emerging Innovator Award, from the Kiwi Innovation Network (KiwiNet), recognises an upcoming entrepreneurial researcher who is making outstanding contributions to business innovation. The award shows the significance of Geoff's work in developing seismic damping solutions to prevent irreversible earthquake damage to buildings.

The Royal Society Te Apārangi Early Career Research Excellence (Cooper) Award is awarded annually to encourage New Zealand–based, early-career researchers in technology, applied sciences, and engineering. Geoff was the inaugural recipient, again recognising his significant contribution to seismic strengthening of New Zealand buildings.

Brendon Bradley

In March 2017, Professor Brendon Bradley was awarded the 2016 Prime Minister's MacDiarmid Emerging Scientist Prize. This Prize is awarded to an outstanding emerging scientist with a PhD or equivalent qualification conferred within the past eight years. Brendon was awarded this prestigious award for his sophisticated seismic hazard analysis and pioneering ground motion simulation to identify and mitigate the effects of earthquakes. The selection panel was impressed with Brendon's research and his ability to express its scope and impact in a highly accessible way.

The Prime Minister's MacDiarmid Emerging Scientist Prize for an outstanding scientist.

Financials, People & Outputs

Financials

Category	Total ($000s)
CoRE Funding	4,163
Total Revenue	**4,163**
Directors and Principal Investigators	116
Associate Investigators	22
Postdoctoral Fellows	322
Technology Platform Staff & Research Technicians	263
Others	222
Total Salaries & Salary–related Costs	**945**
Overheads	905
Project Costs	377
Travel	184
Postgraduate Students	372
Equipment Depreciation/Rental	0
Subcontractors(s)	70
Total Other Costs	**1,908**
Total Expenditure	**2,853**
Net Surplus/(Deficit)	**1,310**

2017 at a glance

Category	Detailed category	FTE	2017
People	Principal Investigators	0.71	8
	Associate Investigators	0.33	42
	Postdoctoral Fellows	3.69	14
	Technology Platform Staff/ Research Technicians	3.10	4
	Administration/Support	3.50	4
	Research Students	74.70	91
	Total	**86.03**	**163**
Peer-reviews research outputs	Journal Articles		42
	Conference Papers		25
	Total		**67**
Value of external research contracts awarded	Vote Science and Innovation Contestable Funds		$4,719,212
	Other NZ Government		$865,423
	Domestic – Private Sector Funding		$156,825
	Overseas		$129,987
	Domestic – Other Non-government Funding		$40,933
	Total		**$5,912,380**
Students studying at CoRE	Doctoral Degree		72
	Other		19
	Total		**91**
Number of students completing qualifications	Doctoral Degree		6
	Other		7
	Total		**13**
Immediate post-study graduate destinations	Further study in NZ		1
	Further study Overseas		0
	Employed in NZ		9
	Employed Overseas		0
	Other		3
	Total		**13**
Commercial activities	Patent Applications		0

People

50
Investigators

91
Students

14
Post-docs

Board

Dean Kimpton (Chair)	Auckland City Council
Rod Carr	University of Canterbury
Mary Comerio	University of California, Berkeley
John Hare	Holmes Group Limited
Margaret Hyland	University of Auckland
Nick Miller	Fulton Hogan
John Reid	Ngāi Tahu Research Centre
Sulo Shanmuganathan	Opus International Consultants

Leadership Team/Principal Investigators

Ken Elwood (Director)	University of Auckland
Brendon Bradley (Deputy Director)	University of Canterbury
Misko Cubrinovski	University of Canterbury
Nick Horspool	GNS Science
Jason Ingham	University of Auckland
David Johnston	Massey University / GNS Science
Erica Seville	Resilient Organisations
Liam Wotherspoon	University of Auckland

International Science Advisory Panel

Mary Comerio (Chair)	University of California, Berkeley
Jack Baker	Stanford University
Tom O'Rourke	Cornell University
Ellen Rathje	University of Texas at Austin

Associate Investigators

Ann Brower	Lincoln University
Charlotte Brown	Resilient Organisations
Alice Chang-Richards	University of Auckland
Gabriele Chiaro	University of Canterbury
Charles Clifton	University of Auckland
Kaley Crawford-Flett	University of Canterbury
David Dempsey	University of Auckland
Dmytro Dizhur	University of Auckland
Temitope Egbelakin	Massey University
Olga Filippova	University of Auckland
Jeff Fraser	Golder Associates
Francesca Ghisetti	University of Canterbury
Sonia Giovinazzi	University of Canterbury
Bruce Glavovic	Massey University
Tatiana Goded	GNS Science
Rick Henry	University of Auckland
John Hopkins	University of Canterbury
Mehrdad Hosseini	AECOM
Matthew Hughes	University of Canterbury
Christine Kenney	Massey University
Virginie Lacrosse	Tonkin & Taylor
Greg MacRae	University of Canterbury
Chris Massey	GNS Science
Chris McGann	University of Canterbury
Hugh Morris	University of Auckland
Ilan Noy	Victoria University of Wellington
Caroline Orchiston	University of Otago
Rolando Orense	University of Auckland
Alessandro Palermo	University of Canterbury
Didier Pettinga	Holmes Consulting Group
Venkateswarlu Pulakanam	Univeristy of Canterbury
Sean Rees	Tonkin & Taylor
Geoff Rodgers	University of Canterbury
Allan Scott	University of Canterbury
Nicola Smith	Market Economics
Joanne Stevenson	Resilient Organisations
Mark Stirling	University of Otago
Mark Stringer	University of Canterbury
Tim Sullivan	University of Canterbury
SR Uma	GNS Science
Sjoerd van Ballegooy	Tonkin & Taylor
Colin Whittaker	University of Auckland
Tom Wilson	University of Canterbury

Postdoctoral Fellows

In addition to the postdoctoral fellows listed below, there are a number of additional postdoctoral fellows that are funded with aligned funding.

