

# **The 1855 Wairarapa Earthquake Symposium**

150 years of thinking about magnitude 8+ earthquakes and  
seismic hazard in New Zealand

8–10 September 2005  
Museum of New Zealand Te Papa Tongarewa

Proceedings Volume

Compiled by John Townend, Rob Langridge,  
and Andrew Jones

The papers collated in this volume have been reformatted, where necessary, from the authors' originals, but have not otherwise been edited.

The views expressed in these papers are those of the respective authors.

The 1855 Wairarapa Earthquake Symposium — Proceedings Volume  
Published by Greater Wellington Regional Council  
Greater Wellington Publication Number: GW/RINV-T-05/205  
ISBN: 0-909016-87-9  
September 2005

## PREFACE

John Townend, Organising Committee Chair  
Victoria University of Wellington, PO Box 600, Wellington  
(john.townend@vuw.ac.nz)

The 2004 Sumatra–Andaman earthquake and tsunami remind us of the brutal levels of destruction that a large earthquake can wreak. This symposium, held to commemorate the 150<sup>th</sup> anniversary of the 1855 Wairarapa earthquake, is intended to facilitate discussion between people working on different facets of the problem of understanding and anticipating earthquakes in New Zealand.

During planning for this event, the invited speakers were asked to address one or more of four key themes: *what happened then; what has happened since; what is happening now; and where should we focus future efforts?* As the abstracts in this volume attest, the significance of the 1855 Wairarapa earthquake lies not simply in the dramatic scale of its immediate geological and social effects, but in the much longer-term, ongoing influence it has exerted on research and practice in New Zealand science, engineering, and civil defence and emergency management planning.

While the scientific and engineering communities' understanding of earthquakes and their effects has developed immensely in recent decades, the growth of the wider community's exposure to those earthquakes has been even more dramatic. The diversity of institutions and disciplines represented in this extended abstracts volume underscores the importance of experts in all fields being aware of what their colleagues elsewhere know and need to know.

The organising committee gratefully acknowledges the generous support received from the following organisations, without which this event would not have been held:

- The Earthquake Commission (**Gold sponsor**);
- The Institute of Geological & Nuclear Sciences, the Wellington Emergency Management Office (Absolutely Positively Wellington), Greater Wellington Regional Council, and the Ministry of Civil Defence & Emergency Management (**Silver sponsors**);
- Victoria Link Ltd., Victoria University of Wellington, and the International Conference Fund, administered by the Royal Society of New Zealand (**Bronze sponsors**).

We particularly thank David Middleton (General Manager, Earthquake Commission) for his enthusiastic support of this symposium throughout its gestation. We also thank the Institute of Geological & Nuclear Sciences for its targeted sponsorship of student registrations, and Greater Wellington Regional Council for assistance in printing this volume and the accompanying field-trip guide.

## **ORGANISING COMMITTEE**

John Townend (Chair, Victoria University of Wellington)  
Dave Brunson (Wellington Lifelines Group)  
Ursula Cochran (Geological Society of New Zealand)  
Sophie Dalziel (Victoria Link Ltd.)  
Andrew Jones (Greater Wellington)  
Rob Langridge (Geological and Nuclear Sciences)  
Euan Smith (New Zealand Geophysical Society)

The committee thanks Suzanne Vintiner and Judith Wayers (Te Papa) for their assistance in organising this event; Penny Murray (GNS) for help in formatting the abstracts; Anita Vallely (Victoria Link Ltd.) for designing the proceedings volume and field-trip guide covers; and Absolutely Organised, particularly Chris Wong Nam and Jill Herman, for handling the registrations and finances ([www.absolutelyorganised.co.nz](http://www.absolutelyorganised.co.nz)).

## PROGRAMME

**Thursday 8 September (Soundings Theatre, Level 2)**

Topic	Speaker	Organisation	Start	Duration	
<b>Registration</b>			0800	30	
<b>Welcome</b>		<b>Cr Ian Buchanan</b>	Greater Wellington	0830	10
<b>On the 23<sup>rd</sup> of January, 1855... [What happened then?]</b>					
The 1855 January 23 M8+ Wairarapa earthquake — what contemporary accounts tell us about it	Gaye Downes	GNS	0840	40	
Co-seismic slip during the 1855 earthquake, southern Wairarapa Fault, New Zealand	Tim Little	Victoria University	0920	20	
Wairarapa Fault rupture — vertical deformation in 1855 and a history of similar events from Turakirae Head	John Begg	GNS	0940	20	
Fault slip in the 1855 Wairarapa earthquake based on new and reassessed vertical motion observations: did slip occur on the subduction interface?	John Beavan	GNS	1000	20	
Earthquakes from fault rupture: the scientific impact of the 1855 Wairarapa earthquake	Rick Sibson	University of Otago	1020	20	
		<b>Tea</b>	1040	20	
<b>Regional tectonic context [What we know about why it happened]</b>					
Active faulting in the Wellington region	Kelvin Berryman	GNS	1100	20	
The region's paleoseismic record	Russ Van Dissen	GNS	1120	20	
The southern end of the Wairarapa Fault, and surrounding structures in Cook Strait	Phil Barnes	NIWA	1140	20	
Wairarapa and Wellington earthquakes: past, present, and future	Martin Reyners	GNS	1200	20	
		<b>Lunch</b>	1220	60	
<b>Earthquake hazards [Specific hazards, now and in the future]</b>					
Strong ground shaking in the 1855 Wairarapa earthquake	David Dowrick	GNS	1320	20	
Landslides and liquefaction effects caused by the 1855 Wairarapa earthquake: then and now	Graham Hancox	GNS	1340	20	
Tsunami: curiosity or calamity?	Rob Bell	NIWA	1400	20	
Post-earthquake fire and the 1855 Wairarapa earthquake	Geoff Thomas	Victoria University	1420	20	
		<b>Tea</b>	1440	20	
<b>Assessing hazards in the future [New developments]</b>					
Earthquakes: their strategic importance in CDEM Group plans	Peter Kingsbury	MCDEM	1500	20	
Earthquake risk: how bad and how often?	Warwick Smith	GNS	1520	20	
Regional riskscape model: progress on developing a multi-hazard risk toolbox	Rob Bell	NIWA	1540	20	
<b>Discussion on hazards research: priorities for the next five years</b>					
Selected speakers as discussion catalysts			1600	40	
Session chairs to summarise the day's highlights			1640	10	
<b>Drinks</b>			1715		
<b>Te Papa Spring Lecture Series (free public event)</b>					
The 1855 Wairarapa earthquake: what if it happened tomorrow?	3 × 15 min presentations and panel discussion: Gaye Downes, Richard Sharpe (Beca), David Johnston (GNS), and Chair (Hamish Campbell)		1830	75	

## Friday 9 September (Soundings Theatre, Level 2)

Topic	Speaker	Organisation	Start	Duration
<b><i>Impact on humans and the built environment</i></b>				
<i>Humans</i>				
The 1855 earthquake: societal impact and response in Wellington	Hamish Campbell	GNS	0840	20
Individuals' response to natural hazard events	John McClure	Victoria University	0900	20
Understanding the vulnerability of organisations	Erica Dalziell	University of Canterbury	0920	20
<i>The built environment</i>				
The promise of destruction — urban design in response to past and future earthquakes	Chris McDonald	Victoria University	0940	20
The earthquake's impact on property boundaries	Graeme Blick	LINZ	1000	20
Key developments: seismic isolation	Bill Robinson	Robinson Seismic	1020	20
		<b>Tea</b>	1040	20
Issues associated with making existing buildings safe	Rob Jury	NZSEE Study Group	1100	20
Issues associated with the design and construction of new buildings	Des Bull	University of Canterbury	1120	20
As safe as houses?	Stuart Thurston	BRANZ	1140	20
Taking natural disaster events into account for transportation planning: time for a new approach	Warwick Walbran	Wellington Lifelines Group	1200	20
The role of communications in earthquakes	Brian Potter	Telecom NZ	1220	20
The vulnerability of lifelines to liquefaction: a Wairarapa perspective	George Butcher	Wairarapa Eng. Lifelines Assoc.	1240	20
		<b>Lunch</b>	1300	60
<b><i>Managing the event</i></b> [ <i>Readiness, response and recovery</i> ]				
Managing the event — a regional CDEM Group perspective	Rian van Schalkwyk	GW/Wellington CDEM Group	1400	20
National Controller's perspective	Mike O'Leary	MCDEM	1420	20
Central government's role in disaster management	Pat Helm	DPMC	1440	20
Understanding the scope of the recovery process	Sarah Norman	MCDEM	1500	20
		<b>Tea</b>	1520	20
1855, then and now — an EQC perspective on the 1855 South Wairarapa earthquake	Doug Bent Lance Dixon	EQC	1540	40
Business response and recovery after major earthquakes — what can we expect?	Karen Stephens	Resilience	1620	20
<b><i>Another today: what effects would the 1855 earthquake have now?</i></b>				
Selected speakers as discussion catalysts			1640	30
Session chairs to summarise the day's highlights			1710	10

## Saturday 10 September

Event	Presenters	Start	Meeting point
Full-day field-trip along the Wairarapa Fault focussing on fault slip during the 1855 earthquake (pre-registration required)	Tim Little, John Begg	0800	Te Papa forecourt
Waterfront walking field-trips: earthquake impacts and mitigation measures in and around Te Papa (free public event)	Hamish Campbell, Richard Sharpe	1100 1230 1400	Information Desk, Level 2
Water storage display (free public event)	Dave Brunson, John Morrison, Rian van Schalkwyk	1000	Information Desk, Level 2

## CONTENTS

<b>Preface</b> .....	<b>i</b>
<i>J. Townend</i>	
<b>Organising committee</b> .....	<b>ii</b>
<b>Programme</b> .....	<b>iii</b>
<b>Contents</b> .....	<b>v</b>
<b>The 1855 January 23 M8+ Wairarapa earthquake — what contemporary accounts tell us about it</b> .....	<b>1</b>
<i>G.L. Downes</i>	
<b>Co-seismic slip during the 1855 earthquake, southern Wairarapa Fault, New Zealand</b> .....	<b>11</b>
<i>T.A. Little and D.W. Rogers</i>	
<b>Wairarapa Fault rupture — vertical deformation in 1855 and a history of similar events from Turakirae Head</b> .....	<b>21</b>
<i>J.G. Begg and M.J. McSaveney</i>	
<b>Fault slip in the 1855 Wairarapa earthquake based on new and reassessed vertical motion observations: did slip occur on the subduction interface?</b> .....	<b>31</b>
<i>J. Beavan and D. Darby</i>	
<b>Earthquakes from fault rupture: the scientific impact of the 1855 Wairarapa earthquake</b> .....	<b>42</b>
<i>R.H. Sibson</i>	
<b>Active faulting and paleoearthquakes in the Wairarapa and Wellington regions</b> .	<b>49</b>
<i>R.M. Langridge, R.J. Van Dissen, U.A. Cochran, N.J. Litchfield, K.R. Berryman, J.G. Begg, P. Villamor, D. Heron, A. Nicol, and D. Townsend</i>	
<b>The southern end of the Wairarapa Fault, and surrounding structures in Cook Strait</b> .....	<b>66</b>
<i>P.M. Barnes</i>	
<b>Wairarapa and Wellington earthquakes: past, present, and future</b> .....	<b>72</b>
<i>M. Reyners</i>	
<b>Strong ground shaking in the 1855 Wairarapa earthquake</b> .....	<b>79</b>
<i>D.J. Dowrick</i>	
<b>Landslides and liquefaction effects caused by the 1855 Wairarapa earthquake: then and now</b> .....	<b>84</b>
<i>G.T. Hancox</i>	
<b>Tsunami: curiosity or calamity?</b> .....	<b>95</b>
<i>R.G. Bell, J.R. Goff, R.A. Walters, and G. Downes</i>	

<b>Post-earthquake fire and the 1855 Wairarapa earthquake .....</b>	<b>101</b>
<i>G.C. Thomas, W.J. Cousins, and D.W. Heron</i>	
<b>Earthquakes: their strategic importance in Civil Defence and Emergency Management Group plans .....</b>	<b>108</b>
<i>P. Kingsbury</i>	
<b>Earthquake risk: how bad and how often? .....</b>	<b>111</b>
<i>W. Smith</i>	
<b>Regional riskscape model: progress on developing a multi-hazard risk toolbox..</b>	<b>117</b>
<i>R. Bell and A. King</i>	
<b>The 1855 earthquake: societal impact and response in Wellington .....</b>	<b>119</b>
<i>R. Grapes and H. Campbell</i>	
<b>Individuals' response to natural hazard events.....</b>	<b>124</b>
<i>J.L. McClure, D.M. Johnston, and D. Paton</i>	
<b>Understanding the vulnerability of organisations.....</b>	<b>130</b>
<i>E.P. Dalziell</i>	
<b>The promise of destruction — urban design in response to past and future earthquakes.....</b>	<b>136</b>
<i>C. McDonald</i>	
<b>The earthquake's impact on property boundaries.....</b>	<b>144</b>
<i>G. Blick and A. Haanen</i>	
<b>Key developments: seismic isolation.....</b>	<b>150</b>
<i>W.H. Robinson</i>	
<b>Issues associated with making existing buildings safe .....</b>	<b>157</b>
<i>R.D. Jury</i>	
<b>Issues associated with the design and construction of new buildings.....</b>	<b>164</b>
<i>D.K. Bull and A.B. King</i>	
<b>As safe as houses? .....</b>	<b>171</b>
<i>S.J. Thurston and G.J. Beattie</i>	
<b>Taking natural disaster events into account for transportation planning: time for a new approach.....</b>	<b>179</b>
<i>W.A. Walbran and D.R. Brunsdon</i>	
<b>The role of communications in earthquakes.....</b>	<b>184</b>
<i>B. Potter</i>	
<b>The vulnerability of lifelines to liquefaction: a Wairarapa perspective.....</b>	<b>189</b>
<i>G.W. Butcher</i>	
<b>Managing the event — a regional CDEM Group perspective .....</b>	<b>200</b>
<i>R. van Schalkwyk</i>	



<b>Central government’s role in disaster management.....</b>	<b>207</b>
<i>P. Helm</i>	
<b>Understanding the scope of the recovery process .....</b>	<b>208</b>
<i>S. Norman</i>	
<b>1855, then and now — an EQC perspective of the 1855 South Wairarapa earthquake.....</b>	<b>211</b>
<i>D. Bent and L. Dixon</i>	
<b>Business response and recovery after major earthquakes — what can we expect? .....</b>	<b>220</b>
<i>K.E. Stephens</i>	
<b>Symposium Delegates .....</b>	<b>223</b>



# THE 1855 JANUARY 23 M8+ WAIRARAPA EARTHQUAKE — WHAT CONTEMPORARY ACCOUNTS TELL US ABOUT IT

G.L. Downes

Institute of Geological & Nuclear Sciences, PO Box 30368, Lower Hutt  
(g.downes@gns.cri.nz)

An earthquake must be felt to be [believed?], there is no describable or known disaster to which it bears resemblance and to the last day of my life I shall never forget the extraordinary thrill which ran through me on first experiencing it. It was not one of fear but accompanied by a sickening sensation and an idea of general instability and the insecurity of everything which we had ever before regarded as [solid?] and immovable. (Extract from Theodore Morton Jones' 1855 Journal)

## INTRODUCTION

The January 23 1855 M8+ Wairarapa earthquake occurred just after 9 pm on Wellington's Anniversary, 15 years to the day after the first immigrant ships anchored at Petone and the first European settlers stepped ashore. The earthquake left a lasting impression on the lives of the people who felt it, particularly those in the Wellington region, which bore the brunt of what we now recognise as New Zealand's largest earthquake in the last 165 years. It shattered many of their buildings and the landscape, and changed the level of the land relative to the sea. It was something to write home about, and many did. Several hundred contemporary and reliable later documents and descriptive accounts have been found (see Downes & Grapes 1999). These provide the means to build a good picture of the earthquake's effects - the damage to the built and natural environments, the casualties, the faulting, the raising of the land, the tsunami and the aftershocks.

Fortuitously for our understanding of the effects on the buildings and the landscape in the Wellington area, the relatively large European population (Wellington population ~3200; Hutt Valley population ~1600) provides a relatively large amount of the contemporary material. For example, two newspapers were published in Wellington. Other sources of information include contemporary diaries, letters and journals, newspaper reports and articles, memoranda and reports of the Wellington Provincial Government as well as later reminiscences, extracts from published scientific papers of the times, books, hydrographical charts and sketches.

