2019 Te Hiranga Rū QuakeCoRE Annual Meeting Poster List

3rd – 5th September, 2019 – Rutherford Hotel, Nelson, New Zealand

Abeling, S., Ingham, J., Dizhur, D., Horspool, N. 21

Fragility and vulnerability curves of unreinforced masonry buildings using empirical data from the 2010/11 Canterbury earthquakes

The two main shocks of the Canterbury earthquake sequence, the September 2010 Darfield earthquake (Mw 7.1) and the February 2011 Christchurch earthquake (Mw 6.2), had a devastating effect on the unreinforced masonry (URM) building stock of the region and caused a large amount of debris from damaged URM buildings to fall onto foot paths, streets and neighbouring buildings. Damage photographs, satellite images, and supporting data is available for nearly all URM buildings located in the Christchurch area (over 600 buildings) following these earthquakes. Analysis of the photos was undertaken to investigate building volume loss and debris characteristics. Fragility and vulnerability curves were developed using generalised linear models with explanatory variables including ground shaking intensity measures available from SeisFinder (e.g. peak ground acceleration, peak spectral acceleration, etc.), number of storeys, level of retrofit and position in row. Parameters for best fit curves are presented as well as plots of the curves. The purpose of this study was to quantify relationships between URM building characteristics and building fragility/vulnerability for the purposes of risk modelling using volume loss and debris, damage metrics that can be directly correlated with earthquake fatalities

Aigwi, E., Ingham, J., Filippova, O., Phipps, R. 22

Unintended consequences of the earthquake-prone building legislation: An evaluation of city centre regeneration strategies in two New Zealand's provincial areas

The unintended consequences of the earthquake-prone building legislation may have impacted most historical buildings in the city centres of New Zealand's provincial areas through increased building consent applications for demolition due to high strengthening costs and safety concerns. Consequently, the high level of deterioration and vacancy of these inner-city historical buildings have contributed to the quest for city centre regeneration especially for previously vibrant city centres in New Zealand provincial areas currently experiencing a period of protracted decline. This paper reviews existing literature and examines the effectiveness of locally-mobilised city centre regeneration strategies pursued by Whanganui and Invercargill. With the aim of highlighting local strategies that

could improve the city centre regeneration process through the retention of underutilised historical buildings in these areas, the discussion draws together analysis from both case study areas in comparison with international examples. Also, useful recommendations on appropriate programs and policy responses are provided as a guide for other New Zealand's provincial cities that are pursuing city centre regeneration through the strengthening and redevelopment of historical buildings.

Akers, K. 54

Understanding the need for, availability of, and interpretation of information by the public during large scale hazard events. Co-production role

The socio-cultural context in which the public needs, has access to, and interprets information about natural hazards differs radically. This has implications for the effective communication of information by emergency managers and other agencies before, during, and after large scale hazard events. This audience heterogeneity presents challenges for those responsible for communicating critical information. Improved understanding of the target audiences and regular focused work across the spectrum of community sectors is essential to enable greater readiness and resilience. Co-production of risk mitigation solutions – through participatory outreach approaches with schools and the wider community – enable those sectors of the public to become change agents to effectively interpret, manage and mitigate the threats associated with large-scale hazard events. Placing the community at the heart of operations and producing consistent and coherent public messages is essential for maintaining credibility and public trust. Participatory approaches to disaster risk reduction - such as community-based disaster risk reduction and co-production of knowledge - are a prerequisite for effective risk action.

This project will use a mixed-methods approach, initialising both qualitative and quantitative methodologies and will gather data from a range of communities located in the Taupō Volcanic Zone, to identify the factors that influence audience needs, their access to information, and their interpretations of information during large-scale hazard events. Through this, we aim to develop guidelines for emergency managers and other providers for the improved communication to, and communication with, the diverse range of audiences involved in a large scale natural hazard response.

Alger, B. 95

Fostering Natural Hazard Resilient Communities Through Gameplay

QuakeCoRE and Quake Centre's Outreach Programme has developed two main projects which encourage participants to play, build, and discuss resilience. Secondary students design, build, and test seismic structures on a shake table with real earthquake data. Community leaders play an "escape room" style game, which leads to scenario based discussions. The outcome of both programmes is to encourage participants to have fun and also learn through engaging and educational games leading to a more resilient Aotearoa.

Allen, N., Wilson, T., Kennedy, B., Scott, A., Stewart, C. 55

Multi-volcanic hazard impact assessment for residential buildings in the Auckland Volcanic Field

Volcanic eruptions can produce many hazards which can impact society yet many cities, including Auckland, are built on or near active volcanoes. Auckland rests on the Auckland Volcanic Field (AVF), an active volcanic field of 500km2, including 53 volcanic centres, which poses a significant risk to Auckland and its residents. Volcanic eruptions are inherently multi-hazard, yet the majority of volcanic impact assessments focus on a single hazard or ignore any interactions between multiple hazards. A multi-volcanic hazard impact assessment considers the impacts of more than one volcanic hazard occurring at a given location and time period. The process recognises that there are significant interactions between volcanic hazards and the differing damage mechanisms of these hazards. Multi-volcanic hazard impact assessments can provide greater understanding of the impacts of interacting hazards, for which there are many applications. This research will focus on the impacts to timber framed residential buildings in the Auckland Volcanic Field and will be used to improve the quantitative assessment of volcanic hazard impacts by considering the effects of multiple volcanic hazards impacting buildings in different sequences over various timescales. Research will be completed using empirical experiments to simulate ash fall and volcanic ballistic impacts to residential buildings. This research will include testing of a timber-framed roof structure and will be complimented by post-eruption impacts assessments, geospatial analysis and review of relevant literature. It will also investigate how multiple volcanic hazards can influence habitability of housing in Auckland. This research will contribute to improving volcanic risk assessment and resilience decision making for Auckland city and reduce the impact of a habitability crisis when the next Auckland Volcanic Field eruption occurs.

Bae, S. 91

On-demand web-enabled ground motion simulation and seismic hazard information

Ground motion simulation methods over significant potential over conventional empirical models and are beginning to gain widespread recognition for use in engineering applications. The computational requirements to perform such analyses (typically >1 million core hours) and store the ground motion time series (on the order of Terabytes of data) are seen as currently prohibitive from a practical standpoint. A paradigm-shift from ground motion and seismic hazard analysis being computed on-the-fly to pre-computed and available on-demand through web-based services provides a practical solution to perceived problems.

This poster presents software technologies that have been employed in order to serve ground motion simulation and seismic hazard analysis results for New Zealand in a web-enabled on-demand fashion.

Terabytes of the pre-computed data at 27,481 nation-wide locations on a spatially-variable grid were restructured and stored in HDF5 format for optimised storage footprint and efficient data retrieval. HDF5 data sets contain intensity measure values of various types and metadata such as source to site measures (Rrup, Rjb, Rx), magnitude, rupture type. When a user specifies a location from the web interface, our cloud-based software finds the closest location on the grid, extracts the intensity measure values for the grid point and computes the seismic hazard analysis on-the-fly.

The technologies currently support scientific outputs from 11,362 ground motion simulations resulting from 380 distinct faults in New Zealand (as part Cybershake v18.6), and the ability to undertake probabilistic seismic hazard analysis and derivative products such as disaggregation and ground motion selection using both simulation-based and conventional empirical ground motion models.

Bhanu, V., Chandramohan, R., Sullivan, T. 38

Investigating the influence of earthquake ground motion duration on structural dynamic deformation capacity

Recent studies have demonstrated the effect of earthquake ground motion duration on structural collapse capacity. They have also proposed methods to explicitly account for this effect of duration in structural design and assessment procedures via an adjustment to the design ground motion intensity. The objective of this study is to explore an alternative method to account for the effect of duration by adjusting the permissible peak deformations instead. This study investigates the effect of ground motion duration on the dynamic deformation capacity of modern-ductile reinforced concrete and steel framed structures. To this end, a method is proposed to evaluate the structural dynamic deformation capacity, associated with collapse, through incremental dynamic analysis. The proposed method is then utilised to investigate the correlation between dynamic deformation capacity and ground motion duration. Preliminary results indicate a reduction in the dynamic deformation capacity of the analysed structures under the increased cyclic demands imposed by long duration ground motions. These results will be assimilated to propose a modification to the peak deformation acceptance criteria employed by seismic design and assessment procedures to explicitly account for the effect of duration.

Bolomope, M., Filippova, O., Amidu, A., Levy, D. 23

Expectations vs Reality: Institutional Analysis of Property Investors' Decision-making Behaviour in a Seismically Active Country

Property investors are important stakeholders in the built environment. Their investment behaviour in an increasingly complex environment is, however, constantly challenged by social, economic, technological and environmental disruptions. Amongst these disruptions, natural hazards are major

threats that influence property investors' portfolio preference in regions prone to earthquakes. Although traditional economic theories view property investment decision making as rational, there is a greater recognition that investors operate in a world characterised by uncertainty and asymmetric information, questioning the rationality assumption. In New Zealand, local and central governments are implementing regulatory mechanisms to increase resilience of our built environment. However, the response of property investors often deviates from the expectation of the policymakers.

This study therefore, attempts to analyse the complexity in property investment decision making in order to understand how actual investors make investment decisions instead of modelling how they should do it. Using an institutional approach, this study sets out to understand the formal and informal interactions that exist amongst various stakeholders in earthquake-prone environments as a way of establishing a legitimate form of reasoning. Thus, providing insights for informing our resilience policies and implementation framework in an increasingly complex and uncertain world.

Boston, M. 56

Creating a Tool for Rapid Holistic Assessment and Rating of Post-Earthquake Hospital Functional

Hospitals play a critical role in ensuring community safety. It is imperative that they remain operational during and after an earthquake, to provide immediate and ongoing medical care. However, experience shows frequent closures and evacuations of hospitals during and after earthquakes. These decisions are frequently made quickly out of concern for patient and staff safety, and occur within minutes or hours of the event, prior to any formal assessment of structural and non-structural components. Emergency managers and facility operators need a rapid rating tool to assess damage and predict hospital functionality based on limited information. Such a tool would improve access to medical services and reduce the number of unnecessary hospital evacuations and closures during a critical time of earthquake recovery.

This research project works on creating the framework for developing a modelling tool that estimates functionality based on estimated physical damage and other disruptions at the time of an earthquake and predicts the ability of the hospital to provide medical care to the injured. The model incorporates a holistic evaluation matrix that takes inputs of physical damage, utility and back up outages, supplies and equipment, staffing, business and record functions, and facility access to estimate hospital functionality (service availability and capacity). The matrix and model aim to address challenges in estimating quantity and quality of service after a disaster. Outputs of the final model will provide a hospital rating – an indication of the hospital safety and functionality – and inform decisions for evacuations, partial or complete closure, or continued operations.

Bradley, B., Huang, J., Motha, J., Tarbali, K., Lee, R., Bae, S., Polak, V., Zhu, M., Schill, C., Paterson, J., Lagrava, D. 1

Cybershake NZ v19.5: New Zealand simulation-based probabilistic seismic hazard analysis

This poster presents the computational components and results of the May 2019 version (v19.5) of probabilistic seismic hazard analysis (PSHA) in New Zealand based on physics-based ground motion simulations ('Cybershake NZ'). A total of 11,362 finite fault simulations were undertaken and seismic hazard results are computed on a spatially-variable grid of 27,481 stations with distributed seismicity sources considered via conventional empirical ground motion models. In the current work completed to date a NZ-specific modification of the Graves and Pitarka (2010,2015) hybrid broadband ground motion simulation approach was utilized based on improvements identified from extensive validation efforts. Specific simulation features include a transition frequency of 0.25 Hz, a detailed crustal model (NZVM v2.0) that represents eight distinct sedimentary basins in NZ using a grid spacing of 0.4 km, and an empirically-calibrated local site response model. A Monte Carlo scheme is used to sample variability in the seismic source parametrization (i.e. varying the hypocenter location and slip distribution for each realization) with the total number of ruptures for each source being a function of the source magnitude. The generated uniform hazard maps across the country are presented. Immediate near-term advances associated with crustal velocity modelling, simulation methodology, and treatment of modelling uncertainty are also discussed.

Brenin, M., Stewart, C., Horswell, J., Johnston, D., McLaughlin, V., Kaiser, L., Wotherspoon, L. 57

Minimising public health risks from human waste after a large Wellington Fault earthquake: What shall we do with the poo?

The greater Wellington region, New Zealand, is highly vulnerable to large earthquakes. While attention has been paid to the consequences of earthquake damage to road, electricity and water supply networks, the consequences of wastewater network damage for public health, environmental health and habitability of homes remain largely unknown for Wellington City.

The Canterbury and Kaikōura earthquakes have highlighted the vulnerability of sewerage systems to disruption during a disaster. Management of human waste is one of the critical components of disaster planning to reduce faecal-oral transmission of disease and exposure to disease-bearing vectors. In Canterbury and Kaikōura, emergency sanitation involved a combination of Port-a-loos, chemical toilets and backyard long-drops.

While many lessons may be learned from experiences in Canterbury earthquakes, it is important to note that isolation is likely to be a much greater factor for Wellington households, compared to Christchurch, due to the potential for widespread landslides in hill suburbs affecting road access.

This in turn implies that human waste may have to be managed onsite, as options such as chemical toilets and Port-a-loos rely completely on road access for delivering chemicals and collecting waste. While some progress has been made on options such as emergency composting toilets, significant knowledge gaps remain on how to safely manage waste onsite.

In order to bridge these gaps, laboratory tests will be conducted through the second half of 2019 to assess the pathogen die-off rates in the composting toilet system with variables being the type of carbon bulking material and the addition of a Bokashi composting activator.

Bueker, F., Parr, M., Elwood, K., Bull, D. 24

Development and Testing of Hollow-core Retrofits

Precast concrete floors are the predominant flooring system in New Zealand. Cost efficiency, low self-weight and the ability to span long distances are some reasons for their popularity. The 2016 Kaikoura Earthquake, however, exposed significant vulnerabilities of precast flooring systems in Wellington's multi-storey buildings. In particular, precast, prestressed hollow-core floors performed unsatisfactorily even at low drift levels and raised concerns about the ability to withstand moderate to severe future seismic events. While previous research on hollow-core floors has mainly focused on improving the seating details, little attention was devoted to the retrofitting of earthquake-prone hollow-core floors in existing structures. This emphasises the importance and urgent need of the development and the experimental validation of retrofit solutions, particularly for areas with high seismicity such as Wellington.