Abdul Baki	University of Canterbury
Sarah Bastin	University of Canterbury
Daniel Blake	University of Canterbury
Dmytro Dizhur	University of Auckland
Tracy Hatton	Resilient Organisations
Robert Kipp	Resilient Organisations
Saree Lawler	Resilient Organisations
Robin Lee	University of Canterbury
Yiqiu Lu	University of Auckland
Ahsan Nazer	University of Canterbury
Hoby Razafindrakoto	University of Canterbury
Karim Tarbali	University of Canterbury
Jagdish Vyas	University of Canterbury
Trevor Yeow	University of Canterbury

Technology Platform

In addition to the Technology Platform Staff listed below, there are a number of related roles that are supported with aligned funding.

Sung Bae	University of Canterbury
Seokho Jeong	University of Canterbury
Sharmila Savarimuthu	University of Canterbury

Students

QuakeCoRE had 91 postgraduate students during 2017, 72 of which were studying towards their PhD. More than 60% received direct support with the others all working on aligned QuakeCoRE research.

QuakeCoRE Prestige Scholarship Recipients

Shannon Abeling	University of Auckland
Rizwan Ahmad	University of Canterbury
Kaveh Andisheh	University of Canterbury
Xavier Bellagamba	University of Canterbury
Pavan Chigullapally	University of Auckland
Chris de la Torre	University of Canterbury
Gary Dojo	University of Auckland
Francisco Gálvez González	University of Auckland
Martin Garcia	Massey University
Vahid Loghman	University of Canterbury
Ana Isabel Sarkis Fernandez	University of Canterbury
Nikolaos Ntritsos	University of Canterbury
Eyitayo Opabola	University of Auckland
Negin Papen	University of Auckland
Shahab Ramhormozian	University of Auckland
Mehdi Sarrafzadeh	University of Auckland

QuakeCoRE Students

Mina Adhikari	Massey University
Jonathan Andrew	University of Auckland
Mohammad Asadi	University of Auckland
Sadeq Asadi	University of Auckland
Ananth Balachandra	University of Auckland
Tyler Barton	University of Canterbury
Tyler Best	University of Auckland
Alia Bojiliva	University of Waikato
Ann Brown	University of Canterbury
Nancy Brown	Massey University
Robert Cardwell	University of Auckland
Miles Crawford	Massey University
Signy Crowe	University of Auckland
Sabrina Daddar	University of Canterbury
Alistair Davies	University of Canterbury
Hannah Dawson	University of Auckland
James Dismuke	University of Canterbury
Alexandre Dunant	University of Canterbury
Andrew Elcoat	University of Auckland
Farzad Farvizi	University of Auckland
Kevin Foster	University of Canterbury
Trevor Garrett	University of Canterbury
Farzin Ghahramanian Golzar	University of Canterbury
Megan Gibbs	University of Canterbury
Ronald Gultom	University of Auckland
Henrieta Hamilton-Skurak	University of Canterbury
Mahdi Hatami	University of Canterbury
Daniel Jones	University of Canterbury
Shreedhar Khakurel	University of Canterbury
Nikoo Khanmohammadi Hazaveh	University of Canterbury
Alan Kwok	Massey University
Robin Lee	University of Canterbury

Shong Wai Lew	University of Auckland
Duncan Maina	University of Auckland
Kai Marder	University of Auckland
Jessica McHale	University of Canterbury
Lisa McLaren	Massey University
Rebecca McMahon	University of Auckland
Romain Meite	University of Auckland
Harriet Miller-Brown	University of Canterbury
Sunil Nataraj	University of Auckland
Nhu Cuong Nguyen	Victoria University Wellington
Matthew Ogden	University of Auckland
Amirhossein Orumiyehei	University of Canterbury
Negin Papen	University of Auckland
Jacob Pastor	Victoria University Wellington
Anastasiia Plotnikova	University of Auckland
Benjamin Popovich	University of Auckland
Robert Prileszky	University of Canterbury
Aimee Rhodes	University of Canterbury
Jeremy Riffault	University of Auckland
Marcus Rodger	University of Canterbury
Catherine Sangster	University of Otago
Aleksey Shegay	University of Auckland
William Stovall	University of Otago
Tomomi Suzuki	University of Auckland
Lucinda Swatton	Massey University
Moustafa Swidan	University of Auckland
Yasir Imtiaz Syed	Massey University
Haozhi Tan	University of Auckland
Marion Tan	Massey University
Zhenghao Tang	University of Auckland
Karim Tarbali	University of Canterbury
Kristie-Lee Thomas	University of Canterbury
Leonie Thompson	University of Canterbury
Ethan Thomson	University of Canterbury
Charles Tucker	University of Auckland
Stacy Vallis	University of Auckland
James Williams	University of Canterbury
Itohan Yakubu	Massey University
Yang Yang	University of Auckland
Liqiang Zhang	University of Auckland
Lev Zhuravsky	University of Otago
Conrad Zorn	University of Auckland

Support Staff

Susie Meade	Manager
Brandy Alger	Outreach Coordinator
Ruth Hartshorn	Research Coordinator
Danica Nel	Administrator

Publications

155 Peer-reviewed Outputs

81 Annual Meeting Posters

Journal Publications (Direct Peer-Reviewed)

In addition to the 67 direct outputs listed below, there were more than 85 aligned publications published in peer-reviewed journals.

