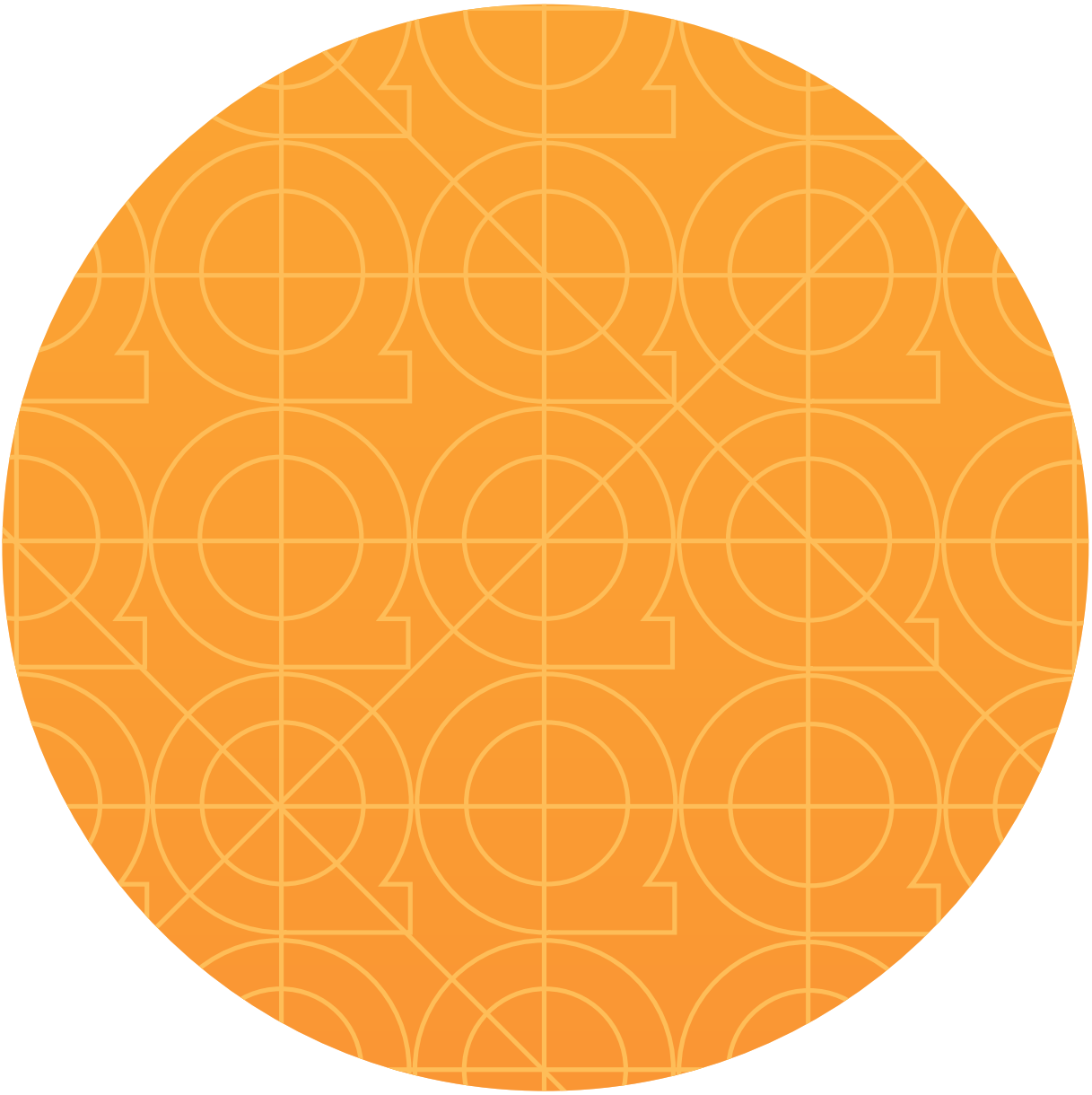


QuakeCoRE

NZ Centre for Earthquake Resilience

2016 Annual Report

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 around excellence, collaboration, impact and education.

Our *excellence* has initially emerged from our world-class research arising from the 2010-2011 Canterbury Earthquake Sequence – learning from our unique natural laboratory – with lessons for the rest of New Zealand and the world beyond. In 2016, our 60 researchers have shared their findings via more than 130 peer-reviewed publications aligned with the QuakeCoRE mission. Several of the feature stories in the subsequent pages highlight selected notable research achievements.

With a strong focus on *collaboration* across institutions and disciplines, QuakeCoRE has brought together researchers from across seven New Zealand institutions, building on our collective efforts and diverse knowledge and perspectives for transformative outcomes. Nowhere is the benefit of this collaboration more evident than through the concerted response after the 14 November 2016 Kaikoura Earthquake, with QuakeCoRE researchers playing an integral role in scientific reconnaissance and investigation to provide critical input to stakeholders about on-going risks, impacts and recovery. In a global context, QuakeCoRE has attracted attention as demonstrated by more than 30 international participants at our first Annual Meeting, the active collaboration of international researchers across our various research programmes and the signing of new Memorandums of Understanding for access to internationally unique experimental facilities in China and Japan.

QuakeCoRE is having an *impact* on the resilience of New Zealand communities, with our research on earthquake-prone buildings already informing government policy decisions. Our *education* initiatives span from community outreach to training of the next generation of world-class researchers. We have developed an exciting high school programme, QuakeCraft, where students learn about earthquake resilience through interactive and stimulating building activities. Finally, our first-year education and training achievements are exemplified by the growing number of PhD students joining QuakeCoRE and the initiation of the QuakeCoRE Emerging Researcher Network.

We look forward to building on our first year's success.

Ken Elwood

Director

Brendon Bradley

Deputy Director

Chair's report

2016 has been an immense year for QuakeCoRE. Ken Elwood and Brendon Bradley have successfully established QuakeCoRE as the preeminent earthquake research centre in New Zealand, with a growing international reputation. QuakeCoRE's focus on research excellence, international leverage and collaboration across academia and industry augurs well for the future, the team, TEC and private-sector investment. We have much to be proud of.

To that end I have really appreciated the wisdom, guidance and leadership of the Board (Rod Carr, Margaret Hyland, Mary Comerio, John Hare, Nick Miller, John Reid and Sulo Shanmuganathan). The international academic and industry combination has really worked well.

Success in our first year has also meant more than just establishing the programme. Significant research findings have been published, TEC funding has been leveraged with an additional $8.3 million in external research income in 2016, formal relationships have been established with international peers and there has been growing demand for QuakeCoRE researchers to speak on earthquake issues, both to technical audiences and the general public.

Building on the concept of New Zealand being a unique seismic research laboratory, the team's efforts redoubled after the 2016 Kaikoura Earthquake. We continue to challenge ourselves to make a difference, be involved and understand where and when our research matters most.

My gratitude to this research community for your passion and the difference you make; likewise for the efforts of Ken, Brendon and each member of the QuakeCoRE Leadership Team.

On behalf of the Board, we are looking forward to 2017.

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 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.

