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the ROYAL SOCIETY of NEW ZEALAND
TE APĀRANGI

THE DARFIELD EARTHQUAKE

The value of long-term research

Introduction

In January this year, a Magnitude 7.0 earthquake struck Haiti, leading to a calamity that killed over 200,000 people. In September, a Magnitude 7.1 earthquake struck near Christchurch, in which no-one was killed. In part, this outcome was down to luck. The timing of the Darfield earthquake (at 4.35 am on a Saturday morning) meant that masonry fell into empty streets. Despite this, it is remarkable to have a Magnitude 7 earthquake near a city without any fatalities. Modern understanding of seismic risks, the corresponding construction standards and the resulting performance of buildings in such an earthquake are not a matter of luck. In this paper, the Royal Society of New Zealand explores how seismologists and earthquake engineers have developed the critical knowledge and understanding of earthquakes, which has been implemented into the building practices that saved lives in Canterbury.

Understanding the seismic hazard

For engineers to build earthquake-resilient buildings, they need to know what level of shaking is expected. Like many natural phenomena, earthquake shaking is probabilistic, i.e., earthquakes that cause higher degrees of shaking happen less often. However, determining the probability and strength of earthquakes in the past was hampered by the lack of understanding why earthquakes occurred. The 1855 earthquake in Marlborough was one of the first ones to be used to show that earthquakes were related to faults. However, even by 1965 all that could be said was that earthquakes were more of a hazard to buildings near the Southern Alps and in the south and east of the North Island.

The 1960s saw a revolution in geology with plate tectonics becoming the theoretical basis of the field. In 1970, the Royal Society of New Zealand ran a symposium on recent crustal movements that widely publicised the idea throughout the local seismology community. The slow but measured deformations of the earth could then be understood and connected with the sudden slips at faults that produce earthquakes. In parallel with that theoretical progress, our measurements of the earth's deformations continued to improve, from traditional surveying to today's sub-centimetre resolution GPS measurements.

Today, four factors are used to assess seismic hazards: the numbers and types of faults in an area, the history of earthquakes in a region, the characterisation of those earthquakes, and how that translates into an intensity of shaking at the surface. New Zealand now has probabilistic assessments that combine these factors, at least at a regional level, into estimates of the chance of a given level of ground shaking within the lifetime of a building. We understand how crusts are moving and how faults accommodate that movement, how that builds up strain energy, how likely it is that earthquakes will release that energy, and we have a good idea of how that energy release translates to shaking at the surface.

However, as the Darfield earthquake shows, there are still surprises to be found. The most recent earthquake in Canterbury occurred on an unknown fault. The history we have of recorded earthquakes is not long, by geological timescales. While many small and deep earthquakes occur each week in New Zealand, since 1840 only seven large shallow earthquakes have occurred close to the Canterbury region.

The development of seismic design philosophies

Making buildings strong

Building regulations in New Zealand started to include earthquake resistance after the 1931 Hawke's Bay earthquake (magnitude 7.8). Significant earthquakes have often served to drive changes in building practice, with the Wairarapa earthquake in 1855 (of magnitude 8 or more) being responsible for the prevalence of wooden buildings over masonry in Wellington. The damage from the 1931 earthquake, the political will for regulation arising from that damage, and burgeoning engineering profession all combined to produce, in 1935, the Standard Model Building By-Law setting requirements for the strengths of buildings. Earthquakes were presumed to cause horizontal loads on walls and the philosophy was one of making the building strong enough to resist those simple loads. To be fair, engineers and regulators at that time had little knowledge of the outcomes that earthquakes caused, how buildings shook, or the forces that shaking created.