Fortuitous, also, was the interest that Sir Charles Lyell, the eminent British geologist, took in the earthquake. He recognised in 1856 the importance of the earthquake to geologists, as causing the greatest deformation and fault rupture then known. Lyell's publications (Lyell 1856a, b; 1868), together with a memorandum of Edward Roberts (1855), are crucial to our understanding of the 1855 earthquake as they provide the only scientific account of the uplift and subsidence and apart from Robert's memorandum and one other passing reference, are the *only* contemporary data on the surface rupture of the Wairarapa Fault. Lyell was not in New Zealand during the earthquake. His inferences were based on information supplied to him by three New Zealand eye witnesses, Walter Mantell (son of the prominent geologist, Gideon Mantell), Edward Roberts (a Royal Engineer) and Frederick Weld (a Marlborough landowner), all of whom he met in London on several occasions in early 1856.

Through Lyell, the effects of the 1855 earthquake went far beyond our shores. It changed the way geologists thought about earthquakes and the evolution of the landscape. For Lyell, the earthquake clearly demonstrated the principle that uplift and

tilting of the landscape could be achieved incrementally rather than catastrophically, and that the past could be explained by what was happening in the present.

This paper is a brief insight of the 1855 earthquake's effects, using excerpts from contemporary accounts to highlight the effects in the Wellington, Wairarapa and Kapiti coast areas. Except where otherwise referenced, it is based on the comprehensive analysis of contemporary accounts by Grapes & Downes (1997), and on the accompanying compilation of historical material related to the earthquake in Downes & Grapes (1999).

## **THE EARTHQUAKE AND ITS EFFECTS**

### **When and where**

The first and main earthquake of January 23, 1855 occurred at 2111 WCT (Wellington Civil Time) or 0932 UT (Universal Time). Based on the extent of its felt effects and on the dislocation modelling of Darby & Beanland (1992), Grapes & Downes (1997) estimated its magnitude to be  $M_w$ 8.1-8.2. Geological evidence now suggests the magnitude could have been higher (Little & Rodgers 2004). The earthquake ruptured over 100 km of the Wairarapa Fault, the surface trace of which runs along the western side of the Wairarapa Valley. The fault is thought to extend into Cook Strait and to the plate interface beneath the Wellington Region (e.g. Darby & Beanland 1992; Beavan & Darby 2005, this volume). As accounts from Wellington, Wairarapa and Marlborough suggest an epicentre closer to Wellington than to the north-eastern part of the fault, Grapes & Downes (1997) placed the epicentre at  $41.4^\circ\text{S } 174.5^\circ\text{E} \pm 0.5^\circ$ , depth 25 km, to reflect the southwestern limit of the probable earthquake source zone. For earthquake catalogue and earthquake engineering purposes and statistical analysis of earthquake occurrence a hypocentre down-dip from the centre of the fault, or on the surface trace of the Wairarapa Fault, might be considered by some as more appropriate.

### **The felt and damage effects**

A large part of New Zealand from at least Auckland to Dunedin (Figure 1) felt the earthquake. It was probably felt in the Chathams, although there is no known account. Being close to the source of the earthquake, Wellington residents were strongly shaken:

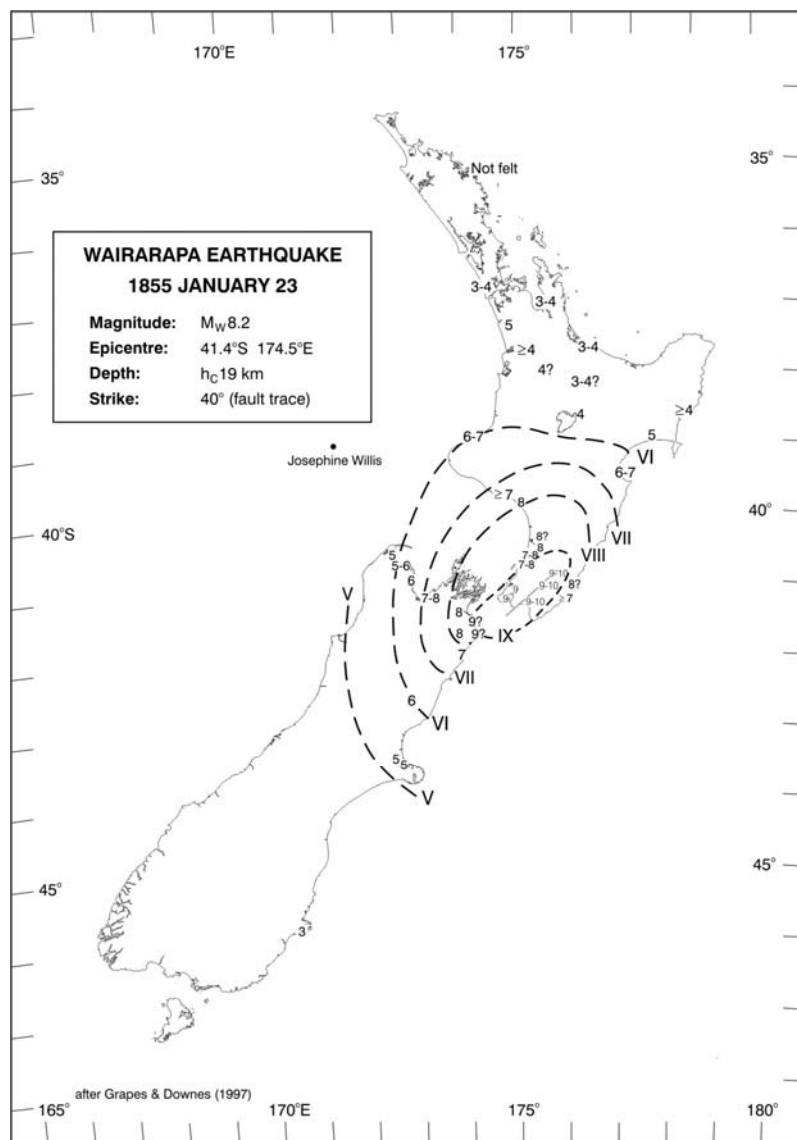
I had been seated but a short time [at the Royal Hotel in Mulgrave St], when suddenly the whole of the hotel began to move violently, as if some great force were exerted at each of its ends to pull it rapidly and horizontally backwards and forwards. The first thought that instantly occurred to me was to get out of the house and run home to see how my wife and child had fared. I jumped up from my seat in the little back parlour, and amidst the din and noise of breaking and jingling bottles and glasses, which were packed close together on the shelves of the bar, I hurried out, on to the road; I could see but little that was going on; I could hear the waves dashing on the beach, and I could feel the ground heaving and rolling, as it were under me; and when, as I bounded along and my feet were off the ground, the earth seemed to me to rise up and meet them half -way. When I had run about a hundred yards, I stopped in front of the Council Chamber, for I heard a crashing noise, and I saw it enveloped in a cloud of dust - the ground was still heaving and shaking - and as the dust partially cleared away, I distinguished through the gloom of night sufficient to convince me that this two storied building had settled down into one, and that the upper story now rested on the broken timbers and ruins of the lower one. I should think that I remained in front of it while the earthquake continued, about one minute; altogether I should say that the duration of the shake was about two minutes. (Carter 1866)

And also in Otaki:

At a quarter past nine, p.m., I was thrown out of my chair into the middle of the room, and the house began to heave fearfully. My chimney came into my room and that of the boys, not touching any one... After the chimney was down, the only danger was lest the heavy beams over our heads should fall, so we stood at the door, ready to run at the first warning. The first shock lasted in its violence

four or five minutes. It was impossible to stand without holding. The motions of the earth did not cease for half-an-hour, and from then up till now - eight o'clock [24 Jan.] - we have had at least 250 shocks, some very sharp. At one time of the night, as soon as one had ceased, we could hear the warning rumble of another. The earthquakes are still going on [written on Jan 25], and we may have another as violent any moment. I never wish to pass such another night.... (Stock 1855)

Severe damage occurred throughout the southern half of the North Island, particularly in the settlements of Wellington, Hutt Valley and Wanganui, and throughout the northern part of the South Island. A maximum intensity of MM9 was reached in Wellington and Hutt Valley, MM9, possibly MM10 in the Wairarapa Valley, MM8 in the Wanganui, Manawatu areas, and MM8-MM9 in the northern part of the Awatere Valley. There are no contemporary accounts of the effects between Masterton and Napier as this was mostly densely forested at the time.



**Figure 1.** Isoseismal map of the January 23 1855 earthquake. Approximate position of the *Josephine Willis* when the earthquake was felt. Line of 1855 rupture along the Wairarapa Fault shown in area of highest intensity.

Outside these areas, minor damage to buildings and chimneys occurred as far south as Cheviot in north Canterbury and as far north as New Plymouth ( $\geq$ MM6). Damage to household items ( $\geq$ MM5) was experienced from Christchurch to at least Napier.

Within the highest intensity (MM8-MM10) areas, many brick, cob, and stone buildings were seriously damaged, some collapsing during the earthquake and many requiring demolition after. However, there were a few brick buildings that suffered little damage. Some wooden structures were also seriously damaged and several collapsed. Most wooden buildings, however, seemed to have remained standing although many were damaged by falling chimneys. In Wellington/Hutt Valley, where reportedly the strong shaking lasted at least 50 seconds, possibly 1½ minutes, official reports variously estimate the number of seriously damaged or demolished chimneys at 80-92%. Not all chimneys were brick — some had metal flues.

Many contemporary writers express the opinion that damage in Wellington in 1855 was less than it could have been because of lessons learned in the previous earthquakes in October 1848. For example:

“the amount [of damage in Wellington] in 1855 was very much less than in 1848. This may easily be accounted for from the fact that there were not so many brick houses, and those that were are all strongly bonded with wood and iron” (Ludlam, 1855 letter in Ward 1928).

It was clear that earthquake resistant design had been considered. For example, from the diary of R. Coote (1855):

I have not mentioned that finding houses so scarce and extravagant in price, Henry sent home for one soon after we arrived, and just about this time we heard of the arrival of the ship the "Royal Stuart", in which it was, first at Canterbury and now on January 29 it reached Wellington and was pronounced to be of all kinds the most suited to stand the shock of earthquakes, wooden walls with iron posts.

Apparently, not all agreed that sufficient lessons had been learned from the 1848 earthquake:

“since the last earthquake, all kinds of flimsy prettinesses have sprung up in the architecture of the place, as though the earthquake had left assurance that it would not return” (*Australian & New Zealand Gazette* May 26 1855)

“the damage done by this one [earthquake] was occasioned by the absence of proper forethought and judgement; for if people, knowing they are in a country subject to earthquakes, will build houses of brick and other material not securely braced ... they run the risk of the accident that has befallen them” (letter signed Observer, in *Nelson Examiner & New Zealand Chronicle*, Jan 31 1855).

It is relevant to note that social, political and economic conditions of the period often influence the way historical accounts, especially in official documents, were written. This was the case in 1855 and this fact makes it difficult to extract the real story. Newspapers and public meetings in Wellington downplayed the worst effects of the earthquake and emphasised the benefits, e.g. the uplift improving the road to Petone. The reasons were closely linked with important political issues, namely the concern about the effect on immigration, especially to Wellington, and Wellington's aspiration to become the future centre of government. Fortuitously the earthquake resulted in only one death and very few injuries in Wellington, a factor that probably hastened the process of recovery and reconstruction.

## Casualties

The number of reported injuries and fatalities in the earthquake are low for the magnitude of the event. Fatalities are variously put at between five and nine, one in Wellington, 4-6 in the Wairarapa, and possibly two in the Manawatu area. In

Wellington/Hutt Valley, this can probably related to time of day when, after a holiday celebrating Anniversary Day, most people were in their predominantly wooden buildings or the local hotels, which were also mainly wooden.

### **Ground damage**

The earthquake caused ground disturbance and damage as far north as Napier and as far south as Kaikoura. Ground damage in the form of fissuring, differential settlement, lateral spreading, liquefaction, and sand boils was severe in river valleys and coastal plains in the MM8-9 areas, particularly in the settlements of Wanganui, Hutt Valley, Manawatu and the Wairarapa. Willray's account in the *New Zealand Spectator and Cook's Strait Guardian*, February 3 1855, is one of the most descriptive of the ground damage in the Hutt Valley:

Left Wellington on Wednesday at 10 o'clock, the morning after the shock; found several landslips on the Petoni Road; only one of any size, and, that at present but a slight obstacle to the communication into the Hutt, a road now being rapidly pushed round its base; swing bridge over the river gone, broken, and ground burst up at each abutment, lower end fallen into the water, the whole aslant up stream: visible effects of the shock on the roads and country in general; presented stronger manifestations on entering the valley: as a rule, chimneys are down along whole line; mills reported as damaged, houses damaged internally rather than externally: road, for seven miles, that is, up to three miles the other side Buck's Hotel [at Taita], considerably injured; many of the smaller bridges gone at the lower gorges [Taita Gorge?]; several considerable landslips occur, impassable for carts; from this point, for thirteen miles, as far as Hodder's [Kaitoke] the roads are all right, but three miles beyond, on the ascent up the Rimutaka gorges, for upwards of seven miles, the landslips and crevices are both numerous, dangerous, and almost impassable, even on foot. Barricades of the largest trees, stumps, and rocks, valances of earth, underwood, decayed trees, and boulders, bar your progress, and conceal your line of road, while loose logs and stones hang in threatening positions far above your head, so that a steady hand and cool head are necessary to carry you safely over the precipices that sweep down below you to the bottom of the valley: no sort of conveyance can pass; all horses are left at Hodder's Hotel, on this side the gorges, and you proceed on foot to Burling's [Featherston], at the entrance of the valley: all parties should avoid the Blue Rock, and diverge to the left down the stream.

Landslides occurred throughout the southern North Island and northern South Island, but were most severe about Wellington and the Wairarapa. The landslides in the southern part of the Rimutaka Range were particularly severe:

The high mountains behind Wainuiomata were split [as viewed from Wellington], the fronts falling, all the trees and bush being covered up, leaving an almost perpendicular face in places and very ugly scarred and rugged faces. The writer remembers how ugly and desolate they looked 44 years ago. Since then time has partially covered their nakedness with growths but some of the scars still remain. (McDowell 1910-11)

The Rimutaka range was very much shaken in its elevation and a great many large slips occurred, laying bare the western side as well as on the eastern. (Roberts 1855)

Detailed maps of the extent of ground damage as well as a contemporary painting of the landslide along the Hutt Road can be found in Hancox (2005, this volume).

### **Fault rupture**

The principal contemporary accounts of rupture are those found in Sir Charles Lyell's published and personal papers (Lyell 1856a, b; 1868). They record the appearance of the Wairarapa fault in a cliff at Palliser Bay and along the western side of the Wairarapa Valley. Lyell's informant and eyewitness, Edward Roberts, a Royal Engineer, "observed a very distinct fault line; on one side of the line, the rocks had been raised vertically to a height of 9 feet [2.7 m]; on the other side there had been no movement of

any sort", and recorded that in the Wairarapa Valley, the boundary between old argillaceous and "Tertiary " rocks seen at Palliser Bay (i.e. the fault) are:

marked inland by a continuous north-south escarpment along the Rimutaka Mountains. The eastern side is escarped and looks down on the Wairarapa Plain formed of tertiary deposits. According to a witness, Mr Borlase [Borlase] who lives in the Wairarapa Valley about 60 miles (97km) north of Cook Strait, the course of the fault direction produced by the upheaval was rendered visible by the formation of an almost vertical wall. This contains the mark of the recent rupture of 9 feet [2.7m] and can be followed for the amazing distance of 90 miles (145km). Moreover, the fault is marked in many places by an open fissure into which cattle fell, and sometimes from which no-one could pull them out. At other places there are fissures, from six to nine feet (1.8 to 2.7m) wide, that are filled with mud and top soil" (Lyell 1856b).

The 145 km estimate of fault rupture in this extract above is somewhat high, but given the era and the presumed difficulty in measuring distance, it is not unreasonable.

Although several settlers clambered over the Rimutaka Hill and across the fault near Featherston after the earthquake, only one remarked on the sudden 1.8 m height change in the track. Horizontal movement along the fault does not seem to have been noticed, but there were few places where man-made features crossed the fault.