Therefore, an experimental test programme has been initiated to provide engineers with appropriate assessment methods and retrofit techniques. The first part of the test series consists of sub-assembly tests, representing the connection of the support beam to a single unit with topping concrete. These tests will be used to trial various retrofit solutions. Following, the suitable retrofit solutions will be tested in two three-dimensional full-scale super-assembly tests.

Various retrofit designs addressing the detrimental effect of steel sections placed flush against the soffit as seating extension has been successfully tested in the simple sub-assembly tests. Further investigations looking at over-reinforced support details as well as the negative effect of poor bond conditions of prestressing strands on seismic performance are underway.

Campbell, E. 58

Communicating earthquake risk information to Tamariki: challenges and opportunities in a digital world

Rapid advances in our understanding of earthquake risk need effective communication pathways to policy and practice. The growing body of communication research provides an improved comprehension of what is required for effective knowledge transfer, stakeholder engagement and behaviour change. One of the most successful communication strategies is the use of narrative and storytelling to deliver content in an engaging manner. From a Te Ao Māori perspective, oral storytelling is a primary medium for engaging with whakapapa, whānau and tīpuna. However, in a growing digital world, how can our messages speak through a screen to trigger information uptake? This poster will showcase the process undergone by a rōpū of local iwi, educators, civil defence, and researchers in creating an interactive bilingual storybook using Māori pūrākau from Ngāti Kahungunu. It will also illustrate the growing collaborative partnership between Te Ao Māori, risk communication, design and behavioural science.

Cappellaro, C., Cubrinovski, M., Bray J[2], Chiaro, G., Riemer, M., Stringer, M. 11

Cyclic Undrained DSS Testing of Christchurch Sandy Silty Soils

Earthquake-triggered soil liquefaction caused extensive damage and heavy economic losses in Christchurch during the 2010-2011 Canterbury earthquakes. The most severe manifestations of liquefaction were associated with the presence of natural deposits of clean sands and silty sands of fluvial origin. However, liquefaction resistance of fines-containing sands is commonly inferred from empirical relationships based on clean sands (i.e. sands with less than 5% fines). Hence, existing evaluation methods have poor accuracy when applied to silty sands.

The liquefaction behaviour of Christchurch fines-containing (silty) sands is investigated through a series of Direct Simple Shear (DSS) tests. This type of test better resembles earthquake loading conditions in soil deposits compared to cyclic triaxial tests. Soil specimens are reconstituted in the laboratory with the water sedimentation technique. This preparation method yields soil fabrics similar to those encountered in fluvial soil deposits, which are common in the Christchurch area. Test results provide preliminary indications on how void ratio, relative density, preparation method and fines content influence the cyclic liquefaction behaviour of sand-silt mixtures depending on the properties of host sand and silt.

Cave, A., Jeong, S., Stolte, A., Wotherspoon, L. 2

Dynamic site characterisation of the Waikato basin using passive and active surface wave methods

Despite the relatively low seismicity, a large earthquake in the Waikato region is expected to have a high impact, when the fourth-largest regional population and economy and the high density critical infrastructure systems in this region are considered. Furthermore, Waikato has a deep soft sedimentary basin, which increases the regional seismic hazard due to trapping and amplification of seismic waves and generation of localized surface waves within the basin. This phenomenon is known as the "Basin Effect", and has been attributed to the increased damage in several historic earthquakes, including the 2010-2011 Canterbury earthquakes. In order to quantitatively model the basin response and improve the understanding of regional seismic hazard, geophysical methods will be used to develop shear wave velocity profiles across the Waikato basin. Active surface wave methods involve the deployment of linear arrays of geophones to record the surface waves generated by a sledge hammer. Passive surface wave methods involve the deployment of two-dimensional seismometer arrays to record ambient vibrations. At each site, the planned testing includes one active test and two to four passive arrays. The obtained data are processed to develop dispersion curves, which describe surface wave propagation velocity as a function of frequency (or wavelength). Dispersion curves are then inverted using the Geopsy software package to develop a suite of shear wave velocity profiles. Currently, more than ten sites in Waikato are under consideration for this project. This poster presents the preliminary results from the two sites that have been tested. The shear wave velocity profiles from all sites will be used to produce a 3D velocity model for the Waikato basin, a part of QuakeCoRE flagship programme 1.

Cetiner, B., Koc, E., Taciroglu,E., Soibelman, L. 82

A Data-Driven Approach for Granular Simulation of Potential Earthquake Damage to Bridge Networks and Resulting Decreases in Mobility

Quantified investigation of resilience in regional transportation networks has been a growing research focus. Despite this increased attention, state-of-the-art studies fall short of devising and utilizing explicit transportation network models where infrastructure components (roads, bridges, etc.) and travel behaviors of network users are modeled in high fidelity. This study presents a novel model-based approach that couples a semi-automated, image-based structure-specific bridge modeling method with a metropolis-scale travel demand model towards achieving a comprehensive and high-resolution resilience assessment. As a result of its data-driven approach, the proposed method is capable of capturing and incorporating many details that are usually omitted in traditional analyses, promising improved accuracy in estimating the resilience and sustainability metrics of transportation networks. As a small-scale testbed for the proposed approach, this study displays the results of a preliminary investigation of potential seismic losses for the Los Angeles Metropolitan Area due to a

hazard-consistent scenario earthquake primarily affecting the Ports of Los Angeles and Long Beach. This analysis makes use of structure-specific fragility functions of 200 bridges in the vicinity of the port facilities, generated from street-level imagery, and provides a detailed picture of the expected disruptions to truck freight mobility resulting from the scenario event.

Chiaro, G., Palermo, A., Bansiak, L., Granello, G., Tasalloti, A., Hernandez, E. 39

Eco-rubber seismic-isolation foundation systems: a sustainable and cost-effective way to build resilience

Seismic isolation (SI) with energy dissipation has the ability to significantly improve the seismic performance of structures. Historically, SI has been applied to buildings with special functional requirements and bridges. Nevertheless, its application to create new earthquake-resilient residential housing would be of great significance in New Zealand. In this context, this paper proposes an innovative and cost-effective SI methodology, particularly suitable for medium-density low-rise buildings, making use of a dissipative filter made of granulated tyre rubber–gravel mixtures and fibre-reinforced rubberised concrete foundation structural elements. While detailed experimental and numerical results are not available yet, in this poster the results of a state-of-the-art literature review demonstrating the feasibility of this technology are presented and the MBIE Smart Idea project "Eco-rubber seismic isolation foundation systems" that aims at developing this technology is introduced.

Chigullapally, P., Wotherspoon, L., Wood, J., Hogan, L., Pender, M. 83

Seismic Response of an Instrumented Reinforced Concrete Bridge Subjected to Varying Excitation Levels

The Awatere River Bridge, located in the north-eastern region of the South Island of New Zealand, has experienced a number of earthquakes since its construction in 2007. This includes the Cook Strait earthquake sequence in 2013, the 2016 Kaikoura earthquake and their aftershocks. The damage was evident after two of these events, with cracking and spalling of a number of the piers, and as a result, there were repairs carried out after both events. Following each of these events, a network of triaxial accelerometers was installed to monitor its response, including free field motions. In this study, the records from the bridge monitoring network were used to develop and calibrate finite element models of the bridge, and the structural and geotechnical characteristics. The acceleration records, the damage locations, and severities after each event were used as part of this calibration process and the progressive change in dynamic properties after each large event. Sensitivity analyses were performed to assess the influence of a range of structural and geotechnical characteristics on system response. In general, there was good agreement between the recorded and modeled bridge response, which required the incorporation of details from post-event surveys of changes in pier heights due to scour effects. Modeling also highlighted the importance of assumptions related to the representation of abutment characteristics.

Collins, T., Eade, C. 25

Legal responsibility for the mitigation of risks associated with earthquakes

Until relatively recently earthquakes and other natural disasters were considered to be acts of God. As our understanding of these events has grown, so too has the finger of blame and the need for someone to be held responsible. This work explores the concept of accountability for earthquakes in the modern day. It argues that advancements in scientific understanding and technical resilience against natural phenomena is creating an increasingly blurred line between naturally-caused and human-caused disasters. Concepts of vulnerability and injustice are discussed to illustrate the socialised aspect of many modern disasters. International case studies of legal accountability, such as the L'Aquila earthquake and Chilean tsunami, are further used to advance this argument. The western world's rising focus on human rights denotes the need for disaster prevention and response approaches to be human-centric in nature, prioritising individual safety and wellbeing above all else.

Darling, M., Wilson, T., Bradley, B., Orchiston, C., Adams, B. 59

Understanding disaster risk exposure to visitors to the South Island of New Zealand

Underpinning strong disaster risk reduction initiatives are representative disaster risk assessments of communities, regions or nations. Often risk modelling focuses on understanding the physical hazard and its spatial extent; however, it often draws on old or static population datasets. We consider geospatial and big data methods to understanding fluctuations in populations, to ultimately better inform disaster risk assessments. This is particularly relevant in areas of both significant fluctuations in population movement (through tourism), and high disaster risk. We consider the case study of the Alpine Fault in the South Island of New Zealand. The initial findings of this research draw on the case study of Rakiura, Stewart Island, where the total fluctuations in the population are known (though passenger movements through the Foveaux Strait), and we compare these to more novel indicators; such as infrastructure load, social media data, and visitor counter networks. We then consider how such indicators are applicable at a regional national scale to understand fluctuations in population movement, to better inform disaster risk modelling.

De Francesco, G., Sullivan, T. 40

Development of a local approach for tangent-stiffness-proportional damping model

This research investigates the effects of modelling initial-stiffness-proportional and tangent-stiffness-proportional viscous damping models at system and local level. A formulation is developed to model tangent-stiffness-proportional and initial-stiffness-proportional viscous damping model at local level. The effects of modelling viscous damping at local level and global level are examined for both the initial-stiffness-proportional and tangent-stiffness-proportional viscous damping models. Different hysteretic systems are considered and analysed under earthquake excitation. The results

are presented in terms of time-history displacement and strength demand. An analysis of the variation of the viscous and hysteretic energy distribution is also presented to highlight the effects of the different viscous-damping models on the system energy balance.

de la Torre, C., Bradley, B., McGann, C. 3

3D Seismic Site Response with Soil Heterogeneity and Wave Scattering

This poster discusses the on-going development of a 3D site response analysis framework that considers three important non-1D aspects of seismic site response: soil heterogeneity (spatial variability), bidirectional input ground motion, and multi-directional soil constitutive response. The focus is on the development and implementation of spatial variability explicitly modelled through correlated random fields, leading to seismic wave scattering. Importantly, the required site-specific inputs to apply the proposed approach in a practical setting are the same as those associated with conventional 1D site response analysis. This approach requires addressing several numerical and computational hurdles in order to enable 3D FE simulations with spatial variability to be computed and processed in a tractable manner. We present our theoretical and computational developments to date for an initial sensitivity study involving 960 2D model realizations (as a stepping stone to 3D), requiring extensive parallelization and high-performance computing resources. Insights on the scalability and parallelization of large dynamic OpenSEES models from this study are shared.

Dong, W., Li, M. 41

A Preliminary Study on Cyclic Behaviour of SFS Dowelled Connections in Glulam Frames

SFS self-drilling dowels are a special type of metal fasteners in timber construction which can go through relatively thin steel plates and timber members without pre-drilling. The application of SFS dowels makes wood-steel connection assembling more efficient and accurate. Due to tight fitting between holes and fasteners, initial slips in SFS dowelled connections are much smaller than that in conventional dowelled or bolted connections which have predrilled holes typically oversized with 1~2mm. So far, design of SFS dowelled connections in New Zealand mainly follows European practice and very limited experimental testing has been done to validate the SFS dowelled connection strength and stiffness with NZ Radiata Pine (RP). This paper presents a preliminary experimental study to investigate cyclic performance of SFS dowelled connections in RP glulam that are designed to connect diagonal braces with glulam beams and columns. Connection properties in terms of strength, stiffness, ductility and overstrength were derived from the force-displacement curves. The test results showed that the SFS connections performed well with high ductility. The design equations in Eurocode 5 also provided reasonably accurate ultimate strength and ultimate stiffness predictions.

Elwood, K., Puranam, A., Lee, H., Tsai, R., Hsiao, F., Hwang, S., Suzuki, T. 26

Testing of a seven-storey reinforced concrete soft-storey structure with torsional and damaged irregularities under unidirectional ground motion

Reinforced concrete buildings with torsional eccentricities/irregularities are vulnerable to damage and collapse as highlighted in past earthquake events. The irregularities in these buildings generally result from the eccentric alignment of primary or secondary structural elements, and the primary issue in these buildings is related to large displacement demands resulting in localised damage or failure of structural elements on the flexible sides. Such torsional response becomes more complex when associated with the nonlinear behaviour of structural elements.

In nonlinear responses, the damage due to previous torsional response or brittle behaviours of the elements could also trigger the torsion of the systems. To prevent catastrophic failures in future earthquakes, it is necessary to understand the nonlinear torsional responses during earthquakes, yet, little number of experiments has done for the system level. This study aims to investigate through experiments the torsional displacement demand of existing reinforced concrete buildings. The irregularities considered in this study are a) torsional irregularities created by a masonry wall, b) damaged irregularity due to torsion and c) non-ductile irregularity. Two half-scale seven-storey RC structure (with torsional irregularities at the soft first storey) were designed to test on a shake table at the NCREE Tainan laboratory under uni-directional input from a 1999 Chi-Chi Earthquake record. One of the specimens with ductile detailing has been recently tested and this poster presents the preliminary test results including observed displacement demand.

Filippova, O., Sullivan-Taylor, B. 60

Balancing [EQPB] act: Heritage preservation, regulations and their impact on the future of small towns

In the wake of the Canterbury earthquakes, one of the biggest threats to our heritage buildings is the risk of earthquakes and the associated drive to strengthen or demolish buildings. Can Small Town NZ balance the requirements of the EQPB legislation and economic realities of their places? The government's priority is on safety of building occupants and citizens in the streets. However, maintaining and strengthening privately-owned heritage buildings is often cost prohibitive. Hence, heritage regulation has frequently been perceived as interfering with private property rights, especially when heritage buildings occupy a special place in the community becoming an important place for people (i.e. public benefits are larger than private).