Baker, J. & **Bradley, B.** (2017). Intensity measure correlations observed in the NGA-West2 database, and dependence of correlations on rupture and site parameters. *Earthquake Spectra,* **33(1)**, 145-156.

Bradley, B., Bae, S., Polak, V., Lee, R., Thomson, E. & Tarbali, K. (2017) Ground motion simulations of great earthquakes on the Alpine Fault: Effect of hypocentre location and comparison with empirical modelling. *New Zealand Journal of Geology and Geophysics*, **60(3)**, 188-198.

Bradley, B., **Pettinga, D.**, Baker, J., & Fraser, J. (2017). Guidance on the utilisation of ground motion simulations in engineering practice. *Earthquake Spectra,* **33(3)**, 809-835.

Bradley, B., Razafindrakoto, H., & Nazer, M. (2017). Strong ground motion observations of engineering interest from the 14 November 2016 Mw7.8 Kaikōura, New Zealand Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 85-93.

Bradley, B., Razafindrakoto, H., & Polak, V. (2017). Ground motion observations from the 14 November 2016 Mw 7.8 Kaikōura, New Zealand, Earthquake and insights from broadband simulations. *Seismological Research Letters,* **88(3)**, 740-756.

Bradley, B., **Wotherspoon, L.**, & Kaiser, A. (2017). Ground motion and site effect observations in the Wellington region from the 2016 Mw7.8 Kaikōura, New Zealand Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 94-105.

Bray, J., Markham, C., & **Cubrinovski, M.** (2017). Liquefaction assessments at shallow foundation building sites in the central business district of Christchurch, New Zealand. *Soil Dynamics and Earthquake Engineering,* **92**, 153-164.

Brown, N., Rovins, J., Feldmann-Jensen, S., **Orchiston, C.**, & **Johnston, D.** (2017). Exploring disaster resilience within the hotel sector: A systematic review of literature. *International Journal of Disaster Risk Reduction,* **22**, 362-370.

Brunsdon, D., **Elwood, K.**, & Hare, J. (2017). Engineering assessment processes for Wellington buildings following the November 2016 Kaikōura Earthquakes. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 338-342.

Chandramohan, R., Ma, Q., **Wotherspoon, L.**, **Bradley, B.**, Nayyerloo, M., **Uma, S.**, & Stephens, M. (2017). Response of instrumented buildings under the 2016 Kaikōura Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 237-252.

Cubrinovski, M., Bray, J., De La Torre, C., Olsen, M., **Bradley, B.**, **Chiaro, G.**, Stocks, E. & **Wotherspoon, L.** (2017). Liquefaction effects and associated damages observed at the Wellington CentrePort from the 2016 Kaikōura Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 152-173.

Davies, A., Sadashiva, V., Aghababaei, M., Barnhill, D., Costello, S., Fanslow, B., Headifen, D., **Hughes, M.**, Kotze, R., Mackie, J., Ranjitkar, P., Thompson, J., Troitino, D., **Wilson, T.**, Woods, S. & **Wotherspoon, L** (2017). Transport infrastructure performance and management in the South Island of New Zealand, during the first 100 days following the 2016 Mw 7.8 Kaikōura Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 271-299.

Dizhur, D., Giaretton, M., & **Ingham, J.** (2017). Performance of early masonry, cob and concrete buildings in the 14 November 2016 Kaikōura Earthquake. *Bulletin of the New Zealand society for earthquake engineering,* **50(2)**, 194-205.

Dizhur, D., Simkin, G., Giaretton, M., Loporcaro, G., **Palermo, A.**, & **Ingham, J.** (2017). Performance of winery facilities during the 14 November 2016 Kaikōura Earthquake. *Bulletin of the New Zealand society for earthquake engineering,* **50(2)**, 206-224.

Egbelakin, T., Wilkinson, S., **Ingham, J.**, Potangaroa, R., & Sajoudi, M. (2017). Incentives and motivators for improving building resilience to earthquake disaster. *Natural Hazards Review,* **18(4)**, 4017008.

Giovinazzi, S., Austin, A., Ruiter, R., Foster, C., Nayyerloo, M., Nair, N., & **Wotherspoon, L.** (2017). Resilience and fragility of the telecommunication network to seismic events: Evidence after the Kaikōura (New Zealand) Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 318-328.

Golzar, F., **Rodgers, G.**, & Chase, G. (2017). Nonlinear spectral design analysis of a structure for hybrid self-centring device enabled structures. *Structural Engineering and Mechanics,* **61(6)**, 701-709.

Hatton, T., Kipp, R., **Brown, C.**, & **Seville, E.** (2017). Assessing research priorities and practices following the 2016 Earthquake: Research update. *Australasian Journal of Disaster & Trauma Studies,* **21(2)**, 83-89.

Hazaveh, N., **Rodgers, G.**, Chase, G., & Pampanin, S. (2017). Reshaping structural hysteresis response with semi-active viscous damping. *Bulletin of Earthquake Engineering,* **15(4)**, 1789-1806.

Hazaveh, N., **Rodgers, G.**, Chase, G., & Pampanin, S. (2017). Experimental test and validation of a direction- and displacement-dependent viscous damper. *Journal of Engineering Mechanics,* **143(11)**, 4017132.