### **Uplift and Subsidence**

After the tsunami had subsided, the uplift of the land was very obvious to the settlers in the Wellington Region. The elevation of Lambton Quay and the road to the Hutt Valley by about 1.4 m meant that these areas were no longer washed by the sea in bad



Figure 2. Post-earthquake (1860) photograph of Lambton Quay. Typical wooden houses are shown together with the fill (earthquake debris?) behind the uncompleted sea wall that was presumably abandoned after uplift made it unnecessary to protect the shops from waves. The cutting shown in the central part of the photo is the location of the present cable car. (Ref. No. B3926-½, Alexander Turnbull Library, NLNZ).

weather or high tides, and reclamation was made easier. Further, the coastal route to the Wairarapa, frequently used to take stock to the Wairarapa and Hawke's Bay, was



improved by the raising of the coast, in particular the Muka Muka rocks, notorious for preventing safe passage except at low tide and in fine weather. The maximum uplift recognised at the time was 9 ft or 2.7 m at and to the west of the fault. Geological evidence (Begg & McSaveney 2005, this volume) now indicates the maximum uplift was 6.4 m.

The best known and most reliable contemporary evidence for uplift of the Wellington peninsula west of the Wairarapa Fault, as well as subsidence of the Wairau coast, is that reported by Edward Roberts of the Royal Engineers (Roberts 1855), who at the time of the earthquake was surveying the coastal route to the Wairarapa. Because of his profession as a surveyor, Roberts was able to accurately measure the uplift by the stranding of shellfish and coralline growths relative to the new tidal levels. According to Roberts (1855):

This range [Rimutaka Range], which appears to have been in the direct line of the subterranean action, was elevated nine feet, while the whole country as far as Wai-nui, about two miles northward of the foot of the road leading down the Pari-pari [near Paekakariki], was elevated with it, though the elevation at the last named point was on the sea coast very slight. On the Eastern side of the range is the valley of the Wairarapa, the centre of which is occupied by a lake. This valley and plain remain on the same level as before, the range of hills having gone up alone, forming a perpendicular precipice of nine feet in height which has been traced to a distance of ninety miles inland.

The valley of the Wai-rau, on the middle island ... together with parts of the adjoining coast, subsided, during the shock, about five feet; so that now the tide flows eight miles further into the Wai-rau river than it formerly did.

The harbour of Port Nicholson, together with the valley of the Hutt, is elevated from four to five feet, the greater elevation being on the eastern side of the harbour, and the lesser on the western.

A rock, known as the "Ballet Rock," a short distance from one of the points of Evans's Bay, which was formerly two feet under water at the lowest tides, and over which was placed a buoy to mark its position, is now nearly three feet above the surface at low water.

The subsidence at the Wairau was possibly a combination of tectonic subsidence and settlement of the lands near the river due to strong shaking.

Lyell (1856a) records that Roberts also made measurements of the uplift at other locations, and monitored whether the uplift decreased in the three months he remained in Wellington after the earthquake.

### **The tsunami and seiching**

The 1855 earthquake generated a tsunami with a maximum known run-up<sup>1</sup> of 10 m at Te Kopi in eastern Palliser Bay and up to 4–5 m in several locations in Wellington and along the northern Marlborough coast. The Rongotai isthmus and Miramar was reportedly covered in water to about a metre deep, rushing in many times from Lyall Bay and from Evans Bay (“the tidal wave flowed over the low ground for a considerable distance and left lots of fish dead on the racecourse [in northern Miramar]” (Jolliffe 1855)). In Lambton Quay, the tsunami was no more than 2–2.5 m, washing into shops that fronted onto what was then the beach:

“The first thing we noticed [the morning after the earthquake] was the extreme lowness of the tide; the sand extended far beyond its usual limits, and then all at once it was covered again by the sea, this

---

<sup>1</sup> TSUNAMI RUN-UP (m), a measure much used in tsunami-hazard assessment, is the vertical height the waves reach above the instantaneous sea level at the time of impact at the farthest inland limit of inundation. This measure has a drawback in that its relationship with the amplitude of the waves at the shore depends markedly on the characteristics of waves and on the local slopes, vegetation, and buildings on the beach and foreshore areas, so it is highly site-specific.

advancing and receding of the tide took place three times in twenty minutes, and eventually left the harbour raised about three feet. The Beach [Lambton Quay] where all the shops are situated was a miserable picture, few houses uninjured whilst many were perfect wrecks, and the contents of many of the shops were floating about on the water or thrown up on the shore. (Coote 1855)

The tsunami waves swept around Wellington Harbour and in Cook Strait for more than 12 hours after the earthquake, being observed as far south as the Kekerengu and at least as far north as Otaki, where the run-up was probably about 2-3 metres. It is estimated that at least 300-500 km of coastline was affected with run-ups of 1 m or more, the first waves arriving within a few minutes of the earthquake in Cook Strait, and within an hour at Otaki. While submarine landslides and coastal may have contributed to the tsunami, the raising and lowering of the sea bed in Cook Strait were probably the main cause of the tsunami. Disturbance of the tides in the week after the main earthquakes suggests small tsunami, some possibly caused by large aftershocks, some possibly by submarine landslides.

The earthquake also caused seismic seiching (sloshing caused by the passage of seismic waves) in many rivers, lakes and harbours from the Waipa River (Waikato District) in the north to possibly Port Chalmers and Dunedin in the south.

### **The aftershocks**

Aftershocks of the January 23 event were numerous and protracted over several months. At least five aftershocks had magnitudes greater than 6.5, but probably less than 7.0. Hundreds with magnitudes 5.0 - 6.4 occurred and accounted for the frequent smaller shocks and vibrations felt over several weeks as far afield as Christchurch, Motueka, Wanganui, New Plymouth and Napier. Many hundreds, and probably thousands of aftershocks of magnitude 4 and above are indicated by the constant tremor and small shocks experienced at Wellington, Wanganui and Otaki (see transcription earlier in this paper). For example:

[In Wellington, after the main shock] The earth continued to vibrate all night like the panting of a tired horse, with occasional shocks of some violence, decreasing in frequency and violence towards morning, and nearly all in the NE SW direction, some of them a single jerk back and forwards like that of one railway carriage touching another, but generally they were followed by a vibration gradually decreasing. These lasted with increasing intervals, until I left Wellington on the 11th of April. For the first week after the first shock, the vibration never wholly ceased. (Mallet 1858)

A report from Kekerengu on the Kaikoura coast suggests that at least one aftershock was more severely felt there than the main shock. This event could have been local and initiated close to Kekerengu, outside the main rupture zone of the seaward extension of the Wairarapa Fault. The number of aftershocks and their magnitude range are consistent with the assumed mainshock magnitude.

## **CONCLUSIONS**

The contemporary accounts provide a remarkably good picture of the effects of the New Zealand's largest historical earthquake. They provide an insight into what might happen in future large earthquakes in Wellington, but they only tell part of the story. The rest of story can only be uncovered by geological, geomorphological, seismological, and earthquake engineering research. With that research come the answers to many questions that will enable the Wellington region to better understand the risk of future earthquakes and better withstand and recover from its effects.

In some ways, people in the Wellington region are fortunate – they have had a very large and damaging earthquake in the relatively recent past – just a few generations ago - so it is not so difficult for them to recognise that earthquakes are an inevitable part of living here and that they must be prepared for them.

## ACKNOWLEDGEMENTS

Much of this paper is based on research by R Grapes and G Downes, which was largely funded by an Earthquake Commission (EQC) Research Grant and the Foundation for Research, Science and Technology.

## REFERENCES

- Beavan, J, Darby, D 2005. Fault slip in the 1855 Wairarapa earthquake based on new and reassessed vertical motion observations: did slip occur on the subduction interface? This volume.
- Begg, JG, McSaveney, MJ 2005. Wairarapa Fault Rupture — vertical deformation in 1855 and a history of similar events from Turakirae Head. This volume
- Carter, CR 1866. *Life and recollections of a New Zealand colonist*. R Madley, London.
- Coote, RC 1855. Extracts from Diary 1853-67. MS-Papers-1248-2A, Alexander Turnbull, Library, NLNZ
- Darby, JD, Beanland, S 1992. Possible source models for the 1855 Wairarapa Earthquake, New Zealand. *Journal of Geophysical Research* 89: 12375-12389.
- Downes, G, Grapes, R 1999. The 1855 Wairarapa, New Zealand, earthquake – historical data. Institute of Geological & Nuclear Sciences science report 99/16, 267p.
- Grapes R, Downes, G 1997. The 1855 Wairarapa, New Zealand, earthquake - Analysis of historical data. *Bulletin of the New Zealand National Society for Earthquake Engineering* 30: 271-368.
- Hancox, GT 2005. Landslides and liquefaction effects caused by the 1855 Wairarapa earthquake: then and now. This volume
- Jolliffe, J 1855. The diary of John Jolliffe, R. N., written during the voyage to New Zealand 1851-56 [as Staff Surgeon on board H.M.S. *Pandora*]. *New Zealand Journals 1851-1856*. Micro-MS-130. Reel 1, Alexander Turnbull Library, NLNZ.
- Jones TM 1855. *Journal*, 2 June 1851-5 April 1856. Vol. 1. Original is in the Mitchell Library, Sydney, Australia. Copy Micro-MS-0220, Alexander Turnbull Library, NLNZ.
- Little, TA, Rodgers DW 2004. 1855 Wairarapa Fault earthquake: world record strike-slip displacement now even bigger, *In: Manville, V. & Tilyard, D. (eds.) Programme and Abstracts, Geol. Soc. N. Z. Misc. Publ., 117A, 64-65.*

- Lyell, C 1856a. Correspondence from Sir Charles Lyell to his sister, Sophia Lyell, and to Walter Mantell, April-May 1856. Originals: Kinnordy House, Scotland.
- Lyell, C 1856b. Notebooks of Sir Charles Lyell. Notebook 213. Originals: Kinnordy House, Scotland.
- Lyell, C 1868. *Principles of Geology* Vol.2, 10th ed. John Murray, London, England.
- Mallet, R 1858. On the facts and theory of earthquake phenomena [including a letter by W.C. Bennett, “The New Zealand earthquake – Wellington, 23<sup>rd</sup> January 1855”]. *British Association for the Advancement of Science Report 1858*: 105-106
- McDowell, J ca.1910-11. Letter to the Editor *In: Evening Post?* Family scrapbook of Alistair Stuart of Gladstone, Wairarapa Archives, Masterton, New Zealand.
- Roberts, E 1855. Appendix F. *In: Taylor, R. 1855. Te Ika a Maui or New Zealand and its inhabitants.* Wertheim & Macintosh, London, England.
- Stock, A 1855. Extract from letter of the Rev. A. Stock. *In: Church Missionary Gleaner, 1855.* London. Seeley, Jackson, and Halliday, London, England. Fildes Collection, Victoria University of Wellington, Wellington, New Zealand.
- Ward, L. E. 1975. Early Wellington. Reprinted by: Capper Press, Christchurch, New Zealand

# CO-SEISMIC SLIP DURING THE 1855 EARTHQUAKE, SOUTHERN WAIRARAPA FAULT, NEW ZEALAND

T.A. Little<sup>1</sup> and D.W. Rogers<sup>2</sup>

<sup>1</sup>Victoria University of Wellington, Wellington, NZ

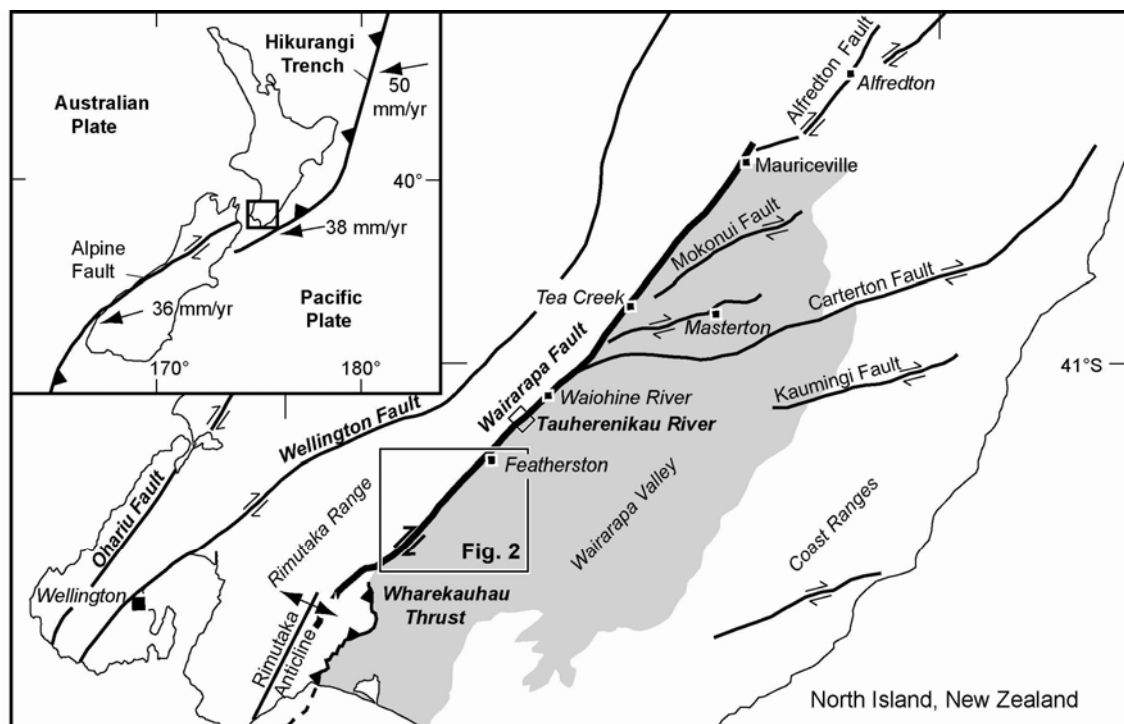
<sup>2</sup>Idaho State University, Pocatello, ID 83209, USA

(tim.little@vuw.ac.nz)

## INTRODUCTION

We traversed on foot and mapped a ~10 km section of the historic rupture to the south of the town of Featherston using ~1:3,000 scale colour aerial photographs as a base. Modern Global Positioning System (GPS) and laser-ranging techniques were used to construct microtopographic maps at 6 sites containing the best preserved smallest-offset landforms along this part of the 1855 rupture trace, as well as of three displaced channels at Tauherenikau River. Three other offset measurements were made with tape at newly discovered sites in areas of thick bush cover. These data yielded eleven measurements of fault offset at sites previously described by Grapes and Wellman (1988) as well as seven new measurements. Finally, <sup>14</sup>C dating of four sediment samples at two localities was undertaken to test the hypothesis that the measured displacements accumulated during a single earthquake in 1855. While the case that a specified offset seen in the landscape today was the product of a single slip in 1855, rather than compound displacement, is almost always ambiguous, we argue that the internal consistency of the data set as a whole supports the conclusion that co-seismic strike-slip during 1855 was of a very large magnitude, typically 13-17 m (mean  $15.5 \pm 1.6$  m), and at two other sites as high as 17.5-18.7 m. These data imply that the 1855 earthquake accommodated the largest co-seismic strike-slip offset so far recognized globally. Our best estimate for last-event throw based on one site is  $2.5 \pm 0.5$  m (up-to-the NW). The next-largest dextral offsets that we observed suggest that slip during the penultimate earthquake was 13.3-14.4 (mean 13.9; n = 3). We will also consider the implications of this oblique-slip earthquake's large co-seismic displacement (D) and displacement/length (D/L) ratio in terms of its likely down-dip extent and the relationship of its rupture plane to the Hikurangi subduction interface, and for the earthquake's moment magnitude ( $M_w$  8.2-8.4).

Dipping steeply to the northwest, the dextral-reverse Wairarapa Fault cuts across the eastern foothills of the Rimutaka Range, forming a topographic step between the range and the alluvial plain of the Wairarapa Valley to the east (Fig. 1). Its surface deformation zone in some cases consists of a single scarp, but in others an up to 250 m width containing multiple fault traces. One estimate of the late Quaternary slip rate is based on  $125 \pm 5$  m of cumulative dextral-slip and  $20 \pm 2$  m vertical slip of abandoned river channels on the Waiohine terrace at Waiohine River (Lensen & Vella, 1971; Grapes and Wellman, 1988). Recent Optically Stimulated Luminescence (OSL) dating of silt overlying post Last-Glacial gravel of the Waiohine terrace on the upthrown part of the fault at Waiohine River have yielded ages of  $10.2 \pm 1.2$  and  $13.0 \pm 0.9$  ka (mean ~11.6 ka). These imply a late Quaternary dextral-slip rate of  $11.5 \pm 0.5$  mm/yr, and a vertical slip rate of  $1.7 \pm 0.2$  mm/yr at this site (Wang, 2001).



