CURRENT DIRECTION FOR IMPROVING STRUCTURAL ENGINEERING AND RESILIENCY IN NEW ZEALAND

Mike Stannard
Chief Engineer
Ministry of Business Innovation & Employment, New Zealand

Abstract

The 2010 to 2011 Canterbury Earthquake sequence has been the most destructive earthquake New Zealand has experienced in recent times. Rebuild costs are estimated at $40 billion or 20% of New Zealand's GDP, 185 people died, and much of the Christchurch Central Business District, New Zealand's second largest city, needs to be rebuilt. Approximately 170,000 houses have needed to be repaired or rebuilt and some eight thousand properties have been red zoned. It has been one of the most complex insurance events world-wide. While the social and economic consequences have been very significant and sometimes tragic, it has presented a real opportunity to learn from the event and better understand building and land performance during earthquake shaking. Generally modern buildings performed well from a life-safety perspective with New Zealand having been a leader in capacity design principles. However, plastic hinging, uncertainty about the residual capacity of buildings and poor ground performance have led to high demolition numbers.

The New Zealand Government initiated a Canterbury Earthquakes Royal Commission of Inquiry after the February 2011 damaging event. Their final report presented 189 recommendations, providing an important direction towards improving structural engineering and resiliency. Changes are being made to structural design standards where under-performance has been observed. Earthquake-prone building legislation has been changed, requiring retrofitting or removal of the most vulnerable buildings throughout New Zealand. Reviews of the Building Code requirements are also underway which may test the societal appetite for changes to code settings. Guidance has been developed to address repair strategies and rebuilding on liquefaction-prone land. An increase in geotechnical and structural research activity is occurring with close international collaboration. Importantly, the sequence has provided the opportunity for a much higher level of collaboration between all parties involved in building decision making.

This paper describes some of the recent experience in New Zealand to address resiliency from a central government technical public policy decision making perspective and signals future direction.

Introduction/Context

New Zealand is a highly seismically active country, being situated along the intersection of the Pacific and Australasian tectonic plates. New Zealanders are very conscious of earthquakes with most people sensing earthquake shaking several times each year. However, the Canterbury earthquake sequence, with five major destructive shocks between September 2010 and December 2011, along with thousands of smaller ones, all in close proximity to Christchurch, has changed public perceptions. (Stannard 2014).

This was the most destructive earthquake sequence in a New Zealand urban setting since 1931 when 235 people lost their lives in the Napier earthquake. Wellington has always been regarded as the city most at risk from earthquakes where numerous active faults are clearly evident. In 1848, very shortly after the first Europeans settled in Wellington, a magnitude c7.7 earthquake struck, followed by an M c8.3 in 1855 when the Wairarapa fault ruptured. Large areas were uplifted by up to 6.4 metres significantly changing the land form, a tsunami entered Wellington harbour, and horizontal displacements of up to 18 metres have been recorded, among the largest movement measured anywhere (Wright 2014). These events changed early settler building practices. Rather than relying on the heavy stone construction they were used to in Europe, they resorted to light weight timber framed construction, more akin to indigenous Maori practices.

While there have numerous earthquakes through subsequent decades, with the exception of the 1931 Napier event, damage to major cities from earthquakes had been relatively modest, up until 2010. Most had occurred away from populated areas. While there had been several significant Canterbury earthquakes during the period mid 19th century to early 20th century, most Cantabrians did not worry too much about the earthquake hazard. Christchurch City had done very little about addressing its many vulnerable unreinforced masonry buildings. It had a passive earthquake-prone building policy, only requiring owners to strengthen when they were making significant alterations, rather than the very active policy pursued by Wellington City to strengthen such older buildings. Additionally, large areas of Christchurch were built on low lying, loose and saturated sands and silts, sediment brought down from the Southern Alps. The liquefaction hazard was well known by experts but was largely ignored. Highly vulnerable areas were consented for residential subdivisions. The liquefaction hazard was disclosed on public documentation for many residential properties but, as the risk was not generally appreciated, property values were not affected.