Henry, R., **Dizhur, D.**, **Elwood, K.**, Hare, J., & Brunsdon, D. (2017). Damage to concrete buildings with precast floors

during the 2016 Kaikōura Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 174-186.

Hughes, M., Nayyerloo, M., Bellagamba, X., Morris, J., Brabhaharan, P., Rooney, S., Hobbs, E., Wooley, K., & Hutchison, S. (2017). Impacts of the 14th November 2016 Kaikōura Earthquake on three waters systems in Wellington, Marlborough and Kaikōura, New Zealand: Preliminary observations. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 306-317.

Jeong, S., & **Bradley, B.** (2017). Amplification of strong ground motions at Heathcote Valley during the 2010–2011 Canterbury Earthquakes: Observation and 1D site-response analysis. *Soil Dynamics and Earthquake Engineering,* **100**, 345-356.

Jeong, S., & **Bradley, B.** (2017). Amplification of strong ground motions at Heathcote Valley during the 2010–2011 Canterbury Earthquakes: The role of 2D nonlinear site-response. *Bulletin of the Seismological Society of America,* **107(5)**, 2117-2130.

Kaiser, A., Balfour, N., Fry, B., Holden, C., Litchfield, N., Gerstenberger, M., D'Anastasio, E., **Horspool, N.**, McVerry, G., Ristau, J., Bannister, S., Christophersen, A., Clark, K., Power, W., Rhoades, D., **Massey, C.**, Hamling, I., Wallace, L., Mountjoy, J., Kaneko, Y., Benites, R., Van Houtte, C., Dellow, S., **Wotherspoon, L.**, **Elwood, K.**, & Gledhill, K. (2017). The 2016 Kaikōura, New Zealand, Earthquake: Preliminary seismological report. *Seismological Research Letters,* **88(3)**, 727-739.

Lee, R., **Bradley, B.**, **Ghisetti, F.**, & Thomson, E. (2017). Development of a 3D velocity model of the Canterbury, New Zealand, region for broadband ground motion simulation. *Bulletin of the Seismological Society of America,* **107(5)**, 2131-2150.

Lee, R., **Bradley, B.**, & **McGann, C.** (2017). 3D models of Quaternary-aged sedimentary successions within the Canterbury, New Zealand region. *New Zealand Journal of Geology and Geophysics,* **60(4)**, 320-340.

McGann, C., **Bradley, B.**, & **Cubrinovski, M.** (2017). Development of a regional Vs30 model and typical Vs profiles for Christchurch, New Zealand from CPT data and region-specific CPT-Vs correlation. *Soil Dynamics and Earthquake Engineering,* **95**, 48-60.

McGann, C., **Bradley, B.**, & **Cubrinovski, M.** (2017). Investigation of shear wave velocity depth variability, site classification, and liquefaction vulnerability identification using near-surface Vs model of Christchurch, New Zealand. *Soil Dynamics and Earthquake Engineering,* **92**, 692-705.

Motter, C., Clauson, A., Petch, J., Hube, M., **Henry, R.**, & **Elwood, K.** (2017). Seismic performance of repaired lightly-reinforced concrete walls. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(4)**, 574-585.

Palermo, A., Liu, R., Rais, A., McHaffie, B., Andisheh, K., Pampanin, S., Gentile, R., Nuzzo, I., Granerio, M., Loporcaro, G., **McGann, C.**, & **Wotherspoon, L.** (2017). Performance of road bridges during the 14 November 2016 Kaikōura Earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 253-270.

Ramhormozian, S., **Clifton, G.**, **MacRae, G.**, & Davet, G. (2017). Stiffness-based approach for Belleville springs use in friction sliding structural connections. *Journal of Constructional Steel Research,* **138**, 340-356.

Sarrafzadeh, M., **Elwood, K.**, Dhakal, R., Ferner, H., **Pettinga, D.**, Stannard, M., Maeda, M., Nakano, Y., Mukai, T., & Koike, T. (2017). Performance of reinforced concrete buildings in the 2016 Kumamoto Earthquakes and seismic design in Japan. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(3)**, 394-435.

Shafaei, J., Hosseini, A., Marefat, M., **Ingham, J.**, & Zare, H. (2017). Experimental evaluation of seismically and non-seismically detailed external RC beam-column joints. *Journal of earthquake engineering,* **21(5)**, 776-807.

Smith, N., **Brown, C.**, Smith, G., Ayers, M., Kipp, R., & Saunders, W., & McDonald, G. (2017). Challenges and opportunities for economic evaluation of disaster risk decisions. *Economics of Disasters and Climate Change,* **1(1)**, 111-120.

Stevenson, J., Becker, J., Cradock-Henry, N., Johal, S., **Johnston, D.**, **Orchiston, C.**, & **Seville, E.** (2017). Economic and social reconnaissance: Kaikōura Earthquake 2016. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 343-351.

Stringer, M., Bastin, S., **McGann, C.**, Cappellaro, C, El Kortbawi, M., McMahon, R., **Wotherspoon, L.**, Green, R., Aricheta, J., Davis, R., McGlynn, L., Hargraves, S., **Van Ballegooy, S.**, **Cubrinovski, M.**, **Bradley, B.**, Bellagamba, X., Foster, K., Lai, C., Ashfield, D., Baki, A., Zekkos, A., Lee, R. & Ntritsos, N. (2017). Geotechnical aspects of the 2016 Kaikōura Earthquake on the South Island of New Zealand. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 117-141.