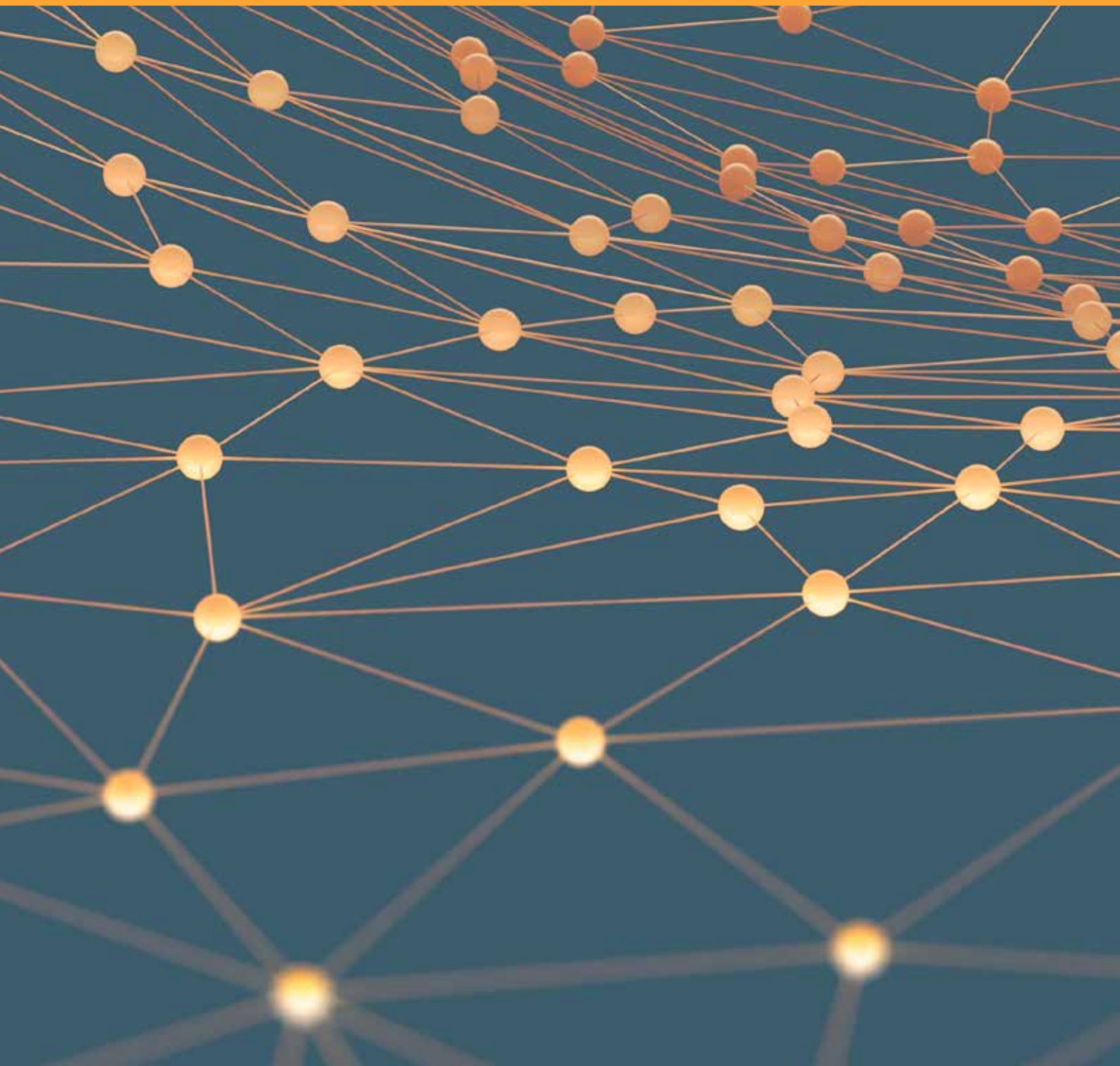
5

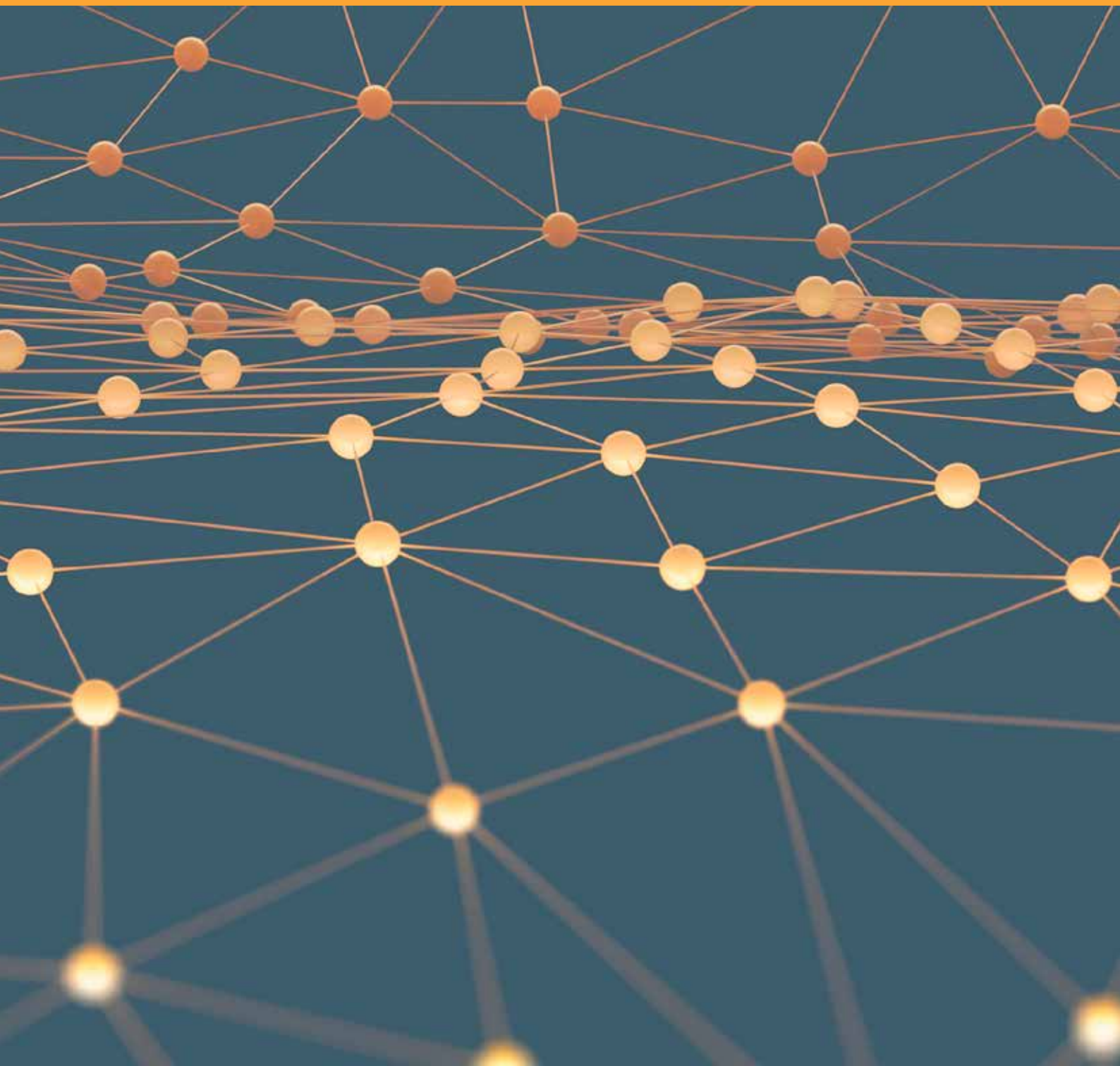
International Recognition
We will be a focal point for international earthquake resilience, attracting the best talent and business alongside national and international research collaborations.

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 plays an integral role in supporting and linking multi-institutional, national, 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 meaningful two-way communication at all levels between researchers and end-users.

Flagship programmes

FP1

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.

FP2

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 NZ.

FP3

Hertage, 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.

FP4

Next-generation Infrastructure: Low-damage and Repairable Solutions
Leaders: Ken Elwood & Stefano Pampanin[1], Industry Representative: Peter Smith
This flagship seeks a new design paradigm where reparability and damage control is explicitly considered in the design process of buildings and infrastructure.

FP5

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.

FP6

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 program is developing tools to assess the performance of spatially-distributed infrastructure networks subject to extreme natural hazards.

[1] From 1 January 2017, Flagship 4 will be led by Ken Elwood, with Tim Sullivan as the Deputy Leader.

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: Chris McGann
This platform provides computational workflows to connect the multi-disciplinary research activities within QuakeCoRE and to provide a means by which research results can be understood in terms of their wider impacts on earthquake resilience.

Supercomputer simulations shed new light on Alpine Fault shaking

QuakeCoRE research is generating the most accurate simulations to date of ground shaking that is likely to be produced from a future Alpine Fault earthquake. The Alpine Fault poses the biggest seismic risk to the South Island, with a high probability that it could produce a magnitude 8 earthquake in the next 50 years.

Professor Brendon Bradley is leading an international team of engineers, scientists, research students, software developers and IT experts to produce sophisticated new physics-based models that generate significantly better predictions of shaking by simulating seismic waves moving through the earth.

Previous empirical models used observational data of past earthquakes to predict how earthquakes of a certain magnitude and location would impact ground shaking. However, such models could not determine how the specific characteristics of the location might affect the shaking. The new models include information in the form of a three-dimensional model of the earth's crust and the earthquake fault to make much more realistic predictions.

"The point of our simulations is to accurately predict ground shaking based on where you are, not just how far away from the rupture you are," Brendon says.

The new models have been made possible because of a dense array of devices called strong motion instruments, which collected an unprecedented data set during the 2010-11 Canterbury Earthquake Sequence. In addition, the project has required state-of-the-art computing power, which has only been available in New Zealand recently through the New Zealand eScience Infrastructure (NeSI).

The computations needed for the models would have been unworkable without NeSI's high performance computers and support systems. The Alpine Fault simulations used a model of the South Island, comprising 25 billion data points and requiring the full capacity of one of NeSI's largest supercomputers for four days, an effort that would have taken 30 years on a normal laptop.

The simulations have helped researchers understand where shaking will be stronger or weaker than predicted by the previous generation of models, as well as the substantial impact that the location of the epicentre and direction of rupture will have on ground shaking. Compared to older empirical models, the new simulations predict that significantly more shaking will occur in the north and southwest of the South Island. In Canterbury, the shaking duration will be much longer than during the 2010 - 2011 Canterbury Earthquake Sequence, because it will take much longer for the fault to rupture across its entire length.

Ongoing validation of the simulation models is a critical part of the project to enable further refinement. By comparing the predicted shaking with the actual shaking from earthquakes, the team can determine how accurate the models are and how they can continue to improve their predictive power.

Project AF8, a cutting-edge Civil Defence Emergency Management (CDEM) planning project, is using the simulations to provide updated Alpine Fault damage and impact scenarios to prepare for such an event and to improve community resilience and disaster response.

Dr Caroline Orchiston from Otago University, the Science Lead for Project AF8, says, "The best possible science is being used to inform the development of the Alpine Fault scenario, and the

Project AF8 Steering Group is very grateful to the science community for their contributions."

Dr Tom Wilson (AF8 Science Team Member, University of Canterbury) says, "These simulations allow potentially much greater accuracy in assessing the likely impact to people, buildings and what cascading geomorphological hazards the ground shaking may produce, such as liquefaction and landslides. Access to these simulations is a real step change for disaster risk assessment."

Liquefaction research helps build more resilient infrastructure

Professor Misko Cubrinovski is leading our flagship programme on soil liquefaction and its impacts on buildings and infrastructure. The aims are to identify key factors that affect liquefaction, to understand their relative importance and to provide guidance for improved infrastructure and building design.

Liquefaction involves a very complex behaviour of soils during earthquake shaking, in which the soil is transformed from a solid to a liquid state, resulting in ground settlement and lateral spreading (failure and sliding of sloping ground near waterways). These ground movements and deformations have widespread impacts on infrastructure.

Liquefaction was a major feature of the 2010-11 Canterbury Earthquake Sequence. While other countries have also experienced liquefaction in major earthquakes, the issues in Canterbury were extremely complex due to the widespread impacts and pronounced spatial and behavioural variability of soils.

Previous case studies had primarily focused on one soil type (clean sands), whereas the layers of different soil types in Christchurch produced a wide range of performance. QuakeCoRE researchers are now trying to understand these observations and identify the factors affecting and governing the complex behaviour.

Because of the challenging ground conditions in Christchurch and complexities of the problem, researchers employed a range of research tools including field testing, soil sampling and lab testing, advanced numerical analyses and documented case histories. Case histories are especially important because they involve both the complexities of the natural environment and the specifics of the built environment in New Zealand.

The QuakeCoRE team, recognised internationally as one of the leading groups in this field, has collaborated with researchers overseas to develop an integrated understanding of how infrastructure performs with various levels of liquefaction. For example, the group co-organised the US – New Zealand – Japan International Workshop on "Liquefaction-Induced Ground Movements Effects" at the University of California, Berkeley in November 2016.

This workshop identified five cross-cutting liquefaction research priorities: case history data, integrated site characterisation, numerical analysis, complex soils and effects and mitigation of liquefaction in the built environment and communities.

Misko says, "The QuakeCoRE team has made serious advances during the last year in all five areas, and we are addressing them in an integrated manner rather than in isolation."

The project is also integrating geological sciences and earthquake engineering, a new approach that Misko believes will result in a "step-change" for the discipline. Dr Sarah Bastin, a postdoctoral fellow in QuakeCoRE, is bringing geological expertise to the group, studying lateral spreading and paleo-liquefaction, which is used to identify historical earthquakes and previous episodes of liquefaction.

The team's research findings are being translated into engineering practice through the development of Guidelines for Geotechnical Earthquake Engineering Practice in New Zealand, giving professional engineers specific guidance on implementing the latest research. QuakeCoRE also led and edited the publication of the Special Issue of the top-tier journal *Soil Dynamics and Earthquake Engineering,* which includes five QuakeCoRE-authored journal papers on liquefaction studies from the 2010-2011 Canterbury Earthquakes.


T1
T2
T3
T5
T6
T7
T8
T9

Resilience framework helps decision-makers prioritise investment

The Pathways to Improved Resilience Flagship Programme is exploring a diversity of decision support frameworks to help decision makers choose the best options for investing their resources in improved seismic resilience.

There are two major challenges for decision makers that this programme was set up to address. First, there are stark differences between the options to improve resilience that cannot be easily compared. For example, how do you compare measures that might save lives with options to reduce the economic impacts on an organisation? Programme leader, Dr Erica Seville, says that "the options are so varied, it becomes hard to make rational choices."

Second, decision makers often do not have full visibility of all the costs and benefits of the various options, which Erica compares to having a "menu without prices". This makes it difficult to make informed choices.

To address these challenges, QuakeCoRE postdoctoral fellows, Bob Kipp and Tracy Hatton, have been searching beyond the seismic resilience field to explore what other decision-making tools might be available. The researchers have been particularly interested in tools that have been developed to make decisions about climate change adaptations. Such models have conditions of "deep uncertainty", where a sudden change in one variable can mean a big change in the range of options for decision makers. The goal is to test all assumptions, to look at a spectrum of different futures, and make decisions that are robust across this variety of potential futures.

The team's focus is on developing frameworks that encourage decision makers to ask the right questions. "The framework becomes a conversation and engagement tool to stimulate discussion about the range of options," says Erica.