**Figure 1.** Tectonic index map of southern North Island, New Zealand (adapted in part from Begg and Johnston, 2000), showing Wairarapa Fault and our study areas to the north and south of Featherston. Inset shows location of Fig. 1 and plate motions (from DeMets et al, 1990, 1994).

## 1855 AND PRE-1855 RUPTURES ON THE WAIRARAPA FAULT

Four radiocarbon ages from a paleoseismic trench excavated at Tea Creek Road (Fig. 1) have been used to infer a mean recurrence of ~1500-1600 yrs for the last 5 surface rupturing events on the Wairarapa Fault (Van Dissen and Berryman, 1996). The only other paleoseismic data for the Wairarapa Fault are the ages of the four uplifted beach ridges at Turakirae Head, the youngest of which was uplifted in 1855 (Hull and McSaveney, 1996). The Holocene ages of these ridges imply a mean recurrence for earthquakes on the Wairarapa Fault of ~1900 yrs (Hull and McSaveney, 1996). The paleoseismic chronology at Tea Creek differs from the ages of uplifted beach ridges at Cape Turakirae; for example, the former suggests that the penultimate earthquake on the Wairarapa Fault took place at 1400-1530 cal yrs BP, whereas the latter suggests that it took place ~2250 cal yrs BP. Taken together, however, both data sets indicate a long (1.5–2 kyr) recurrence of earthquakes on the Wairarapa Fault. More specifically, they record an absence of surface rupturing on the Wairarapa Fault during the 1250-2150 years that preceded 1855.

Historic accounts indicate that the 1855 earthquake ruptured the Wairarapa Fault, causing intense shaking, landsliding, and surface faulting (Grapes and Downes, 1997). Scarps attributed by Grapes (1999) to the 1855 rupture are preserved in the landscape from Palliser Bay to Mauriceville, ~88 km farther to the north. More recent work suggests that slip in 1855 may also have ruptured a northward continuation of the Wairarapa Fault, the Alfredton fault, as scarps along that fault were rejuvenated sometime after 250 - 330 years BP, an observation that implies that the 1855 rupture may have extended as much as 30 km north of Mauriceville (Schermer et al., 1999).

These data suggest that the onshore part of the 1855 rupture could have been ~120 km long (e.g., Dowrick and Rhoades, 2004).

The onshore Wairarapa Fault is flanked to the west by an active anticline in the Rimutaka Range to the west. Near the southern end of the onshore Wairarapa Fault, the fold is cut by an active thrust, the Wharekauhau Thrust (Grapes and Wellman, 1993; Begg and Johnston, 2000). This thrust system transfers strike-slip on the Wairarapa Fault southward across a ~5-km wide left-stepover into the offshore region. About 5 km to the NE of Cape Turakirae, at the crest of the anticline, a beach ridge was uplifted ~6.4 m relative to sea level in 1855, the maximum vertical-slip (relative to sea level) attributed to 1855 (Hull and McSaveney, 1996). Along the exposed part of the fault trace to the NE, Grapes (1999) inferred 1855 vertical-slip (relative to the footwall) of ~2.7 m near the Palliser Bay coast, decreasing northward to as little as ~0.5 m near Mauriceville. South of the coast, the 1855 rupture is inferred to have extended offshore into Palliser Bay, the probable location of its epicenter (Darby and Beanland, 1992; Grapes and Downes, 1997). Seismic reflection data have imaged a ~35-40 km-long offshore extension of the Wairarapa Fault, a structure which appears to terminate southwestward into Cook Strait (Barnes and Audru, 1999). These observations can be used to infer a maximum surface rupture length in 1855 of 145 -160 km, but beyond this there is little “room” in which to place a longer rupture.

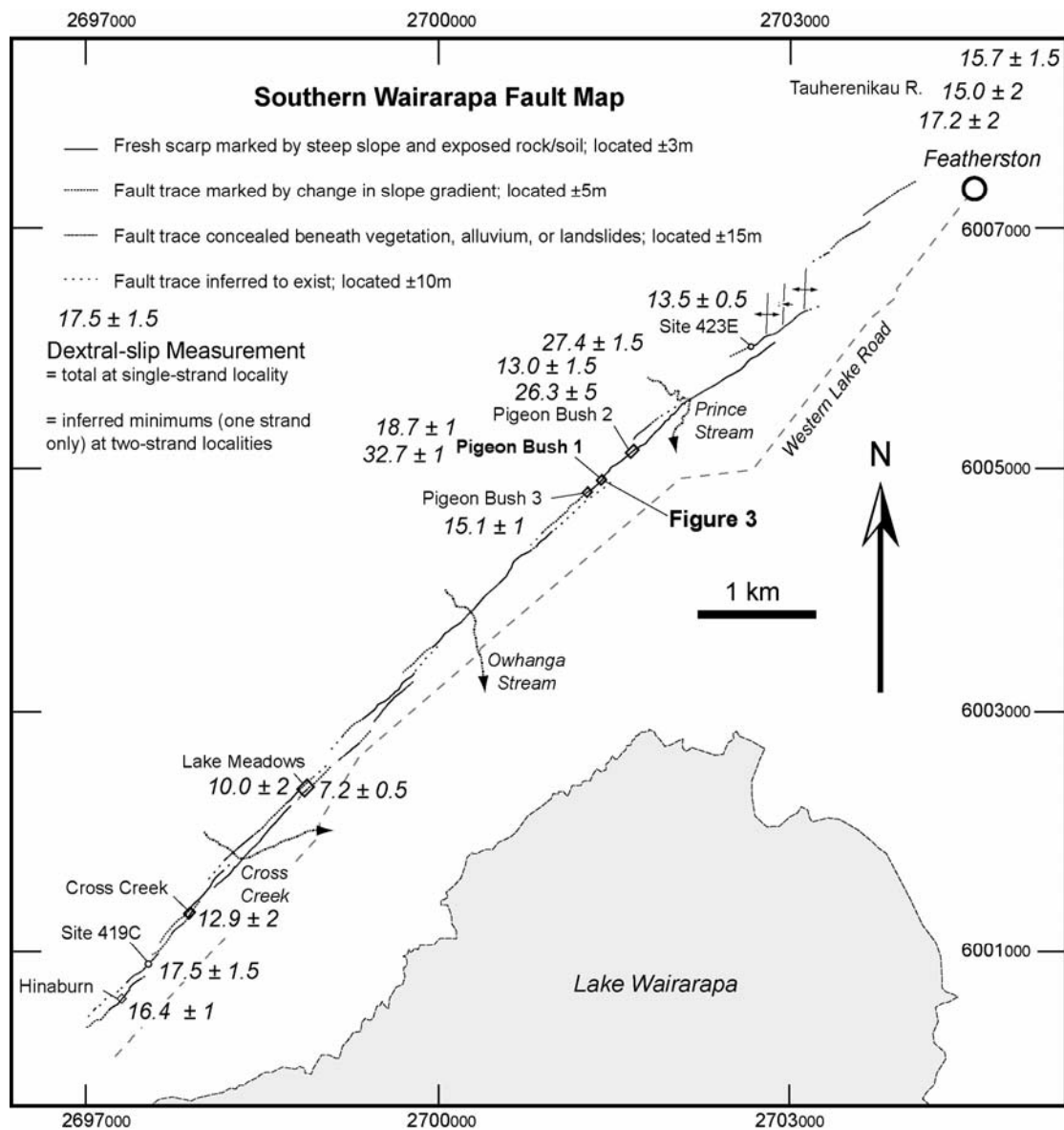
## **PATTERN AND MORPHOLOGY OF ACTIVE FAULT SCARPS**

Although within a few decades of 1855 the land was largely deforested and converted to grazing land, many of the fault scarps in the Featherston-Lake Wairarapa region are still remarkably fresh looking, and are inferred by us (and Grapes and Wellman, 1988) to be of 1855 age. The most prominent scarps of the Wairarapa Fault zone border its eastern edge, where they typically displace late Quaternary alluvium of the Waiohine terrace by 5-20 m in an up-to-the-NW sense. Most of these scarps are linear, ~1-3 km-long, and discontinuous. The fifteen individual strands that we mapped are 1200±700 m long and define a left-stepping, *en echelon* pattern. The overlapping parts of the stepovers are typically 400-600 m long (range of 100-1000 m) and 20-200 m wide. These stopovers are compressional, and coincide with uplifted horst blocks or active anticlines warping the alluvial terrace surfaces. Right-stepping (dilatational) stepovers are relatively uncommon. Both situations cause rapid along-strike variations in slip and locally complicate the interpretation of 1855 slip.

## **MEASURING SMALLEST DISPLACEMENTS ALONG THE 1855 RUPTURE TRACE**

We measured 18 fault smallest (and next-smallest) offsets at 9 sites along the fault where small, southeast-flowing streams have been dextrally displaced across the fault. Of these, 11 had been identified by Grapes and Wellman (1988), and 7 are newly recognized. Using a combination of GPS data and 3D laser-ranging, detailed microtopographical surveys were made at 7 sites in order to quantify 15 of the 18 fault-offset observations. These surveying methods, and the techniques by which the elevation data were contoured and analysed to calculate fault displacements in 3-D are explained in Rodgers and Little (in review). At three sites, trees and bushes were too dense for surveying, so a dextral offset was measured using a tape stretched out along the fault scarp. Four samples were submitted for radiocarbon dating, two in the

youngest beheaded channel at Pigeon Bush 1 (see below) and two in an abandoned channel at Tauherenikau River. For this abstract, we present survey data at one site only (Pigeon Bush 1, Fig 2).



**Figure 2:** Neotectonic fault trace map of a southern part of the Wairarapa Fault, based on field traverses and interpretation of low-level aerial photographs (taken by Lloyd Homer, IGNS). Labelled localities are sites where slip measurements were undertaken as a part of this study. Graticules refer to NZ Coordinate Grid system as shown in LINZ (1:50,000) topographic map series. Quoted dextral-slip values are total offset at single strand localities, and inferred minimums (one strand only) at two-strand localities, except at Lake Meadows, where smallest slip on both of two closely spaced strands are shown.

### THE PIGEON BUSH OFFSET SITE

At Pigeon Bush Grapes and Wellman (1988) interpreted two beheaded streams as evidence of dextral offset of a small stream gully traversing Wairarapa Fault during two sequential earthquake events, most recently in 1855. The fault is marked by a SE-facing scarp exposing gravels of the Waiohine terrace. On the uplifted (NW) side of the fault, these gravels have been backtilted to the southwest by  $\sim 5^\circ$  on the limb of an anticlinal



bulge that crests farther to the NE. Over time, this tilting has diverted the stream's headwaters southward, where they have been in part pirated by another stream. Thus, the gorge on the up-thrown side of the scarp now seems disproportionately deep with respect to the small, low-discharge stream that currently flows within it. On the downthrown side, the terrace gravels are overlain by a scarp-derived colluvial apron for which Wang (2001) obtained OSL ages of  $4.3 \pm 0.5$  ka and  $7.0 \pm 0.5$  ka.

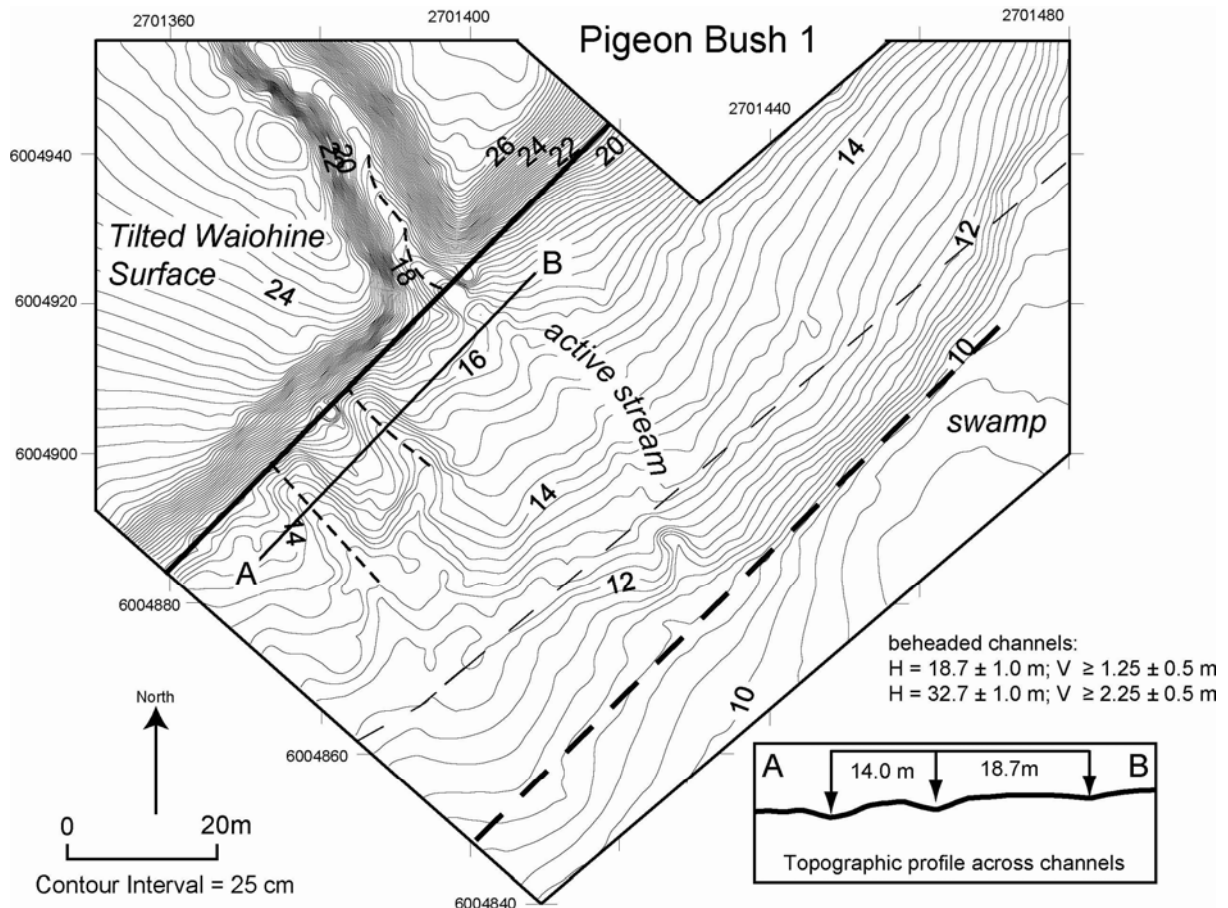
The proximal beheaded channel has been displaced  $18.7 \pm 1.0$  m dextrally and  $\geq 1.25 \pm 0.5$  m vertically relative to the deeply entrenched active channel on the upstream side of the fault. The other channel is displaced  $32.7 \pm 1.0$  m dextrally and  $\geq 2.25 \pm 0.5$  m vertically from its source. The larger offset of the more distal channel suggests that it had previously been displaced by  $14.0 \pm 1.0$  m of dextral-slip and  $\sim 1.0$  m vertical-slip prior to incision of the more proximal channel. Our vertical-slip estimates do not account any post-slip incision of the uplifted upstream channel and are considered to be minimums. If the  $18.7 \pm 1.0$  m shift of the proximal channel occurred in one event, it would be the largest single-site measurement of co-seismic slip so far measured on a strike-slip fault globally (the next largest, at 16.3 m, was measured along the 2001 Ms 8.1 rupture of the Kunlun fault in China, Lin et al, 2002). The geomorphology of the beheaded streams at Pigeon Bush supports a single-event origin for slip of the proximal channel, rather than as a composite displacement involving one or more intermediate stages. Both of the beheaded channels on the downstream side of the fault remain linear all the way up to the fault, where they are abruptly and orthogonally truncated against the scarp. We could not find any evidence for a channel running along the fault scarp between the modern stream and either of the beheaded channels that might reflect an intermediate phase of stream dog-legging induced by shutter ridge damming.