Tan, M., Prasanna, R., Stock, K., Hudson-Doyle, E., Leonard, G., & **Johnston, D.** (2017). Mobile applications in crisis informatics literature: A systematic review. *International Journal of Disaster Risk Reduction,* **24**, 297-311.

Wei, H., Wu, H., Lindell, M., Prater, C., Shiroshita, H., **Johnston, D.**, & Becker, J. (2017). Assessment of households' responses to the tsunami threat: A comparative study of Japan and New Zealand. *International Journal of Disaster Risk Reduction,* **25**, 274-282.

Wood, C., Cox, B., Green, R., **Wotherspoon, L.**, **Bradley, B.**, & **Cubrinovski, M.** (2017). Vs-based evaluation of select liquefaction case histories from the 2010-2011 Canterbury Earthquake Sequence. *Journal of Geotechnical and Geoenvironmental Engineering,* **143(9)**, 4017066.

Woods, R., McBride, S., **Wotherspoon, L.**, Beavan, S., Potter, S., **Johnston, D.**, **Wilson, T.**, Brunsdon, D., Grace, E., Brackley, H., & Becker, J. (2017). Science to emergency management response: Kaikōura Earthquakes 2016. *Bulletin of the New Zealand Society for Earthquake Engineering,* **50(2)**, 329-337.

Yakubu, I., **Egbelakin, T.**, **Dizhur, D.**, **Ingham, J.**, Park, K., & Phipps, R. (2017). Why are older inner-city buildings vacant? Implications for town centre regeneration. *Journal of Urban Regeneration and Renewal,* **11(1)**, 44-59.

Published Conference Proceedings (Direct Peer-Reviewed)

Bradley, B. (2017). On-going challenges in physics-based ground motion prediction and insights from the 2010-2011 Canterbury and 2016 Kaikōura, New Zealand Earthquakes. *Australian Earthquake Engineering Society Annual Conference.*

Bradley, B., & Razafindrakoto, H. (2017). Preliminary broadband ground motion simulations of the 14 November 2016 Mw7.8 Kaikōura, New Zealand Earthquake. *Seismological Society of America Annual Meeting*.

de la Torre, C., **Bradley, B.**, Jeong, S., & **McGann, C.** (2017). Incorporating soil nonlinearity into physics-based ground motion simulation with site-specific ground response analysis. *3rd International Conference on Performance-based Design in Earthquake Geotechnical Engineering*.

Djojo, G., **Clifton, G.**, **Henry, R.**, & **Mwacrae, G.** (2017). Experimental validation of Rocking CBFs with Double Acting Ring Springs. *New Zealand Society for Earthquake Engineering Annual Conference*.

Golzar, F., **Rodgers, G.**, & Chase, J. (2017). Impact of Hybrid Damping Devices on Structural Response Parameters, Including Base Shear and Peak and Residual Drifts. *16th World Conference on Earthquake Engineering*.

Hazaveh, N., Rad, A., **Rodgers, G.**, Chase, J., Pampanin, S., & Ma, Q. (2017). Shake table test a structure retrofitted using 2-4 Direction Displacement Dependent (D3) viscous dampers. *New Zealand Society for Earthquake Engineering Annual Conference*.

Hazaveh, N., **Rodgers, G.**, Chase, J., & Pampanin, S. (2017). Spectral Analysis of Customized 2-4 Viscous Damping for Mitigating Seismic Response. *16th World Conference on Earthquake Engineering*.

Henry, R., Corney, S., Dizhur, D., **Elwood, K.**, & Brundson, D. (2017). Damage to buildings with precast concrete floors during the 2016 Kaikōura Earthquake and implications to the design and seismic assessment. *Proceedings of the 2017 New Zealand Concrete Industry Conference*.

Hogan, L., **Henry, R.**, & **Ingham, J.** (2017). Recent testing and design recommendations for precast concrete panel-to-foundation connections. *Proceedings of the 2017 New Zealand Concrete Industry Conference*.

Horspool, N., **Elwood, K.**, & Stephens, M. (2017). Informing Post-event Decision Making using Smart Seismic Cities. *New Zealand Society for Earthquake Engineering Annual Conference*.

Kaiser, A., McVerry, G., **Wotherspoon, L.**, **Bradley, B.**, Benites, R., Bruce, Z., Bourguignon, S., Giallini, S., & Hill, M. (2017). The role of complex site and basin response in Wellington city, New Zealand, during the 2016 Mw7.8 Kaikōura Earthquake and other recent earthquake sequences. *American Geophysical Union Annual Meeting*.

Maurer, B., Green, R., **van Ballegooy, S.**, **Bradley, B.**, & Upadhyaya, S. (2017). Performance Comparison of Probabilistic and Deterministic Liquefaction Triggering Models for Damage Assessment in 23 Global Earthquakes. *Geo-Risk 2017 Conference*.

McGann, C., **Bradley, B.**, & Jeong, S. (2017). Comparison of CPT-Vs relationships developed for Loess and Alluvial Christchurch New Zealand Soils using sCPTu. *3rd International Conference on Performance-based Design in Earthquake Geotechnical Engineering*.

McMahon, R., & **Wotherspoon, L.** (2017). Dynamic Site Characterisation of the Nelson Tasman Region. *20th New Zealand Geotechnical Society Geotechnical Symposium*.

Mellsop, N., Bastin, S., **Wotherspoon, L.**, & **van Ballegooy, S.** (2017). Development of detailed liquefaction case histories from the 1987 Edgecumbe Earthquake. *20th New Zealand Geotechnical Society Geotechnical Symposium*.