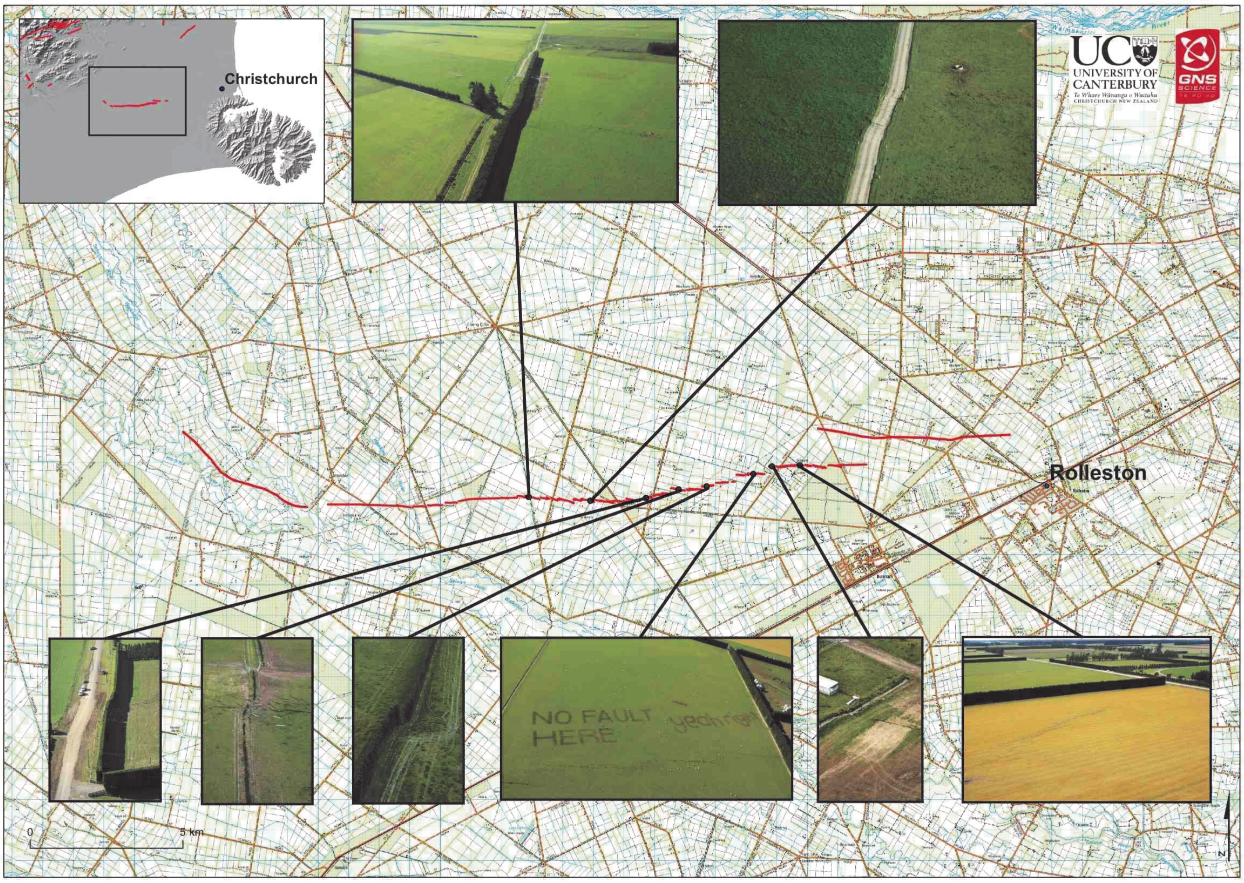

Figure 1 : Fault map of the Darfield earthquake. Courtesy of Dr Mark Quigley, University of Canterbury

In 1940 the El Centro earthquake in California was recorded by an accelerometer. These data provided much-needed information about the shaking that earthquakes cause and revealed that ground shaking could be much greater than assumed by simple loading analysis. This information, the deployment of accelerometers in New Zealand, and better mapping of active seismic faults was used by Dr Ivan Skinner and others to update the seismic loading code published in 1965. This new code introduced the idea of different risk zones, with Wellington in the highest, Christchurch in the medium risk zone, and Auckland in the lowest risk zone. The zones implied nothing about the probability of earthquakes, but did describe the expected degree of shaking for each area.

Making buildings ductile – capacity design

The growing understanding of the strength of earthquake forces showed that buildings could be built strongly enough, but only at great cost. Driven by this, the approach changed to one of ductility - absorbing energy by plastic deformation within a structure's steel frame or reinforcing. Much like crumple zones in cars, which can absorb energy in a crash, buildings were designed using plastic deformation zones.

During the 1960s and onwards, seismic design began to focus on the idea of using plastic deformation to absorb the energy of shaking. John Hollings began the developments that led to what is now called "capacity design". For large, multi-storey buildings, the columns and floors can be thought of as rigid, but joined by flexible hinges. As the columns sway from side to side, the steel reinforcement at the hinges bends but does not break, and absorbs energy while it does so.

For this approach to succeed, a great many questions had to be thoroughly researched. The Department of Engineering at University of Canterbury led efforts to understand and quantify the shaking expected for a given ground movement, both through testing on shake tables and through modelling, beginning in 1966 with Robin Shepherd's work using an "electronic digital computer". Bob Park and Tom Paulay led much of this research, including addressing the critical questions of how much plastic deformation could be survived by reinforcing bar in corner joints between columns and floors; how plastic zones could extend away from joints and into columns, floors, beams and walls; and how reinforcing bars should be tied to other reinforcing bars.