A 1.8 m-deep pit was dug in the center of the proximal beheaded channel to investigate the channel's alluvial infill. Two pieces of charcoal in alluvium at depths of 15 cm and 154 cm yielded calibrated ages of AD 1364  $\pm 63$  and AD 1355  $\pm 60$  ( $2\sigma$ ), suggesting that the channel was infilled rapidly, perhaps as a consequence of a burning and deforestation in its headwaters. We infer that the stream was not only active  $\sim 500$  years before the 1855 earthquake, but that it was also capable of moving and depositing gravel. Thus, large offset and beheading of this small stream must have taken place sometime after this. Because the geomorphology implies that the channel was displaced as the result of a single event, and because the data at Tea Creek Road (Van Dissen and Berryman, 1996) and at Cape Turakirae (Hull and McSaveney, 1996) do not identify a surface rupturing event on the Wairarapa Fault between 1855 and AD 420-550, we infer that the  $18.7 \pm 1.0$  m offset at Pigeon Bush took place in 1855.

## **SUMMARY OF RESULTS**

The amount of dextral-slip that we measured at a given site was affected by several factors: first, the age of the landform and how many slip events it had experienced; and second, the multiplicity of scarp development at that site and how co-seismic slip has been partitioned between adjacent strands, and also the tectonic bulges, during successive earthquakes. At six of our offset localities, the Wairarapa Fault consists of one strand. The three smallest of these offsets ranged between 13.0 and 18.7 m (mean of  $16.4 \pm 1.5$  m). The other three offsets are distinctly larger,  $>26$  m (see below). In addition to being the largest, the  $18.7 \pm 1.0$  m offset at Pigeon Bush is also the most compelling of the inferred single-event displacements. At all the other sites where one or more smallest offsets were measured, the fault zone consists of multiple, overlapping

strand. At one of these, Tauherenikau River, three different abandoned channels are dextrally displaced across an especially steep and fresh-looking scarp. These offsets range from 15.0 - 17.2 m with an average  $16.0 \pm 1.5$  m.  $^{14}\text{C}$  dating of bog material that has accumulated on down-thrown side of one of these channels has yielded near-modern ages (indistinguishable from AD 1855). At four other 2-strand localities, smallest dextral offsets on the freshest (or best exposed) scarp ranged from 12.9 - 16.4 m, with a mean of  $14.5 \pm 1.3$ . Measured on only one strand, we have interpreted these to be minimum estimates of total dextral-slip during the last-event, as they exclude any slip that may have been accommodated on the other strand. At Lake Meadows, the sum of smallest-slip on two closely spaced strands is  $17.2 \pm 2.1$ . Combining all 10 of the above single-strand and minimum two-strand slip-estimates (excluding Lake Meadows) yields an average of  $15.5 \pm 1.6$  m. A “smallest” throw measurement (minimum value) at a single-strand site (Pigeon Bush 2) was  $\geq 2.0 \pm 0.5$  (minimum value). At Hinaburn, we measured an inferred last-event throw of  $2.5 \pm 0.5$  m (up-to-the-NW), which we interpret to be our best estimate of the cumulative throw on this southern part of the fault in 1855. These data imply an H:V slip ratio of 6-10. In the transpressional stopovers between overlapping strands, throw is variable in both magnitude (0.5-4.3 m) and sense of relative uplift (either up-to-the-SE or up-to-the-NW).



**Figure 3.** Microtopographic map of the Pigeon Bush 1 site, showing beheaded channels displaced by slip on the Wairarapa Fault. See Fig. 2 for location. Contour interval is 25 cm. Map is based on a survey data set consisting of >10,000 points. Graticules are NZ Coordinate Grid System (metres).

Our revised estimates of the smallest increment of slip recorded in the landscape are larger than previously reported. Grapes (1999) reported a dextral-slip range of 9-13 m and a mean of  $11.6 \pm 1$  m for 23 smallest offsets attributed to slip in 1855. For the 6 offset features that we measured in common with Grapes and Wellman (1988), they obtained a mean smallest dextral displacement of 11.9 m, whereas we obtained a mean of  $16.2 \pm 1.5$  m, an increase of 36%. We thus infer that previous estimates of the magnitude of slip during 1855 on the Wairarapa Fault were too small.

In addition to sites associated with a “smallest” offset, we studied three sites where the morphology of offset landforms and the large magnitude of offset provided compelling evidence of a “next-smallest” offset on the Wairarapa Fault. These sites have cumulative dextral offsets that range from 26.3-32.7 m (mean of 28.8 m). Two of these larger displacements occur within a few meters of “smallest” offsets, and the third is only 20 m from the single-offset. These imply incremental slip estimates of 13.3-14.4 m (mean of 13.9 m) for the previous dextral offset. At ~14 m, this is similar to the smallest displacements that we measured, implying the occurrence of repeated, very large earthquake slip events on the Wairarapa Fault. Repeated very large earthquakes on the fault, similar in magnitude to the 1855 event, have also been inferred from the pattern of uplifted beach terraces at Turakirae Head, where there is a correlation between uplift magnitude and elapsed time since previous uplift (Hull and McSaveney, 1996). Whereas Grapes (1999) suggested a characteristic slip of about 12 m during each of the past 10 events, our data suggests that at least the last two slip increments were both somewhat larger than this.

### **ARGUMENT FOR A VERY LARGE CO-SEISMIC SLIP DURING 1855**

We believe that the internal consistency of data set supports a conclusion that strike-slip during the 1855 earthquake along the southern part of the Wairarapa Fault was typically between ~13-17 m (mean 15-16 m), and at some sites (at least two) locally ~17.5 - 18.5 m. In the absence of contemporary observations of slip or high-precision dating at every site, inferring single-event slip magnitude from a data set of “smallest” offsets will always be an uncertain exercise. On a case-by-case basis, one can generally supply an argument for multiple-event slip to explain a specific offset in the landscape. Notwithstanding this ambiguity, there are several lines of evidence to support a very large dextral-slip (mean ~15.5 m) on the southern part of Wairarapa Fault in 1855. These include: 1) the historically documented coincidence of the 1855 earthquake rupture with the study area; 2) the consistently steep expression of the surveyed scarps and excellent preservation of the small-relief features offset across them; 3) the relative unambiguity of the smallest dextral offsets that were measured at the 3 single-strand localities (mean 16.4 m.). Of these, Pigeon Bush 1 is the least ambiguous, yet it yielded the largest single-event slip; 4) the similar magnitude of smallest slip (mean  $15.5 \pm 1.6$  m;  $n = 7$ ) measured on the most active-looking (or well-exposed) strand at sites where the fault zone included two closely-spaced scarps. These one-strand offsets probably underestimate the total slip during 1855, yet their mean is within error of that determined at the single-strand sites; 5) our  $^{14}\text{C}$  dating, although limited to 4 samples, support an 1855 age for two offsets; and 6) the similarly large magnitude of slip (~14 m) inferred for the penultimate earthquake at the three sites where that incremental displacement could be measured by subtracting the “smallest” slip from a displacement of 26.3-32.7 m. Thus, 1855 was not an anomalous, “one-off” event.

## HIGH D/L RATIO OF THE 1855 RUPTURE AND REVISED MOMENT MAGNITUDE ESTIMATE

Prior to this study, estimates of the slip and rupture length of the 1855 earthquake suggested a displacement (D) to surface rupture length (L) ratio, D/L that was anomalously large with respect to regressions of global earthquake data sets (e.g., Wells and Coppersmith, 1994). Our enlarged measurements of 1855 slip require this D/L ratio to have been even larger. We believe that the high D/L ratio in 1855 simply reflects the very large down-dip extent of the rupture. For an equal stress-drop, ruptures with a low aspect ratio of length (L) to width or depth (W) (i.e., with  $L < 10W$ ; Regime 2 of Scholz, 1997, 2002) follow a different scaling law between displacement (D) and length (L) than do those with a much larger, typical ratio (i.e.,  $L \gg 10W$ ). Viewed in this context, the D/L ratio of the 1855 earthquake is no longer anomalous, but is exemplary of such low-aspect ruptures. As is consistent with this inference, Darby and Beanland's (1992) elastic dislocation modeling of the 1855 event yielded a best-fit rupture that included a 50 km extent of the subduction interface to the west of its intersection with the Wairarapa fault. Their solution implies an 1855 rupture width, W, of 30-80 km, and a corresponding L/W ratio of only 0.2 - 0.5. Recent GPS studies of the contemporary velocity field in the upper plate of the Hikurangi subduction thrust at the southern end of the North Island reveal a pattern of interseismic strain accumulation that is consistent with a locked subduction interface extending westward beyond its intersection with that west-dipping Wairarapa Fault at ~25 km depth (Darby and Beavan, 2001). The gently west-dipping locked part of the interface extends  $29 \pm 1$  km depth for a 100% coupled model, and  $>40$  km depth for a variably coupled model. Coulomb stress calculations indicate that the Wairarapa fault is currently being loaded at seismogenic depths by the accumulation of strain related to the locked subduction interface (Darby and Beavan, 2001). By inference, the obverse may have taken place in 1855; i.e., co-seismic slip on the Wairarapa fault elastically unloaded an adjacent, failed part of the subduction interface to the west. The most tangible expression of this at the surface may simply be the high D/L ratio of the 1855 earthquake slip.

A final implication of our study is that the seismic moment of the 1855 earthquake may have been larger than previously estimated: 1) because of our upward revision of its mean displacement ( $\sim 15 \pm 2$  m), and 2) because the large D/L ratio suggests that W and thus the rupture area, A, may have been larger than previously estimated. Using the revised slip estimate; a rupture length (L) of 145 - 160 km; a width (W) 40 - 60 km; and a shear modulus of  $3.0 \times 10^{10}$  N/m<sup>2</sup>, implies an 1855  $M_w$  of 8.2 - 8.4.

## REFERENCES

- Barnes, P. M., and Audru, J.-C., 1999, Quaternary faulting in the offshore Flaxbourne and Wairarapa Basins, southern Cook Strait, New Zealand: *New Zealand Journal of Geology and Geophysics*, v. 42, p. 349-367.
- Begg, J. G., and Johnston, M. R., 2000, *Geology of the Wellington area, New Zealand*: Institute of Geological and Nuclear Sciences, Ltd., Lower Hutt; Geological Map 10 (Scale 1:250,000).
- Darby, D. J., and Beanland, S., 1992, Possible source models for the 1855 Wairarapa Earthquake, *New Zealand: Journal of Geophysical Research*, v. 97(B9), p. 12375-12389.

- Darby, D. J., and Beavan, J., 2001, Evidence from GPS measurements for contemporary interplate coupling on the Southern Hikurangi subduction thrust and for partitioning of strain into the upper plate: *Journal of Geophysical Research*, v. 106(B12), p. 30881-30891.
- DeMets, C., Gordon, R. G., Argus, D. F., and Stein, S., 1990, Current plate motions: *Geophysical Journal International*, v. 101, p. 425-478.
- DeMets, C., Gordon, R. G., Argus, D. F., and Stein, S., 1994, Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions: *Geophysical Research Letters*, v. 21, p. 2191-2194.
- Dowrick, D. J., and Rhoades, D. A., 2004, relations between earthquake magnitude and fault rupture dimensions: How regionally variable are they?: *Bulletin of the Seismological Society of America*, v. 94, p. 766-788.
- Grapes, R. H., 1999, Geomorphology of faulting: the Wairarapa Fault, New Zealand: *Zeitschrift für Geomorphologie*, v. 115, p. 191-217.
- Grapes, R. H., and Downes, G., 1997, The 1855 Wairarapa, New Zealand, Earthquake- analysis of historical data: *Bulletin of the New Zealand National Society of Earthquake Engineering*, v. 30, p. 271-369.
- Grapes, R. H., and Wellman, H. W., 1988, The Wairarapa Fault: Victoria University of Wellington Geology Board of Studies, v. 4, p. 54.
- Grapes, R., and Wellman, H. W., 1993, Wharekauhau Thrust (Palliser Bay) and Wairarapa Fault (Pigeon Bush) [Field-trip Guide]: *Geological Society of New Zealand Miscellaneous Publication*, v. 79B, p. 27-44.
- Hull, A.G., and McSaveney 1996, A 7000-year record of Great Earthquakes at Turakirae Head, Wellington, New Zealand. GNS Client Report 33493B.10. Prepared for EQC
- Lensen, G. J., and Vella, P., 1971, The Waiohine River faulted terrace sequence: *Bulletin Royal Society of New Zealand*, v. 9, p. 117-119.
- Lin, A., Fu, B., Guo, J., Zeng, Q., Deng, G., He, W., and Zhao, Y., 2002, Co-seismic strike-slip and rupture length produced by the 2001 Ms 8.1 Central Kunlun earthquake: *Science*, v. 296, p. 2015-2017.
- Rodgers, D. W., Little, T. A., in review, Very large co-seismic slip associated with 1855 rupture of the Wairarapa Fault, New Zealand (submitted to *Journal of Geophysical Research*).
- Schermer, E. E., and Van Dissen, R., 1999, In Search of the Source of the 1934 Pahiatua Earthquake: EQC Research Report, v. 97/320.
- Scholz, C. H., 1997, Size distributions for small and large earthquakes: *Bulletin of the Seismological Society of America*, v. 87, p. 1074-1077.
- Scholz, C. H., 2002, *The Mechanics of Earthquakes and Faulting*: Cambridge, Cambridge University Press, second edition, 471 p.

- Van Dissen, R. J., and Berryman, K. R., 1996, Surface rupture earthquakes over the last ~100 years in the Wellington region, New Zealand, and implications for ground shaking hazard: *Journal of Geophysical Research*, v. 101, p. 5999-6019.
- Wang, N., 2001, *Optically Stimulated Luminescence Dating Techniques and their Application to Dating the Loess in Southern North Island* [M. Sc. thesis]: Victoria University of Wellington, 131 p.
- Wells, D. L., and Coppersmith, K. J., 1994, Empirical relationships among magnitude, rupture length, rupture area, and surface displacement: *Bulletin of the Seismological Society of America*, v. 84, p. 974-1002.

# **WAIRARAPA FAULT RUPTURE — VERTICAL DEFORMATION IN 1855 AND A HISTORY OF SIMILAR EVENTS FROM TURAKIRAE HEAD**

J.G. Begg and M.J. McSaveney

Institute of Geological & Nuclear Sciences, PO Box 30-368, Lower Hutt  
(j.begg@gns.cri.nz)

## **INTRODUCTION**

While many people were living in the Wellington region at the time of the 1855 Wairarapa Earthquake, there are relatively few first hand accounts written at the time. A number of reports published at a later date are based on memory and have only general, or at best little, accurate information. This paper summarises 150 years' observations on vertical deformation associated with the 1855 Wairarapa Earthquake.

A key figure in unravelling the vertical deformation associated with the earthquake is Edward Roberts, a surveyor with the Royal Engineers at the time. Roberts was on the Turakirae coast at Mukamuka (Fig. 1) at the time, surveying a stock track to the Wairarapa. Following the earthquake, he made detailed observations in the area, then travelled widely in the Wellington and Marlborough regions, noting its effects. His written observations (Roberts 1855) and verbal description reported by Lyell (1856, 1868) are clear and precise and provide a vital record of observations made at the time.

Of the many observations made by subsequent workers, those with accurate data relevant to vertical deformation in 1855 are relatively few. While these observations post-date the earthquake, mostly by many years, some provide insight into its effect. Absolute control on uplift associated with the 1855 earthquake is rare as survey marks were minimal and there were few benchmarks. The best datum for assessing uplift therefore, is sea-level. New conclusions on the nature of the 1855 earthquake have been derived from examining its effects at and near Turakirae Head.

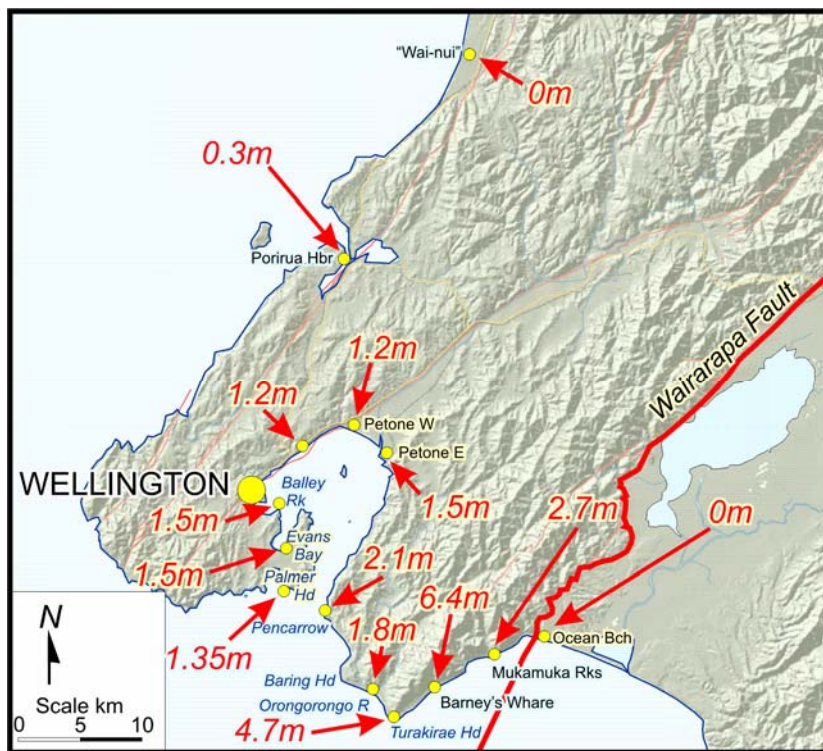
## **OBSERVATIONS ON VERTICAL DEFORMATION MADE AT THE TIME**

Roberts' key observations of vertical deformation in the Wellington and Marlborough regions (with an additional one by Crawford, 1855) are shown in Table 1 (see also Fig. 1). They are based largely on the relative elevations of sea-level before and after the earthquake and, given Roberts' profession, are here considered reliable.