The Canterbury experience has provided a much greater awareness nationally of resilience. There is a realisation that it's not just a Wellington problem. A number of workshops and conferences (refer Section 4.1) have been devoted to the topic over the past five years and it has generated considerable media attention (Press 2011, Smyth 2012, Wright 2013). While the social and economic consequences have been very significant and sometimes tragic, it has presented a real opportunity to learn from the sequence; to improve processes responding to emergencies, to improve our understanding of building and land performance in rare events, and to review the structure of the building sector. By setting up the Canterbury Earthquakes Royal Commission, CERC, and instructing the Ministry of Business, Innovation & Employment, MBIE, (then the Department of Building and Housing, DBH) to investigate building specific failure in mid-2011, the New Zealand Government provided this opportunity. Indeed, it strongly signalled our responsibility to those who have experienced loss to make sure we do learn and make improvements to decision making processes and in the way we build.

Canterbury Earthquakes Royal Commission and DBH Investigation

The Canterbury Earthquakes Royal Commission provided a very valuable opportunity to review the performance of CBD buildings during the earthquakes and consider the adequacy of current legal and best-practice requirements for design, construction and maintenance of buildings. Public hearings were held during 2011 and 2012, covering seismicity, soils and the seismic design of buildings, the performance of CBD buildings, low-damage building technologies, earthquake-prone buildings, building management after earthquakes, and roles and responsibilities within the current regulatory framework. The 189 CERC recommendations, covering the spectrum from wider systemic issues to specific changes to New Zealand Standards, are now the basis for a large work programme. This is being overseen by MBIE in collaboration with all parts of the construction sector, in particular with the engineering profession.

Four central city multi-storey Christchurch buildings, CTV, PGC, Forsyth Barr and Hotel Grand Chancellor, experienced significant failure in the 22 February 2011 Christchurch earthquake. These were investigated by DBH using external consulting engineers and an expert review panel (DBH 2012). The CTV building, constructed in 1987, was the most catastrophic collapse, tragically killing 115 people, a significant number of whom were international English-language students. There were serious eccentricities in the structural system with the core being situated outside the main building footprint, and the investigation found that the non-ductile columns carrying high axial loads couldn't sustain the very high levels of shaking, causing the building to collapse in a very brittle manner. There were issues with the design, the construction and permitting. The Royal Commission found similar inadequacies (CERC Volume 6) but also emphasised the lack of capacity of the beam-column joints. The presence of non-ductile columns resulted in a review of other buildings of a similar era throughout New Zealand. Approximately 370 multi-storey buildings built between 1982 and 1992 (the era during which the New Zealand Standard NZS 3101arguably allowed this practice) were identified as possibly having non-ductile columns. Owners were advised to get a structural review undertaken to ensure this was not a critical weakness. Almost all have now complied and some remediation work has been necessary. There remains a research question – the capacity of non-ductile columns carrying high axial loads is not well understood. There are very limited tests available.

The 18-storey Forsyth Barr building suffered an internal collapse of its stairs designed in a 'scissor' arrangement, the only means of emergency egress from the building. A landing detail for the precast stair flights, used not uncommonly in other buildings at the time, provided inadequate deformation capacity. This also led to recommendations for building owners to check their stairs and significant remediation work has occurred.

Based on the experience of undertaking the four CBD building investigations and an earlier one for the failure of the Southland Stadium following a snow storm, MBIE commissioned a detailed forensic investigation guide to ensure the regulatory system learns from failure (Stannard 2014). Legislation changes are also being proposed to clarify the mandate and powers for undertaking investigations.

Collaboration

With its philosophy to "shape, collaborate, and deliver", MBIE's authorising environment has positively facilitated and enabled groups to work together. Responding to the Canterbury earthquakes highlighted the importance of collaboration. In excess of 500 engineers volunteered to assess damaged buildings and houses following the 22 February 2011 quake using green, yellow, or red placards based on the ATC20 system. Building officials from many consenting authority jurisdictions throughout New Zealand, architects, researchers, seismologists, contractors, and others were also working closely together with the civil and structural engineers, all based in the Emergency Response Centre. Another group of geotechnical engineers surveyed the stability of the Port Hills, directly above the focus of the earthquake, where some of the strong motion stations had recorded 2.2g vertical and 1.8g horizontal shaking. Deaths had occurred from cliff collapse and rock roll. Slope instability had caused significant surface cracking and many residential houses were at risk.