We investigate several case studies where building owners have been given green light to demolish heritage listed buildings to make way for modern developments. In two of the case studies developers provided evidence of unaffordable strengthening costs. A new trend that has emerged is a voluntary

offer of contributing to an incentive fund to assist with heritage preservation of other buildings. This is a unique example where private owners offer incentives (via council controlled organisations) instead of it being purely the domain of the central or local governments.

Francis, T., Sullivan, T., Filiatrault, A. 42

A Value Case for Seismic Isolation of Residential Buildings

Seismic isolation is an effective technology for significantly reducing damage to buildings and building contents. However, its application to light-frame wood buildings has so far been unable to overcome cost and technical barriers such as susceptibility to movement during high-wind loading. The precursor to research in the field of isolation of residential buildings was the 1994 Northridge Earthquake (6.7 MW) in the United States and the 1995 Kobe Earthquake (6.9 MW) in Japan. While only a small number of lives were lost in residential buildings in these events, the economic impact was significant with over half of earthquake recovery costs given to repair and reconstruction of residential building damage. A value case has been explored to highlight the benefits of seismically isolated residential buildings compared to a standard fixed-base dwellings for the Wellington region. Loss data generated by insurance claim information from the 2011 Christchurch Earthquake has been used by researchers to determine vulnerability functions for the current light-frame wood building stock. By further considering the loss attributed to drift and acceleration sensitive components, and a simplified single degree of freedom (SDOF) building model, a method for determining vulnerability functions for seismic isolated buildings was developed. Vulnerability functions were then applied directly in a loss assessment using the GNS developed software, RiskScape. Vulnerability was shown to dramatically reduce for isolated buildings compared to an equivalent fixed-base building and as a result, the monetary savings in a given earthquake scenario were significant. This work is expected to drive further interest for development of solutions for the seismic isolation of residential dwellings, of which one option is further considered and presented herein.

Fraser, B. 61

Temporal Drivers of Disaster Risk and Resilience in Rural New Zealand

Aotearoa-New Zealand's rural communities are an essential part of the nation's economy, society and culture. Whilst there is a growing body of rural focused disaster resilience research in New Zealand, (such as the Resilience to Nature's Challenges' Rural Programme) there is not yet a cohesive summary that investigates the drivers and outcomes of resilience over multiple dimensions in the rural sector. Nor is there a cohesive summary of the impacts of this on current and future disaster risk. This study addresses aspects of these gaps by identifying and assessing the factors which influence resilience in New Zealand rural communities and the impact of this on current and future disaster risk. This will focus on quantifying the evolution of communities through dynamic longitudinal social, economic and physical change, primarily using national geospatial datasets and with more in depth case study analysis. Ultimately the research proposed here aims to effectively evaluate the implications of rural

change over time and explore how this information could be more useful and usable for community members, policy makers and disaster decision makers.

Galvez, F., Dizhur, D., Ingham, J. 27

Analytical and numerical prediction of the vulnerability of post-earthquake observed URM macroblocks

Unreinforced masonry (URM) structures are known to perform poorly when subjected to earthquake-induced ground shaking. Among others, connections between structural elements and interlocking across the cross-section play an important role in the capacity of URM structures. Consequently, a large variety of collapse mechanisms is observed after earthquakes. Nevertheless, laboratory tests have shown that heritage structures are not only vulnerable but also newly built are. The high complexity of URM behaviour has made that, only recently, researchers have shown interest in it. Such challenging mechanical behaviour makes numerical simulation a highly complicated process. Different numerical modelling approaches are available to simulate the response of masonry structures, within those, the Discrete Element Method (DEM) is summarised herein.

Existing research has shown significant correlation between the behaviour exhibited in experimental campaigns and DEM numerical simulations. Different challenges arise when in-plane or out-of-plane benchmarks are modelled. Based on post-earthquake observations, a parametric study regarding geometry and boundary conditions of the walls were performed. In-depth insight of the overturning mechanism behaviour and the DEM helped to understand the details of the nature of masonry, allowing the improvement of existing assessing procedures in standards and guidelines.

García, M. 62

Governing community resilience: Interconnections between community resilience, well-being and capitals.

The lived reality of the 2010-2011 Canterbury earthquakes and its implications for the Waimakariri District, a small but rapidly growing district (third tier of government in New Zealand) north of Christchurch, can illustrate how community well-being, community resilience, and community capitals interrelate in practice generating paradoxical results out of what can otherwise be conceived as a textbook 'best practice' case of earthquake recovery. The Waimakariri District Council's integrated community based recovery framework designed and implemented post-earthquakes in the District was built upon strong political, social, and moral capital elements such as: inter-institutional integration and communication, participation, local knowledge, and social justice. This approach enabled very positive community outputs such as artistic community interventions of the urban environment and communal food forests amongst others. Yet, interests responding to broader economic and political processes (continuous central government interventions, insurance and

reinsurance processes, changing socio-cultural patterns) produced a significant loss of community capitals (E.g.: social fragmentation, participation exhaustion, economic leakage, etc.) which simultaneously, despite local Council and community efforts, hindered community well-being in the long term. The story of the Waimakariri District helps understand how resilience governance operates in practice where multi-scalar, non-linear, paradoxical, dynamic, and uncertain outcomes appear to be the norm that underpins the construction of equitable, transformative, and sustainable pathways towards the future.

Garcia, E., Bray, J. 4

Capturing the Influence of Soil Density on Surface Fault Rupture Propagation using the Discrete Element Method

The relative density of a granular soil medium has an important influence on its mechanism of shear deformation. Dense soils tend to shear in a brittle manner with distinct localization; whereas, loose soils tend to show broadly distributed deformation with no distinct localization. These general modes of shear deformation also manifest at the field scale as evidenced by case studies of earthquake surface fault rupture. The influence of relative density on earthquake surface fault rupture is important to fully understand because of the devastating effects this hazard can have on the built environment as demonstrated most recently by the 2016 Kaikoura, New Zealand earthquake. The discrete element method (DEM) is a valuable numerical tool for analyzing the influence of relative density on earthquake surface fault rupture propagation because it models directly the grains and pore space within a granular medium. This influence is modeled in the context of fault rupture-soil-foundation interaction (FR-SFI) in which a fault rupture surface interacts with a foundation located atop the soil. Parametric analyses with different void ratio distributions and foundations having different contact pressures and positions provide insight into the influence of soil density on FR-SFI mechanisms. Fault rupture in nature also rarely occurs in homogeneous soil deposits. Thus, free-field surface fault rupture is modeled with alternating layers of loose and dense soils of varying thickness to better understand how fault rupture propagation behavior differs in homogeneous and inhomogeneous soils. Simulations with layered soil deposits are shown to capture features of free-field surface fault rupture that are more consistent with observations made through field reconnaissance activities than simulations with homogeneous soil deposits.

Gray, L., Becker, J., MacDonald, C., Johnston, D. 63

CONSPICUOUS INVISIBILITY in Disaster Risk Reduction

Background: People with very high body mass (extreme obesity) have been left behind in disasters (Gray, 2017). However, disaster risk reduction (DRR) considerations are not visible in literature to understand risk, adaptive capacities and concerns (Gray & MacDonald, 2016).

Method: Semi-structured interviews with up to 20 people who have extreme obesity in Aotearoa about their experiences in disasters, plans and preparedness. Interviews are audio recorded, transcribed, coded and thematically analysed.

Results: Initial analysis suggests size, shape, weight and age of participants in this study are no proxy for health, mobility or preparedness status. There were shared concerns regarding assistance requirements in the event of a fall or becoming trapped. Other themes relate to replacement clothing, evacuation centre facilities, and the expectation that emergency management will plan and be prepared for their particular needs in the community. Other than routine General Practice visits, participants felt their DRR needs associated with high body mass would not be flagged with any health agency and less mobile participants were unclear if they were registered 'disabled' with any agencies. Discussion: Earlier research found some emergency managers, planners and responders (EMs) felt that health agencies would advise specific needs of people with extreme obesity, yet this research suggests that cannot not be assumed. Other EMs questioned the need to consider this population and yet participants did feel their EMs should have some knowledge and have planned for their needs. Such mis-alignment needs further exploration given the high levels of extreme obesity in Aotearoa (MoH, 2017).

Harrison, S. 64

Capturing impacts, experiences, and behaviour during disaster: An online participation and crowdsourcing approach for resilience

Developing a holistic understanding of social, cultural, and economic impacts of disasters can help in building disaster risk knowledge for policy making and planning. Many methods can help in developing an understanding of the impacts of a disaster, including interviews and surveys with people who have experienced disaster, which may be invasive at times and create stress for the participants to relive their experiences. In the past decade, social media, blog posts, video blogs (i.e. "vlogs"), and crowdsourcing mechanisms such as Humanitarian OpenStreetMap and Ushahidi, have become prominent platforms for people to share their experiences and impacts of an event from the ground.

These platforms allow for the discovery of a range of impact information, from physical impacts, to social, cultural, and psychological impacts. It can also reveal interesting behavioural information such as their decision to heed a warning or not, as people tend to share their experiences and their reactions online. This information can help researchers and authorities understand both the impacts as well as behavioural responses to hazards, which can then shape how early warning systems are designed and delivered. It can also help to identify gaps in desired behavioural responses.

This poster presents a selection of cases identified from the literature and grey literature, such as the Haiti earthquake, the Christchurch earthquake, Hurricane Sandy, and Hurricane Harvey, where online

platforms were widely used during and after a disaster to document impacts, experiences, and behavioural responses. A summary of key learnings and areas for future research is provided.

Hashemi, A., Bagheri, H., Yousef Beik, S., Zarnani, P., Quenneville, P. 43

The Equivalent Ductility approach for designing the structures using Resilient Slip Friction Joints (RSFJs)

The innovative Resilient Slip Friction Joint (RSFJ) technology has recently been developed and introduced to the New Zealand construction industry. The RSFJ is a friction-based energy dissipation device that provides the required seismic performance regardless of the material used for the main structural components. It can be used in various lateral load resisting systems including (but are not limited to) shear walls, rocking columns, tension-compression braces, tension-only braces and moment resisting frames. The performance of the RSFJ technology has previously been verified by joint component testing and full-scale experimental tests.

Different design codes around the world have different approaches to determine the design seismic loads yet most of them recommend to reduce the elastic base shear by a factor that is related to the ductility. Most of the codes recommend ductility-related values for different types of conventional structures based on the type of lateral load resisting system and the material used. Nevertheless, there is still lack of information about the seismic design of buildings with more advanced technologies such as RSFJ.

This research aims to provide a simple analysis and design procedure for the structural engineers when designing a seismic resilient building with RSFJs. A step-by-step forced-based design procedure is provided that generally requires the use of the Equivalent Static Method (ESM) to specify the structural design actions followed by non-linear static pushover and non-linear dynamic time-history simulations to verify the performance. In this procedure, the designer adopts a force reduction factor at the start and verifies it at the end. A case-study structure that uses RSFJ braces as the lateral load resisting members is considered to explain and follow the proposed design procedure.

Haymes, K., Sullivan, T., Chandramohan, R. 44

A Practice-Oriented Method for Predicting Elastic Floor Acceleration Response Spectra

Significant losses have been incurred due to damage to nonstructural components within buildings in recent seismic events, even in instances where the structural systems have performed well. This observation warrants improving the methods currently employed in practice to design nonstructural components to resist seismic demands. Procedures to accurately predict elastic floor response spectra, which can in turn be used to infer the acceleration and deformation demands induced in the nonstructural components, form an important part of the design methodology. Prediction accuracy is often traded off for simplicity in current design practice due to limitations in the available resources

for nonstructural component design. This study proposes to develop a practice-oriented modal superposition method to predict elastic floor response spectra that balances accuracy with simplicity. This method is applied to directly produce floor acceleration response spectra. Conversion from acceleration to velocity and displacement spectra is also explicitly considered. The proposed method is verified using earthquake records from case study buildings in New Zealand, as recorded by the GeoNet structural array.

Hewa Algiriyage, N., Prasanna, R., Stock, K., Hudson-Doyle, E., Johnston, D. 65

Identifying Research Gap and Opportunities in the use of Multimodal Deep Learning for Emergency Management

With the proliferation of smart mobile devices, people are now increasingly using social media applications during disasters to share updates, check on loved ones, or inform officials. Additionally, there are many other sources such as remote sensing, CCTV monitoring, wireless sensor networks and mobile GPS which provide disaster-related data. As a result, an overwhelming amount of data is generated in different modalities (text, audio, video and images) during a crisis. However, extracting, analysing and interpreting a huge variety of multimodal data within a short period of time is a major challenge faced by emergency responders. Therefore, decisions still mostly depend on text-based reports prepared by field officers.

In order to better understand the problem, to make more informed decisions and to have well-coordinated responses, it is necessary to process multiple modalities of data. As Multimodal Deep Learning (MMDL) techniques gain popularity among Artificial Intelligence (AI) researchers, it is timely to discuss the potential of such techniques for use in emergency management. MMDL addresses the problem of relating different representations from multimodal data to each other. Applying MMDL techniques on disaster data would help decision makers by improving the accuracy of data, reducing uncertainty in decision making, and reducing the time taken to analyse data thus assisting emergency responders to understand the "big picture" clearly and support effective disaster relief. Furthermore, the community may benefit by being better prepared, stronger and more resilient during emergencies.

This work focuses on defining the research gap, opportunities and limitations of using MMDL techniques in disaster research.

Hoang, T., Noy, I. 28

Prioritising Earthquake Retrofitting in the High Seismic Risk City of Wellington

Strengthening buildings can minimize the earthquakes' life safety risk. Wellington has around 800 office buildings that might have structural and non-structural seismic vulnerabilities. Given a limited budget and other constrains, prioritization of retrofitting buildings has become a fundamental topic

for decision makers. Different methods have been developed to define prioritisation strategies of retrofitting building on a wide territorial scale. In this paper, we applied the multi-criteria decision making (MCDM) analysis to define different propriety ranking able to satisfy different purpose. Moreover, Fuzzy TOPSIS and VIKOR are two MCDM methods are applied to compare the results. In order to help decision makers in choosing the optimal mitigation strategy with multidimensional perspective, different political and social scenarios are also defined. Based on available seismic risk information (vulnerability, seismic hazard, exposure) the prioritization can be identified. Our aims are: (1) to describe the priority scenarios based on the seismic risk. (2) to rank retrofitting buildings based on different purpose. (3) to relate these findings to possible lessons for policy makers when designing retrofit building strategies.