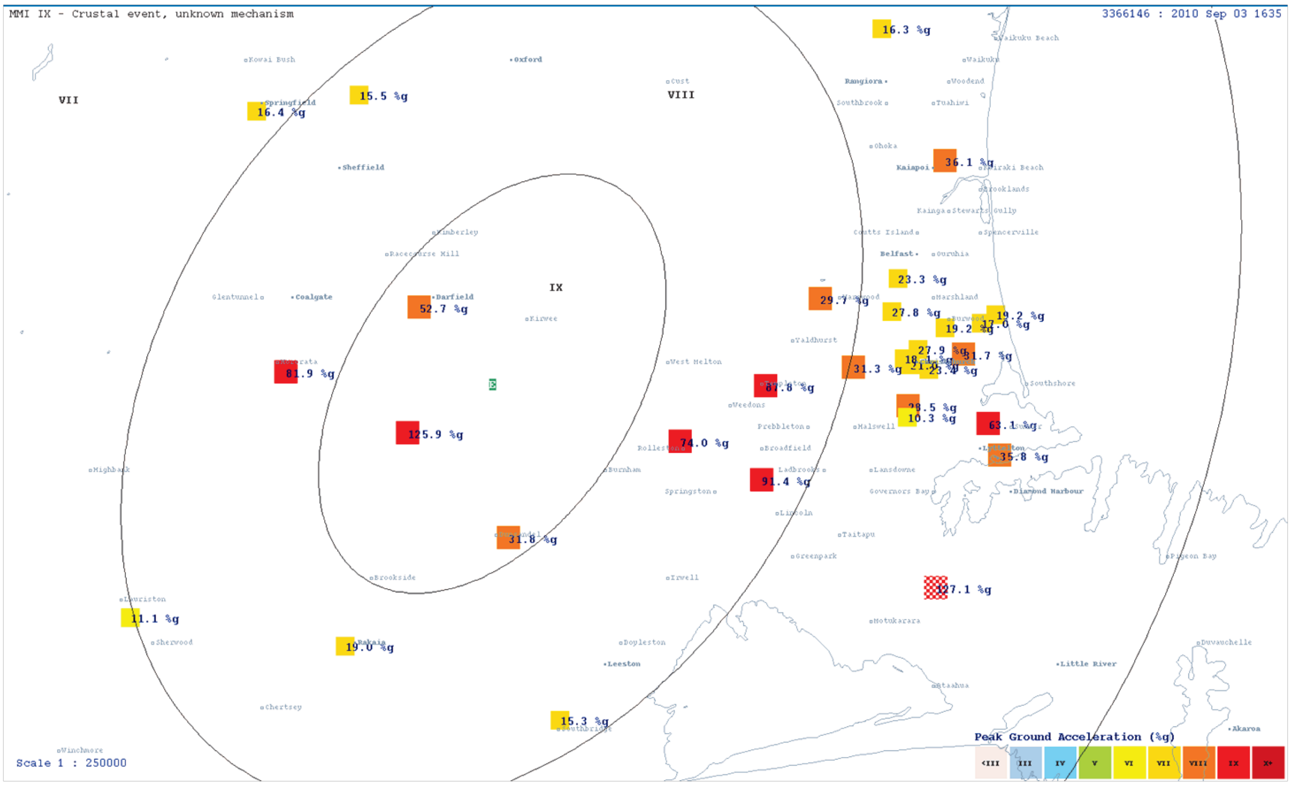

Figure 2 : Peak ground accelerations during the Darfield earthquake. We acknowledge the New Zealand GeoNet project and its sponsors EQC, GNS Science and LINZ, for providing this image.

Professor Tom Paulay, FRSNZ, FIPENZ & Professor Bob Park, FRSNZ, FIPENZ, FEng

Professors Tom Paulay and Bob Park helped build the global reputation of the University of Canterbury's Department of Civil Engineering, developing large-scale models of structures, and promoting the idea that it was not enough for buildings to be strong – they should also have the capacity to deform to absorb the shaking that earthquakes induce. The world-wide influence of their work was recognized in 2008 when Tom Paulay became the only New Zealander to be elected as a "Legend of Earthquake Engineering" by the International Association of Earthquake Engineering.

In 1975, Park & Paulay's combined research culminated in the publication of the book "Reinforced Concrete Structures", now translated into Spanish and Chinese and in regular use today across the world, and the updated building loading code in 1975 and revised Concrete Code in 1982. These standards, and the work behind them, revealed the earthquake vulnerability of numerous older buildings in New Zealand. In Wellington alone, over four hundred buildings needed strengthening or replacing, driving redevelopment across New Zealand's cities in the 1980s.