This cross-cutting, cross-disciplinary effort has forged closer links which remain active today. Just one example was the establishment of the Critical Buildings Group during the response. It was set up to stabilise and advise on demolition of around 40 high-rise stricken buildings in the CBD, notably the 22 storey Hotel Grand Chancellor that had a dangerous lean of some seven metres at the top. Other significant buildings were in an equally precarious state. International academics serendipitously present in the city for an earthquake workshop assisted engineers from the central regulator and other experienced practitioners. One of those visiting academics has since been recruited to become the MBIE Chair in Earthquake Engineering at Auckland University and has opened many international collaboration opportunities, of which this workshop is one.

Engineering Advisory Group – Residential Guidance. Based on relationships strengthened during the response and to assist with the recovery, a small team of experienced structural and geotechnical engineers, and remediation specialists came together shortly after the 4 September 2010 Darfield earthquake to form the MBIE (and Earthquake Commission, EQC) sponsored Engineering Advisory Group, EAG, to advise government agencies on repair and rebuild strategies.

A signal aspect of the Canterbury earthquakes was the extensive land damage. There was widespread damage to houses and services on the loose saturated sandy or silty soils of the Canterbury Plains from liquefaction and lateral spreading (Leeves 2012). Slope stability, rock roll and cliff collapse in the Port Hills also affected many other properties. This resulted in some 8,000 properties being 'red zoned', ie government purchase. The regulatory system for building work did not adequately address repair work following natural hazards or building on liquefaction-prone areas. The EAG closely advised MBIE in the production of good practice guidance on the assessment, repair and rebuild of houses damaged by the earthquakes (MBIE 2012). The guidance has been updated progressively as new requests for assistance or developments arose during the rebuild. Mechanisms such as the Canterbury Technical Forum were used to get feedback. Updates have included building on mass movement areas, repairing multi-unit properties, seismic design of retaining walls, incorporating ground improvement trial research results, new market developments or general clarifications. A key principle was to focus the scarce engineering resource to areas where it was most needed, ie the areas of highest risk. Land technical categories were established (TC1, TC2 and TC3), primarily based on observed land damage, to direct where deep geotechnical investigation was needed and where standard foundation systems could be used. Given the on-going nature of the earthquake sequence and the nervousness of insurers to have repair work subsequently damaged again, the guidance and the creation of the technical categories provided a circuit breaker to progress approximately 80% of repairs in less vulnerable areas without having to wait for specific engineering design input and deep investigation and geotechnical assessment (Leeves 2012).

This work has now created a demand from other areas within New Zealand to make sure the planning rules consistently identify the liquefaction hazard and that building foundations are built, or not built, appropriate to the ground conditions. Guidance is being prepared in collaboration with the Ministry for the Environment, the government agency responsible for land use planning. One of the objectives is to avoid future 'red zones' as a result of earthquakes in other locations.

Geotechnical Database. Another significant development from this Canterbury work was the establishment of the highly successful Canterbury Geotechnical database, given the emphasis on undertaking deep geotechnical investigations in the most vulnerable TC3 land. The database has provided a platform for geotechnical professionals to store and readily assess the data files of geotechnical investigations (bore holes, cone penetration tests, piezometers and groundwater monitoring, and other relevant data) during the rebuild. It now contains over 45,000 records, or in the order of $100 million worth of investigation information, and the data has on averaged been reused 30 times over. MBIE has now taken over the stewardship of the database in partnership with EQC and geographic constraints have been removed allowing data to be entered and accessed for anywhere in New Zealand. Once there is sufficient data entered it will enable a much greater understanding of subsurface conditions allowing building projects to be much better informed about the likely ground behaviour under seismic actions. Buildings can be more economically designed appropriate to ground conditions. The database supports the government philosophy of maximising the use of data, upload once and download multiple times. This is an extremely valuable dataset commanding international interest and is changing the way in which New Zealand geotechnical consultants operate, competing on service and data interpretation rather than holding on to data.

Seismicity, Industrial Guidance. The more devastating 22 February 2011 Christchurch earthquake brought additional demands on the Engineering Advisory Group and in addition to residential rebuild advice it also required a separate focus on commercial and industrial buildings.