While the record of subsidence in the lower Wairau Valley is accepted as reliable, it is not further considered in this paper because its amplitude and spatial separation from the bulk of the observations in the southern North Island seem anomalous. Data from offshore (see Barnes, this volume; Beavan, this volume) may contribute to an explanation.

**Table 1:** Reliable uplift values and their sources recorded immediately following the 1855 earthquake. Refer to Fig. 1 for location of these data points.

Location	Observed uplift	Source
Wairarapa (Ocean Beach?)	0 m	Lyell (1856)
Mukamuka Rocks	2.7 m	Roberts (1855); Lyell (1868)
Pencarrow	2.1 m	Lyell (1856); Adkin (unpub)
Petone E	1.5 m	Roberts (1855); Lyell (1868)
Petone W	1.2 m	Roberts (1855); Lyell (1868)
NW harbour	1.2 m	Roberts (1855)
Balley Rock	1.5 m	Roberts (1855); Lyell (1868)
Evans Bay	1.5 m	Crawford (1855)
“Wai-nui” (Raumati)	?0+ m	Lyell (1856)
Porirua Harbour	est. 0.3 m	Lyell (1856)
Wairau Valley	-1.5 m	Roberts (1855); Lyell (1868)



**Figure 1:** Locations and values of reliable historical uplift (see Table 1) and those subsequently derived for the 1855 Wairarapa Earthquake. Note that the record of subsidence for the Wairau Valley (Grapes & Downes 1997) is not shown.

## IMPORTANT OBSERVATIONS ON VERTICAL DEFORMATION MADE SINCE

The most significant subsequent observations on vertical deformation associated with the 1855 earthquake, are the recognition and study of raised beach ridges at Turakirae Head (e.g. McKay 1901; Aston 1912; Adkin unpublished; Wellman 1967; Moore 1987; Hull and McSaveney 1996), and at Palmer Head (Bell 1910; Cotton 1918; Adkin unpublished; Huber 1994).



Bathymetry, rock platform elevation, and elevations of beach ridges and zonal boundaries of attached intertidal organisms potentially provide uplift values. We consider that relative elevations of rock platforms provide unreliable values for uplift because we do not believe they can be cut in the hard and heterogeneous rock at Turakirae Head in the time interval between major earthquakes, and less likely still that they may have equilibrated since 1855.

We believe that elevations of beach ridges provide the best and most easily estimated values for uplift. The elevation of a beach ridge varies due to many factors, including relative coastal exposure, aspect and sediment supply. Where adequate sediment is available, they build rapidly to their maximum elevation during periods (usually storms) of extreme wave action, then prograde seawards through time at that same elevation (McSaveney et al. submitted). This characteristic means that after a relatively short period of time, the elevational difference in the beach ridge crest before and after a large uplift earthquake approximates the uplift value. Where subsidence happens, the pre-existing beach ridge is rapidly destroyed and re-distributed to a new position further landward.

Wellman (1967) identified the axis of a growing anticline, the Rimutaka Anticline, just east of Turakirae Head near Barney's Whare, on the basis of his profiles of raised beach ridges. While Hull and McSaveney (1996) corrected confusion in the age of the beach ridges at Turakirae Head by identifying BR2 as the beach ridge raised in the 1855 earthquake, their more precise surveying confirmed the location of the Rimutaka Anticline. The maximum uplift of 6.4 m associated with the 1855 earthquake is located at Barney's Whare. Barney's Whare is just 6.8 km southwest of Mukamuka Rocks where Roberts measured uplift of only 2.7 m. From there, uplift reduced rapidly northeastwards to the east of the rupture at Ocean Beach (Roberts 1855). Uplift reduces from 4.7 m at Turakirae Head to just 1.8 m at the Orongorongo River mouth, just 2.5 km to northwest (Hull and McSaveney 1996).

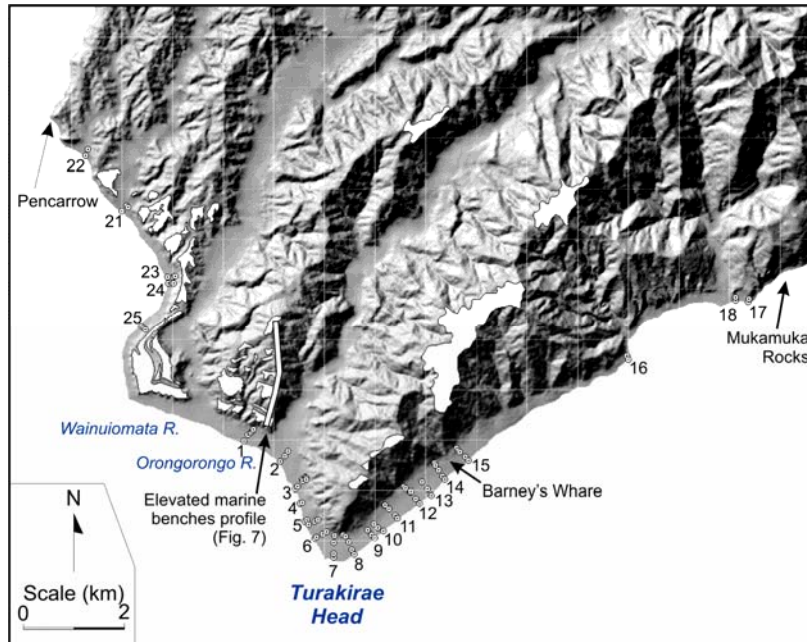
## **SPATIAL DISTRIBUTION OF VERTICAL DEFORMATION IN 1855**

Figure 3 presents uplift contours for the 1855 Wairarapa Earthquake based on the observed values discussed above. A feature of this map is the relatively limited extent of the area of extreme uplift, and its NE–SW elongation along the axis of the Rimutaka Anticline, though the latter is not well constrained.

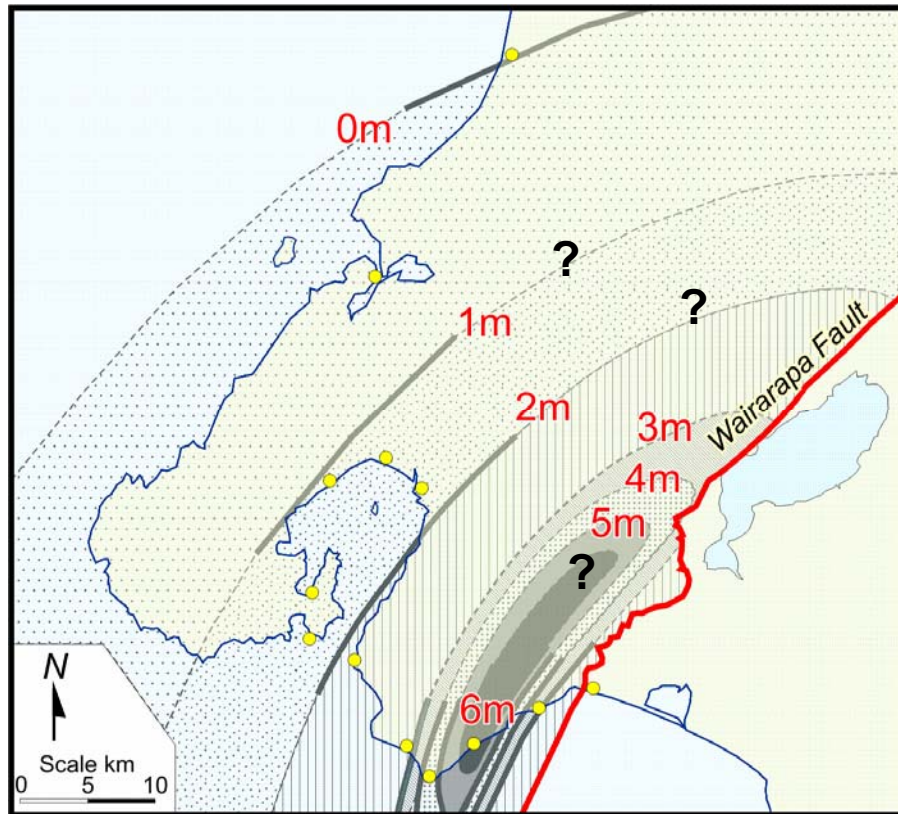
## **EARLIER HOLOCENE UPLIFT EVENTS AT TURAKIRAE HEAD**

Profiling the 1855 uplift at Turakirae Head provided an opportunity to gather information on older Holocene beach ridges as well. Hull and McSaveney (1996) surveyed a series of profiles across the Holocene marine bench between Pencarrow and Mukamuka Rocks (Figs. 3, 4, 5 and 6). These provide a unique definition of local Holocene uplift history using the sea-level datum. They reveal a succession of four raised beach ridges elevated progressively above their modern analogue (Fig. 4). The lowest beach ridge is the presently active one (BR1), and the lowest of the raised ones represents the stranded 1855 ridge. The older three ridges in the sequence provide information on three uplift (earthquake) events older than 1855.

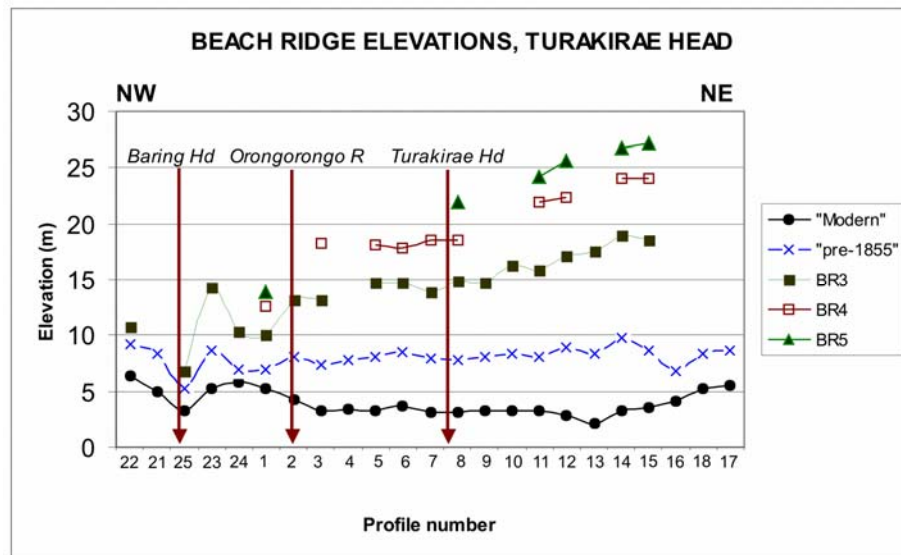
Approximate cumulative uplift curves for each beach ridge have been calculated by subtracting the elevation of the modern beach ridge from each profile (Fig. 5). These illustrate the progressive growth of the Rimutaka Anticline through the Holocene (Fig. 5). This relationship strongly suggests that each earthquake in the series was associated with an event similar in style to that of 1855. The location of maximum uplift is close to Barney's Whare.



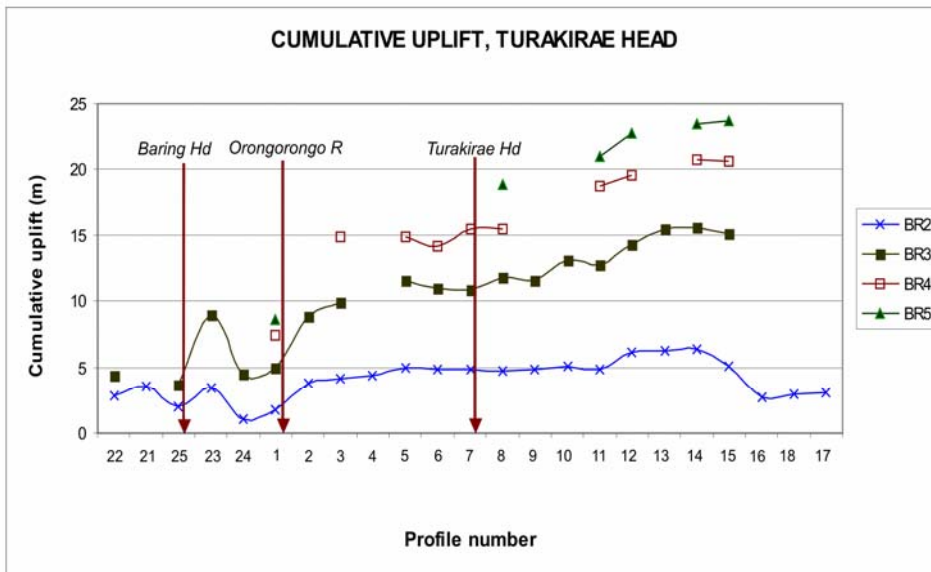
**Figure 2:** Location of beach ridge survey points between Pencarrow and Mukamuka Rocks (McSaveney & Hull 1996). Elevated surfaces are marked (see Long-term uplift), and the heavy line marks the profile illustrated in Figure 7. The white grid is the 1 km NZ metric grid.



**Figure 3:** Map depicting smoothed one metre uplift contours associated with the 1855 Wairarapa Earthquake for the Wellington region. Heavy, solid black lines mark places where the contours are well constrained, and question marks areas of uncertainty. Small spots mark the location of information regarded as reliable (Table 1).

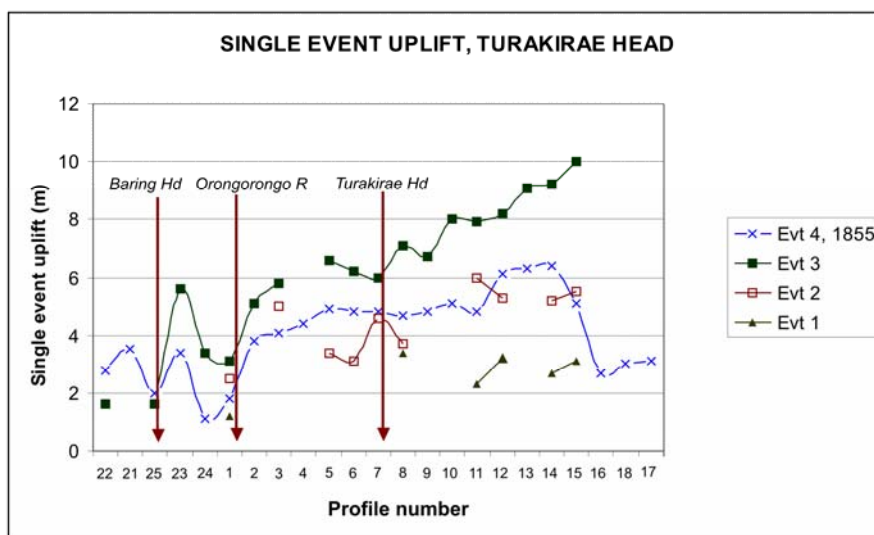


**Figure 4:** Plot showing beach ridge elevations (m above mean sea-level) along the coast between Pencarrow (Profile 22) and Mukamuka Rocks (Profile 17). Note that the X axis merely lists profile numbers in a west-east series with no distance connotation. The locations of Baring Head, Orongorongo River mouth and Turakirae Head are marked for reference. Lines connect correlative ridges on adjacent profiles, but are absent where no beach ridge is measurable.



**Figure 5:** Cumulative uplift of Turakirae Head beach ridges obtained by subtracting the modern beach ridge elevation from each profile. Note the marked development of the Rimutaka Anticline (axis about Profile 14) through time.