Hopkins, W., Collins, T., Jacomb, K. 29

Regulating Seismic Risk in Existing Multi-Storey Buildings in NZ: The Wellington Case Study

This paper presents the preliminary conclusions of the first stage of Wellington Case Study project (Regulating For Resilience in an Earthquake Vulnerable City) being undertaken by the Disaster Law Research Group at the University of Canterbury Law School. This research aims to map the current regulatory environment around improving the seismic resilience of the urban built environment. This work provides the basis for the second stage of the project which will map the regulatory tools onto the reality of the current building stock in Wellington.

Using a socio-legal methodology, the current research examines the regulatory framework around seismic resilience for existing buildings in New Zealand, with a particularly focus on multi-storey in the Wellington CBD. The work focusses both on the operation and impact of the formal seismic regulatory tools open to public regulators (under the amended Building Act) as other non-seismic regulatory tools. As well as examining the formal regulatory frame, the work also provides an assessment of the interactions between other non-building acts (such as Health and Safety at Work Act 2015) on the requirements of seismic resilience. Other soft-law developments (particularly around informal building standards) are also examined.

The final output of this work will presents this regulatory map in a clear and easily accessible manner and provide an assessment of the suitability of this at times confusing and patchy legal environment as Wellington moves towards becoming a resilient city. The final conclusion of this work will be used to specifically examine the ability of Wellington to make this transition under the current regulatory environment as phase two of the Wellington Case Study project.

Horspool, N., Elwood, K, Johnston, D., Deely, J., Ardagh, M. 66

Cause of injury and death from recent New Zealand earthquakes

In the past ten years, a series of eight damaging earthquakes have caused 189 deaths and over 16,000 injuries in New Zealand. This is more than the previous 80 years combined. Understanding the cause of casualties (deaths and injuries) from past earthquakes is critical for underpinning effective risk reduction activities such as building codes, education of protective actions during shaking, as well as informing the development of casualty estimation models. In this study, a rare dataset of all earthquake casualties treated through the New Zealand health care system including hospitals and community health care facilities, is analysed to understand the cause of injuries from the eight damaging earthquakes. The earthquakes range from magnitude M6.0 to M7.8 and include the devastating 2011 M6.3 Christchurch Earthquake and the 2016 M7.8 Kaikoura Earthquake. Results reveal new insights into the cause of casualties in New Zealand with relevance for other countries with robust building codes. While over 90 % of the deaths are caused by structural damage through either collapse of reinforced concrete buildings or failure of unreinforced masonry, over 95 % of injuries are caused by, in order of prevalence, loss of stability from strong ground shaking, by individuals behaviour causing an injury, and impacts from contents and non-structural elements. Many of these causes are not explicitly considered in earthquake casualty models and as a result casualty models underestimate casualties from these earthquakes by a factor of 7. This paper will present the findings from this analysis that can help inform more targeted risk reduction activities and improvement of earthquake casualty models.

Kahandawa, R., Domingo, N., Chawynski, G., Uma, S. 30

Investigation into the factors affecting costs of earthquake damage repair work

New Zealand is a nation prone to earthquakes. It is widely documented that continuous seismic activity can lead to the devastation of buildings and infrastructure. After such events, the strategy adopted by building owners on their decision of repair or rebuild has been based on independent professional assessments undertaken by engineers and builders as well as estimated repair costs budgeted by costing experts.

There are currently some basic models available that pre-estimate the repair costs for earthquake damaged structures. These include the following probability based models; PACT, SLAT and SP3. However, research has identified that there are other factors affecting the repair costs associated with earthquake damaged buildings which are not entirely covered by these models.

Document analysis, semi-structured interviews and a questionnaire survey has been conducted to identify and verify the above mentioned factors affecting repair costs of earthquake damaged buildings. These factors have been analysed and integrated into a theoretical cost estimation model

which is represented as a poster. This theoretical model will be further developed into an actual cost estimation model as part of a PhD research project.

Kearns, N., Blake, D. 67

Stories from a Hazardscape: Living with Chronic Illness in Petone

Natural hazards such as earthquakes, flooding, and landslides can interrupt routine medical treatment for people living with chronic illness including heart disease, diabetes, asthma, and renal failure causing people's conditions to become acute. Past events have shown that the chronically ill face the greatest risk of adverse health outcomes from a natural hazard, and require the most medical treatment after an event compared with other groups. However, emergency management plans provide little or no specific planning for people with chronic illnesses, instead focus on the needs of people critically injured by a natural hazard. In the event of a disaster the lack of planning for the chronically ill has resulted in people dying because of lack of medication and essential medical treatment. This research sets out to gain understanding of people's experience of living with a chronic illness in Petone, a hazard prone environment, and how this may matter to their ongoing health and wellbeing. With little research exploring narratives of people with chronic illness living in hazard prone areas, this research will benefit the health and emergency management sector by providing insight into the specific needs of the chronically ill.

Khansari, T., Hayden, C., Wotherspoon, L. 12

Liquefaction Constitutive Model Validation Using Pore Pressure Records from the Canterbury Earthquake Sequence

Well-validated liquefaction constitutive models are increasingly important as non-linear time history analyses become relatively more common in industry for key projects. Previous validation efforts of PM4Sand, a plasticity model specifically for liquefaction, have generally focused on centrifuge tests; however, pore pressure transducers installed at several free-field sites during the Canterbury Earthquake Sequence (CES) in Christchurch, New Zealand provide a relatively unique dataset to validate against. This study presents effective stress site response analyses performed in the finite difference software FLAC to examine the capability of PM4Sand to capture the generation of excess pore pressures during earthquakes. The characterization of the subsurface is primarily based on extensive cone penetration tests (CPT) carried out in Christchurch. Correlations based on penetration resistances are used to estimate soil parameters, such as relative density and shear wave velocity, which affect liquefaction behaviour. The resulting free-field FLAC model is used to estimate time histories of excess pore pressure, which are compared with records during several earthquakes in the CES to assess the suitability of PM4Sand.

Kowal, A., Stirling, M., Gorman, A., Wotherspoon, L. 5

Strong Ground Motions Simulations for Dunedin: recent progress

We present our on-going QuakeCoRE-funded work on strong motion seismology for Dunedin–Mosgiel area, focusing on ground motion simulations for the Dunedin Central Business District (CBD). Source modelling and ground motion simulations are being carried out using the Southern California Earthquake Center (SCEC) Broadband Simulation Platform (SCEC BBSP). As large earthquakes have not been experienced in Dunedin in the time period of historical observation (since 1840), user-specified scenario simulations need to be developed. The sources considered for ground motion simulations include major active faults near Dunedin that have been the foci of recent paleoseismic studies (Akatore, Titri, Dunstan and Hyde faults), along with the distant Alpine Fault source.

Current work and ongoing goals focus on modelling non-linear site effects. Seismic site effects are related to the amplification of seismic waves in surficial geological layers. We are presently undertaking site response analysis for ground motion simulations via nonlinear total stress and effective stress 1D wave propagation methods.. The simulated, amplified motions are compared against recorded events from strong motion stations in the city centre and southern Dunedin to quantify the amplification characteristics of soil sites relative to rock sites. These recorded events are also being applied to simulation validations. Our work will soon progress to undertaking ground motion simulations that utilize a 3D shear-wave velocity model for the greater Dunedin-Mosgiel area.

Lambie, E., Campbell, E., Johnston, D., Elwood, K., Stephens, M., Uma, S., Prasanna, R., Becker, J., Rangika, N., Tan, M., Imtiaz-Syed, Y., Hudson-Doyle, E., Hopkins, J. 68

Smart Resilient Cities

Emerging technology and data processing tools are transforming the cities we live in, and the way we live in them. Understanding the confluence of trends and evolving relationship between people, systems and data is key to designing for resilience in an equitable way. Globally, the Smart Cities model uses open and shared data to better understand local vulnerabilities and inform development decisions as well as the operation of physical and service infrastructure.

Smart Resilient Cities is a research project which will explore how we can best use emerging technology for Disaster Risk Reduction. The aim is to understand the use of sustainable and low cost:

- *State of the art sensors capable of maintaining the sensing ability of a city/region before, during and after an big disaster*
- *Wired and wireless communication platform linking smart sensors before, during and after a big disaster*

- *End-user accepted and trusted technology application covering users' needs for gauging human and infrastructure impacts*

When considering the appropriate application of emerging technologies to solve local issues, human factors and institutional aspects need to be included as essential components of the ecosystem. The initial objective of Smart Resilient cities is to engage with a cross-section of urban residents to explore: What people expect from sharing their data? How do they weigh up the trust-benefit of sharing their data?

Lew, S., Wotherspoon, L., Hogan, L., Al-Ani, M. 84

Assessment of the Historic Seismic Performance of the New Zealand Bridge Stock

This poster presents the assessment of historic seismic bridge performance of the New Zealand highway bridge stock from the 1968 Inangahua earthquake through to the 2016 Kaikōura earthquake. Spatial ground motion details based on recorded and observed ground motion intensities were used to estimate the peak ground acceleration (PGA), as a measure of the seismic demand at each bridge location. Across all events PGA of 0.05g or greater was experienced on approximately 800 occasions at bridge sites. Damage characteristics were collated from available literature, with the majority of the bridges experiencing either no damage or only minor damage across all events. To further assess the performance in historic events, outcomes from a national-scale seismic screening process were utilized. The majority of bridges performed well in the historic earthquakes, with only a few bridges experiencing significant damage. Some shorter bridges may have performed well due to the effect of abutment stiffness and damping. Similarly, some longer bridges performed well due to integral abutment response and wall type piers that likely have higher capacity than originally assessed. These findings will inform future assessment methods and design, and inform assessment of the accuracy of analytical models of the bridge stock.

Lin, A., Wotherspoon, L., Blake, D., Bradley, B., Motha, J. 13

Liquefaction exposure across New Zealand transport networks

Liquefaction can lead to significant damage of infrastructure networks disrupting important services such as the transport of people or freight. Hazard maps help to identify exposed infrastructure sections and to support decision making processes regarding infrastructure investment, emergency planning, as well as prioritisation of post-earthquake reconstruction projects. The information required for hazard maps, however, usually relies on labour-intensive and high-cost field investigations. Considering the great amount of data required to assess large distributed infrastructure, an in-situ approach appears to be unsuitable. In this case, geospatial methods combined with probabilistic evaluation can be used as an alternative approach. The research focuses on a recently developed geospatial model to estimate liquefaction exposure across New Zealand transport networks. Based on ten ground shaking scenarios, liquefaction probability was calculated

for State Highways and rail showing general hotspots in Waikato, Wellington and West Coast. Despite a similar track, results for rail (incl. rail bridges) are slightly higher compared to the State Highway network.

Further research needs to consider more earthquake scenarios in order to achieve a more accurate evaluation of the networks' overall exposure to liquefaction. In addition, other seismic hazards (e.g. landslides) and other infrastructure networks (e.g. power transmission) can be included in the assessment.

Little, M., Rathje, E., DePascale, G., Bachhuber, J. 14

Assessment of Empirical Lateral Spreading Displacement Models using Data from the 2011 Christchurch Earthquake

Liquefaction-induced lateral spreading during the 2011 Christchurch earthquake in New Zealand was severe and extensive, and data regarding the displacements associated with the lateral spreading provides an excellent opportunity to better understand the factors that influence these movements. Horizontal displacements measured from optical satellite imagery and subsurface data from the New Zealand Geotechnical Database (NZGD) were used to investigate four distinct lateral spread areas along the Avon River in Christchurch. These areas experienced displacements between 0.5 and 2 m, with the inland extent of displacement ranging from 100 m to over 600 m. Existing empirical and semi-empirical displacement models tend to under estimate displacements at some sites and over estimate at others. The integrated datasets indicate that the areas with more severe and spatially extensive displacements are associated with thicker and more laterally continuous deposits of liquefiable soil. In some areas, the inland extent of displacements is constrained by geologic boundaries and geomorphic features, as expressed by distinct topographic breaks. In other areas the extent of displacement is influenced by the continuity of liquefiable strata or by the presence of layers that may act as vertical seepage barriers. These observations demonstrate the need to integrate geologic/geomorphic analyses with geotechnical analyses when assessing the potential for lateral spreading movements.

Loghman, V., Bradley, B., Chandramohan. R., McGann, C. 7

Validation of ground motion simulations via response history analysis of special moment resisting frames using an automated workflow

Validation is an essential step to assess the applicability of simulated ground motions for utilization in engineering practice, and a comprehensive analysis should include both simple intensity measures (PGA, SA, etc), as well as the seismic response of a range of complex systems obtained by response history analysis.

In order to enable a spectrum of complex structural systems to be considered in systematic validation of ground motion simulations in a routine fashion, an automated workflow was developed. Such a workflow enables validation of simulated ground motions in terms of different complex model responses by considering various ground motion sets and different ground motion simulation methods. The automated workflow converts the complex validation process into a routine one by providing a platform to perform the validation process promptly as a built-in process of simulation post-processing.

As a case study, validation of simulated ground motions was investigated via the automated workflow by comparing the dynamic responses of three steel special moment frame (SMRF) subjected to the 40 observed and 40 simulated ground motions of 22 February 2011 Christchurch earthquake. The seismic responses of the structures are principally quantified via the peak floor acceleration and maximum inter-storey drift ratio. Overall, the results indicate a general agreement in seismic demands obtained using the recorded and simulated ensembles of ground motions and provide further evidence that simulated ground motions can be used in code-based structural performance assessments in-place of, or in combination with, ensembles of recorded ground motions.

Lu, Y., Henry, R., Elwood, K., Rodgers, G., Zhou, Y., Gu, A., Yang, T. 45

ILEE-QuakeCoRE Shake Table Test on a Full-scale Low-Damage Concrete Wall Building

QuakeCoRE has given New Zealand researchers the opportunity to access some of the world's top earthquake engineering facilities. A system level shake-table test of a full-scale low-damage concrete wall building has been conducted on the multi-functional shake-table array at Tongji University as part of the ILEE-QuakeCoRE international collaborative research project. The test aimed to verify the seismic response of a low-damage concrete wall building implementing state-of-art design concepts and practical construction details that are currently being used in New Zealand buildings.