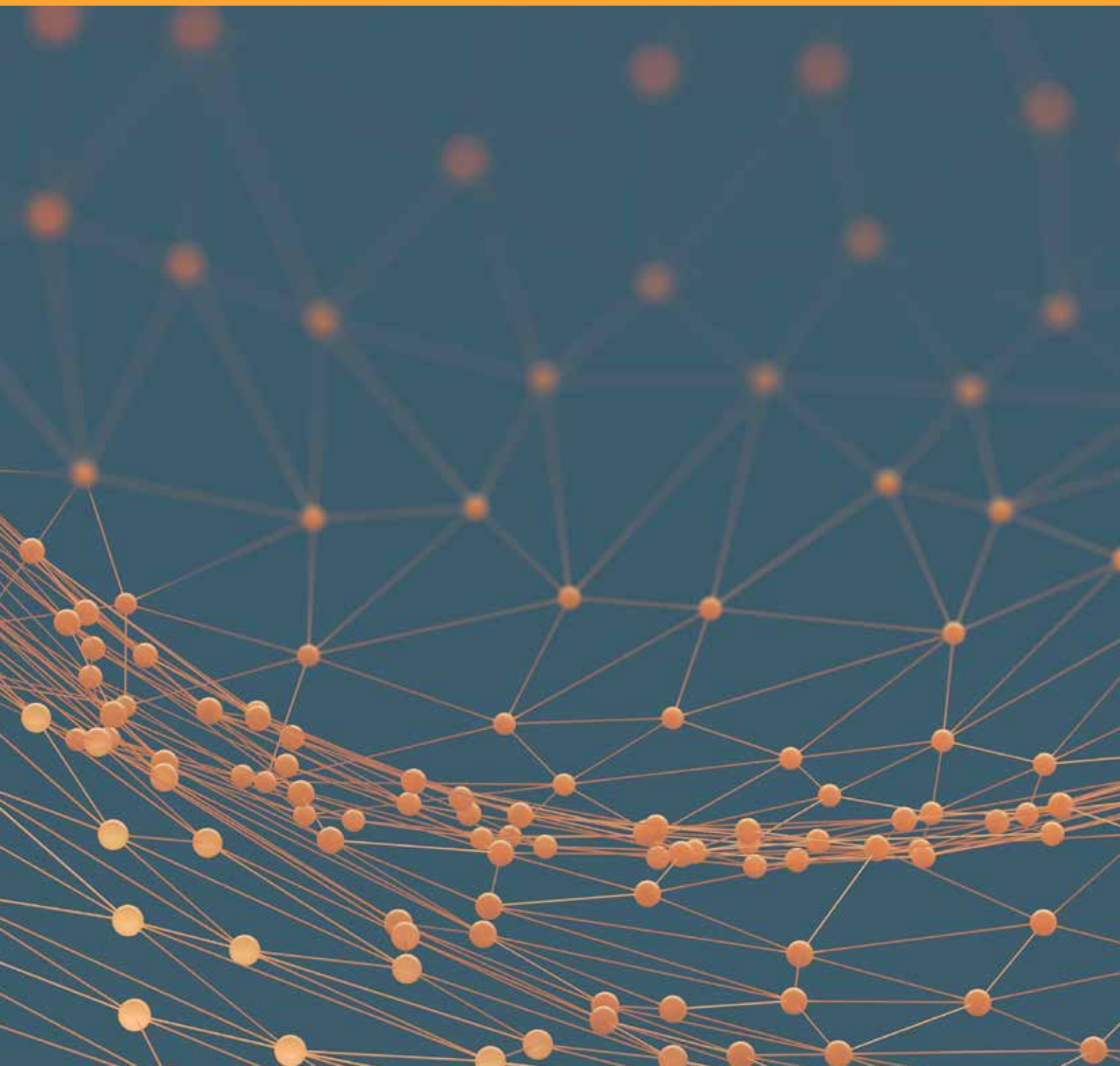
Towards the end of 2016, the team, including Dr Charlotte Brown from Resilient Organisations, began putting a prototype framework into practice, working with the Canterbury District Health Board (CDHB) to develop a decision-making framework to help them prioritise where and how to invest $200 million in insurance settlements to improve the seismic resilience of their buildings.

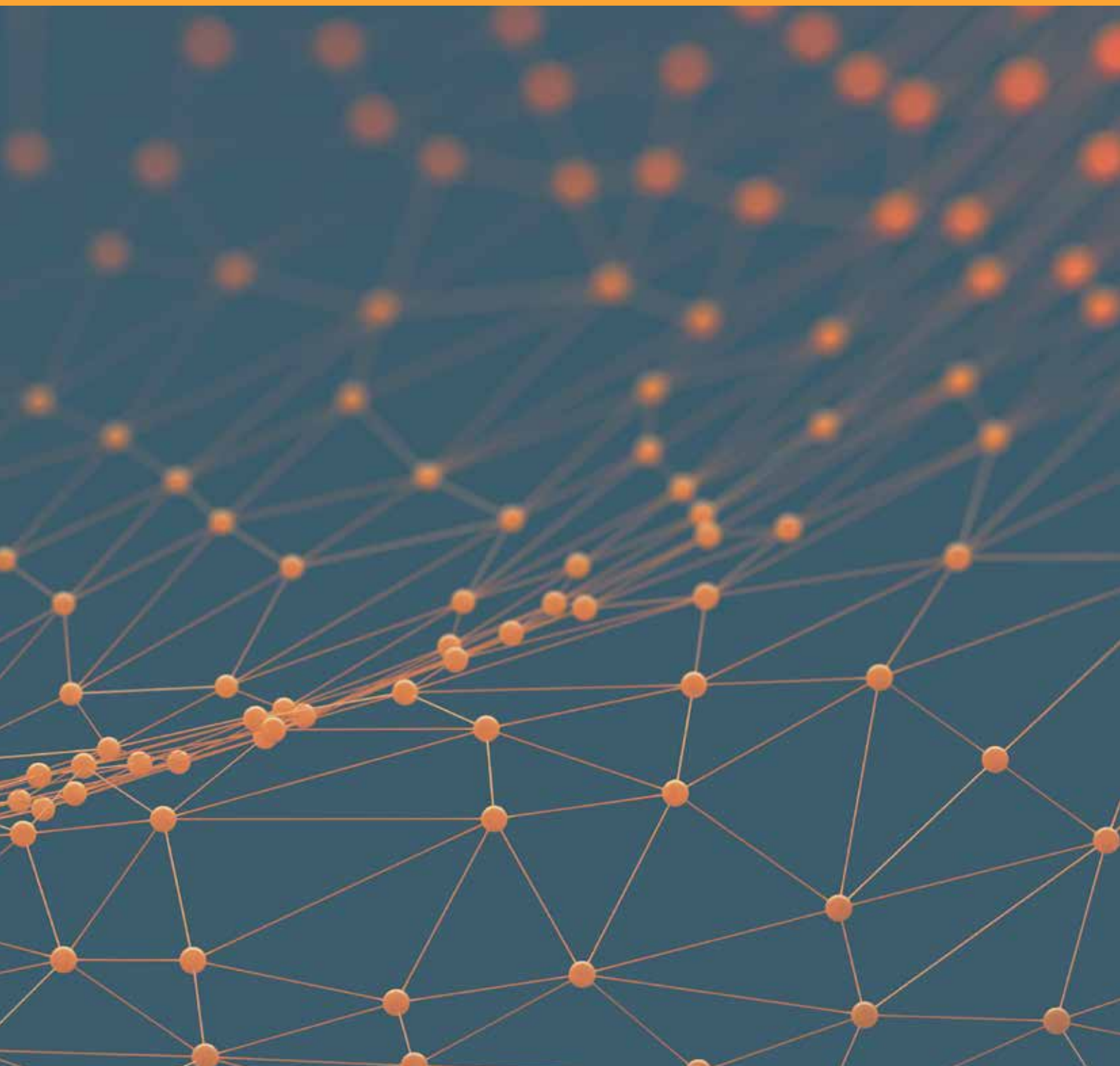
Erica comments that "this research has informed our ability to help organisations like the CDHB who have a very complex decision-making context. Their issues are not just about individual buildings, but also about the networks amongst them and the services provided, as well as strategic planning and continued operability."

"We have to understand their services and their flexibility around those services, as well as the range of priorities and values. From all of this, we are working to develop a decision-making framework that will get them asking the right questions and tease out this complexity so it is manageable."


Time frame
RMA Planning Cycle?
Yearly — 1 Yr
5 Yr
50 Yr
500 Yr events?
Community Resilience
Governance
Education
Economic
local economy
national
Co-benefits?
Co-pay?

Collaboration





QuakeCoRE enables coordinated response to Kaikoura Earthquake

Photo:©MARNEY BROSNAN

The formation of QuakeCoRE has provided the framework for better integration of efforts across the science and engineering sector to respond to earthquakes, encouraging researchers from a broad range of disciplines and agencies to collaborate, share information and maximise their collective resources.

The sector's response to the magnitude 7.8 Kaikoura Earthquake on 14 November 2016 showed how QuakeCoRE has enabled the sector to collaborate in reconnaissance and the collection of perishable data, as well as providing critical science and engineering input to key organizations during the ongoing recovery efforts.

Professor Jason Ingham, leader of the Heritage, Safety and Economics Flagship Programme, says, "The fact that QuakeCoRE partners had been talking non-stop for a year made it natural for us to work together when the earthquake happened."

Sharing information

When the earthquake occurred, the QuakeCoRE team was positioned to deploy resources quickly to deliver the most effective response. Immediate actions included engaging with media, sending researchers to collect photographic evidence and deploying monitoring instruments in Wellington within 24 hours.

Another key decision made within 24 hours of the earthquake was to station Dr Liam Wotherspoon, leader of the Spatially Distributed Infrastructure Flagship Programme, at GeoNet in Avalon. Liam worked alongside Nick Horspool at GNS Science, who is also a member of the QuakeCoRE Leadership Team, to coordinate the engineering and science response across the breadth of New Zealand research groups. The two developed a process for data dissemination, initially through

teleconferences and then through the development of a virtual clearinghouse for the sharing of data from teams in the field.

This clearinghouse, developed by QuakeCoRE and GNS Science in partnership with the Earthquake Engineering Research Institute (EERI) and the New Zealand Society for Earthquake Engineering (NZSEE) enabled a coordinated approach to the collation of data that was not evident following previous events.

Weekly meetings also enabled researchers to discuss their findings and industry needs. From these meetings, Professor Ken Elwood, QuakeCoRE's Director, was asked to lead a group providing input to the Wellington City Council on how to assess buildings. This Council programme identified critical damage states for the inspection of 72 buildings in the Wellington central business district.

Ken says, "This work allowed QuakeCoRE to take a step forward in visibility with the professional community by responding to the event. People really appreciated the work that went into that process."

Collaborative data collection

Data collection was also a well-coordinated effort amongst various agencies and interested parties. The collection of geotechnical data built upon the six years of collaborative research between New Zealand and American agencies since the 2010-11 Canterbury Earthquakes.

Liam believes that the Kaikoura response was different to that in previous earthquakes thanks to the formation of QuakeCoRE. He says, "All groups across science and engineering were working together to collate information and strategy for discussion, collect data on infrastructure impacts and liaise with stakeholders."

During the 2010-2011 Canterbury Earthquakes, New Zealand had to rely on the resources and expertise that international research organisations were able to provide. But Liam says this time around, "We had built up significant capacity that we were capable of mobilising effectively, so international collaboration was more about adding experience and building off existing relationships."