Orense, R., **Wotherspoon, L.**, Pender, M., **van Ballegooy, S.**, & **Cubrinovski, M.** (2017). Applicability of field-based methods for evaluating liquefaction potential of pumiceous deposits. *20th New Zealand Geotechnical Society Geotechnical Symposium*.

Razafindrakoto, H., & **Bradley, B.** (2017). Examination of ground motion simulation uncertainties for the 2010 Mw7.1 Darfield 2011 Mw6.2 Christchurch, New Zealand Earthquakes. *Seismological Society of America Annual Meeting*.

Sarkis, A., & **Palermo, A.** (2017). Low damage technologies and resilience-based design for concrete bridges: Beyond ductility concepts. *High Tech Concrete: Where Technology and Engineering Meet - Proceedings of the 2017 fib Symposium*.

Shegay, A., Motter, C., **Henry, R.**, & **Elwood, K.** (2017). Experimental study on reinforced concrete walls with high axial loads. *New Zealand Society for Earthquake Engineering Annual Conference*.

Shegay, A., Motter, C., **Henry, R.**, & **Elwood, K.** (2017). Modelling of RC walls with ductile detailing subjected to high axial loads. *16th World Conference on Earthquake Engineering*.

Vallis, S., Galvez, F., Swidan, M., **Orchiston, C.**, & **Ingham, J.** (2017). Safeguarding an identity carved in stone: Heritage Conservation of the Oamaru historic area in Otago, New Zealand. *International Council on Monuments and Sites General Assembly*.

Wood, C., **McGann, C.**, **Bradley, B.**, **Cubrinovski, M.**, Cox, B., Green, R., & **Wotherspoon, L.** (2017). A comparison of CPT-Vs correlations using a liquefaction case history database from the 2010-2011 Canterbury Earthquake Sequence. *3rd International Conference on Performance-based Design in Earthquake Geotechnical Engineering*.

Wotherspoon, L., **Bradley, B.**, Kaiser, A., McVerry, G., Ma, Q., **McGann, C.**, Razafindrakoto, H., Nazer, A., de la Torre, C., van Houtte, C., Ni, Y., Robinson, D. (2017). Ground motion and site effects observations from the 2016 Mw7.8 Kaikōura Earthquake. *New Zealand Society for Earthquake Engineering Annual Conference*.

Wotherspoon, L., Cox, B., Stokoe II, K., Ashfield, D., & Phillips, R. (2017). Assessment of the degree of soil stiffening from stone column installation using direct push crosshole testing. *16th World Conference on Earthquake Engineering*.

Yusa, M., Bowman, E., & **Cubrinovski, M.** (2017). Observation of microstructure of silty sand obtained from gelpush sampler and reconstituted sample. *Powders and Grains 2017 – 8th International Conference on Micromechanics on Granular Media*.

QuakeCoRE Annual Meeting Posters

81 posters were presented at the QuakeCoRE Annual Meeting in Taupo from 4-6 September 2017.

Abeling, S., Vallis, S., Gálvez, F., **Dizhur, D.**, & **Ingham, J.**, Seismic vulnerability assessment of New Zealand church inventory.

Andrew, J., Tucker, C., & **Whittaker, C.**, Tsunami loading characteristics on utility poles.

Aslam, K., & Taborda, R., 3D earthquake ground motion simulations for the Christchurch area including the effects of the surface topography.

Bae, S., Lagrava, D., **McGann, C.**, Chandramohan, R., Motha, J., & **Bradley, B.**, QuakeCoRE SW workshops and training.

Bae, S., Lagrava, D., Zhu, M., **Bradley, B.**, **McGann, C.**, Robinson, D., & Ni, Y., Visualisation for scientific discovery and communication: Kaikōura Earthquake as a case study.

Bahrebar, M., & Lim, J., Nonlinear seismic behaviour of perforated steel plate shear walls with curved corrugated infill plates.

Baki, A., **Cubrinovski, M.**, & **Stringer, M.**, Effects of partial saturation on liquefaction triggering.

Bastin, S., **Cubrinovski, M.**, **Van Ballegooy, S.**, & Russell, J., Characterisation and interpretation of lateral spreading observations from the 2010-2011 Christchurch Earthquakes.

Becker, J., Carter, L., **Brower, A.**, McBride, S., Beaven, S., Schoenfeld, M., Saunders, W., Improving the input of earthquake science and engineering information into decision making: Results of a workshop.

Bellagamba, X., **Bradley, B.**, **Wotherspoon, L.**, & **Hughes, M.**, Fragility functions for buried pipelines in liquefiable soils based on New Zealand data.

Best, T., Stephens, M., **Elwood, K.**, & **Horspool, N.**, Smart seismic cities: Informing pre earthquake planning and post event response with near real-time impact tools (NRITs).

Blick, G., de Raadt, A., Johns, B., & Reese, I., Earthquake impact on geodetic and topographic infrastructure in New Zealand.

Blount, S., **Henry, R.**, Ryan, K., Lu, Y., Li, Z., & **Elwood, K.**, Experimental evaluation of various low damage solutions for concrete shear walls.

Boersen, K., East Coast LAB (Life at the Boundary).

Bradley, B., Motha, J., Polak, V., Thompson, E., Wald, D., Maurer, B., & **van Ballegooy, S.**, Coupling ground motion simulation with regional modelling for rapid impact assessment.