An early post 22 February EAG activity was to review, with seismologists, the seismic hazard Z-factor from the New Zealand Design Actions Standard NZS1170.5, for the Canterbury region. This resulted in an immediate increase to the Z-factor of 35% (0.22 to 0.3) to account for the increased seismic activity over the intermediate term, ie next several decades. At the time there remained some uncertainty about the extent of faults that ruptured in the two events. The engineering view about the performance of buildings and the best scientific understanding at the time were reflected in the new level. Five years on considerable additional research has occurred and MBIE is commissioning a review by North American experts of the New Zealand seismic hazard model system, involving, in particular, GNS Science and University of Canterbury. The review will provide high-level direction for understanding the hazard and how it is reflected in Standards and guides and to ensure key elements are in place for practitioners undertaking probabilistic seismic hazard analysis.

Christchurch has a substantial manufacturing and distribution industry centre, much located in eastern Christchurch on land susceptible to liquefaction. There was a strong imperative to keep businesses running or enable them to quickly return to work. Repairing or rebuilding often light weight wide span industrial structures meant that expensive ground improvement or deep piled foundation systems were not generally economic. The guidance developed for MBIE by the EAG included the concept of a 'disposable' concrete floor (thick grey carpet) that could deform with liquefaction and be separated from and therefore not affect the superstructure (MBIE 2014). This idea has been developed further by the New Zealand Ministry of Education, recommending 'settlement tolerant' foundations in such locations for school buildings (MoE 2016), a concept that still meets the New Zealand performance based Building Code.

Building Management Following Emergency – Detailed Damage Evaluation. Building collapses in February highlighted the need for guidance and methodology for undertaking the detailed assessment of damaged buildings. Rapid assessments undertaken during the response were focussed on damage identification rather than actual capacity. The EAG developed the Detailed Engineering Evaluation, DEE, procedure (SESOC 2012). This has been well road tested because CERA required building owners to have a DEE undertaken progressively, on a risk priority basis. The intention is for the DEE to become the Detailed Damage Evaluation, DDE, procedure, part of a suite of documents and processes supporting 'Building Management following Emergency'. Understanding the residual capacity of buildings that have experienced plastic hinging, has been contentious from an insurance view point and the DDE procedure needs to provide guidance. MBIE has formed a research group to investigate this and is seeking international collaboration (Elwood 2016).

Meanwhile, changes to legislation are being proposed to provide the clear mandate for undertaking building assessments following emergencies. Rapid Assessment Field Guides and other guidance have been developed and extensive training of assessors is occurring, based on a three tier system: a national resource capable of leading a building post emergency operation; senior building officials and Chartered Professional Engineers leading assessment teams; and assessment team support.

Sustaining Collaboration. Collaborating during crises is easier than sustaining it during normal times. A number of strategies have been put in place to assist in continuing constructive dialogue between groups and professions for the overall good.

The EAG continues to operate, providing support, direction and quality assurance to the technical MBIE work programme. An Engineering & Design Reference Group comprising the engineering and architectural professional bodies and the technical societies has also been established to provide wider input into public policy issues within the building profession.

Memoranda of Understanding have been signed with New Zealand Earthquake Engineering (NZSEE), Geotechnical (NZGS), Structural (SESOC) and Fire (SFPE) technical societies supporting joint work programmes. Good progress is being made on producing joint MBIE–NZGS earthquake geotechnical engineering guidance, an area where there has been an underinvestment in recent years. The Overview module, an updated Liquefaction module, and a Ground Improvement Specification module have been published. Geotechnical investigations, seismic design of foundations, ground improvement, and rock protection structure modules are nearing completion. Other geotechnical guidance is planned and a training programme is being developed. MBIE is also working with SESOC and NZSEE to develop low damage design, base isolation, and seismic assessment of existing building guidance.

Earthquake-Prone Buildings. New Zealand has had legislation relating to earthquake-prone buildings since 1968. Significant changes came into effect with the Building Act 2004 to require each local council to have a policy on assessing and strengthening the most vulnerable existing buildings. The Canterbury experience exposed flaws, as passive policies in some cities resulted in a lack of strengthening activity. New legislation has now been enacted providing a nationally consistent framework to address the worse performing building stock progressively over time, targeting buildings that pose the greatest risk and providing improved public information. Striking an appropriate balance between life safety risk, cost, timeframe and built heritage has been a complex task. A number of details remain to be resolved and regulations (secondary legislation) consulted on and drafted before the Act comes into force, likely in mid-2017. One of the very big tasks for the New Zealand engineering profession has been the complete review of the Assessment Guidelines (NZSEE 2006) incorporating new research and recent experience. A key objective of the new document, supported by MBIE and EQC and involving all the technical societies, is to get greater consistency of assessments and communicate better the risks and building vulnerabilities. A geotechnical section is now included. Displacement based methods of assessment are now preferred. To avoid some of the overly conservative assessments, it encourages engineers to think more deeply about how the building as a whole performs with respect to life safety rather than just the level at which the first member failure occurs. Briefings are now occurring and feedback is being sought. Training workshops are planned for the second half of this year.