Novel interdisciplinary approach

Another unique aspect of QuakeCoRE's Kaikoura response was its interdisciplinary approach, again the result of collaboration developed during the past year.

A charrette organised by the Heritage, Safety and Economics Flagship Programme was an example of this approach. The charrette included engineers, architects, planners, economists, social scientists and physical scientists, as well as city and government officials. Jason thinks this interdisciplinary approach was only possible because all of those involved had been thinking about the relevant issues during the last year through their involvement in QuakeCoRE.

The goal of the charrette was to address the increased risk to unreinforced masonry buildings in Wellington due to aftershocks. The heritage and community values of the buildings as well as the economic impacts of any actions were taken into consideration alongside the need to protect lives and property.

The charrette was also possible because of data sharing between QuakeCoRE partners. "Part of the models sat with the universities and part with GNS Science, so we linked them for a more powerful message," Jason says.

The charrette established that the preferred approach was a public awareness exercise, along with parapet securing and to a lesser extent more general façade securing. These results were given to MBIE, and eventually assisted in the development of new government policy for unreinforced masonry buildings in areas with a heightened risk of seismic activity following the November Kaikoura Earthquake.

A key outcome from the Kaikoura Earthquake is the need to monitor and understand the performance of urban networks and buildings in Wellington to inform the response to a future earthquake. Although this gap has been talked about for a long time, the collaborative nature of QuakeCoRE and the awareness raised by the Kaikoura Earthquake makes it possible for researchers to finally address it.

QuakeCoRE researchers are leading reconnaissance and research teams in response to the 14 November 2016 M7.8 Kaikoura Earthquake.

International collaboration gives New Zealand researchers access to cutting-edge facilities

QuakeCoRE has joined a partnership with the International Joint Research Laboratory of Earthquake Engineering (ILEE) to give New Zealand researchers the opportunity to access some of the world's best earthquake engineering test facilities at Tongji University in China.

ILEE and QuakeCoRE have signed a Memorandum of Understanding, and have begun a joint large-scale experimental research project on low-damage building structures. ILEE has provided approximately NZ$190,000 for the project, with QuakeCoRE securing a matching contribution from MBIE.

The ILEE labs are some of the largest and most well-equipped labs worldwide. They have four shake tables that can be used together to test large-scale structures. The QuakeCoRE project will use two of the tables connected together for dynamic testing of a full-scale, three-storey reinforced concrete building that weighs 140 tonnes.

Testing will be undertaken in two directions simultaneously, to more closely represent the demands imposed upon structures during real earthquakes. The project will investigate building performance using both conventional and low-damage structural design methods, and the results will be presented directly to the Building Systems Performance branch of MBIE, as well as to engineers and practitioners both nationally and internationally.

QuakeCoRE's Director Ken Elwood says, "This is an example of how QuakeCoRE has enabled New Zealand as a whole to access an international facility. This is the start of a long-term relationship, and QuakeCoRE and ILEE will be conducting joint projects for many years to come."

"QuakeCoRE has enabled the earthquake engineering community to take the greatest advantage of the facilities we have, while also leveraging off other unique facilities available internationally through partnerships. This builds our international collaborative networks."

QuakeCoRE's Large-scale Experimental Facilities Technology Platform is taking advantage of the recent investment in new engineering facilities at both the University of Auckland and the University of Canterbury. This investment has resulted in the best large-scale experimental earthquake engineering facilities to date in New Zealand.

The new Structural Engineering Laboratory (SEL) at the University of Canterbury was officially opened on 15 April 2016 in conjunction with the launch of QuakeCoRE. The facility will expose students to modern testing techniques and provide first-hand experience of the impact of seismic loadings on structures and soils.

Other international collaborations have helped expand QuakeCoRE's access to the world's best earthquake engineering technology, including agreements with facilities in Japan, the US and Australia.

Ken thinks that overseas institutions in general are very interested in collaborating with QuakeCoRE. He says, "There is a desire to engage with New Zealand researchers because of how progressive we are in the fields of earthquake engineering and earthquake resilience. In many other countries, these issues are largely theoretical, whereas in New Zealand they are front and centre."

National Science Challenge partnership improves lifeline resilience

Historically, earthquake resilience has focused on the robustness of individual physical assets such as buildings and bridges. However, the resilience of lifeline networks plays a critical role in the ability of society to rapidly recover after a major disaster. Lifelines include electric power, transportation, telecommunications, potable water, stormwater, wastewater and liquefied/gas fuels, as well as other distributed infrastructure such as flood control networks. These networks provide the services that we cannot live without.

National Science Challenge 10, Resilience to Nature's Challenges, and QuakeCoRE have developed a synergistic partnership to improve the resilience of New Zealand's lifeline networks, by combining the Resilience Challenge's 'all-hazard approach' with QuakeCoRE's focused research on earthquake impacts.

The Resilience Challenge takes a broad approach to resilience by considering multiple natural hazards including; earthquakes, volcanoes, landslides, tsunami, weather, coastal and rural fire hazards. This complements QuakeCoRE's more specific in-depth focus on earthquake resilience.

Together, the Resilience Challenge and QuakeCoRE have developed a joint programme of work in the Spatially Distributed Infrastructure Flagship Programme. The programme is developing tools to assess the performance of spatially-distributed infrastructure networks subject to natural hazards.

The programme's leader, Dr Liam Wotherspoon, says that bringing together the various groups involved in the Resilience Challenge and QuakeCoRE "presents a unique opportunity to develop an integrated infrastructure research approach leading to enhancements for both programmes without duplicated efforts".

Liam says, "We are trying to incorporate the actual functionality and management of networks into the research approach, which is the most important aspect for society, rather than only focusing on the robustness of the individual physical assets themselves."

Given the interdisciplinary nature of infrastructure, this programme has drawn on researchers not typically involved in natural hazard research. These include transportation engineers, electrical engineers and telecommunication engineers, all of whom are experts in modelling network functionality.

This programme is working to develop an "infrastructure resilience rating" across the infrastructure networks supporting each city/town, which can be used to assess and improve infrastructure resilience. This system will be used to drive public policy in infrastructure investment and advise asset owners of externalities when investing in building resilience.


National Science Challenges
RESILIENCE TO NATURE'S CHALLENGES
QuakeCoRE
FP 6: Spatially-distributed Infrastructure (with National Science Challenge 10: Resilience to Nature's Challenges)
Planning Document
Flagship Leader: Liam Wotherspoon
This Flagship is a joint research program with the National Science Challenge 10
and its Spatially Distributed Infrastructure Toolbox. The joint p
performance of spatially-distributed infrastructure networks subject t
The resilience of the NZ built environment to natural hazards has hist
physical assets (individual buildings, bridges etc.), with less emphas
between individual assets, as well as the performance of spatially-distri
of lifeline networks (electric power, transportation, telecomm
water/wastewater, and liquefied/gas fuels) and other distributed inf
critical role in the ability of society to rapidly recover after a major disa
The research in this flagship will be directed toward developing too
distributed infrastructure networks subject to extreme natural hazards. W
we will develop methodologies to quantify system-level performance o
subject to natural hazards and cascading impacts, leading to improv
identification of multi-hazard related vulnerabilities in infrastructure critical
asset owners do not currently have methods to fully quantify resilience of key
of their disruption due to natural hazards. Nor are there consistent methods t
resilience within or across infrastructure types, organisations, or investment c
options to improve resilience.
System-level resilience methodology outputs will be based on
vulnerabilities, and mechanistic models for the integ
Uncertainties in such analyses can be rigorously
Most recent concepts of resilience
of post disaster recov

Outreach & Community

Inaugural Annual Meeting highlights collaborations and research excellence

The inaugural QuakeCoRE Annual Meeting attracted a diverse audience from those interested in facilitating resilience outcomes including local and central government, consulting engineers, physical and social scientists, academics and practitioners. The main purpose of the three-day meeting, which was held in Taupo in early September, was to develop a collective vision to tackle the overarching issues facing earthquake resilience professionals.

The meeting also included six satellite workshops and more than 80 posters featuring the research excellence of the flagship programmes, as well as a session devoted to emerging researchers. The distinguished lecture was given by Professor Tom Jordan from the Southern California Earthquake Center (SCEC). As the director of a centre that has been conducting earthquake research for over 25 years, Tom shared his wealth of experience with the 180 meeting participants. Of these, more than 30 attendees were from overseas, and more than 50 were from industry or stakeholder organisations.

QuakeCoRE Director, Professor Ken Elwood, says that the meeting was "an important first step toward our collective vision of an earthquake-resilient New Zealand, realised through innovative world-class research, human capability development and deep national and international collaborations".

The first Annual Meeting was the first chance for researchers across QuakeCoRE to connect and to share progress to date, and the attendance by diverse stakeholders provided an opportunity for the nexus between research development and innovation and the application into wider seismic resilience practice. It was also an opportunity for stakeholders to get involved in the early stages of research programmes and influence their direction. EQC provided sponsorship for the meeting, and Dr Richard Smith, Manager of Research Strategy and Investment at EQC, says that "it was encouraging to see the breadth of interactions and the connections across institutional and disciplinary boundaries. Many silos are being broken down, and substantial steps have been made in initiating a cohesive programme in science and engineering."

QuakeCoRE postgraduate students were also heavily involved in the annual meeting. Richard observed, "There was a sense of emerging leadership and that an active academic community is forming and creating their own networks."

The postgraduate student lightning talk session showcased QuakeCoRE's student talent, with the eight finalists from regional heats presenting to the meeting.


Real-Time Hybrid Simulation of Base Isolation Bearings Using Mixe
Control

QuakeCraft encourages students to explore earthquake design and resilience

QuakeCoRE has developed an outreach programme, QuakeCraft, in partnership with the University of Canterbury's Quake Centre, Ara Institute and Fabriko Ltd to encourage high school students to understand all aspects of earthquake resilience. The multi-day school holiday programme was piloted in August 2016 to 29 Year-10 students from various Christchurch schools.

A key goal of the programme was to encourage students to pursue occupations related to earthquake resilience, including civil engineering, structural engineering, geotechnical engineering and architecture.

The programme invited students to learn about the physics of external forces and the importance of resilient and sustainable buildings through an engaging and challenging project to design, build and test a model house. Students utilised the same aspects of computer-aided design used in popular physics-based video games to unlock the connection of virtual design to real-world principles.

Students then fabricated their houses using a laser cutter and 3D printers as well as custom-made parts. They tested their designs on a shake table located in the Structural Engineering Laboratory at the University of Canterbury.

Students were free to use their own creativity to design, while also having access to industry and tertiary student mentors for feedback and advice. Students were encouraged to think about the real-world connection to what they were learning as well as the community importance of engineering. QuakeCoRE's Outreach Coordinator Brandy Alger says, "The value of the programme was that it allowed students to think of solutions, not just problems. Having students create their own sustainable and resilient pop-up houses allowed students to fully understand the connections between physics, maths and social sciences to understand the full scope of resilience."

The programme targeted groups with low engagement with science and technology as well as limited resources, especially lower decile schools. In addition, the programme specifically targeted female, Maori and Pasifika students, groups that are under-represented in engineering. Of the 29 students who participated, 20% identified as Māori or Pasifika and 30% identified as female.