Brown, N., **Johnston, D.**, Rovins, J., **Orchiston, C.**, & Feldmann-Jensen, S., Building disaster resilience within the hotel sector.

Cardwell, R., Wilkinson, S., **Smith, N.**, & **Brown, C.**, Defining the value of built infrastructure.

Ceferino, L., Markhvida, M., Cremen, G., Heresi, P., Husley, A., Balbi, M., Deierlein, G., Probabilistic framework for quantifying resilience performance objectives.

Chandramohan, R., Baker, J., & Deierlein, G., Incorporating ground motion duration in structural performance assessment and design guidelines.

Chang-Richards, A., **Brown, C.**, & **Smith, N.**, A system dynamics model of post earthquake reconstruction pathways.

Chen, F., Wang, Z., Dhakal, R., Khakurel, S., & Yeow, T., Development of cladding loss contribution functions for use in loss optimisation seismic design.

Crawford, M., **Johnston, D.**, Saunders, W., Hudson-Doyle, E., & Leonard, G., Risk modelling as a tool to support natural hazard risk management in New Zealand local government.

Crawford-Flett, K., Wilson, M., & Shamseldin, A., Characterisation of New Zealand stopbank (flood protection) infrastructure.

Davies, A., Assessment of post disaster distributed infrastructure level of service expectations by stakeholders and isolated settlement communities.

de la Torre, C., & **Bradley, B.**, Modelling nonlinear site effects in physics-based ground motion simulation.

Dempsey, D., Using physics-based models to forecast future earthquakes at the Groningen gas field, The Netherlands.

Egbelakin, T., Yakubu, E., **Ingham, J.**, & **Glavovic, B.**, Improving earthquake resilience in provincial towns – A town centre regeneration approach.

Fauzi, U., Site-specific probabilistic seismic hazard maps of New Zealand for 475 years and 2,475 return period.

Fikri, R., **Dizhur, D.**, Walsh, K., & **Ingham, J.**, Seismic performance of reinforced concrete frame with masonry infill buildings in the 2010-2011 Canterbury, New Zealand Earthquakes.

Foster, K., **Bradley, B.**, **Wotherspoon, L.**, & **McGann, C.**, A Vs30 map for New Zealand based on surficial geology, topography and direct measurements.

Galvez, F., **Ingham, J.**, & **Dizhur, D.**, Using the macroelement method to seismically assess complex URM buildings.

Gauland, M., **Bradley, B.**, & Moghaddasi, M., OpenSLAT software for estimating seismic risks.

Hashemi, A., Zarnani, P., & Quenneville, P., Seismic resilient structures using rocking walls coupled with innovative resilient slip friction joints (RSFJs).

Hatami, M., **MacRae, G.**, **Rodgers, G.**, & **Clifton, C.**, The performance of friction connections with large grip length bolts.

Hatton, T., Lawler, S., & **Seville, E.**, Interdisciplinary options for improving the seismic resilience of New Zealand.

Hazaveh, N., Rad, A., **Rodgers, G.**, **Chase, G.**, Pampanin, S., & Ma, Q., Shake table testing of low damage steel buildings with 2-4 direction displacement dependent (D3) damper.

Hogan, L., **Scott, A.**, Nataraj, S., **Dizhur, D.**, & **Ingham, J.**, Seismic performance of corroded New Zealand buildings.

Hopkins, J., & Thompson, L., Safe As? The impact of the Building (earthquake-prone buildings) Amendment Act 2016 on New Zealand's existing building stock.

Huang, J., Bae, S., Polak, V., **Bradley, B.**, Razafindrakoto, H., Thompson, E., Motha, J., Real-time ground motion simulation workflow.

Jeong, S., **Wotherspoon, L.**, & Ma, Q., Recent research activities of QuakeCoRE Technology Platform 2.

Johnson, E., Yu, T., Brewick, P., & Christenson, R., Modelling of a full-scale experimental base-isolated building.

Johnston, D., Ardagh, M., Deely, J., MacDonald, C., Lambie, E., Doyle, E., Lindell, M., Characterising human behaviour in earthquakes: The 2010-2016 Sequence in New Zealand.

Johnston, D., **Orchiston, C.**, Becker, J., Sullivan-Taylor, B., **Egbelakin, T.**, **Ingham, J.**, McBride, S., Earthquake awareness and preparedness in low(er) seismic hazards in New Zealand: Challenges for preparedness and risk communication.

Lee, R., **Bradley, B.**, Graves, R., Rodriguez-Marek, A., & Stafford, P., Investigation of systematic ground motion effects through ground motion simulation of small-to-moderate magnitude earthquakes in the Canterbury, New Zealand region.

Liu, L., Defining and quantifying the resilience of electric power systems to natural disasters.

Lu, Y., **Henry, R.**, **Elwood, K.**, **Rodgers, G.**, Gu, A., Xiao, Y., Yang, T., ILEE-QuakeCoRE proposed shake-table test of a low-damage concrete wall building.

Malla, M., Fenton, C., & Davies, T., Development of Vs30 profiles in regions with sparse site-specific data: Examples from South Island of New Zealand.

Markhvida, M., & Baker, J., Post earthquake decision making: Modelling a commercial building owner's decision to repair or replace a property using real estate investment analysis.

Massey, C., Townsend, D., Rathje, E., Kaneko, Y., Lukovic, B., **Horspool, N.**, Villeneuve, M., Landslides triggered by the 14 November 2016, MW 7.8 Earthquake, Kaikoura, New Zealand.