Building System

To increase the resilience of our building stock, we firstly need to better understand building performance in New Zealand's hazardous environment. To this end MBIE is strongly supporting the research effort. We then need to build using this knowledge. Even if we just built now according to what we already know we would have a far more resilient built environment. Therefore, system issues become important.

As the steward of the building regulatory system, MBIE needs to consider the role of all actors and how they interact. I have used a structural metaphor to illustrate the building control system – a statically indeterminate truss, refer Figure 1. If all the truss elements are in place with good connections between them, you have a strong system. I've used the truss because our experience has shown that failure occurs when multiple links are inadequate. Not just one. If one chord is broken the truss might sag a bit but not necessarily fail. There is redundancy in the system.

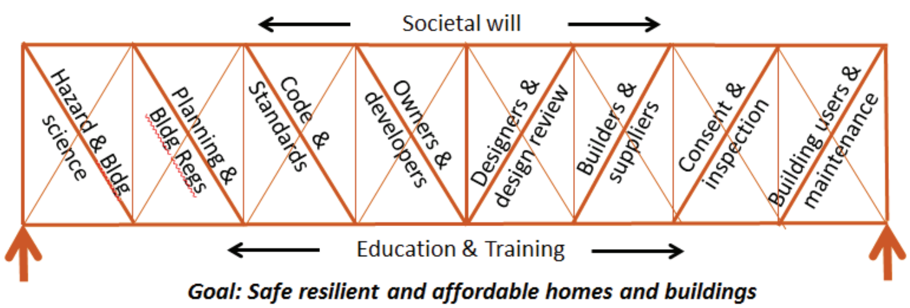

Figure 1. Integrated construction system.

Considering Figure 1 from the left, research is fundamental and important both on understanding the hazard, the demand side, and how buildings perform, the capacity side. Robust evidence-based planning and building regulations are needed to ensure that buildings are built, or not built, appropriate to the risk. These need to be underpinned with a good Code, Standards and Guidance. Owners initiate the building decision and will be key to the outcome. There is nothing better for any building project than an informed client. Competent designers with proper design review are also fundamental. Then, it's having good builders and suppliers, adequate construction monitoring and inspection, and adequate maintenance during the life of the building. To achieve the goal of safe, resilient and affordable buildings all these elements need to be in place, underpinned by education and training and overridden by societal expectations.

Societal Will for Resilience. Public demand and mandate are needed to effect change. The recent Canterbury, Tohoku, Sumatra and Chilean earthquakes with attendant cascading risks (tsunami and Fukushima melt down) have brought the resilience of our built environment to the public consciousness. At a significant two day Built Environment Leaders Forum in September 2015, MBIE, EQC and the Building Research Association of New Zealand (BRANZ) brought together public and private sector leading decision makers to reflect on the lessons from Canterbury and develop an action plan for achieving a more resilient built environment. Improving resilience raises a number of questions. What can society not tolerate? How do we prioritise resources for the extraordinary? How do we understand consequences, particularly cascading hazards? Actions identified from the forum included: creating a strong national joint public and private leadership; a community engagement programme to build understanding of risks; improving the resilience of critical infrastructure; better understanding interdependencies and community expectations for levels of service; and developing better tools and incentives to increase building resilience (MBIE 2016). How these actions are to be addressed in a coordinated manner remains a question, but strong support has been received for continuing engagement.

Research. The Royal Commission have made a number of recommendations regarding research into building behaviour. To address these, MBIE and others are helping sponsor a number of research initiatives, either directly or through other platforms such as the Natural Hazard Research Platform, QuakeCoRE, QuakeCentre and the National Science Challenges. A significant MBIE programme is the Reinforced Wall Programme being carried out by the Universities of Canterbury and Auckland. It includes research into ductile wall details, lightly reinforced walls, bidirectional response of walls, global and local buckling, diaphragm design forces and residual capacity.