Additional funding for the project came from the government-funded Unlocking Curious Minds grant, which supports innovative projects that provide New Zealanders with more opportunities to learn about and engage with science and technology.


STR
ESTR

Investigator accolades

International

Brendon Bradley, EERI Shah Family Innovation Prize for creativity, innovation and entrepreneurial spirit in earthquake risk mitigation and management, *Earthquake Engineering Research Institute (EERI),* 2016

Jason Ingham and Stan Shaw, Best Paper Award, 24th Australasian *Conference on the Mechanics of Structures and Materials,* 2016

Roberto Leon, Weng Yuen Kam and **Stefano Pampanin,** ACI Design Award recognising a paper that contributes advanced concepts and techniques applied to a specific design project, *American Concrete Institute (ACI),* 2016

Brett Maurer and Russell Green, **Misko Cubrinovski** and **Brendon Bradley,** Norman Medal for the best paper in an ASCE administered journal, *American Society of Civil Engineers (ASCE)*, 2016

Sjoerd van Ballegooy, Pierre Malan, **Virginie Lacrosse,** Mike Jacka, **Misko Cubrinovski,** Jonathan Bray, Thomas O'Rourke, Steve Crawford, and Hugh Cowan, EERI Outstanding Paper Award, *Earthquake Engineering Research Institute (EERI),* 2016

National

Ivano Giongo, Aaron Wilson, **Dmytro Dizhur,** Hossein Derakhshan, Roberto Tomasi, Michael Griffith, Pierre Quenneville and Jason Ingham, Otto Glogau Award for the best paper in NZSEE Bulletin in the past three years, *New Zealand Society for Earthquake Engineering (NZSEE),* 2016

David Johnston, Ministerial CDEM Silver Award for important contributions to CDEM, *Ministry of Civil Defence and Emergency Management (MCDEM),* 2016

Greg MacRae and Ben Westeneng, NZSEE Conference best student presentation, *New Zealand Society for Earthquake Engineering (NZSEE),* 2016

Geoff Rodgers, Early and Emerging Career Researcher Award recognising emerging researchers and their contributions to research, *University of Canterbury,* 2016

Masoud Sajoudi, Suzanne Wilkinson and **Seosamh Costello,** The Urban Research Network Highly Commended Paper Award, *International Conference on Building Resilience,* 2016

Alex Shegay, **Rick Henry, Chris Motter** and **Ken Elwood,** Sandy Cormack Award for the best paper at the 2016 NZSC conference, *New Zealand Concrete Society (NZCS),* 2016

Award highlights

David Johnston
2016 Ministerial CDEM Silver Award

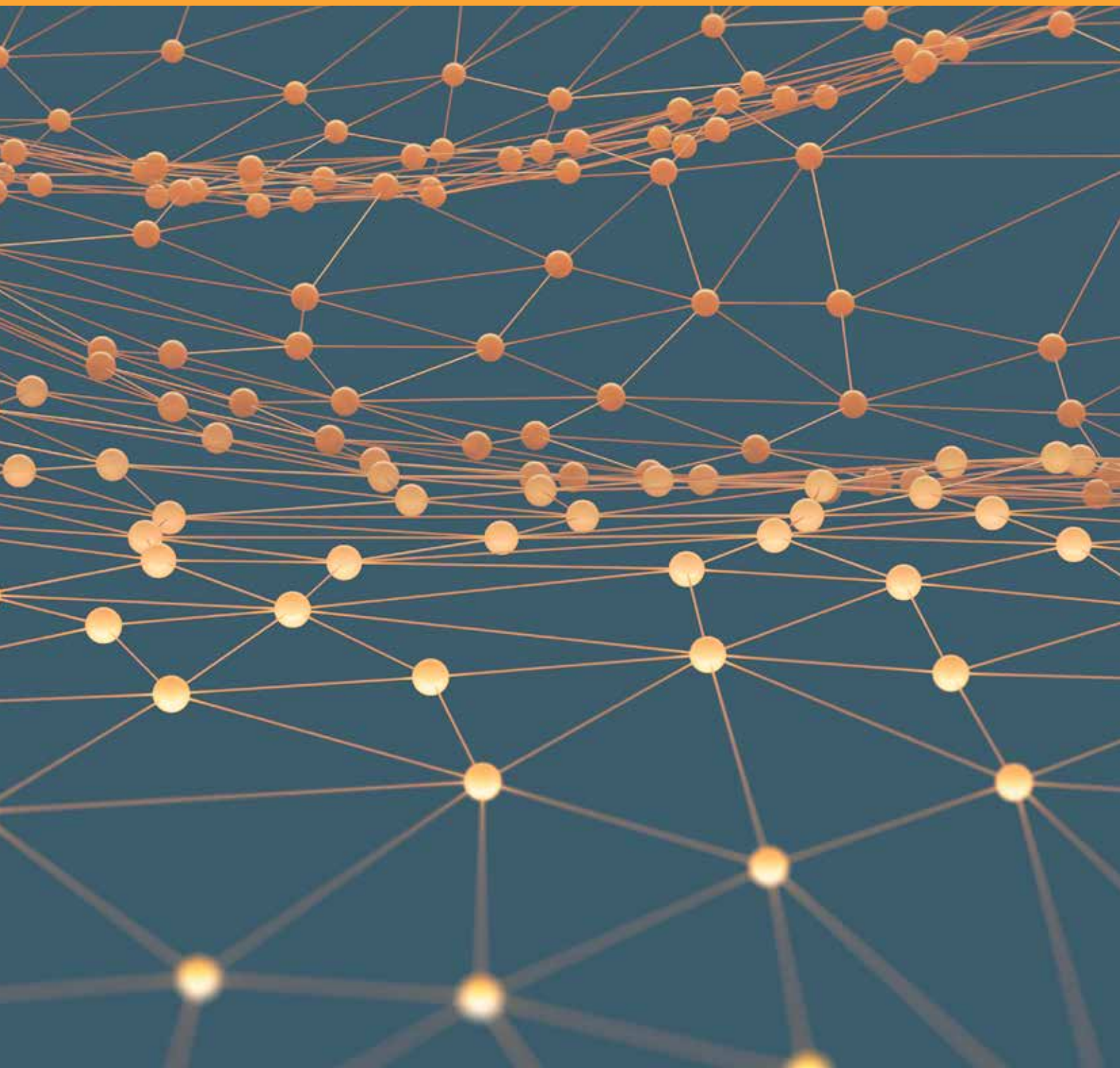
In June, Professor David Johnston received the 2016 Ministerial Civil Defence Emergency Management (CDEM) Silver Award for outstanding and sustained contribution to emergency management in New Zealand over the past 25 years. The award was presented at the National Emergency Management Conference in Wellington. Amongst David's many accomplishments, he was a key contributor to the five-year effort that culminated in the Third World Conference on Disaster Risk Reduction in March 2015 in Sendai, Japan and the follow-up New Zealand Symposium on Disaster Risk Reduction held in Wellington in June 2015.

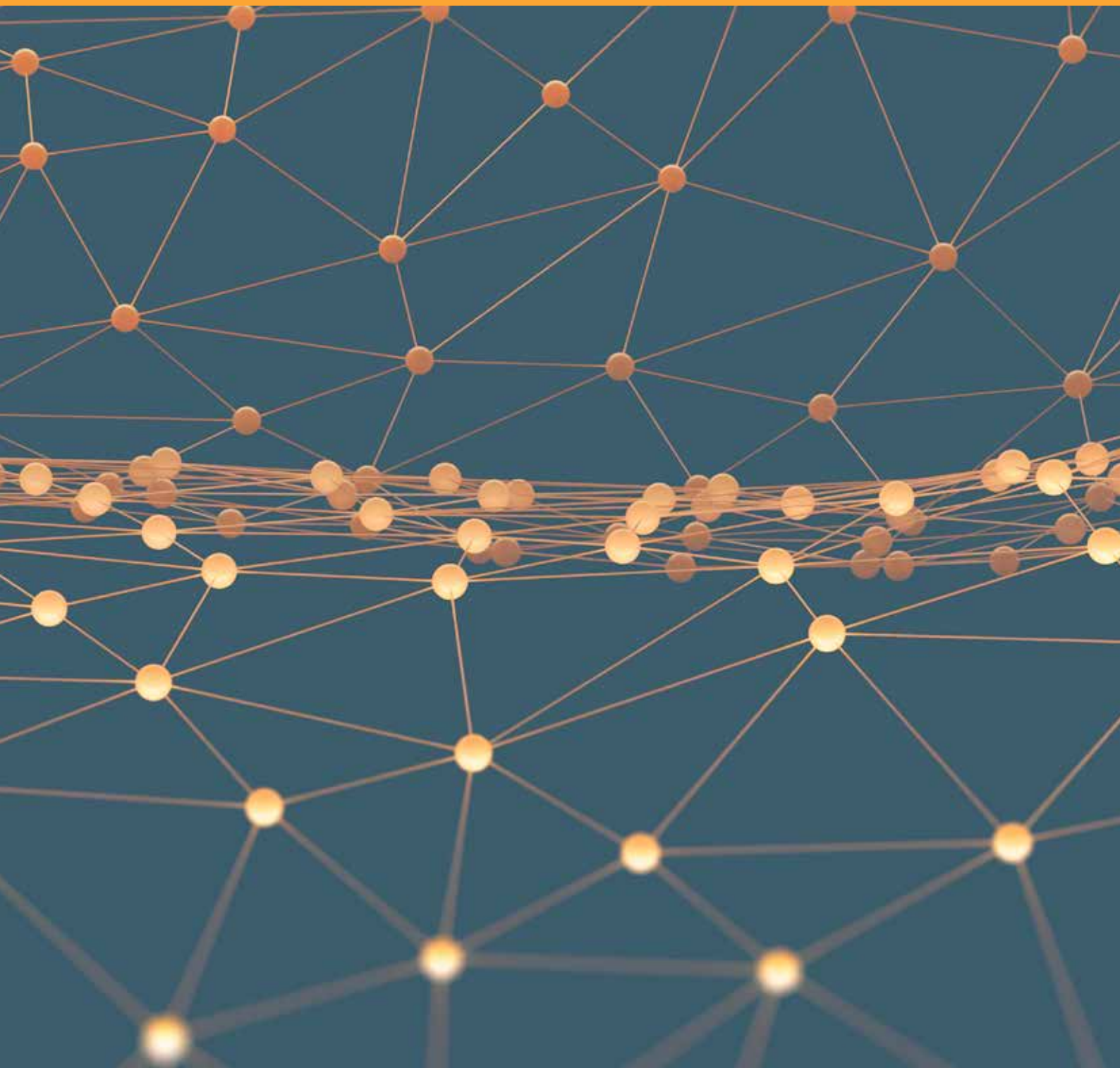
Misko Cubrinovski and Brendon Bradley
2016 ASCE Norman Medal

Professors Misko Cubrinovski and Brendon Bradley were awarded the prestigious 2016 American Society of Civil Engineers (ASCE) Norman Medal for their paper "Evaluation of the Liquefaction Potential Index for Assessing Liquefaction Hazard in Christchurch, New Zealand," published in the *Journal of Geotechnical and Geoenvironmental Engineering* in July 2014. The paper represents the culmination of four years of collaborative research between Misko, Brendon and collaborators Brett Maurer and his supervisor, Russell Green, at Virgnia Tech in the US.