Maurer, B., **Bradley, B.**, & **van Ballegooy, S.**, Predicting liquefaction in real-time: An assessment of geospatial models during the Canterbury Earthquakes.

McGann, C., **Bradley, B.**, Jeong, S., & Lagrava, D., QuakeCoRE and OpenSees (Year 2): Optimisation of source code, pre and post processing tools, and community development.

McMahon, R., & **Wotherspoon, L.**, Nelson Tasman site characterisation study.

Misnon, A., Abeling, S., Hare, J., **Ingham, J.**, & **Dizhur, D.**, A case study of heritage hotel: Performance after 2010/2011 Canterbury Earthquake.

Mohammadi, K., Jeong, S., Asimaki, D., & **Bradley, B.**, Simulation and validation of topographic effects on Mt Pleasant, Christchurch, New Zealand.

Noy, I., & **Filippova, O.**, Increasing earthquake resilience: Internalising externalities through regulation and financial risk transfer tools.

Ntritsos, N., **Cubrinovski, M.**, & Rhodes, A., Liquefaction performance and characterisation of 55 Christchurch sites.

Ogden, M., **Wotherspoon, L.**, & **van Ballegooy, S.**, Scrutiny of the simplified liquefaction assessment frameworks based on historical New Zealand case histories.

Orchiston, C., **Ingham, J.**, Stovall, W., & Vallis, S., Tourism and the Oamaru Victorian heritage precinct: Decision making for resilient solutions associated with heritage, earthquake-prone buildings.

Pettinga, D., **Bradley, B.**, Fraser, J., & Tarbali, K., Response history analyses of structural and geotechnical systems using simulated and recorded ground motions.

Rad, A., **MacRae, G.**, Hazaveh, N., & Ma, Q., Shake table testing of low damage steel building with asymmetric friction connections.

Ramhormozian, S., Abeling, S., Sarrafzadeh, M., Aquino, H., & **Clifton, C.**, The 2016 IDEERS Seismic Design World Conference and Competition: A report by New Zealand Postgraduate Team from the University of Auckland (UoA).

Ramhormozian, S., **Clifton, C.**, Takayama, Y., Lam, J., & **MacRae, G.**, Self-centring capability of the seismic friction dampers: A conceptual study on the static and dynamic self-centring requirements for the single degree of freedom (SDOF) asymmetric and symmetric friction connections (AFC and SFC).

Razafindrakoto, H., & **Bradley, B.**, Insights on the effects of the 2010 Mw 7.1 Darfield source uncertainty on ground motion simulations.

Rhodes, A., **Cubrinovski, M.**, & Ntritsos, N., Liquefaction evaluation in stratified soils.

Riffault, J., & **Dempsey, D.**, Ground motion simulations for Hauraki Rift earthquakes.

Roeslin, S., Ma, Q., & **Elwood, K.**, Key parameters in pre event data collection for emergency response and loss estimation in buildings.

Saunders, W., & Becker, J., The Christchurch recovery: An example of resilience and sustainability.

Savarimuthu, S., Lagrava, D., **Bradley, B.**, Huang, J., Motha, J., Polak, V., & Bae, S., SeisFinder: A web application for extraction of data from computationally-intensive earthquake resilience calculations.

Shahmohammadi, A., **Clifton, C.**, & Lim, J., A novel cold-formed section for mid to long span portal frame buildings.

Stringer, M., **Orense, R.**, Pender, M., **Cubrinovski, M.**, & Asadi, S., Undisturbed sampling of pumiceous soils in New Zealand.

Sullivan, T., **MacRae, G.**, **Clifton, C.**, **Elwood, K.**, & Orumiyehei, A., Would loss estimation help motivate the use of low-damage steel building design solutions?

Sullivan-Taylor, B., Livschitz, S., & **Johnston, D.**, Exploring New Zealand's historical heritage risks and the policy implications. Linking risk mitigation, cultural values and sustainable communities.

Syed, Y., **Uma, S.**, Prasanna, R., **Horspool, N.**, & McDonald, G., 'End to End' linkage structure for integrated impact assessment of infrastructure networks under natural hazards.

Taborda, R., & Isbiliroglu, Y., A preliminary study about the influence of building clusters on the variability of the ground motion during earthquakes.

Tan, M., Prasanna, R., Stock, K., Leonard, G., Hudson-Doyle, E., & **Johnston, D.**, Usability of disaster apps: Insight from the app markets.

Tarbali, K., **Bradley, B.**, & Polak, V., Simulation-based PSHA (Cybershake) for the Canterbury region.

Thomson, E., **Bradley, B.**, Cox, B., **Wotherspoon, L.**, & Wood, C., Generalised parametric functions and spatial correlations for seismic velocities in the Canterbury region based on dynamic site characterisation.

Vallis, S., Galvez, P., **Giovinazzi, S.**, Abeling, S., & **Ingham, J.**, Unreinforced masonry churches in New Zealand: Towards a holistic framework for the identification of optimal seismic retrofit intervention.

Yakubu, E., **Egbelakin, T.**, **Ingham, J.**, & **Glavovic, B.**, Economics of strengthening and redeveloping buildings for adaptive reuse purposes.

Yeow, T., **Sullivan, T.**, & **Elwood, K.**, Component damage fragility functions for use in New Zealand.

Ziotopoulou, K., Seismic response of liquefiable sloping ground: Numerical predictions of the LEAP centrifuge model responses.

Zorn, C., Thacker, S., Pant, R., & Shamseldin, A., Vulnerability of interdependent infrastructures to spatially localised hazards.