New Zealand researchers and practitioners have been at the forefront of seismic engineering. However, given our resources, increasingly there is a need to collaborate internationally to gain new insights and understanding. Providing leveraging opportunities was very much the motivation for appointing Prof. Ken Elwood to a new position at the University of Auckland, the MBIE Chair in Earthquake Engineering. The establishment of the International Wall Institute led by Prof. John Wallace from UCLA, with participation from North America, Chile, Japan and Europe, and an opportunity to collaborate with the International Joint Research Laboratory of Earthquake Engineering at Tongji University, Shanghai, are examples. We are hoping that such collaborative efforts will enable larger-scale whole of building and system interaction testing. There have also been significant international joint research projects with leading earthquake geotechnical engineering academics, particularly related to liquefaction, given the Canterbury experience.

Regulation, Codes and Standards. New Zealand has a performance based building code. Code clauses provide minimum performance requirements and criteria. Supporting documents provide prescriptive acceptable solutions or verification methods as mans of compliance. New Zealand or international Standards are often referenced in the supporting documents. This is a straightforward framework, but Canterbury experience and earlier weathertightness issues question whether requirements are sufficiently clear. Using earthquake design methods cannot guarantee performance outcomes for individual buildings. Design methods included in Standards achieve what is generally considered to be acceptable for the building population as a whole. A review of the Structural Building Code clause B1 is underway to provide better public policy guidance on tolerable impacts for different levels of shaking to Standard committees when developing design procedures (Lawrance 2014). Public consultation, scheduled for early 2017, may test society's appetite for change to the performance settings and the level of resilience demanded. Meanwhile, changes to the Seismic Design Action Standard NZS 1170.5 and the Reinforced Concrete Building Standard NZS 3101 are soon to be published, based on observations and issues raised during the earthquake sequence. It is proposed to significantly increase the level of investment into the suite of building Standards to improve clarity, currency and how they work together. One strong recommendation from a recent workshop on the priority and direction for Standards was for some form of continuity for committees, rather than establishing new ones each time the Standard is renewed, currently in the order of seven to ten years.

Designer Competence and Occupational Regulation. Canterbury has raised the public profile of the engineering profession and an appreciation for 'engineering matters' (Hopkins 2012). However, building failure has also brought a scrutiny and a call for increased accountability. The Royal Commission made a number of recommendations, including the need for enhanced institutional technical capability (Brundson 2015), a review of the Code of Ethics, now completed and coming into effect on 1 July 2016, and competencies and qualifications for designers of complex buildings. MBIE, IPENZ and the technical societies are in the process of developing the 'body of knowledge' required for both structural and geotechnical engineers. IPENZ is also changing its accountability framework to provide for a more nuanced approach, with options for support, not only disciplinary procedures.

A consultation document proposing changes to the occupational regulation of engineers was released in 2014 and there was general support for the review objectives. A wider review of the other trades and professions within the building sector has identified opportunities for more consistency in governance issues and a public consultation document is likely to be released later this year to address occupational regulation, liability and a vision for the future.

Conclusions

The paper has taken a mostly high level sweep of issues from recent New Zealand experience related to the resilience of our built environment. There remain many future challenges. Better integration of planning and building regulations will be essential for improved resilience, as will be addressing critical infrastructure. Wellington infrastructure, particularly the three waters, is likely to be considerably more vulnerable than those of Christchurch. With New Zealand's 17,000 km coastline and 12 of the largest 15 cities being coastal, climate change and attendant coastal erosion from sea level rise and storm surge is a serious threat to resilience (NZ Geographic 2015). Land settlement of up to a metre in eastern Christchurch from tectonic tilt, liquefaction and ejecta removal has brought forward issues, such as managed retreat, that other coastal communities will be facing in the next 100 years. Globalisation of the supply chain raises questions of compliance and quality assurance.

However, with these future challenges in mind, there is a clear and comprehensive programme of work underway, now with good momentum under MBIE's leadership. The tragedies of Canterbury have provided opportunities to improve resilience for the benefit of communities elsewhere. It will need champions, vision, compromise and wisdom.

To quote from Leonard Cohen's Anthem:
Ring the bells for those that ring, forget your perfect offering, there is a crack, a crack in everything. That's what lets the light in.

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It has been a very intensive period since the Darfield 2010 earthquake, probably inevitable given the international scale of the Canterbury experience. I would like to acknowledge and pay tribute to:

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