Misko and Brendon accepted the award during the 2016 ASCE Annual Convention in Portland, Oregon in September. They are the first New Zealand recipients since the award was established in 1874. The Norman Medal is the highest honor granted by ASCE for a technical paper that "makes a definitive contribution to engineering science".

Financials, People & Outputs





2016 Financials

Category	Total
CoRE Funding	4,163,008
Total Revenue	**4,163,008**
Directors and Principal Investigators	165,097
Associate Investigators	32,806
Post Doctoral Fellows	167,259
Research Technicians/Tech Platform Staff	126,883
Others	219,023
Total Salaries & Salary-related Costs	**711,069**
Overheads	714,506
Project Costs	428,859
Travel	136,949
Postgraduate Students	267,747
Equipment Depreciation/Rental	0
Subcontractor(s)	38,586
Total Other Costs	**1,586,647**
Total Expenditure	**2,297,716**
Net Surplus / (Deficit)	**1,865,292**

At a glance - 2016

Broad category	Detailed category	FTE	2016
People	Principal Investigators	2.12	9
	Associate Investigators	3.55	51
	Postdoctoral Fellows	4.25	9
	Research Technicians/Tech Platform Staff	2.46	4
	Administrative/Support	2.83	4
	Research Students	46.63	53
	Total	**61.84**	**139**
Peer reviewed research outputs	Journal Articles		30
	Conference Papers		15
	Total		**45**
Value of external research contracts awarded	Vote Science and Innovation Contestable Funds		$6,236,147
	Other NZ Government		$1,432,440
	Domestic – Private Sector Funding		$171,000
	Overseas		$409,295
	Domestic - Other Non-Government Funding		$3,000
	Total		**$8,251,882**
Students studying at CoRE	Doctoral degree		41
	Other		12
	Total		**53**
Number of students completing qualifications	Doctoral Degree		0
	Other		7
	Total		**7**
Immediate post-study graduate destinations	Further Study in NZ		1
	Further Study Overseas		0
	Employed in NZ		2
	Employed Overseas		1
	Other		3
	Total		**7**
Commercial activities	Patent Applications		1

People

60 Investigators

53 Students

9 Post Docs

Board

Dean Kimpton (Chair)	Auckland City Council
Rod Carr	University of Canterbury
Mary Comerio	University of California, Berkeley
John Hare	Holmes Consulting Group
Margaret Hyland	University of Auckland
Nick Miller	Fulton Hogan
John Reid	Ngai 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
GNS Science/ Massey University

Stefano Pampanin
University of Canterbury

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

Graeme	Beattie		BRANZ
Julia	Becker	Risk and Society	GNS Science
Chris	Bowie		Opus Research
Ann	Brower	Department of Environmental Management	Lincoln University
Charlotte	Brown		Resilient Organisations
David	Carradine		BRANZ
Alice	Chang-Richards	Department of Civil and Environmental Engineering	University of Auckland
Gabriele	Chiaro	Department of Civil and Natural Resources Engineering	University of Canterbury
Charles	Clifton	Department of Civil and Environmental Engineering	University of Auckland
Maureen	Coomer	Risk and Society	GNS Science
Tim	Davies	Department of Geological Sciences	University of Canterbury
Joanne	Deely		Consultant
Roger	Fairclough		NeoLeaf Global
Olga	Filippova	Faculty of Business and Economics	University of Auckland
Sonia	Giovinazzi	Department of Civil and Natural Resources Engineering	University of Canterbury
Bruce	Glavovic	School of People, Environment and Planning	Massey University
Emily	Harvey		Market Economics
Matthew	Hughes	Department of Civil and Natural Resources Engineering	University of Canterbury
Christine	Kenney	School of Psychology	Massey University
Virginie	Lacrosse		Tonkin & Taylor
Quincy	Ma	Department of Civil and Environmental Engineering	University of Auckland
Carol	MacDonald		Independent Consultant
Greg	MacRae	Department of Civil and Natural Resources Engineering	University of Canterbury
Chris	Massey	Active Landscapes	GNS Science
James	Mathieson	Risk and Society	GNS Science
Chris	McGann	Department of Civil and Natural Resources Engineering	University of Canterbury
Hugh	Morris	Department of Civil and Environmental Engineering	University of Auckland
Chris	Motter	Department of Civil and Environmental Engineering	University of Auckland
Mostafa	Nayyerloo	Risk and Society	GNS Science
Ilan	Noy	School of Economics and Finance	Victoria University of Wellington
Caroline	Orchiston	Centre for Sustainability	University of Otago

Rolando	Orense	Department of Civil and Environmental Engineering	University of Auckland
Alessandro	Palermo	Department of Civil and Natural Resources Engineering	University of Canterbury
Stuart	Palmer		Tonkin & Taylor
Michael	Pender	Department of Civil and Environmental Engineering	University of Auckland
Didier	Pettinga		Holmes Consulting Group
William	Ries	Active Landscapes	GNS Science
Geoff	Rodgers	Mechanical Engineering	University of Canterbury
James	Russell		Tonkin & Taylor
Wendy	Saunders	Risk and Society	GNS Science
Allan	Scott	Department of Civil and Natural Resources Engineering	University of Canterbury
Nicola	Smith		Market Economics
Paul	Somerville		AECOM
Mark	Sterling	Department of Geology	University of Otago
Mark	Stringer	Department of Civil and Natural Resources Engineering	University of Canterbury
Merrick	Taylor		ARUP
SR	Uma	Risk and Society	GNS Science
Sjoerd	van Ballegooy		Tonkin & Taylor
Chris	van Houtte	Risk and Society	GNS Science
John	Vargo		Resilient Organisations
Tom	Wilson	Department of Geological Sciences	University of Canterbury

Post Doctoral Fellows

In addition to the Post Doctoral Fellows listed below, there are a number of additional Post Doctoral Fellows that are funded with aligned funding.

Sarah	Bastin	QuakeCoRE Flagship 2	University of Canterbury
Jacqueline	Dohaney		University of Canterbury
Dmytro	Dizhur	QuakeCoRE Flagship 3 (University of Auckland funded)	University of Auckland
Tracy	Hatton	QuakeCoRE Flagship 5	Resilient Organisations
Lucas	Hogan	Department of Civil and Environmental Engineering	University of Auckland
Robert	Kip	QuakeCoRE Flagship 5	Resilient Organisations
Ahsan	Nazer	QuakeCoRE Flagship 1	University of Canterbury
Hoby	Razafindrakoto	Department of Civil and Natural Resources Engineering	University of Canterbury
Francesco	Sarti	Department of Civil and Natural Resources Engineering	University of Canterbury

Technology Platform Staff

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

Sung	Bae	QuakeCoRE	University of Canterbury
Seokho	Jeong	QuakeCoRE	University of Canterbury
Viktor	Polak	QuakeCoRE	University of Canterbury
Sharmila	Savarimuthu	QuakeCoRE	University of Canterbury

Students

QuakeCoRE had 53 postgraduate students during 2016, 41 of which were studying towards their PhD. More than 55% received direct support with the others all working on aligned QuakeCoRE research.

QuakeCoRE Prestige Scholarship Recipients

Shannon	Abeling	University of Canterbury
Kaveh	Andisheh	University of Canterbury
Xavier	Bellagamba	University of Canterbury
Chris	de la Torre	University of Canterbury
Gary	Dojo	University of Auckland
Martin	Garcia	Massey University
Ana Isabel	Sarkis Fernandez	University of Canterbury
Nikolaos	Ntrits	University of Canterbury
Negin	Papen	University of Auckland
Shahab	Ramhormozian	University of Auckland
Mehdi	Sarrafzadeh	University of Auckland

QuakeCoRE Students

Mujaddad	Afzal	University of Auckland
Mohammad	Aghababaei	University of Auckland
Sadeq	Asadi	University of Auckland
Baqer	Asadi	University of Auckland
Mike	Bethany	University of Canterbury
Ann	Brown	University of Canterbury
Zeinab	Chegini	University of Canterbury
Aaron	Clauson	University of Auckland
Sabrina	Daddar	University of Canterbury
Alistair	Davies	University of Canterbury

Hannah	Dawson	University of Auckland
Toby	Finn	University of Auckland
Kevin	Foster	University of Canterbury
Marjus	Gjata	University of Auckland
Gabriele	Granello	University of Canterbury
Yujia	Han	University of Auckland
Matthew	Hoffman	University of Auckland
Rabia	Ijaz	University of Canterbury
Nikoo	Khanmohammadi Hazaveh	University of Canterbury
Ruth	Kimani	Lincoln University
Jason	Le	University of Auckland
Khiam	Lee	University of Canterbury
Robin	Lee	University of Canterbury
James	Maguire	University of Auckland
Kai	Marder	University of Auckland
Jack	Marshall	University of Canterbury
Rebecca	McMahon	University of Auckland
Nick	Mellsop	University of Auckland
Aina Noor	Misnon	University of Auckland
Sally	Owen	Victoria University Wellington
James	Petch	University of Auckland
Anastasiia	Plotnikova	University of Auckland
Ben	Popovich	University of Auckland
Bilel	Ragued	University of Auckland
Adnan	Rais	University of Canterbury
Alex	Shegay	University of Auckland
Zhenghao	Tang	University of Auckland
Karim	Tarbali	University of Canterbury
Ethan	Thomson	University of Canterbury
Nariman	Valizadeh	University of Auckland
Tongyue	Zhang	University of Auckland
Lev	Zhuravsky	University of Otago

Support Staff

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

Publications

130
Peer-reviewed Ouputs

81
Annual Meeting Posters

Journal Publications (Direct Peer-Reviewed)

In addition to the 30 direct outputs listed below, there were more than 85 aligned journal publications published in peer-reviewed journals.

Bastin, S., Bassett, K., Quigley, M., Maurer, B., Green, R., **Bradley, B.**, & Jacobson, D. (2016). Late Holocene liquefaction at sites of contemporary liquefaction during the 2010-2011 Canterbury Earthquake Sequence, New Zealand. *Bulletin of the Seismological Society of America,* **106(3)**, 881-903. **doi: 10.1007/s11069-016-2735-9**

Bradley, B. (2016). Strong ground motion characteristics observed in the 13 June 2011 Mw6.0 Christchurch, New Zealand earthquake. *Soil Dynamics and Earthquake Engineering,* **91**, 23-38. doi: 10.1016/j.soildyn.2016.09.044

Carter, W., Green, R., **Bradley, B.**, **Wotherspoon, L.**, & **Cubrinovski, M.** (2016). Spatial variation of magnitude scaling factors during the 2010 Darfield and 2011 Christchurch, New Zealand, earthquakes. *Soil Dynamics and Earthquake Engineering,* **91**, 175-186. doi: 10.1016/j.tecto.2016.01.044

Cavalieri, F., Franchin, P., & **Giovinazzi, S.** (2016). Earthquake-altered flooding hazard induced by damage to storm water systems. *Sustainable and Resilient Infrastructure.,* **1 (1-2)**, 14-31. doi: 10.1108/DPM-01-2016-0006

Cubrinovski, M., & Robinson, K. (2016). Lateral spreading: Evidence and interpretation from the 2010–2011 Christchurch earthquakes. *Soil Dynamics and Earthquake Engineering,* **91**, 187-201. doi: DOI:10.1080/23789689.2016.1178560