The profiles have also been used to compare uplift associated with each of the four earthquake events. These single-event uplift curves (Fig. 6) show significant variation in amplitude. The oldest is the smallest with a maximum uplift of 3.4 m, and the largest is the event prior to 1855, which has a maximum uplift value of 10 m. The maximum uplift in 1855 was 6.4 m, close to the mean of the four event maxima, 6.45 m. In each of the earthquakes (except for the one prior to 1855, BR3), uplift continues eastward to close to Barney's Whare, and reduces east from there. BR3 is not preserved to the east of Barney's Whare.



**Figure 6:** Single event uplift calculated for each beach ridge by subtracting the elevation of the ridge immediately below it in each profile. Note that the 1855 uplift is close to the mean of the events recorded. The event prior to the 1855 earthquake (Event 3) is the largest recorded in this Holocene uplift history.

## **TIMING AND CHARACTERISTICS OF HOLOCENE WAIRARAPA FAULT EARTHQUAKES**

Roberts (1855) measured uplift of 2.7 m at Mukamuka Rocks based on the elevation of white encrusted marine “nullipores”. Radiocarbon dating allows independent testing of the age of this uplift and that of older beach ridges.

The age of each beach ridge can be constrained using radiocarbon ages in two ways. Shells or driftwood within the beach ridge were deposited after the death of the molluscs or trees and provide a maximum age for the uplift event. Many of the radiocarbon ages used by Moore (1987) were of this nature. Alternatively, molluscs attached to rocks of the raised intertidal zone, on the seaward side of the raised beach ridge (analogous in location to Roberts’ “nullipores”) can be dated (where found). They provide an accurate age for the uplift event because they were living at the time of the earthquake, dying shortly afterwards through displacement from their life-sustaining environment (tidal influence).

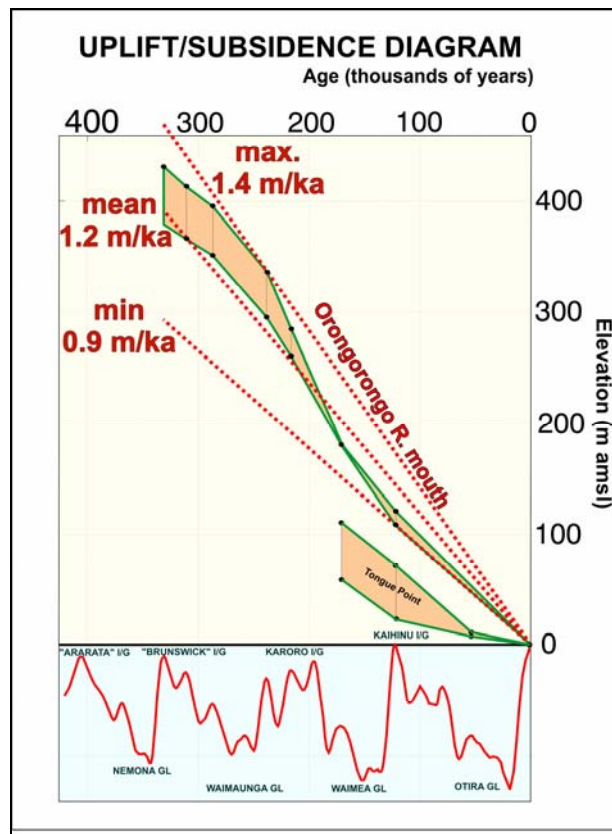
Radiocarbon dates of molluscs attached to rocks immediately seaward of BR2 provide radiocarbon ages coinciding with 1855, confirming BR1 as the modern beach ridge and BR2 as the uplifted 1855 beach ridge. The surveyed elevation of this beach ridge at Mukamuka Rocks coincides with the 2.7 m elevation measured by Roberts (1855). Attached organisms beneath a rock in an analogous location beneath BR3 provide an age of  $\leq 2060$ –2380 cal yr BP for the preceding uplift earthquake. Radiocarbon ages on driftwood on BR5 provide a radiocarbon age constraint of 6610–6920 cal. yr BP, and cosmogenic dating ( $^{10}\text{Be}$ ) of cobbles on the same beach yields an age of c. 6,700 ka (McSaveney et al. submitted). The minimum age of BR4 must be greater than the age of BR3, and the maximum age is constrained by that established for BR5.

A Holocene uplift rate of  $3.54 \pm 0.02$  m/ka can be calculated for the crest of the Rimutaka Anticline on the basis of the elevation and age of BR5. An equivalent uplift rate at Profile 1, at the mouth of the Orongorongo River is  $1.29 \pm 0.02$  m/ka.

On the basis of the Holocene Turakirae beach ridge history, the Wairarapa Fault mean earthquake recurrence interval is calculated at 1.9 ka, although the modal interval is less, at about 1.6 ka.

### **THE LONG-TERM UPLIFT RECORD**

A long-term (c. 330 ka) view of uplift can be derived by supplementing the Holocene profiles with those of older marine benches near the Orongorongo River mouth (Ota et al. 1981). Because the rate of sea-level change associated with climatic change is usually higher than that of tectonic uplift, marine benches cut during periods of low sea-level are commonly not preserved. Their record is destroyed when sea-level rises. In an uplifting coastal setting, marine benches cut at high sea-level stands are elevated above the reach of high sea-level, and are therefore preserved. The ages of marine benches can be estimated from the international sea-level curve (e.g. Imbrie et al. 1984). Progressively higher marine benches represent progressively older high sea-level stands (Fig. 7).



**Figure 7:** Elevations of marine benches at the Orongorongo River mouth (black dots with line connectors) plotted against time (ka before present). The curve approximates a line with a slope of between 1.4 m/ka and 0.9 m/ka (mean about 1.2 m/ka). This rate is comparable with the calculated Holocene uplift rate of c. 1.29 m/ka for Profile 1 derived independently. The oxygen isotope curve of Imbrie et al. (1984) is added to the base of the diagram providing a proxy for international sea-level.

The uplift curve approximates a straight line, defining an uplift rate of somewhere between 0.9 m/ka (minimum) and 1.4 m/ka (maximum), with a mean of about 1.2 m/ka. The long-term rate calculated here approaches that of the short-term (Holocene) record, and the spatial pattern of uplift of these marine benches resembles that surveyed for the Holocene. In light of the similarity of uplift recorded in the 1855 Wairarapa Earthquake to that “typical” for the fault, we conclude that almost all the vertical deformation seen in the Turakirae Head area is attributable to Wairarapa Fault earthquakes. If this is so, the long-term signature at Turakirae Head of vertical deformation that is contributed by subduction interface rupture approaches zero.

## CONCLUSIONS

- The character of uplift in 1855 is reasonably constrained from observations recorded at the time, particularly by those of Roberts (1855);
- Additional observations, particularly at Turakirae Head, provide reliable data on 1855 uplift;
- Because the area of extreme uplift in 1855 appears (on the basis of the map presented here) to have been spatially restricted near the crest of the Rimutaka Anticline, any subduction interface rupture must have been limited;
- Turakirae Head raised beach ridge data provide a reliable history recording the timing and amplitude of four Holocene earthquakes involving uplift;

- The 1855 Wairarapa Earthquake event was about “typical” of the Holocene record in terms of uplift (max. c. 6.4 m);
- Recurrence interval of Wairarapa Fault rupture is well constrained at Turakirae Head (mean recurrence interval c. 1.9 ka; mode c. 1.6 ka);
- The Quaternary uplift history (c. 1.2 m/ka) calculated from older marine benches (back to at least 330 ka) at Orongorongo River is comparable with the Holocene uplift rate (c. 1.3 m/ka at Profile 1);
- Long-term vertical deformation at Turakirae Head is almost completely accounted for through 1855-type Wairarapa Fault rupture, so cumulative vertical deformation associated with other fault displacements and subduction interface events here must approach zero.

## ACKNOWLEDGMENTS

The authors wish to thank Gaye Downes, David Rhoades and John Beavan for discussion relating to this paper. Russ Van Dissen and Ursula Cochran made valuable suggestions in the review process that improved the manuscript.

## REFERENCES

- Aston, B.C. 1912. The raised beaches of Cape Turakirae. Transactions of the New Zealand Institute 44: 208-213.
- Bell, J.M. 1910. The physiography of Wellington Harbour. Transactions of the New Zealand Institute 42: 534-540.
- Cotton, C.A. 1918. The geomorphology of the coastal district of south-western Wellington. Transactions of the New Zealand Institute 50: 212-222.
- Crawford, J.C. 1855. On the geology of the Port Nicholson district, New Zealand (Abridged). Quarterly Journal of the Geological Society of London 11: 530-531.
- Grapes, R.H.; Downes, G.L. 1997. The 1855 Wairarapa, New Zealand, Earthquake – analysis of historical data. Bulletin of the New Zealand National Society for Earthquake Engineering 30: 273-368.
- Huber, P.H. 1994. The Late Quaternary neotectonics and stratigraphy of the Miramar Peninsula and Rongotai Isthmus. Unpublished MSc thesis, Geology Department, Victoria University of Wellington. Wellington, New Zealand.
- Imbrie, J.; Hays, J.D.; Martinson, D.G.; McIntyre, A.; Mix, A.C.; Morley, J.J.; Pisias, N.G.; Prell, W.L.; Shackleton, N.J. 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine  $\delta^{18}O$  record. Proceedings of the NATO Advanced Research Workshop on Milankovitch and Climate, Lamont-Doherty Laboratory, Palisades, New York, Nov. 30-Dec. 4, 1982. Dordrecht, Holland, D. Reidel Publishing Company. NATO ASI Series, Series C, Mathematical and Physical Sciences 126: 269-305.

- Lyell, C. 1856. Sur les effets du tremblement de terre du 23 Janvier, 1855, à la Nouvelle Zélande. Bulletin de la Société Géologique de France, ser 2: 661-667.
- Lyell, C. 1868. Principles of geology or the modern changes of the earth and its inhabitants. Volume II, 10th edition. John Murray, London, England.
- McKay, W.A. 1901. Report on the geology of Cook Strait from Pencarrow Head to the Ruamahanga River, and of the eastern slopes of the Ruahine Mountains between the Tamaki and Makaretu Rivers. Appendix to the Journal of the House of Representatives C-10: 28-34.
- Hull, A.G.; McSaveney, M. 1995. A 7000-year record of Great Earthquakes at Turakirae Head, Wellington. New Zealand. Institute of Geological & Nuclear Sciences Client Report 33493B.10 (for EQC).
- McSaveney, M.J.; Graham, I.J.; Begg, J.G.; Beu, A.G.; Hull, A.G.; Kyeong, K.; Zondervan, A. (submitted). Late Holocene uplift of beach ridges at Turakirae Head, South Wellington coast, New Zealand. New Zealand Journal of Geology and Geophysics.
- Moore, P.R. 1987. Age of the raised beach ridges at Turakirae Head, Wellington: a reassessment based on new radiocarbon dates. Journal of the Royal Society of New Zealand 17: 313-324.
- Ota, Y.; Williams, D.N.; Berryman, K.R. 1981. Parts sheets Q27, R27 and R28 - Wellington, Department of Scientific and Industrial Research, Wellington. Late Quaternary tectonic map of New Zealand.
- Roberts, E. 1855. Memorandum on the earthquake in the islands of New Zealand, January 23, 1855. In: Taylor, R. 1855. "Te Ika a Maui, or New Zealand and its inhabitants". Wertheim and MacIntosh, London, England.
- Wellman, H.W. 1967. Tilted marine beach ridges at Cape Turakirae, New Zealand. Journal of Geoscience, Osaka City University 10: 123-129.



# **FAULT SLIP IN THE 1855 WAIRARAPA EARTHQUAKE BASED ON NEW AND REASSESSED VERTICAL MOTION OBSERVATIONS: DID SLIP OCCUR ON THE SUBDUCTION INTERFACE?**

John Beavan and Desmond Darby  
Institute of Geological and Nuclear Sciences, PO Box 30-368, Lower Hutt  
(j.beavan@gns.cri.nz)

## **INTRODUCTION**

The Hikurangi Trough offshore of the eastern North Island of New Zealand marks the place where the Pacific tectonic plate begins to dive down, or subduct, beneath the North Island. Subduction zones are the locations of the Earth's largest earthquakes, as evidenced by the 1960 Chilean and 1964 Alaskan earthquakes in the Pacific, and most recently the 2004 Sumatra/Andaman earthquake in the Indian Ocean.

The reason these great subduction zone earthquakes occur is that the subducting plate moves inexorably downward, at rates of up to 200 mm/year, under the influence of gravitational and tectonic forces, but the actual interface between the subducting and over-riding plates may remain stuck together for hundreds of years. Just as a stick will strain and eventually break as it is bent further and further, so the interface between the two masses of rock will strain and eventually break as the subducting plate continues to sink. When this happens, the hundreds of years of accumulated strain will be suddenly released with up to 20 m of displacement occurring between the rocks on the two sides of the subduction interface fault. For example, 50 mm/year accumulated over 200 years will result in 10 m of slip. In extreme cases this slip may occur over a fault area more than 100 km wide and 1000 km long, giving rise to an enormous release of energy that causes the massive ground shaking and destruction of the earthquake, as well as a tsunami if the quake occurs offshore.

It appears that not all subduction zones behave in this catastrophic manner. In some the strain builds up for a relatively short period before being released in moderate-sized, and therefore less destructive, earthquakes. In still others, the subducting plate seems to slip down quite easily, as if lubricated, resulting in almost no significant earthquake activity.

What type of subduction zone is the Hikurangi zone off New Zealand? And if it is of the catastrophic variety, how big are the earthquakes it produces, how long has it been since the last one, and how long will it be before the next? These are vital questions about earthquake risk in New Zealand, especially for the eastern and southern North Island.

## **PRESENT-DAY OBSERVATIONS OF GROUND DEFORMATION**

During a great subduction earthquake, the ground surface above the subduction interface rises and expands as the strains accumulated over hundreds of years are released. It does this suddenly, in seconds or minutes. By contrast, during the period of strain accumulation between earthquakes, the ground surface slowly subsides and contracts. The net ground deformation observed on land over the earthquake cycle is

nearly zero; in other words the slow deformation that accumulates in between great subduction zone earthquakes is nearly balanced by the sudden deformation at the time of the earthquake. This is in contrast to earthquakes on surface-cutting faults such as the Wairarapa Fault, where an earthquake results in permanent deformation on land.

GPS observations of ground deformation over the last dozen years show that the southern North Island is being compressed so that the width of the island is decreasing by about 5 mm/year. In addition, there is a sideways (shear) motion of about twice this magnitude between the east and west coasts. By far the most likely explanation for these observations is that the rocks on the two sides of the subduction interface below the southern North Island are presently stuck together, or locked, which means that the deformation in the southern North Island is probably building towards a major subduction zone earthquake. Figure 1 shows the region on the subduction interface beneath the southern North Island that is presently locked.

### **EVIDENCE FOR SUBDUCTION ZONE EARTHQUAKES?**

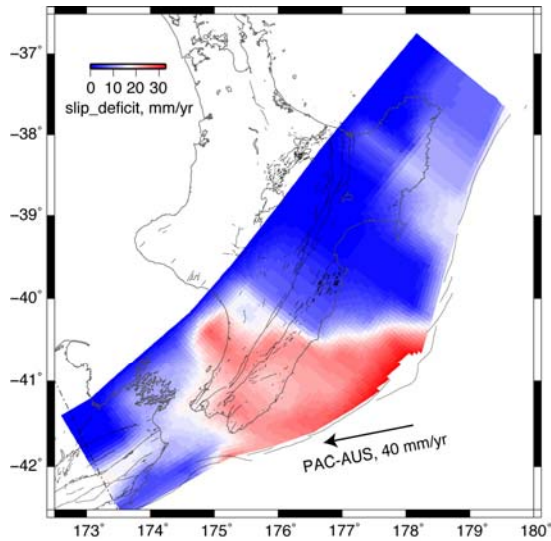
There is no evidence of a major subduction earthquake in the ~200 year historical record, nor has any evidence yet been found in the geological record – though this is an area of active research. So we are at present unable to answer the question of when the last such earthquake occurred.