The 2-storey test building was designed with post-tensioned (PT) walls that provide the primary lateral-load resistance in both directions and a frame that utilised slotted beam connections. Precast concrete double tees were used for the first floor and a steel tray composite floor was used for the second floor. Conventional flexible wall-to-floor connections and isolating device-type wall-to-floor connections were used for longitudinal and transverse directions, respectively. A number of alternative energy dissipation devices were also installed at wall base or/and beam-column joints of the building. The building was subjected to 39 tests with a range of intensity ground motions, incorporating both unidirectional and bi-directional testing on the structure with different combinations of wall strength and energy dissipating devices. The 360 channels of test data has provided a significant dataset to verify design procedures, detailing practice, and numerical models.

Overall, the building performed extremely well during the intense series of tests, providing confidence that the new low-damage concrete buildings are an excellent low-damage building solution. The building exhibited only minor damage, with distributed cracking in the floors and cosmetic spalling in the wall toes that could be easily repaired.

Marafi, N., Berman, J., Makdisi, A., Eberhard, M. 46

Effects of Simulated Magnitude 9 Earthquake Motions on Reinforced Concrete Wall Structures in the Pacific Northwest

The Cascadia Subduction Zone (CSZ) can produce long-duration, large-magnitude earthquakes, whose ground motions will be modified by the deep sedimentary basins, which underlie several cities in the Pacific Northwest (e.g., Portland, Seattle, and Vancouver, BC). The effects of these basins on the ground motion duration and frequency content are poorly understood because no recordings are available for large-magnitude earthquakes in this region.

To compensate for this paucity of recordings, researchers from the United States Geological Survey and the University of Washington generated ground motions for numerous scenarios of an M9 event. The simulations were generated using deterministic, finite-difference (T>1s) and stochastic (T<1s) approaches. This poster incorporated the results from the M9 simulations into the probabilistic seismic hazard assessment and studied the impact on collapse risk for 36 archetypical, reinforced-concrete-core-wall structures, located in Seattle, and ranging from 4- to 24-stories.

The frequency dependent basin amplification increases the spectral accelerations at periods corresponding to tall structures and results in damaging spectral shapes. The duration of the M9 motions are long, but the basins have little effect on the significant duration of the motions. Buildings designed to the minimum requirements set by code (ASCE 7-16) resulted in a collapse risk that exceeded the 1% risk of collapse in 50-year target. It is shown that the 1% target can be achieved by (a) increasing the design forces, (b) decreasing drift limits, or (c) increasing the ductility capacity of the gravity system. The implications for these design changes are quantified in terms of the cross-sectional area of the walls, longitudinal reinforcements, and usable floor space.

McClure, J., Ferrick, M., Johnston, D. 69

Risk judgments and social norms: Do they relate to preparedness after the Kaikoura earthquakes

Research has shown that preparation for natural hazard events reflects several factors including risk judgments and the cost of the actions. Research has also shown the effects of norms in other domains but very little in regard to natural hazards. This study examined risk judgments and preparedness norms following the recent Kaikoura earthquakes. Wellington citizens judged the risk of earthquakes in Wellington, Kaikoura and other parts of New Zealand ('elsewhere') before and after the 2016

Kaikoura earthquake. They also reported their preparation and perception of norms for different categories of preparation. Judgments of the risk of a further earthquake occurring following the Kaikoura earthquake rose more for Kaikoura than for Wellington and elsewhere, but participants still judged an earthquake more likely in Wellington and elsewhere than in Kaikoura. Preparation related to risk judgment and to the judgment that preparing was normative, particularly for survival actions. These findings suggest that normative information adds to the effect of risk perceptions about the probability of an earthquake to enhance preparation for these hazards. This finding can be applied in risk communications for earthquakes and other hazards.

McLaren, L., Johnston, D., Hudson-Doyle, E., Becker, J., Beatson, A. 70

Community science as a tool for increased disaster resilience

The research explores how community science can be used as a tool for building resilience to disaster events. It presents a framework for hazard scientists and practitioners to use if they want to build more citizen participation into their research design. It also highlights how different types of hazard research projects are already utilising citizen engagement in data collection and analysis. A thematic analysis of literature was undertaken on both citizen science and community resilience as concepts. Comparisons were made between citizen science project design themes and three community resilience enablers; informal disaster education, community participation, and trust.

Miranda, C., Raftery, G., Toma, C., Johnston, D. 71

The Effectiveness of Retrofit Technologies in Wooden-Framed Houses in Wellington

New Zealand has a long tradition of using light timber frame for construction of its domestic dwellings. After the most recent earthquakes (e.g. Canterbury earthquakes sequence), wooden residential houses showed satisfactory life safety performance. However, poor performance was reported in terms of their seismic resilience. Although numerous innovative methods to mitigate damage have been introduced to the New Zealand community in order to improve wooden house performance, these retrofit options have not been readily taken up. The low number of retrofitted wooden-framed houses leads to questions about whether homeowners are aware of the necessity of seismic retrofitting their houses to achieve a satisfactory seismic performance. This study aims to explore different retrofit technologies that can be applied to wooden-framed houses in Wellington, taking into account the need of homeowners to understand the risk, likelihood and extent of damage expected after an event.

A survey will be conducted in Wellington about perceptions of homeowners towards the expected performance of their wooden-framed houses. The survey questions were designed to gain an understanding of homeowners' levels of safety and awareness of possible damage after a seismic event. Afterwards, a structural review of a sample of the houses will be undertaken to identify common features and detail potential seismic concerns. The findings will break down barriers to

making improvements in the performance of wooden-framed houses and lead to enhancements in the confidence of homeowners in the event of future seismic activity. This will result in increased understanding and contribute towards an accessible knowledge base, which will possibly increase significantly the use of these technologies and avoid unnecessary economic and social costs after a seismic event.

Moratalla, J., Uma, S., Dellow, S. 15

Compilation and comparison of pipe fragility relationships based on liquefaction severity

Published relationships between pipe damage and liquefaction severity have been compiled. The pipe damage data was collated so results from liquefiable soil layers with similar properties and similar triggering earthquake characteristics could be compared. Liquefaction severity was characterised using three different methods: Liquefaction-Severity-Number (LSN), Liquefaction-Resistance-Index (LRI), and Permanent-Ground-Displacement (PGD).

Sufficient relationships were available for Asbestos-Cement (AC), Cast-Iron (CI), and Polyvinyl-Chloride (PVC) pipes. Pipe materials were also aggregated and grouped as either ductile and non-ductile to estimate pipe damage from liquefaction for a wider range of pipe types.

Flexible pipe materials (PVC) performed best against liquefaction damage. Brittle pipes (AC and CI) were more susceptible to damage. Lack of quality and amount of data for PVC pipes under liquefaction effects gives larger uncertainties by the relationships compiled here. LSN-based relationships proposed by Toprak et al., 2017 show the strongest correlation with empirical data. The effect of pipe diameter to pipe damage was not considered in this work.

Empirical data collected in areas affected by lateral spreading show a significant increase in the pipe damage. In this work, the assumption of lateral spreading effects is considered when conditions for LRI 0 are reached, modifying the pipe damage estimations in PGD-based relationships. LSN is not sensitive to lateral spreading, therefore results provided by those formulations are not consistent with those by LRI and PGD if lateral spreading is assumed to occur at LRI zone 0 and show consistent results for LRI zones 1 to 4. PGD-based fragility formulations show consistency with those results provided by LRI relationships if lateral spreading is assumed to occur only at LRI-0, and with both LRI and LSN for LRI 1 to 4.

Motha, J., Loghman, V., Bradley, B., Lee, R., Lagrava, D., Schill, C., Zhu, M., James, P. 92

Automated workflow for validation of ground motion simulations using conventional and complex intensity measures

Ground motion intensity measures (IMs) are widely used in Performance-Based Earthquake Engineering (PBEE) to quantify seismic hazard and potential demands on structures. The IMs are a particularly useful set of summary statistics by which to validate ground motion simulation results as they enable quantitative comparison between simulation and observation data, in a format consistent with that provided by conventional empirical ground motion models.

We have developed a software workflow that computes and plots a wide range of IM values from simulation and/or observation time series. Available IM metrics include peak ground acceleration (PGA), peak ground velocity (PGV), cumulative absolute velocity (CAV), Arias intensity (AI), duration (Ds575, Ds595), modified Mercalli intensity (MMI) and pseudo-spectral acceleration (pSA) with a range of periods between 0.01 and 10.0 seconds. IM values can also be aggregated for a specified location into a single comma-separated-value (CSV) file, and metadata, such as source-to-site distance metrics (e.g. Rrup and Rjb) can also be computed and stored.

We have recently extended this workflow to also include 'advanced IMs', which are based on the results of response history analysis of complex structural and/or geotechnical systems - typically measures such as inter-storey drift and floor accelerations, but can be any generic measure of seismic response, in general.
This is an open-source software project that provides engineering seismologists and structural/geotechnical earthquake engineers with an easy-to-use IM calculation and plotting capability, seen as a critical toolchain necessary to progress the comprehensive validation of ground motion simulation methods from the perspective of developers as well as users.

Munoz, G., Henry, R., Elwood, K. 47

Repairability of earthquake damaged Reinforced Concrete walls

The 2010-2011 Christchurch earthquakes generated damage in several Reinforced Concrete (RC) buildings, which had RC walls as the principal resistant element against earthquake demand. Despite the agreement between structural engineers and researchers in an overall successfully performance there was a lack of knowledge about the behaviour of the damaged structures, and even deeper about a repaired structure, which triggers arguments between different parties that remains up to these days. Then, it is necessary to understand the capacity of the buildings after the earthquake and see how simple repairs techniques improve the building performance.

This study will assess the residual capacity of ductile slender RC walls according to current standards in New Zealand, NZS 3101.1 2006 A3. First, a Repaired RC walls Database is created trying to gather

previous studies and to evaluate them with existing international guidelines. Then, an archetype building is designed, and the wall is extracted and scaled. Four half-scale walls were designed and will be constructed and tested at the Structures Testing Laboratory at The University of Auckland. The overall dimensions are 3 [m] height, 2 [m] length and 0.175 [m] thick. All four walls will be identical, with differences in the loading protocol and the presence or absence of a repair technique. Results are going to be useful to assess the residual capacity of a damaged wall compare to the original behaviour and also the repaired capacity of walls with simpler repair techniques. The expected behaviour is focussed on big changes in stiffness, more evident than in previously tested RC beams found in the literature.

Neill, S., Lee, R., Bradley, B. 8

Ground motion simulation validation with explicit uncertainty incorporation for small magnitude earthquakes in the Canterbury region

This study explicitly investigates uncertainties in physics-based ground motion simulation validation for earthquakes in the Canterbury region. The simulations utilise the Graves and Pitarka (2015) hybrid methodology, with separately quantified parametric uncertainties in the comprehensive physics and simplified physics components of the model. The study is limited to the simulation of 148 small magnitude (Mw 3.5 – 5) earthquakes, with a point source approximation for the source rupture representations, which also enables a focus on a small number of relevant uncertainties. The parametric uncertainties under consideration were selected through sensitivity analysis, and specifically include: magnitude, Brune stress parameter and high frequency rupture velocity. Twenty Monte Carlo realisations were used to sample parameter uncertainties for each of the 148 events. Residuals associated with the following intensity measures: spectral acceleration, peak ground velocity, arias intensity and significant duration, were ascertained. Using these residuals, validation was performed through assessment of systematic biases in site and source terms from mixed-effects regression. Based on the results to date, initial standard deviation recommendations for parameter uncertainties, based on the Canterbury simulations have been obtained.

This work ultimately provides an initial step toward explicit incorporation of modelling uncertainty in simulated ground motion predictions for future events, which will improve the use of simulation models in seismic hazard analysis. We plan to subsequently assess uncertainties for larger magnitude events with more complex ruptures, and events across a larger geographic region, as well as uncertainties due to path attenuation, site effects, and more general model epistemic uncertainties.

Nguyen, T., Lee, R., Juarez, A., Bradley, B. 9

Synthetic study of Full Waveform Seismic Tomography for geophysical velocity model in Canterbury region based on the Adjoint-Wavefield method

In this paper we apply Full waveform tomography (FWT) based on the Adjoint-Wavefield (AW) method to iteratively invert a 3-D geophysical velocity model for the Canterbury region (Lee, 2017) from a simple initial model. The seismic wavefields was generated using numerical solution of the 3-D elastodynamic/ visco- elastodynamic equations (EMOD3D was adopted (Graves, 1996)), and through the AW method, gradients of model parameters (compression and shear wave velocity) were computed by implementing the cross-adjoint of forward and backward wavefields. The reversed-in-time displacement residual was utilized as the adjoint source. For inversion, we also account for the near source/ station effects, gradient precondition, smoothening (Gaussian filter in spatial domain) and optimal step length.

Simulation-to-observation misfit measurements based on 191 sources at 78 seismic stations in the Canterbury region (Figure 1) were used into our inversion. The inversion process includes multiple frequency bands, starting from 0-0.05Hz, and advancing to higher frequency bands (0-0.1Hz and 0-0.2Hz). Each frequency band was used for up to 10 iterations or no optimal step length found.

After 3 FWT inversion runs, the simulated seismograms computed using our final model show a good matching with the observed seismograms at frequencies from 0 - 0.2 Hz and the normalized least-squared misfit error has been significantly reduced. Over all, the synthetic study of FWT shows a good application to improve the crustal velocity models from the existed geological models and the seismic data of the different earthquake events happened in the Canterbury region.

Nicolin, E., Dempsey, D., Kah, J. 10

What should Auckland expect from a Magnitude 7 Hauraki Rift Earthquake?

The Hauraki Rift is a tectonically active structure extending from Matamata to Waiheke Island. Because it produces earthquakes only infrequently, its seismic hazard is poorly understood. However, together, its faults are capable of generating a magnitude 7.4 earthquake. Thus, the rift poses a massive potential hazard to the 30% of NZ's population living within 50 km. Ground Motion Simulations are used to understand the shaking hazard posed by these kinds of earthquakes at different locations around the country. There are two major obstacles with running these kinds of models. First, there are a large number of uncertainties in the input parameters: what velocity the seismic waves travel at, the length of the fault rupture, or the directivity of the event. Second, the computational burden is massive. The simulations must be performed on NZ eScience Infrastructure, and exploration of parameter space is burdensome.

A series of simulations are run to obtain a preliminary sensitivity analysis, the goal being to explore the extreme ends of parameter space. The ground motion simulation output is processed and various intensity metrics are computed, including peak ground velocities/accelerations and durations. These quantities are measured at important locations e.g. population centres larger than one thousand, economic centres like Auckland CBD and airport, and critical infrastructure. The aims are to assess the extent at which parameter uncertainty affects predictions of ground motion impact, and to develop a better understanding of which data are important to improve the model.