Derakhshan, D., Nakamura, Y., **Ingham, J.**, & Griffith, M. (2016). Simulation of shake table tests on out-of-place masonry buildings. Part I: Displacement-based approach using simple failure mechanisms. *International Journal of Architectural Heritage,* **11(1)**, 72-78. doi: 10.1016/j.engstruct.2016.06.032

Dizhur, D., Schultz, A., & **Ingham, J.** (2016). Pull-out behaviour of adhesive connections in unreinforced masonry walls. *Earthquake Spectra,* **32 (4)**, 2357-2375. doi: 10.1193/121715EQS184M

Giaretton, M., Dizhur, D., Da Porto, F., & **Ingham, J.** (2016). Post-earthquake reconnaissance of unreinforced and retrofitted masonry parapets. *Earthquake Spectra,* **32 (4)**, 2377-2397. doi: 10.1016/j.engstruct.2016.10.035

Giaretton, M., Dizhur, D., & **Ingham, J.** (2016). Dynamic testing of as-built clay brick unreinforced masonry parapets. *Engineering Structures,* **127**, 676-685. doi: 10.1061/(ASCE)ST.1943-541X.0001624

Giaretton, M., Dizhur, D., & **Ingham, J.** (2016). Shaking table testing of as-built and retrofitted clay brick URM cavity-walls. *Engineering Structures,* **125**, 70-79. doi: 10.1193/011115EQS006M

Giovinazzi, S., **Brown, C.**, **Seville, E.**, Stevenson, J., Hatton, T., & **Vargo, J.** (2016). Criticality of infrastructures for organisations. *International Journal of Critical Infrastructures,* **12 (4)**, 331-363. doi: 10.1504/IJCIS.2016.081303

Hatton, T., Grimshaw, E., **Vargo, J.**, & **Seville, E.** (2016). Lessons from disaster: Creating a business continuity plan that really works. *Journal of Business Continuity & Emergency Planning,* **10 (1)**, 84-92. doi: 10.1002/eqe.2721

Hazaveh, N., **Rodgers, G.**, **Pampanin, S.**, & Chase, J. (2016). Damping reduction factors and code-based design equation for structures using semi-active viscous dampers. *Earthquake Engineering and Structural Dynamics,* **45[15]**, 2533-2550. doi: 10.1007/s11069-015-1967-4

Hogan, L., **Wotherspoon, L.**, Beskhyroun, S., & **Ingham, J.** (2016). Dynamic field testing of a three-span precast-concrete bridge. *Journal of Bridge Engineering,* **21 (12)**, 6016007. doi: 10.1061/(ASCE) BE.1943-5592.0000970

Ismail, N., & **Ingham, J.** (2016). In-plane and out-of-plane testing of unreinforced masonry walls strengthened using polymer textile reinforced mortar. *Engineering Structures,* **118**, 167-177. doi: 10.1080/13632469.2016.1185052

Jon, I., Lindell, M., Prater, C., Huang, S.-K., Wu, H.-C., **Johnston, D.**, **Becker, J.**, Shiroshita, H., Doyle, E., Potter, S., McClure, J., & Lambie, E. (2016). Behavioural response in the immediate aftermath of shaking: Earthquakes in Christchurch and Wellington, New Zealand, and Hitachi, Japan. *International Journal of Environmental Research and Public Health,* **13 (11)**, 1137. doi: 10.1016/j. conbuildmat.2015.08.014

Kongar, I., **Giovinazzi, S.**, & Rossetto, T. (2016). Seismic performance of buried electrical cables: evidence-based repair rates and fragility functions. *Bulletin of Earthquake Engineering*, 1-31. doi: 10.1061/(ASCE)BE.1943-5592.0000970

Kwok, A., Doyle, E., **Becker, J.**, **Johnston, D.**, & Paton, D. (2016). What is 'social resilience'? Perspectives of disaster researchers, emergency management practitioners, and policymakers in New Zealand. *International Journal of Disaster Risk Reduction,* **19**, 197-211. doi: 10.3390/ijerph13111137

Lambie, E., Wilson, T., **Johnston, D.**, Jensen, S., Brogt, E., Doyle, E., Lindell, M., & Helton, W. (2016). Human behaviour during and immediately following earthquake shaking: developing a methodological approach for analysing video footage. *Natural Hazards,* **80**, 249-283. doi: 10.1504/IJCIS.2016.081303

Lin, Y., Lawley, D., **Wotherspoon, L.**, & **Ingham, J.** (2016). Out-of-plane testing of unreinforced masonry walls strengthened using ECC shotcrete. *Structures,* **7**, 33-42. doi: 10.1080/15583058.2016.1237590

Liu, M., Scheepbouwer, E., & **Giovinazzi, S.** (2016). Critical success factors for post-disaster infrastructure recovery: Learning from the Canterbury (NZ) earthquake recovery. *Disaster Prevention and Management,* **25 (5)**, 685-700. doi: 10.1007/s10518-016-0077-3

Markham, C., Bray, J., Riemer, M., & **Cubrinovski, M.** (2016). Characterization of shallow soils in the central business district of Christchurch, New Zealand. *Geotechnical Testing Journal,* **39**, 922-937. doi: 10.1016/j.soildyn.2016.09.045

McClure, J., Henrich, L., **Johnston, D.**, & Doyle, E. (2016). Are two earthquakes better than one? How earthquakes in two different regions affect risk judgments and preparation in three locations. *International Journal of Disaster Risk Reduction,* **16**, 192-199. doi: 10.1002/eqe.2782

Monk, C., **Van Ballegooy, S.**, **Hughes, M.**, & Villeneuve, M. (2016). Liquefaction vulnerability increase at North New Brighton due to subsidence, sea level rise and reduction in thickness of the non-liquefying layer. *Bulletin of the New Zealand Society for Earthquake Engineering,* **49 (4)**, 334-340. doi: 10.1016/j.engstruct.2016.03.041

Nakamura, Y., Derakhshan, H., Sheikh, A., **Ingham, J.**, & Griffith, M. (2016). Equivalent frame modelling of an unreinforced building with flexible diaphragms - A case study. *Bulletin of the New Zealand Society for Earthquake Engineering,* **49 (3)**, 234-244. doi: 10.1177/1369433216649853

Patel, V., Van, B., **Henry, R.**, & **Clifton, G.** (2016). Effect of reinforcing steel bond on the cracking behaviour of lightly reinforced concrete members. *Construction and Building Materials,* **96**, 238-247. doi: 10.1520/GTJ20150244

Quigley, M., **Hughes, M.**, **Bradley, B.**, **van Ballegooy, S.**, Reid, C., Morgenroth, J. Horton, T., Duffy, B., & Pettinga, J. (2016). The 2010-2011 Canterbury Earthquake Sequence: Environmental effects, seismic triggering thresholds and geologic legacy. *Tectonophysics,* **672-673**, 228-274. doi: 10.1785/0120150166

Tarbali, K., & **Bradley, B.** (2016). The effect of causal parameter bounds in PSHA-based ground motion selection. *Earthquake Engineering and Structural Dynamics,* **45**, 1515-1535. doi: 10.1016/j.soildyn.2016.09.006

Walsh, K., Dizhur, D., & **Ingham, J.** (2016). Estimating thrust forces resulting from arching action of clay brick masonry infill. *Journal of Structural Engineering (United States),* **142 (12)**, 6016003. doi: 10.1061/(ASCE)ST.1943-541X.0001624

Wang, G., Li, Y., Zheng, N., & **Ingham, J.** (2016). Testing and modelling the in-plane seismic response of clay brick masonry walls with boundary columns made of precast concrete interlocking blocks. *Engineering Structures,* **131**, 513-529. doi: 10.1016/j.engstruct.2016.09.016

Published Conference Proceedings (Direct Peer-Reviewed)

Abeling, S., Dizhur, D., & **Ingham, J.M.** (2016). A multidisciplinary evaluation of URM buildings successfully retrofitted prior to the 2010/11 Canterbury earthquake sequence. *Proceedings of the Australian Earthquake Engineering Society 2016 Conference*

Baker, J., Cremen, G., **Giovinazzi, S.**, & **Seville, E.** (2016). Benchmarking FEMA P-58 seismic performance predictions against observed earthquake data – A preliminary evaluation for the Canterbury earthquake sequence. *New Zealand Society for Earthquake Engineering Annual Conference*

Dohaney, J., **Wilson, T.M.**, Brogt, E., & Kennedy, B. (2016). Lessons in communication: bringing communication training and research to geoscience academics and professionals. *Geological Society of America Annual Meeting, Volume: 48, No. 7.*

Hazaveh, N., **Pampanin, S.**, Chase, J.G., & **Rodgers, G.W.** (2016). Using a direction dependent dissipation (D3) device with off-diagonal (2-4) damping to improve seismic structural responses. *New Zealand Society for Earthquake Engineering Annual Conference*

Hazaveh, N., **Pampanin, S.**, **Rodgers, G.W.**, & Chase, J.G. (2016). Design and experimental test of a Direction Dependent Dissipation (D3) device with off-diagonal (2-4) damping behaviour. *New Zealand Society for Earthquake Engineering Annual Conference*

Jeong, S., & **Bradley, B.A.** (2016). Simulation of strong asymmetrical vertical acceleration at Heathcote Valley in the 2010-2011 Canterbury earthquakes. *New Zealand Society for Earthquake Engineering Annual Conference*

Kaiser, A., **Van Houtte, C.**, Perrin, N., McVerry, G., Cousins, J., Dellow, S., **Wotherspoon, L.**, **Bradley, B.A.**, & Lee, R. (2016). Characterizing GeoNet strong motion sites: Site metadata update for the 2015 Strong Motion Database. *New Zealand Society for Earthquake Engineering Annual Conference*

Lee, R.L., & **Bradley, B.A.** (2016). Investigation of regional quality factors from a New Zealand-wide velocity model. *New Zealand Society for Earthquake Engineering Annual Conference*

Misnon, N.A., Dizhur, D., Mackenzie, J., Abeling, S., & **Ingham, J.M.** (2016). Evaluation of Seismically Retrofitted Masonry Substation Buildings. *Proceedings of the Australian Earthquake Engineering Society 2016 Conference*

Moghaddasi, M., **Bradley, B.A.**, & **Elwood, K.** (2016). Seismic performance and loss assessment of a typical New Zealand code-conforming reinforced concrete frame building. *New Zealand Society for Earthquake Engineering Annual Conference*

Pearse-Danker, E., & **Wotherspoon, L.M.** (2016). Site subsoil class determinations in Tauranga. *New Zealand Society for Earthquake Engineering Annual Conference*

Razafindrakoto, H.N.R., **Bradley, B.A.**, & Graves, R.W. (2016). Broadband ground motion simulation of the 2010-2011 Canterbury earthquake sequence. *New Zealand Society for Earthquake Engineering Annual Conference*

Smith, T., Sarti, F., Granello, G., Marshall, J., Buckton-Wishart, V., Li, M., **Palermo, A.**, & **Pampanin, S.** (2016). Long-term dynamic characteristics of a pres-lam structure. *WCTE 2016 - World Conference on Timber Engineering*

Tarbali, K., & **Bradley, B.A.** (2016). Nationwide seismic hazard maps of New Zealand using recent developments in rupture forecast and ground motion prediction. *New Zealand Society for Earthquake Engineering Annual Conference*

Thomson, E.M., **Bradley, B.A.**, & Lee, R.L. (2016). The Canterbury velocity model (CantVM) version 1. Computational implementation, south island extension, and integration within the UCVM framework. *New Zealand Society for Earthquake Engineering Annual Conference*