Wooden houses, brick chimneys

A similar tale can be told for wooden houses. Early earthquakes created concern, resulting in some changes of practice, but effective regulation did not develop until the basic research had been done and a thorough understanding of how houses behave in earthquakes had been developed.

The Marlborough and Wairarapa earthquakes in 1848 and 1855 (magnitude 7.8 & 8.2) showed the benefit of timber construction over unreinforced masonry. Similarly, after the magnitude 7.8 Murchison earthquake in 1929, C. Dixon of the State Forest Service published an article noting the damage that wooden houses suffer: movement between the foundations and superstructure, lack of bracing in lower walls, and falling chimneys. He made recommendations about the design and construction of wooden houses and the Hawke's Bay earthquake emphasised these, but the resulting bylaws were not published until 1944 and even then, they had significant gaps. It was not until 1978 that a code of practice was published that was backed by substantial research and sound engineering. The 1987 Edgecumbe earthquake provided a test of this code, with houses built to the code undamaged, except for movement between the foundations and superstructure, a noted omission in the code of practice. Numerous chimneys also failed in that quake, although more from poor construction than poor requirements.

Separating buildings from the ground - Lead rubber bearings and seismic isolation

In the 1970s, earthquake researchers began to consider how buildings could absorb the shaking caused by an earthquake without damage to the building itself. Rather than use steel hinges within the building to localize damage and prevent collapse, the idea grew of using separate dampers to protect the building from any damage at all. Lead was used to absorb large amounts of energy through substantial plastic deformation without being damaged itself. Unlike steel, lead's low melting point means that the material can be hot-worked at room temperature – when deformation changes the grain structure, the lead can recrystallise and retain its strength. The use of lead rubber bearings was developed by Bill Robinson and Ivan Skinner at the Physical and Engineering Laboratory of the DSIR.

These new designs were rapidly taken up by the Ministry of Works and lead rubber bearings are now responsible for protecting thousands of buildings and bridges, including Te Papa and the retro-fit to Parliament.

In Christchurch, lead rubber bearings protect the Christchurch Women's Hospital. This building is designed to function after an earthquake as a stand-alone crisis unit. It came through the September earthquake with no structural damage.

Saving money as well as saving lives – current and future research

Research over the past fifty years has focused on saving lives. We have seen the success of this in Christchurch. However, while no lives were lost, the city still suffered several billion dollars worth of damage. Research over the last decade has shifted to reducing the cost and community disruption caused by earthquakes by making buildings more resilient at lower cost and by more specific predictions of ground shaking.

We can now create structures that should keep their occupants alive through an earthquake. However, after strong shaking those buildings may require expensive repair or even demolition. The resilience of our communities is increased by designing buildings to survive shaking and then require less or easier repair, and building designs that make it easier to assess post-quake damage.

Increased understanding of how shaking is transmitted from the bedrock through local soils and to buildings allows for increasingly site-specific risk assessment. The surface effects of an earthquake, such as liquefaction, can vary on an almost street-by-street basis, depending upon local features of the soil and underlying geology. Resolving these details allows building designers to make investments in seismic resilience that are matched to the site-specific hazard rather than overbuilding for the worst seismic hazard in a particular region.

Three other trends are influencing current research. The first is to recognise the increasing reuse and refitting of buildings as our cities change away from development on greenfield sites to more urban densification. The second is the increasing use of more sustainable materials such as timber for large buildings. The third is the increasing use of pre-fabricated components and assemblies in buildings. Key to this work are the facilities such as those at the University of Canterbury, where they proudly say that "we can build anything; we can bust anything". Another key tool is New Zealand's world class network of millimetre-precision continuous GPS recorders. The first pay-off from this tool has been the discovery in New Zealand of 'slow earthquakes' that occur over weeks. What these slow earthquakes mean for earthquake and other hazards is a matter for ongoing research, but our ever-higher-resolution measurement of the earth's deformation will result in further discoveries that inform our understanding of earthquakes.

Conclusion

Improvements in the earthquake resilience of cities comes at a cost, but nothing compared to that of a damaging earthquake without such improvements. Through foresight and luck, New Zealand has been spared such a trial. Our earthquake resilience has been driven by the results of substantial research, into understanding our seismic hazards, the threat to our cities, how we can create resilient buildings and infrastructure, and how to prepare for earthquakes when they do occur. Forethought and long investment, rather than reaction, has led to Christchurch's escape from disaster.

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