Ntritsos, N., Cubrinovski, M. 16

System response of liquefiable deposits

Results from a series of 1D seismic effective stress analyses of natural soil deposits from Christchurch are summarized. The analysed soil columns include sites whose performance during the 2010-2011 Canterbury earthquakes varied significantly, from no liquefaction manifestation at the ground surface to very severe liquefaction, in which case a large area of the site was covered by thick soil ejecta. Key soil profile characteristics and response mechanisms affecting the severity of surface liquefaction manifestation and subsequent damage are explored. The influence of shaking intensity on the triggering and contribution of these mechanisms is also discussed. Careful examination of the results highlights the importance of considering the deposit as a whole, i.e. a system of layers, including interactions between layers in the dynamic response and through pore water pressure redistribution and water flow.

Nwadike, A., Wilkinson, S., Clifton, C. 72

Building code amendment and compliance in post-disaster reconstruction in New Zealand

Amendment to building code has been proved to increase building resilience and reduce the impact of the disaster in the built environment. Following the knowledge gained from pervious disaster, quest for innovation and intensive research, the New Zealand building code has been regularly amended to achieve the primary aim of building code. However, compliance with the building code has proved to be an issue whenever the code is updated. The purpose of this study is to identify and explore the impacts of building code amendment on compliance in New Zealand and how best compliance can be improved through building code amendment in post-disaster reconstruction. The purpose of the study is achieved through a quantitative approach comprised of closed-ended questionnaires derived from the literature review and conceptual context. The questionnaire was administered to building code users, the regulators and the government officials to measure their respective opinion on the impact of building code amendment regarding compliance. The results from the study shows that whenever the building code is amended, it has some impact on compliance which can be reduced and improved through effective awareness, free or low-cost technical assistance, training code users, professional staff as inspection team, reduced compliance cost,

regular consultation and sufficient resources for enforcement. Amendment to the building code without compliance helps to turn natural hazards into the catastrophic disaster, which defies the significant purpose of building code. Therefore, the efficacy of building code amendment largely depends on the rate of compliance to the code updates and technically skilled staff that can be able to detect any form of malpractice with the building code.

Omoya, M., Burton, H. 73

Bayesian Updating of Earthquake-Induced Building Downtime Parameters

Bayesian statistics is used to update ones beliefs about uncertain events or random variables when new information is presented. When an earthquake occurs, there are two types of losses than can be associated with buildings. Direct losses arise from the cost of the repair effort needed to return a damaged building to its intact (or near intact) state. Indirect losses are associated with the revenue losses that occur during the time that the earthquake-impacted building is unusable and the financial cost of human casualties caused by the earthquake. Downtime is defined as the duration between earthquake occurrence and when the functionality of the building is restored. This research focuses on developing a Bayesian statistical framework to update the downtime parameters used in the REDi (Resilience-based Earthquake Design Initiative for the Next Generation of Buildings) Rating System using data obtained from the buildings affected by the 2014 South Napa Earthquake. Bayesian updating can be performed using the conjugate prior or Markov Chain Monte Carlo (MCMC) approach. Three models are developed by varying the updating approach and the prior downtime parameter distribution. They include the conjugate prior approach assuming a gamma prior distribution, the Approximate Bayesian Computation (ABC) algorithm of the MCMC approach assuming a lognormal prior distribution, and again the MCMC-ABC algorithm assuming a uniform (or non-informative) prior distribution. The presented framework can be used to systematically update the parameters used in building downtime assessment when new data becomes available following future earthquakes.

Opabola, E., Elwood, K. 31

Experimental and analytical investigations of uncertainty in seismic response of reinforced concrete components

The seismic response of reinforced concrete (RC) components at the flexure - flexure-shear failure mode transition point was explored through laboratory testing of four full scale nominally identical circular columns. Experimental results showed that the failure mode and collapse response of RC columns are influenced by inherent material uncertainty and displacement history. Using a database of past experiments on RC beams and columns, the failure mode transition zone was analytically studied. Furthermore, a probabilistic failure mode identification model, to be adopted in probabilistic seismic assessment, is proposed. For components expected to exhibit variability in seismic behavior,

it is recommended that probabilistic procedures, accounting for failure mode uncertainty, should be adopted.

Orumiyehei, A. 48

Simplified seismic risk assessment of systems with two failure mechanisms using the improved SAC/FEMA approach

The SAC-FEMA approach quantifies the seismic risk associated with structures in a simplistic way. Enhancements to the accuracy of this approach are presented in two stages. Firstly, improved intensity measure–engineering demand parameter relationships are established. Secondly, the application of this approach is extended to systems in which two different mechanisms could result in the attainment of the assessment limit state. The improved SAC/FEMA approach can be used by practitioners in daily design and assessment to quantify the likelihood of reaching key limit states. This could not only improve the communication between engineers and clients but also facilitates the decision making process for consultants to choose the most suitable structural system at an early stage of design and assessment.

Pascua, C., Henry, R. 49

Review of recently constructed buildings with dual systems combining steel frames and concrete walls

Recent building construction in New Zealand have exhibited a massive increase in the use of structural steel due to its availability and good seismic performance. Despite the renewed popularity of structural steel, concrete walls remain a reliable choice of lateral force resisting system, leading to a trend of buildings with dual systems that combine steel frames and concrete walls. This study aims to understand such hybrid buildings, focusing on buildings constructed in Auckland and Christchurch within the last five years. Through sidewalk surveys and desktop research, an initial list of buildings of interest was developed, and structural drawings were obtained from council property files or from structural engineers. The drawings were reviewed, and designs were discussed with structural engineers. Buildings were classified according to relevant typological information such as building height, design objectives, wall layout, wall construction method, steel framing system, connection features, and floor system, noting any special characteristics such as low-damage solutions used, if any. Ultimately, this study will lead to the identification of critical aspects of this dual system that will require further investigation.

Pastor, J., Filippova, O., Elwood, K., Noy, I., 32

Making Wellington [earthquake] resilient: Creating building inventory dataset for seismic risk assessment and management

Wellington City Council earthquake resilience strategy began addressing the city's building stock as early as 1970's. Major events that shook our country during this decade (in particular the Kaikoura earthquake) highlighted information gaps in the form of scarce of detailed and up-to-date information about the existing stock of buildings in a high earthquake risk city like Wellington. Our project has assembled an inventory of mid- to high-rise buildings in the Central Business District to facilitate multidisciplinary research within Flagship 3's Coordinated Project. Crossing over the engineering and social sciences, the ongoing projects supported by the building inventory are: (1) providing best scientific knowledge about the expected seismic performance of concrete buildings; (2) assessing the impact of multiple building failures including the downstream consequences of associated cordoning; (3) developing a path for seismic retrofitting that includes prioritization of retrofits and (4) informing the design of a regulatory structure that can facilitate the reduction of risk associated with earthquake vulnerable buildings. The inventory dataset is hosted online in a MapViewer where researchers can visualise, filter and download spatial and attribute data of either the entire inventory, or buildings that satisfy specific criteria. Researchers can access the data in GIS conventional formats (as a file relational geodatabase or a Web Feature Service) or non-GIS file formats (e.g. csv files). Further developments include the addition of geophysical information (e.g. hazard information) and socioeconomic data (e.g. Land values). Ultimately, the inventory is intended to be a core input for seismic risk assessment and management, as well as a methodology that can be replicated in the greater Wellington and other parts of NZ.

Pepperell, B. 74

Leadership challenges and opportunities in extreme contexts

Research indicates that aside from the disaster itself, the next major source of adverse outcomes during such events, is from errors by either the response leader or organisation. Yet, despite their frequency, challenge, complexity, and the risks involved; situations of extreme context remain one of the least researched areas in the leadership field.

This is perhaps surprising. In the 2010 and 2011 (Christchurch) earthquakes alone, 185 people died and rebuild costs are estimated to have been $40b. Add to this the damage and losses annually around the globe arising from natural disasters, major business catastrophes, and military conflict; there is certainly a lot at stake (lives, way of life, and our well-being).

While over the years, much has been written on leadership, there is a much smaller subset of articles on leadership in extreme contexts, with the majority of these focusing on the event rather than leadership itself. Where leadership has been the focus, the spotlight has shone on the actions and

capabilities of one person - the leader. Leadership, however, is not simply one person, it is a chain or network of people, delivering outcomes with the support of others, guided by a governance structure, contextualised by the environment, and operating on a continuum across time (before, during, and after an event).

This particular research is intended to examine the following:

- *What are the leadership capabilities and systems necessary to deliver more successful outcomes during situations of extreme context;*
- *How does leadership in these circumstances differ from leadership during business as usual conditions;*
- *Lastly, through effective leadership, can we leverage these unfortunate events to thrive, rather than merely survive?*

Plotnikova, A., Wotherspoon, L., Beskhyroun, S. 85

Dynamic behaviour of reinforced concrete bridges in freezing conditions

The strong influence of ambient temperature variation, and especially freezing of near-surface soils, on the transverse modal response of the bridges in cold earthquake-prone regions has been shown in previous research. This paper extends this work and presents an analytical investigation of the modal characteristics of the range of reinforced concrete continuous beam bridges with integral pile-column systems with various geometries over a range of temperatures. The numerical bridge models were geometric modifications of previously validated finite element models of a soil–pile-bridge system representing a prototype three-span bridge located in Anchorage, Alaska. Frozen conditions increased the fundamental modal frequencies across all the bridge schemes. The mode shapes of the short bridges with a few spans undergo significant transformation mainly due to the changes in the stiffness of the pier-foundation-soil system in winter. More flexible, high column and multi-span bridges are less susceptible to these significant mode shape variations. The findings reveal the need for further assessment of the seismic design code requirements for the bridge stock in the cold regions, given that changes in modal parameters may increase the design seismic lateral loads along with potential redistribution of the loads across the structure due to stiffening of the pile-soil system in winter.

Pujol, S., Gale, D. 33

Estimation of Seismic Drift demands in Torsional Structures

A method is proposed to estimate seismic drift demand in structures with strong torsional irregularities. The method is simple by design. It follows from the method of Velocity of Displacement (VOD) that was developed by M. A. Sozen (2003) from ideas rooted in The Substitute Structure Method. Data from dynamic tests of a structure with extreme torsion are used to vet the method. The vetting shows that for torsional structures with stable hysteresis -as for regular structures-:

1. *Drift demand is nearly proportional to peak ground velocity PGV and mean spectral velocity PSV.*
2. *The proportionality constant between drift and PGV and PSV is in turn proportional to initial period (estimated for uncracked cross sections) for the mode that dominates the displacement at the point of interest.*

These observations suggest that, in absence of failure compromising the stability of load-displacement 'hysteresis' loops, the softening resulting from yielding and cracking in RC structures subjected to earthquake motion does not render them more vulnerable to future earthquakes.

Ramhormozian, S., Clifton, C., Yan, Z., MacRae, G., Dhakal, R., Quenneville, P., Zhao, X., Jia, L., Xiang, P. 50

Shaking Table Test of a Near Full Scale Low Damage Structural Steel Building: Structural Aspects

Recent severe earthquakes worldwide have put emphasis on building resilience. To achieve this, procedures for low damage seismic design have been developed to satisfy both the life safety requirement and the need to minimize the undesirable economic effects of required building repair or replacement following a severe earthquake. The performance of these buildings is dependent on whole building system interactions, which are difficult to determine by numerical modelling. The purpose of this project is to experimentally test the seismic performance of a complete, low damage, full scale building system incorporating a number of friction energy dissipaters in forms of sliding hinge joint asymmetric friction connection (SHJAFC), resilient slip friction joint (RSFJ), symmetric friction connection (SFC) and GripNGrab (GnG). This will also incorporate testing without and with non-structural elements (NSEs) to quantify their effect on the building response. Testing will be based on appropriately scaled actual earthquake records using two linked 70-ton shake tables at Tongji University, Shanghai, China. Unidirectional each axis and biaxial horizontal testing will be undertaken. The structure is expected to have at worst minor damage under a series of severe earthquakes. The design also aims to have economical methods for repairing and straightening such building systems after severe seismic activities, if there is a need. This paper focuses on the design of the structural part in this project, presenting the preliminary design of the structure.

Rhodes, A., Keepa, C., Cubrinovski, M., Krall, T. 17

Seismic site response at CentrePort, Wellington

The Port of Wellington (CentrePort) is a key lifeline located on the Wellington Waterfront. CentrePort is situated on land reclaimed in stages between the 1890's and the 1970's. The land was reclaimed using end-tipped quarry fill (sand-silt-gravel mixture) and hydraulic fill pumped from the seabed (sands and silts). The reclamation fill varies in depth from approximately 5 m to more than 20 m.
As such, CentrePort is located on fill of varying types, ages and depths as well as various locations within the Thorndon Basin. Hence, we anticipate that the site response at one area of the Port may

be different to another for any given seismic event. It is imperative that we understand these effects to enable robust assessment of port resilience, and to develop appropriate mitigation measures to safeguard this key infrastructure for future events.

This study aimed to quantify seismic site response at CentrePort. Five precincts were chosen to represent the variation in ground conditions and distance from the basin edge. 1D site response analysis was conducted on representative soil profiles from each precinct to assess the influence of ground conditions on the surface motion. Comparisons are drawn between prediction and observation and implications for design are considered.

Rickard, H., Noy, I., Emily, L., Sally, O., 93

Development of a GIS platform for Multi-Disciplinary Community Databases to enable Earthquake Resilience and Research

This poster describes the initial steps and benefits in the creation of a GIS platform that will enable the hosting, sharing, and linking of spatial, geotechnical, structural, social, and economic datasets. This will enable interested parties to pursue multi-disciplinary research projects that aim to solve what are inherently complex and multi-faceted problems. A span of datasets will be linked to existing multi-storey buildings and integrated into an easy-to-use GIS platform that will have a range of purposes, including: (1) providing the best scientific knowledge spanning numerous disciplines to inform earthquake resilience research; (2) allowing different organisations, including local councils and iwis to make evidence based decisions regarding event-based planning and emergency management and (3) fostering engagement and sharing of data between separate research communities across different disciplines. Urban areas of Dunedin and Palmerston North are currently being used as repeatable case studies to test the feasibility and relationships required to enable the GIS platform's capabilities. Researchers are being involved in a collaborative, multi-disciplinary, and flexible approach to ensure the GIS platform can benefit a wide array of groups and individuals. Building in flexibility to extend the GIS platform nationwide to construct a national, multi-disciplinary building database using consistent data standards is a primary, long-term goal for the project.