QuakeCoRE Annual Meeting Posters

81 posters were presented at the inaugural QuakeCoRE Annual Meeting in Taupo from the 4th – 6th September 2016

Abeling, S., Dizhur, D., & **Ingham, J.**, Exemplar retrofits: Christ's College School house and dining hall

Aina Misnon, N., Dizhur, D., Mackenzie, J., Abeling, S., & **Ingham, J.**, Successful retrofitting system of masonry substation using steel elements

Bae, S., Polak, V., Clare, R., **Bradley, B.**, & Razafindrakoto, H., QuakeCoRE ground motion simulation computational workflow

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

Bastin, S., **van Ballegooy, S.**, **Wotherspoon, L.**, Mellsop, N., **Orense, R.**, & **Pender, M.**, Whakatane liquefaction case history from the 1987 Edgecumbe Earthquake: Examination of an extensive CPT dataset supplemented by paleo-liquefaction investigations

Becker, J., **Johnston, D.**, Egbelakin, T., **Orchiston, C.**, & **Ingham, J.**, Public perceptions of earthquake risk: Implications for policy makers and educators

Bellagamba, X., **Bradley, B.**, **Hughes, M.**, & **Wotherspoon, L.**, Assessing the seismic resilience of an underground lifeline: Study case of the Christchurch City potable water network

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

Bowie, E., **Stirling, M.**, & **van Houtte, C.**, Validations of ground-motion simulations using precarious Rocks

Brewick, P., Johnson, E., & Christenson, R., Experimental modelling and identification of the force-displacement behaviour in elastic sliding bearings of a base-isolated structure

Brower, A., & Thomas, D., Implementing earthquake-prone building legislation: Comparing earthquake health costs with legislative priorities for earthquake risk remediation

Brown, C., Stevenson, J., & **Vargo, J.**, Data integration and visualisation: Prototyping QuakeCoRE data platform for diverse needs

Cappellaro, C., & **Cubrinovski, M.**, The undrained cyclic response of Monterey Sand in direct simple shear

Chandramohan, R., Baker, J., & Deierlein, G., Influence of ground motion duration on structural collapse risk

Chegini, Z., & **Palermo, A.**, Parametric investigation of dissipative rocking connections for bridge superstructures

Crawford, M., Crowley, K., Potter, S., **Johnston, D.**, Hudson-Doyle, E., Leonard, G., & **Saunders, W.**, Understanding the risk information needs for New Zealand's CDEM sector

Cremen, G., Baker, J., **Giovinazzi, S.**, & **Seville, E.**, Linking building properties to earthquake-induced damage and business downtime using FEMA P-58 and REDi assessments

Cuevas, A., Malek, A., **Pampanin, S.**, Scott, A., Marder, K., & **Elwood, K.**, Experimental investigation of the seismic residual capacity of earthquake-damaged concrete buildings: Preliminary results

Dawson, H., & **Wotherspoon, L.**, Dynamic site characterisation and site response in Auckland, New Zealand

de la Torre, C., **Bradley, B.**, Jeong, S., & **McGann, C.**, Soil nonlinearity in physics-based ground motion simulation

Del Rey Castillo, E., Seismic strengthening of reinforced concrete columns with straight carbon fibre reinforced polymer (CFRP) anchors

Dizhur, D., & **Ingham, J.**, Shake table testing of simple and practical securing solutions for face loaded unreinforced masonry walls

Djojo, G., **Clifton, C.**, & **Henry, R.**, Experimental testing of double acting ring springs type II

Dohaney, J., **Wilson, T.**, **Bradley, B.**, Brogt, E., Kennedy, B., Hudson-Doyle, E., & **Johnston, D.**, Documenting natural hazard risk communication needs, challenges and innovations through participatory engagement

Egbelakin, T., **Becker, J.**, **Johnston, D.**, **Orchiston, C.**, & **Ingham, J.**, Public perceptions of small to-medium enterprises (SMEs) In New Zealand - Implications for policy makers

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

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

Gavin, H., & Yin, B., Seismic response analysis of the Christchurch Women's Hospital

Giovinazzi, S., Ruiter, R., Foster, C., Esposito, S., Stojadinovic, B., Tang, A., Rais, A., & **Nayyerloo, M.**, Physical and functional performance of the telecommunication infrastructure after the Canterbury Earthquake Sequence

Glavovic, B., & White, I., Enabling earthquake resilience and recovery governance: A NZ perspective

Harvey Jr., P., Senarathna, N., & Calhoun, S., Application of floor isolation systems for multi-functional seismic mitigation: Computational results

Hashemi, A., Zarnani, P., & Quenneville, P., New generation of seismic resistant timber structures with resilient slip friction (RSF) joints

Hatton, T., **Brown, C.**, & **Seville, E.**, Creating the business case for investment in organisational resilience

Hazaveh, N., **Rodgers, G.**, **Pampanin, S.**, & Chase, J., Design and experimental test of an off-diagonal (2-4) direction dependent dissipation (D3) device

Henry, R., Lu, Y., Seifi, P., Zhang, T., Hogan, L., **Ingham, J.**, & **Elwood, K.**, Seismic design of lightly reinforced and precast concrete walls

Hogan, L., Collaborative framework for large-scale structural testing between New Zealand research institutions and Swinburne University of Technology

Holden, C., & Kaiser, A., Validation of ground motion modelling of the largest M5.7+ aftershocks of the Canterbury 2010-2011 Earthquake Sequence

Horspool, N., **Elwood, K.**, Stephens, M., **Uma, S.**, & **Nayerloo, M.**, Estimating real-time earthquake impacts in urban environments through smart seismic cities

Ivory, V., **Ingham, J.**, & **Bowie, C.**, Strengthening our buildings, place by place?

Jeong, S., & **Bradley, B.**, Simulation of site amplification effects at Heathcote Valley during the 2010-2011 Canterbury Earthquakes

Johnston, D., **MacDonald, C.**, Lambie, E., Doyle, E., **Becker, J.**, Ardagh, M., **Deely, J.**, Jensen, S., Feldmann-Jensen, S., & Lindell, M., Characterising human behaviour in earthquakes: Implications for improved health outcomes, risk communication, and engineering design

Kipp, B., **Seville, E.**, & Hatton, T., Decision making for seismic resilience

Lacrosse, V., Comparisons between deterministic and probabilistic liquefaction assessment approaches in the Christchurch area

Lee, R., **Bradley, B.**, & Jeong, S., Ground motion simulations of small-to-moderate magnitude events in the Canterbury region using a spectral element method

Linderman, L., Evaluating estimation performance for wireless structural control

Loporcaro, G., **Pampanin, S.**, & Kral, M., Residual strain capacity of earthquake damaged reinforcing bars. Damage assessment and remaining ductility prediction through Vickers Hardness Testing.

MacRae, G., Chanchi Golondrino, J., Chase, G., **Rodgers, G.**, & **Clifton, C.**, Effects of bolt grip length on the behaviour of asymmetrical friction connections (AFC)

Maguire, J., Tang, Z., **Clifton, C.**, Teh, L., & Lim, J., Performance of baseplate energy dissipating mechanisms for cold-formed steel storage racking subjected to rocking motion

Malinen, S., Naswall, K., & Kuntz, J., Building employee resilience

Marshall, J., Rawlinson, T., Zargar, H., & Ryan, K., Case study of a gap damper to control extreme displacement demands in a seismically isolated building

Massey, C., Abbott, E., McSaveney, M., Petley, D., & Richards, L., Earthquake-induced displacement is insignificant in the reactivated Utiku Landslide, New Zealand.

Mathieson, J., & **Saunders, W.**, Are plans at Fault? How active faults are provided for in territorial authority land use plans.

McGann, C., Jeong, S., **Bradley, B.**, Tarbali, K., Lagrava, D., & Bae, S., QuakeCoRE and OpenSees (Year 1): Optimisation of source code, pre- and post-processing tools, and community development

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

McNaughton, E., Canterbury earthquake recovery learning and legacy programme - Our learning infrastructure

Moghaddasi, M., **Bradley, B.**, **Elwood, K.**, & Preston, G., A robust framework for benchmarking seismic performance of modern New Zealand code-conforming buildings

Morris, H., **Carradine, D.**, Li, M., & Bird, E., Improving seismic performance, resilience, repair, and assessment of New Zealand light framed houses with a focus on post-event occupation

Motter, C., & **Elwood, K.**, Loading protocols for quasi-static laboratory testing

Motter, C., Petch, J., Clauson, A., **Elwood, K.**, & Henry, R., Repair and re-testing of lightly-reinforced concrete walls

Nakata, N., Erb, R., & Stehman, M., Real-time hybrid simulation of base isolated structure using mixed force and displacement control

Nazer, M., Razafindrakoto, H., & **Bradley, B.**, Hybrid broadband ground motion simulations of Porters Pass fault earthquakes

Ntritsos, N., & Lai, C., Towards a state-dependent approach for seismic fragility analysis of wharves supported in liquefiable soil

Orchiston, C., **Smith, N.**, & McDonald, G., Tourism and the Merit Model: Post-quake impacts

Orense, R., **Wotherspoon, L.**, **Pender, M.**, **Cubrinovski, M.**, & **van Ballegooy, S.**, Evaluation of liquefaction potential of pumiceous deposits through field testing

Ozbulut, O., Saedi, S., & Karaca, H., High performance shape memory alloys for seismic response control

Pettinga, D., **Bradley, B.**, & Baker, J., Guidance on the utilization of ground motion simulations in engineering practice

Rad, A., & **MacRae, G.**, Dynamically straightening steel buildings after earthquakes

Razafindrakoto, H., **Bradley, B.**, & Graves, R., Effects of realistic fault geometry on simulated ground motions in the 2010 Darfield Earthquake, New Zealand

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

Ryan, K., & Guzman Pujols, J., Horizontal-vertical coupling of a building frame system in shake table testing to 3D motions

Saunders, W., Beban, J., & Kilvington, M., A risk-based approach to land use planning for natural hazards

Smith, T., Sarti, F., Granello, G., **Palermo, A.**, & **Pampanin, S.**, Dynamic characteristics of a PresLam structure

Somerville, P., Bayless, J., Hosseini, M., & Skarlatoudis, A., Validation of strong ground motion simulations of two historical New Zealand subduction zone earthquakes on the SCEC broadband strong ground motion simulation platform

Stringer, M., **Orense, R.**, **Cubrinovski, M.**, & **Pender, M.**, Evaluation of undisturbed sampling techniques for pumiceous soils

Taborda, R., Model validation in ground motion simulations for southern California

Tarbali, K., & **Bradley, B.**, Seismic hazard analysis and ground motion selection in the near-fault region

Thomson, E., **Bradley, B.**, & Lee, R., The South Island Velocity Model (SIVM) - Version 1: Computational implementation and integration within the Unified Community Velocity Model (UCVM) framework

van Ballegooy, S., Bastin, S., **Cubrinovski, M.**, & Russell, J., Geologic and geomorphic influence on the spatial extent of lateral spreading in Christchurch, New Zealand

Wotherspoon, L., & Lee, K., Dynamic site characterisation of Central Auckland reclamation zones

Yakubu, I., Egbelakin, T., Park, K., & Phipps, R., Public perception of earthquake risks & retrofitting of heritage buildings

Zorn, C., The dependence of national transportation infrastructure on electricity