Rushton, A., Kenney, C., Phibbs, S., Anderson, C. 75

"Puck it up and do your role": Men and the Kaikōura earthquake

The purpose of this research is to investigate men's experiences of the 2016 7.8 magnitude Kaikōura earthquake and Tsunami. While, research into the impacts of the earthquake has been conducted, few studies have examined how gender shaped people's experiences of this natural hazard event. Analysing disasters through a gender lens has significantly contributed to disaster scholarship in identifying the resilience and vulnerabilities of individuals and communities pre- and post-disaster (Fordham, 2012; Bradshaw, 2013). This research employs understandings of masculinities (Connell, 2005), to examine men's strengths and challenges in responding, recovering, and coping following

the earthquake. Qualitative inquiry was carried out in Northern Canterbury and Marlborough involving 18 face-to-face interviews with men who were impacted by the Kaikōura earthquake and its aftermath. Interview material is being analysed using thematic and narrative analysis. Some of the preliminary findings have shown that men took on voluntary roles in addition to their fulltime paid work resulting in long hours, poor sleep and little time spent with family. Some men assisted wives and children to high ground then drove into the tsunami zone to check on relatives or to help evacuate people. Although analysis of the findings is currently ongoing, preliminary findings have identified that the men who participated in the study have been negatively impacted by the 2016 Kaikōura earthquake. A theme identified amongst participants was an avoidance to seek support with the challenges they were experiencing due to the earthquake. The research findings align with key characteristics of masculinity, including demonstrating risky behaviours and neglecting self or professional care. This study suggests that these behaviours affect men's overall resilience, and thus the resilience of the wider community.

Sarkis Fernández, A., Sullivan, T., Brunesi, E., Nascimbene, R. 51

Numerical Seismic Performance Assessment of Precast Pre-stressed Hollow-core Concrete Floors

Precast pre-stressed hollow-core (PPHC) floors have been historically designed and constructed in ways that jeopardize their seismic performance. Particularly, early use of PPHC floors in ductile frames had support connections that were inadequate to accommodate earthquake deformations, making them prone to significant damage, and even collapse, at relatively low drift levels. While improved connection details were developed following past experimental research (Fenwick et al., 2010), concerns regarding the seismic performance of buildings containing PPHC floors have been raised following the 2016 Kaikōura Earthquake. In several cases, damage states observed were inconsistent with the failure modes identified by previous research (Henry et al., 2017), bringing into question the seismic assessment of buildings with PPHC floors, the residual capacity of the floors once damage has been sustained, and the effectiveness of existing retrofit techniques.

To address these concerns, a campaign of detailed nonlinear finite element (FE) analyses is proposed, with the overall purpose of improving the understanding of the likely behavior of PPHC floors during earthquakes and enhancing the ability to define and/or validate broadly applicable procedures for design and assessment. The campaign is organized in three phases corresponding to the following topics to be investigated: web shear strength of the PPHC units, drift capacity of support connections, and post-cracking behavior of PPHC diaphragms. The models developed during each phase will be validated against experimental data and then used to parametrically investigate key aspects of the performance of PPHC floors. Advances in the first phase are presented, for which, constitutive models, based on nonlinear fracture mechanics, have been used to numerically predict the shear strength capacity, evolution of shear stress distributions and crack patterns of PPHC units.

Sarrafzadeh, M. 52

Performance of Earthquake Damage Beams Repaired Via Epoxy Injection

A prominent challenge following the 2010-11 Canterbury earthquakes was the insurance decision making process for earthquake-damaged buildings and the lack of robust engineering guidelines for future risk assessment. Similarly, in the aftermath of the 2016 Kaikoura earthquakes, these issues were again highlighted leaving engineers and building owners with limited guidance on the reparability of moderately damaged reinforced concrete (RC) structures in Wellington. Research is ongoing at the University of Auckland with experimental investigations into the post-earthquake residual capacity and impact of epoxy injection on the behaviour of RC beam elements following earthquake damage. Four beam-column assemblies, exhibiting low to moderate damage level after the 2016 Kaikoura earthquake, were extracted from a RC building in Wellington. Specimens were tested at the University of Auckland Structures Laboratory using a reversed-cyclic loading protocol to assess their residual stiffness, strength and deformation capacity. One specimen was repaired using epoxy injection and repair mortar by experienced contractors. The experiments demonstrate that the damaged components still maintain strength and sufficient deformation capacity, but the stiffness is lower than would be expected for the undamaged beam. Recovery of stiffness and energy dissipation capacity using epoxy injection repair is also demonstrated. This report outlines the performance of the tested beam-column assemblies, including the effects of strain aging.

Scheele, F., Wilson, T., Becker, J., Horspool, N., Lane, E., Crowley, K., Hughes, M., Davies, T., Williams, J., Le, L., Uma, S., Lukovic, B., Schoenfeld, M., Thompson, J. 76

Modelling post-disaster habitability, human displacement and population needs

Issues of habitability, sheltering and the needs of populations following disasters is a key issue for emergency management, asset management, planning and prioritisation. Loss of habitability may result in the displacement of occupants from both residential and commercial buildings, with some of those displaced requiring temporary shelter, whereas some residents will prefer to shelter in place. The displacement of populations and assessment of needs following a disaster is a complex process that is influenced by many factors. These include physical factors (e.g. building damage, loss of utilities), social or demographic factors explaining relative levels of vulnerability, and decision-making by affected populations.

We have developed a new model for estimating habitability, displacement and sheltering needs for tsunami (HDS-T). The model uses an additive scoring system incorporating both physical and demographic factors, weighted according to their relative influence. HDS-T is designed to be adaptable to other natural hazards and contexts, such as earthquakes.

Further research is underway into developing a framework and model for assessing the needs of populations following disasters, expanding on the existing HDS-T model. One to two major NZ

scenarios will be considered (e.g. Hikurangi earthquake and tsunami, Alpine Fault earthquake). The outcomes of this research are directed towards supporting decision-makers with rapid impact assessment information, to assist in planning and response to events.

Shirzadi, S. 77

Energy – Communication Resilience

This is a joint Resilience Framework undertaken by the Electrical, Computer and Software Engineering Department of the University of Auckland in association with West Power and Orion networks and partially funded by the New Zealand National Science Challenge and QuakeCoRE.

The Energy- Communication research group nearly accomplished two different researches focusing on both asset resilience and system resilience. Asset resilience research which covers underground cables system in Christchurch region is entitled "2010-2011 Canterbury Earthquake Sequence Impact on 11KV Underground Cables" and system resilience research which covers electricity distribution and communication system in West Coast region is entitled "NZ Electricity Distribution Network Resilience Assessment and Restoration Models following Major Natural Disturbance". As the fourth milestone of the aforementioned research project, the latest outcome of both projects has been socialised with the stakeholders during the Cigre NZ 2019 Forum.

Shrestha, S., Orchiston, C. 34

To cordon or not to cordon: The inherent complexities of post-earthquake cordons learned from New Zealand experiences

The use of post-earthquake cordons as a tool to support emergency managers after an event has been documented around the world. However, there is limited research that attempts to understand the use, effectiveness, inherent complexities, impacts and subsequent consequences of cordoning once applied. This research aims to fill that gap by providing a detailed understanding of first, the cordons and associated processes, and their implications in a post-earthquake scenario. We use a qualitative method to understand cordons through case studies of two cities where it was used in different temporal and spatial scales: Christchurch (2011) and Wellington (Kaikōura earthquake 2016), New Zealand. Data was collected through 21 expert interviews obtained through purposive and snowball sampling of key informants who were directly or indirectly involved in a decision-making role and/or had influence in relation to the cordoning process. The participants were from varying backgrounds and roles i.e. emergency managers, council members, business representatives, insurance representatives, police and communication managers. The data was transcribed, coded in Nvivo and then grouped based on underlying themes and concepts and then analyzed inductively. It is found that cordons are used primarily as a tool to control access for the purpose of life safety and security. But cordons can also be adapted to support recovery. Broadly, it can be synthesized and viewed based on two key aspects, 'decision-making' and 'operations and management', which

overlap and interact as part of a complex system. The underlying complexity arises in large part due to the multitude of sectors it transcends such as housing, socio-cultural requirements, economics, law, governance, insurance, evacuation, available resources etc. The complexity further increases as the duration of cordon is extended.

Soleimankhani, H., MacRae, G., Sullivan, T. 35

Accounting for Building Torsional behaviour during strong Earthquake Shaking

Buildings subject to earthquake shaking will tend to move not only horizontally but also rotate in plan. In-plan rotation is known as "building torsion" and it may occur for a variety of reasons, including stiffness and strength eccentricity and/or torsional effects from ground motions. Methods to consider torsion in structural design standards generally involve analysis of the structure in its elastic state. This is despite the fact that the structural elements can yield, thereby significantly altering the building response and the structural element demands. If demands become too large, the structure may collapse.

While a number of studies have been conducted into the behavior of structures considering inelastic building torsion, there appears to be no consensus that one method is better than another and as a result, provisions within current design standards have not adopted recent proposals in the literature. However, the Canterbury Earthquakes Royal Commission recently made the recommendation that provisions to account for inelastic torsional response of buildings be introduced within New Zealand building standards. Consequently, this study examines how and to what extent the torsional response due to system eccentricity may affect the seismic performance of a building and considers what a simple design method should account for. It is concluded that new methods should be simple, be applicable to both the elastic and inelastic range of response, consider bidirectional excitation and include guidance for multi-story systems.

Stolte, A., Wotherspoon, L., Jeong, S., Ma, Q., Rodgers, G. 94

Recent Research Activities of QuakeCoRE Technology Platform 2

Since its inception, QuakeCoRE Technology Platform 2 (TP2) has worked to build upon existing Aotearoa New Zealand leadership in field testing and monitoring through the development of world-class testing technologies and urban system monitoring. Key thrust areas of this platform include: (1) Training of personnel on state-of-the-art field testing and monitoring techniques and equipment, (2) the development of standardised guidelines for field data acquisition and processing, (3) implementation of equipment for long-term field monitoring studies, and (4) the development of advanced field testing and monitoring techniques that push beyond current practice. In support of these objectives, QuakeCoRE TP2 has either directly led or supported research activities across Aotearoa New Zealand. This poster presents a summary of these recent research efforts. Geotechnical field testing and site characterisation activities have included seismic geophysical

testing in several cities and regions, including: Dunedin, the Blenheim/Wairau plains, the Hauraki plains, Napier/Hastings, Hamilton/Waikato, Tauranga, and Auckland. Recent structural and geotechnical monitoring activities include the monitoring of a bridge in the Marlborough Region and the instrumentation of the joint QuakeCoRE-ILEE low-damage concrete building during shake table testing. QuakeCoRE TP2 has continued to support the development of field testing and monitoring capabilities through the development of testing methods and instrumentation, including the fabrication of direct-push crosshole testing instrumentation, the use of low-cost accelerometers for structural field testing, and the use of low-cost alternatives to seismometers, such as the Raspberry Shake.

Stringer, M. 18

Quantifying pumice content in soil mixtures

Soil deposits containing significant amounts of pumice are found across large areas of the North island of New Zealand. A key property of pumiceous soil grains is their internal and external vesicularity, which gives rise to a very low bulk weight as well as low resistance to crushing (and therefore a high compressibility). As a result of the low resistance to crushing, these materials evolve significantly under changing stresses, particularly deviatoric stress.

The special properties of pumice-rich soils means that they are not well covered by empirical datasets from which engineering properties are typically estimated. In particular, previous studies have shown the insensitivity of the cone penetration test (CPT) to relative density in pure pumice. This implies that poor estimates of liquefaction resistance would be expected from simplified methods based on the results of the CPT.

An ongoing study by the Universities of Auckland and Canterbury aims to establish new methodologies to estimate the in-situ liquefaction resistance of pumice-rich soils through laboratory testing on undisturbed samples recovered at sites in New Zealand. An integral part of the interpretation of these results will be the ability to quantify the "amount" of pumice contained within a natural soil mixture. In this paper, the results from a new analysis technique are presented which allows researchers and practitioners to separate the pumiceous material from the rest of the soil deposit, enabling further detailed characterisation to be performed.

Syed, Y., Prasanna, R., Uma, S., Stock, K., Blake, D. 86

Development of a Decision Support System using a Critical Infrastructure Interdependency Modelling Framework

Critical Infrastructures (CI) such as electricity, water, fuel, telecommunication and road networks are a crucial factor for secure and reliable operation of a society. In a non-emergency situation, most businesses operate on an individual infrastructure. However, after major natural disasters such as

earthquakes, the conflicts and complex interdependencies among the different infrastructures can cause significant disturbances, as a failure can propagate from one infrastructure to another. The aim of this project is to develop a customizable Decision Support System (DSS) that has the capability to integrate electricity, water and road networks through a simulation framework. The framework uses a damage map of electricity and water network components and integrates them with road access times to these damaged components for estimating the electricity and water outage times in a region. The results can be used for recovery planning, identification of vulnerabilities, and adding redundancies in an infrastructure network.

Tan, M., Prasanna, R., Stock, K., Hudson-Doyle, E., Leonard, G., Johnston, D. 78

Conceptualising a disaster app: consolidating public alerting authorities' social media and broadcast messages

Multiple agencies in New Zealand are mandated to warn the public of risks, hazards, or emergencies. The agencies have a plethora of public alerting options; including the capability to deliver alerts to the public through mobile devices. The options directed to mobile devices currently available in New Zealand include SMS-text message, phone calls, and more recently, social media, smartphone applications (apps), and broadcast messaging. Each of these new technological options has its strengths but also has its weaknesses.

The prototype app proposed in this poster tries to address some of the challenges posed by these various mobile delivery options. Apps can be useful platforms for communicating localised and time-critical information. The proposed app targets citizens as end-users and tries to aggregate information from authorised agencies. Apps can contribute to the public's disaster resilience; however, they can also be impractical if not designed according to users' needs.

In this study, a usability inquiry was conducted with 18 members of the public to understand their perspectives, needs, and expectations from a disaster app. The proposed app received an overall positive response from participants. Moreover, the results from the inquiry with the users showcased particular considerations for disaster apps; such as making critical information salient, reducing cognitive load, and leveraging usability to build trust between the app and the user.

Thomas, K., Kaiser, L., Campbell, E., Johnston, D., Campbell, H., Solomon, R., King, D., Jack, H, Borrero, J., Northern, A., Callan, J. 79

Disaster memorial events for increasing awareness and preparedness: Commemorating the 150th anniversary of the 1868 Arica tsunami, Aotearoa-New Zealand

On 15 August 1868, a great earthquake struck off the coast of the Chile-Peru border generating a tsunami that travelled across the Pacific. Wharekauri-Rekohu-Chatham Islands, located 800 km east of Christchurch, Aotearoa-New Zealand (A-NZ) was one of the worst affected locations in A-NZ. Tsunami waves, including three over 6 metres high, injured and killed people, destroyed buildings

and infrastructure, and impacted the environment, economy and communities. While experience of disasters, and advancements in disaster risk reduction systems and technology have all significantly advanced A-NZ's capacity to be ready for and respond to future earthquakes and tsunami, social memory of this event and other tsunamis during our history has diminished. In 2018, a team of scientists, emergency managers and communication specialists collaborated to organise a memorial event on the Chatham Islands and co-ordinate a multi-agency media campaign to commemorate the 150th anniversary of the 1868 Arica tsunami. The purpose was to raise awareness of the disaster and to encourage preparedness for future tsunami. Press releases and science stories were distributed widely by different media outlets and many attended the memorial event indicating public interest for commemorating historical disasters. We highlight the importance of commemorating disaster anniversaries through memorial events, to raise awareness of historical disasters and increase community preparedness for future events – "lest we forget and let us learn."

Tilley, L., Barnhill, D. 80

Understanding Tsunami Evacuation Dynamics: Informing agent-based evacuation modelling through a case study of the 2016 Kaikōura Earthquake.

Tsunami events including the 2004 Indian Ocean Tsunami and the 2011 Tohoku Earthquake and Tsunami confirmed the need for Pacific-wide comprehensive risk mitigation and effective tsunami evacuation planning. New Zealand is highly exposed to tsunamis and continues to invest in tsunami risk awareness, readiness and response across the emergency management and science sectors. Evacuation is a vital risk reduction strategy for preventing tsunami casualties. Understanding how people respond to warnings and natural cues is an important element to improving evacuation modelling techniques. The relative rarity of tsunami events locally in Canterbury and also globally, means there is limited knowledge on tsunami evacuation behaviour, and tsunami evacuation planning has been largely informed by hurricane evacuations. This research aims to address this gap by analysing evacuation behaviour and movements of Kaikōura and Southshore/New Brighton (coastal suburb of Christchurch) residents following the 2016 Kaikōura earthquake.

Stage 1 of the research is engaging with both these communities and relevant hazard management agencies, using a survey and community workshops to understand real-event evacuation behaviour during the 2016 Kaikōura earthquake and subsequent tsunami evacuations. The second stage is using the findings from stage 1 to inform an agent-based tsunami evacuation model, which is an approach that simulates of the movement of people during an evacuation response. This method improves on other evacuation modelling approaches to estimate evacuation times due to better representation of local population characteristics. The information provided by the communities will inform rules and interactions such as traffic congestion, evacuation delay times and routes taken to develop realistic tsunami evacuation models. This will allow emergency managers to more effectively prepare communities for future tsunami events, and will highlight recommended actions to increase the safety and efficiency of future tsunami evacuations.

Vinnell, L., Milfont, T. McClure, J. 81

Identifying cognitive predictors of natural hazard preparedness using the Theory of Planned Behaviour

Natural hazards such as earthquakes and tsunami can have adverse impacts to infrastructures and populations globally. In Wellington, New Zealand, awareness of these hazards is high but preparation is low. Using the Theory of Planned Behaviour, we conducted an online survey with a large community sample (N = 604) to identify predictors of intentions to prepare for natural hazards. Results indicate that attitudes and perceived behavioural control were the only positive predictors of intentions to prepare for natural hazards—in particular, experiential attitudes (perceptions of the experience of preparing as positive), instrumental attitudes (perceptions of the outcomes of preparing as positive), and self-efficacy—with intention predicting information-seeking behaviour. A secondary goal of the study was to examine possible framing effects. "Natural hazards" or "natural disasters" are used inconsistently, and findings in other areas such as climate change communication demonstrate that relatively minor changes in the framing of target issues can impact intentions and actions. Our findings offer preliminary support for a similar framing effect for natural hazards/disasters, both in intention formation and in the association between intentions and behaviour. The findings of this research have important implications for public information campaigns and interventions aimed at increasing preparedness for natural hazards.

Wang, C., Yu, Q., Cetiner, B., McKenna, F., Yu, S., Law, K., Taciroglu, E., Govindjee, S., Deierlein, G. 36

Machine Learning For City-Scale Building Information Model Procurement

The speed and accuracy of seismic loss estimation are central to effective post-earthquake emergency response. Inadequate emergency response can increase the number of casualties by a maximum factor of 10, which suggests the need for research on rapid earthquake shaking damage and loss estimation. For maximum utility, these estimates need to be conducted at as fine a scale as is practically possible. To this end, we propose a framework that leverages the advantages of recent breakthroughs in remote sensing, non-linear structural dynamics and Artificial Intelligence (AI) for shaking damage to buildings at a large (regional) scale. The framework provides a method to quickly build a building inventory of a given region, which enables rapid building damage estimation based on nonlinear dynamic analyses.

Weir, A., Wilson, T., Bebbington, M., Deligne, N. 87

Quantifying the systemic vulnerability of critical infrastructure networks to volcanic multi-hazards at Mt Taranaki, New Zealand

Critical infrastructure are the infrastructural networks and systems deemed essential for the functionality of society and economy. Critical infrastructure systems are globally recognised to be highly interdependent, meaning that the loss of function of an asset within one sector can greatly reduce the functionality of assets that rely on its continued supply. Due to the complexity of such networks, systemic vulnerability (the propensity of a system or network to experience loss of service due to physical damage) is typically qualitatively ascertained, or neglected entirely in impact assessment frameworks. Furthermore, current quantitative methods for systemic vulnerability calculation (such as criticality metrics) tend to be sector-specific, therefore not accounting for trans-sector interdependencies inherent in infrastructural networks.

We propose a new methodology for determining asset criticality, incorporating interdependencies inherent in infrastructural networks. We also demonstrate a new methodology for the quantification of systemic vulnerability, by integrating the new asset criticality classification scheme with hazard-plausibility information. We demonstrate this new methodology in Taranaki, New Zealand, where spatially extensive critical infrastructure networks supply substantial agricultural and energy industry, and also circumnavigate Mt Taranaki volcano, where a large explosive eruption in the next 50 years has a 33 – 42 % likelihood.

Williams, J. 88

Tsunami Vulnerability of Critical Infrastructure: Development and Application of Functions for Infrastructure Impact Assessment

Recent international tsunami events, including the 2011 Tohoku Earthquake and Tsunami, Japan, the 2015 Ilapell Earthquake and Tsunami, Chile, and the 2018 Sulawesi Earthquake and Tsunami, Indonesia, have highlighted the potential for tsunami impacts on the built environment. International research in the tsunami impacts domain have been largely focused on impacts to buildings and casualty estimations, while only limited attention has been placed on the impacts on critical infrastructure. New Zealand, being a developed and tectonically active island nation in the South Pacific, has a large amount of coastal infrastructure exposed to many local, regional and distal source tsunamis. To effectively manage tsunami risk for New Zealand critical infrastructure, the vulnerability of infrastructure networks and components must first be constrained. This research aims to develop relevant asset vulnerability, functionality and repair cost functions based on international post-event tsunami impact assessment data from technologically similar countries, including Japan and Chile and adapts these to New Zealand. These functions are then utilized within a New Zealand based impact framework, allowing for cost benefit analyses, effective tsunami risk management strategies

and mitigation options for exposed critical infrastructure to be determined, which can also be applied internationally.

Wotherspoon, L., Liu, L., Zorn, C., Davies, A. 89

Simulation of direct and indirect infrastructure failures for Alpine Fault earthquake scenarios

Using an integrated framework for simulating infrastructure failures, this project focusses on assessing the direct and indirect failures for the networks across the South Island of New Zealand resulting from different Alpine Fault earthquake scenarios. Spatial infrastructure asset data and functional network models for the South Island of New Zealand are developed using real-world data for the energy, transportation, water & waste, and telecommunications sectors. Asset failures are simulated across each individual network and network disruptions are then propagated across an interdependent network framework. The importance of the simulations to quantify and delineate the spatial reach of both direct and indirect outages are demonstrated using three different Alpine Fault rupture scenarios that highlight the significant variation in outage extent that can develop.

Yang Liu, L., Wotherspoon, L., Nair, N., Blake, D. 90

Quantifying the seismic rick for electric power distribution systems

Electric power distribution systems are generally more prone to disruption from natural hazards than transmission systems due to their often less redundant circuit structures. However, seismic risk analysis for distribution systems is rare compared to the rich body of literature focusing on transmission systems. This paper proposes a seismic risk assessment framework for electric power distribution systems considering both the network topology and the functional vulnerability of distribution substations. Implicit Z-bus method is applied to solve distribution system power flow and evaluate system serviceability. Monte Carlo simulation is applied to obtain probabilities of the scale of unserved loads resulting from disconnection and abnormal voltage condition. The seismic risk is jointly quantified using multiple risk metrics, and importance measures are used to determine criticality of substation components for prioritisation of seismic retrofit. The seismic risk assessment framework is applied to the CIGRE medium voltage distribution test network and two ground motion intensity scenarios – one for peak ground acceleration values based on a scenario earthquake and the other for uniformly distributed peak ground acceleration across the network. The framework allows the quantification of different network topologies and substation configurations. This enables network owners and operators to evaluate the seismic vulnerability of their substation configuration and network topology, identify potential bottlenecks of the systems and thus inform effective planning and risk-reduction investments.

Yao, G. 37

Seismic Retrofit of Automated Storage Systems in a High-tech Fabrication Plant

The Stockers (STK) in a clean room environment are used for automatic storage in several high-tech factories and should be operational after an earthquake. However, STK are vulnerable to earthquake based on the Taiwan experience. In 2016 during Meinong Earthquake, damage of the STK system led to serious impact on high-tech factories. It not only shut down the production line, caused huge economical lose, but also responsible for slow recovery.

This study aims to increase the seismic capacity of STK in a high-tech factory. First, a rough numerical model to realize the true response under earthquake in the factory was developed. By using full-scale static and shaking table test we validated the dynamic characteristic of the numerical model. By considering the in-situ situation, construction feasibility, and the economic demand, a retrofitted bracing system was developed. The efficiency for the retrofitted STK is verified by static and shaking table tests. Finally, the computed response of full STK models in fab showed a most efficient response after the proposed retrofit.

Yarmohammadi, F., Hayden, C., Wotherspoon, L. 19

Seismic performance of adjacent mat-supported structures on liquefiable soil: validation of numerical model using centrifuge tests

Adjacent structures can interact with each other through the underlying soil during earthquakes. This interaction, which is more common in dense urban areas, is known as structure-soil-structure interaction (SSSI) and can modify the response of each structure. However, there is a lack of understanding of the mechanisms governing this interaction, especially when the structures are located on loose liquefiable soil. As a result, the current state of practice for designing structures on liquefiable soils completely ignores this interaction. In this study, a fully-coupled, finite difference model is developed using FLAC and the PM4Sand constitutive model. The results are compared to two centrifuge tests to validate the developed model. This validation can be helpful in understanding the capabilities and limitations of the model. This validation can also help researchers and engineers to perform extensive parametric studies to better understand the problem of SSSI involving liquefaction and use it in structural design. The results show that the numerical model can capture the generation of pore water pressure under the structures and also estimates foundation accelerations well. Additionally, the calculated structure settlements and rotations generally match the centrifuge tests.

Zakerinia, M., Hayden, C., McGann, C. 20

Stress Density Model Validation for Liquefaction Analysis

Liquefaction-induced problems may cause severe damage to infrastructure. Existing simplified empirical relations for estimating deformations based on the free field disregard shear deformation effects on buildings. Constitutive models that take advantage of nonlinear dynamic effective stress framework can provide an estimation of liquefaction-induced phenomena by considering more realistic deformation mechanisms. However, constitutive models also have limitations in predicting the soil behaviour regarding liquefaction. Thus, they require rigorous verification, calibration and validation. The Stress Density Model (SDM) is a constitutive model for effective stress analyses involving liquefaction. The model characterises the soil behaviour using the state concept (initial void ratio and normal stress state of soil), a modified hyperbolic stress-strain relation and an adopted stress-dilatancy relation. This study uses FLAC, an explicit finite difference program capable of performing nonlinear dynamic analyses, in which the SDM has recently been implemented. Single-element simulations serve as the first step to identify the model's functionality. Evaluation of the model's performance at the single-element level lays the groundwork for further application in free-field site response and SSI analyses. This study uses a well-documented centrifuge test for validation of the SDM performance in free-field applications. The procedure includes comparisons between the numerical model and the centrifuge test in terms of accelerations and pore water pressures calculated and recorded at key locations. The effects of the included dilatancy parameters on the model's behaviour are discussed within the state concept.

Zarinkamar, S., Poshdar, M., Quenneville, P., Wilkinson, S. 53

Trust to new seismic-proofing technologies: The influential factors

Earthquakes cause serious damages to the economy of the impacted regions. Many new methods and technologies have been introduced into the construction industry with the aim of reducing the consequences of earthquake damages and their associated repair costs. Still, the low level of trust towards these new technologies poses a significant challenge in adopting them. An enhanced understanding of the factors that affect the trust in the newly introduced the low damage seismic-proofing technologies (SPTs) can play a crucial role in designing policies to leverage their adoption. This study identifies the factors of trust in adopting an innovative low damage SPT, namely the Resilient Slip Friction Joint (RSFJ) as a representative of novel new technologies. This technology has been introduced to the New Zealand construction industry in 2016 and provides seismic energy dissipation and the ability to return the structure to the pre-earthquake position after the event in one compact package.

The data collection stage involved an online survey of three groups of respondents from the New Zealand construction industry including clients, contractors, and consultants. More than 80

responses were collected from different sectors of the industry comprising architects, structural engineers, planners, quantity surveyors and project managers. The survey questions approached the trust factors from different angles, such as organizational and project characteristics. The findings of this research can help to improve and develop a path to facilitate the uptake of new Seismic proofing technologies.