Though there is no evidence for a historical *subduction zone* earthquake, there has been a great earthquake in the Wellington region during the historical period. This is the 1855 Wairarapa earthquake, whose occurrence we are marking at this conference. The 1855 earthquake was to a large extent a strike-slip event involving predominantly horizontal motion along the Wairarapa Fault. The earthquake did not produce the extensive uplift right across the North Island that would be associated with a great subduction zone quake. However, there was some vertical motion associated with the earthquake, especially in the Wellington region and near Turakirae Head. This has led many scientists to speculate that some part of the subduction interface, even if not all of it, may have ruptured in 1855.

The motion of the Pacific Plate relative to the Australian Plate in the Wellington region (Figure 1) is about 40 mm/yr in azimuth  $-101^\circ$  [DeMets et al., 1994; Beavan et al., 2002]. The component of motion normal to the Wairarapa Fault is about 20 mm/yr. If most of this motion is accommodated by slip on the subduction interface, as suggested by the modelling of Wallace et al. [2004], then 2 m of potential slip accumulates every 100 years.

The Wairarapa Fault itself slips at a long-term rate of about 8 mm/yr, with great earthquakes about every 2,000 years [Van Dissen & Berryman, 1996]. If the subduction interface slipped only at times of Wairarapa earthquakes, this would imply 40 m of dip slip on the subduction interface in 1855. It is certain from the observed vertical motions that this magnitude of slip did not occur in 1855, so dip slip on the subduction interface must usually, if not always, occur independently of slip on the Wairarapa Fault.

However, if part of the subduction interface did rupture in 1855, this will clearly have some influence on the timing and likelihood of the next great subduction earthquake.



**Figure 1.** Distribution of locking on the Hikurangi subduction interface from interpretation of >10 years of repeated GPS surveys, adapted from Wallace et al. [2004]. The slip deficit is the rate of build-up of potential slip at the plate interface due to ongoing plate motion, and is as high as 25 mm/yr beneath the North Island. The slip deficit is not well constrained off the east coast. The long-term motion of the Pacific Plate relative to the Australian Plate is shown by the arrow. However, the motion of the Pacific Plate relative to the eastern North Island is approximately in the down-dip direction of the interface (northwest), because of long-term rotation of the Hikurangi forearc [Wallace et al., 2004].

## UPLIFT AND SUBSIDENCE ASSOCIATED WITH THE 1855 EARTHQUAKE

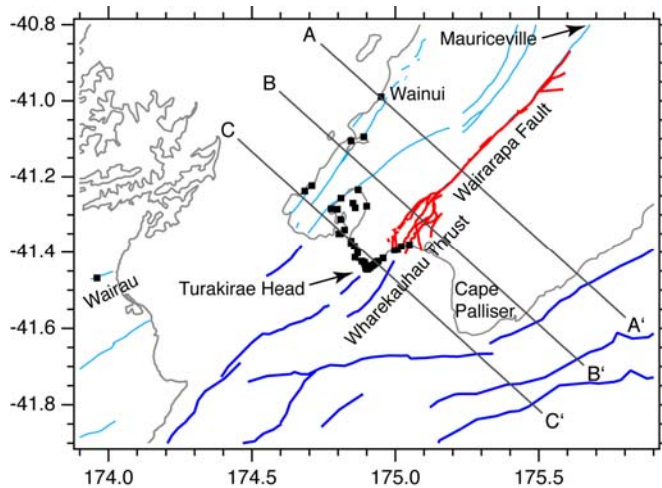
If the 1855 earthquake were to occur today, we would collect a huge quantity of data on the ground displacements – both horizontal and vertical – associated with the event, which would enable us to accurately characterise the amount and location of slip that had occurred on the sub-surface faults. In 1855 there were almost no means in place to accurately measure vertical deformation and none to measure horizontal motion. Also, there was little understanding worldwide – let alone in New Zealand – about the nature of earthquakes, and the fact that they result from slip between the two sides of a geological fault.

In these circumstances it is lucky that any contemporary observations of vertical deformation associated with the 1855 earthquake were made, and have survived to the present. Almost all the observations made in 1855 come from the coastline, as the sea surface was the only reference surface available by which to judge vertical displacement of the land. There were also a few contemporary estimates of vertical offset across the Wairarapa Fault itself. Most of the observations were estimates rather than accurate measurements, and in many instances the observed motion is an inextricable mixture of regional displacement due to the fault slip, and localized subsidence due, for example, to the de-watering and compaction of sediments by the earthquake shaking.

In addition to the observations made in 1855, there have been many later measurements based on the surveyed heights of terraces and wave-cut platforms that are supposed to have been raised by the earthquake.

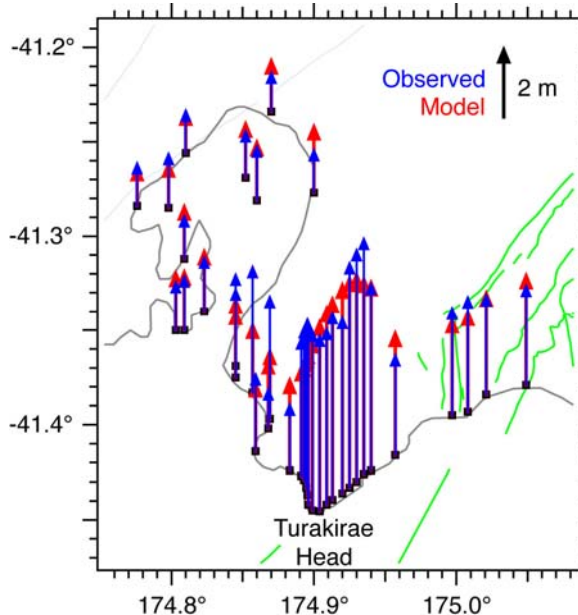
## PREVIOUS MODELLING OF 1855 SURFACE DISPLACEMENTS

In a 1992 paper, Darby & Beanland [1992] modelled the vertical deformation observations available at the time. They used an “elastic dislocation model”, which has become a standard technique since the 1960s for computer modelling of the ground deformation associated with an earthquake fault rupture. They presented four model variations and, for reasons outlined below, expressed a preference for one with the following features.



**Figure 2.** Black squares are locations of coastal uplift observations associated with 1855 earthquake. Light blue lines are on-land active faults. Heavy red lines are the onshore Wairarapa Fault and Wharekahu Thrust, simplified from the QMap database. Heavy blue lines are offshore faults simplified from Barnes [2005, and references therein]. A-A', B-B' and C-C' are cross-sections used in Figures 4 and 5.

- The Wairarapa Fault, whose dip is vertical or steeply westward dipping near the surface, dips less steeply as it gets deeper (a “listric” rather than planar surface).
- The main part of the subduction interface itself – that part to the east of the Wairarapa Fault – could not have slipped a significant amount during the 1855 earthquake.
- However, it is possible that the deeper part, west of the Wairarapa Fault, could have slipped.
- The large vertical motions recorded in raised beaches at Turakirae Head, which were believed at the time to be as much as 2.7 m, may have been due to a localised anomaly in the fault geometry or slip distribution.



**Figure 3.** 1855 coastal uplifts in the Wellington and southern Wairarapa regions. Blue arrows are observations, and red arrows are from one of our best fitting models (see text). The two easternmost observations are those of Roberts [1855]. In addition, Roberts estimated zero uplift just to the east of his easternmost uplift observation (across the Wharekahu Thrust). All other observations around Turakirae Head are from Hull & McSaveney [1996]. Uncertainties in the observations are estimated to be at least  $\pm 0.3$  m. Green lines are onshore and offshore mapped faults.

## NEW AND UPDATED INFORMATION ON THE 1855 EARTHQUAKE

Since Darby and Beanland’s paper, much work has been done on extracting information about the 1855 earthquake from historical records, and on estimating displacements and deformation due to the earthquake from geological information and landforms that we can observe today. The primary historical work is described by Grapes & Downes [1997] and Downes & Grapes [1999]. They identified a significantly larger number of

vertical deformation observations (Figure 2) than were available to Darby and Beanland, as well as reassessing some of those observations. In addition, Hull & McSaveney [1996] reviewed the uplift record at Turakirae Head, following their realization that the beach uplifted in 1855 had been misidentified in previous work. Their reassessment means that the maximum 1855 uplift near Turakirae Head was 6.4 m, even larger than the 2.7 m accepted previously, but was localised to a small region. Little & Rodgers [2004] have more carefully measured the horizontal offsets along the 1855 rupture. They conclude that the horizontal slip could have been as great as ~16-18 m rather than the ~12-14 m accepted previously.

Figure 3 includes most of the vertical displacement observations we use to model the fault slip in the 1855 earthquake. We have interpreted these observations from the publications of Grapes & Downes [1997], Downes & Grapes [1999] and Hull & McSaveney [1996]. Other readers may derive somewhat different values from these sources.

Almost all the vertical observations associated with the 1855 quake are of ground uplift. The one major exception is in the lower Wairau Valley where there were multiple reports of subsidence, based on several lines of evidence including the necessity to go 5 km further upstream to obtain fresh water than before the earthquake. While some of this may be attributed to settling of sediments as a result of ground shaking, Grapes & Downes [1997] believe that at least some of it is genuine regional subsidence, especially as the sediments in the region would have been well shaken only 7 years earlier by the 1848 Marlborough earthquake. The contemporary estimates of subsidence varied between 0.5 m and 1.5 m; we expect that the amount of regional tectonic subsidence is towards the lower end of this range. There is one piece of evidence reported by Grapes & Downes [1997] that is contrary to widespread tectonic subsidence in the lower Wairau region. This is a lack of any contemporary reports that the already-difficult coastal route around White Bluffs south of the Wairau Valley had become more difficult or impassable after the earthquake. However, at about this time the coastal route was superseded by an inland track, though it is not clear whether this occurred before or after the 1855 earthquake [G. Downes, pers. comm., 2005].

There are differences in detail, as well as a larger number of observations, between the uplifts along the Kapiti coast and in the Wellington region reported by Grapes & Downes, and those used by Darby & Beanland. The principal difference, alluded to earlier, is the much larger uplift around Turakirae Head resulting from the work of Hull & McSaveney [1996].

Other vertical deformation information comes from observations of vertical throw on the Wairarapa Fault. This is not the same as vertical displacement relative to sea level, as it is possible, for example, that both sides of the fault may rise relative to sea level with the western side going up more than the eastern. Vertical fault throw in 1855 on the Wairarapa Fault, based on current landforms, is judged to be as much as 2.5 m just north of the junction with the Wharekauhau Thrust (J. Begg, T. Little, pers. comms., 2005). This decreases to ~2 m at Pigeon Bush, and becomes smaller further north.

A number of geologists have examined the extension of the Wairarapa Fault south of where the Wharekauhau Thrust splits off to the east. They find no evidence of significant slip on the Wairarapa Fault in this region in 1855 [Begg & Johnston, 2000; J.

Begg, pers. comm., 2005], suggesting that all the slip transfers onto the Wharekauhau Thrust, at least near the surface.

Barnes [2005] has mapped the offshore Wharekauhau Thrust from multibeam bathymetry data (Figure 2), and believes that at least the mapped section ruptured in 1855. He also observes an offshore lineation typical of strike slip faulting approximately in line with the southward extension of the Wairarapa Fault, but cannot identify dextral offsets on this feature.

## **MODELLING ASSUMPTIONS AND CONSTRAINTS**

We can't tell anything about dip slip on the fault much north of a line from Plimmerton to the southern end of Lake Wairarapa, as we have almost no vertical motion data north of this line.

In particular, we ignore the observed northward decrease in vertical throw on the Wairarapa Fault. The observation of zero uplift at Wainui (south of Paekakariki) can be used to argue that the amount of dip slip on the lower subduction interface decreases northward. We include neither of these possibilities in our modelling, as slip in this northern region has no effect on the uplift observations further south.

We can't tell anything about the strike-slip component on the Wairarapa Fault from our vertical observations, except that a strike-slip component on the deeper part of the fault at its southern end is needed to explain the observed lower Wairau subsidence. (This is because the surface deformation due to a strike-slip fault is almost all horizontal, even for a dipping fault. The only exception is near the ends of the fault, where there is localised uplift and subsidence.) We assume a value of 15 m for the horizontal motion on the Wairarapa Fault; whether we assume 12, 15 or 18 m has a  $\pm 20\%$  influence on the predicted moment.

We assume the rupture ends at the northern end of the main Wairarapa Fault near Mauriceville, even though some 1855 displacement was observed further north on the Alfredton fault system. Again, this has no bearing on the observed uplift data to the south, but will have a minor influence on the predicted moment.

Any slip on the plate interface east (up-dip) of its intersection with the Wairarapa Fault is assumed to be pure dip slip. This is reasonable by analogy with other subduction earthquakes around the world, and is particularly likely because of the large amount of strike-slip on the Wairarapa Fault. It is also consistent with the kinematic modelling of Wallace et al. [2004]. (Adding strike slip to this upper part of the interface would make no difference to our modelled uplifts, but would increase the moment of the model earthquake.)

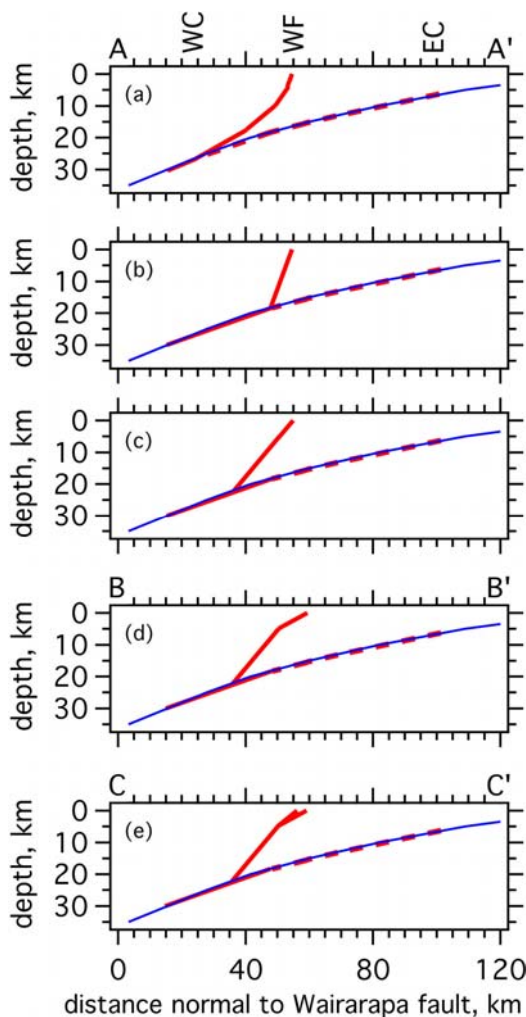
Any slip on the plate interface west (down-dip) of its intersection with the Wairarapa Fault is oblique, and is probably mostly strike slip. This is required by geometry if there are to be no large discontinuities in slip magnitude where faults intersect.

Throw on the Wharekauhau Thrust where it crosses the coastline should be close to Roberts' [1855] observation of 2.7 m at this location. Uplift relative to sea level immediately east of this point should be small, again from Roberts [1855].

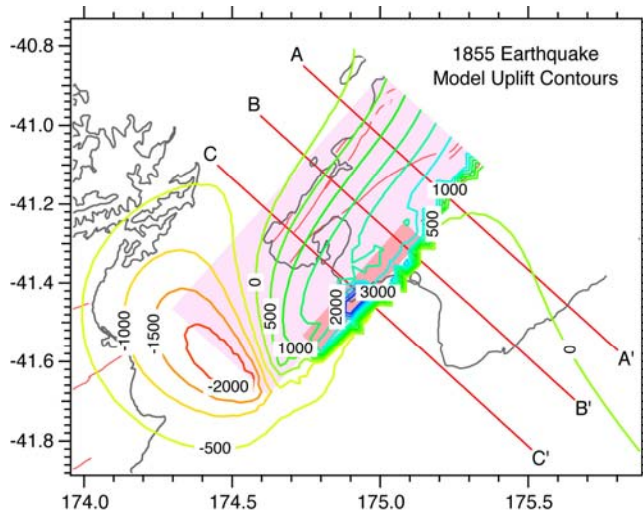
We try three types of forward dislocation model (Figure 4). Two are similar to the steeply dipping and listric Wairarapa Fault models of Darby & Beanland [1992]. The third is similar to the moderately dipping Wairarapa Fault model of Sykes [quoted in Darby & Beanland, 1992]. In all cases, the lower part of the subduction interface, down-dip of its intersection with the Wairarapa Fault, slips obliquely in the earthquake. We investigate how much, if any, of the shallower subduction interface can slip without violating the vertical observations.

We treat the Wharekauhau Thrust as a  $\sim 30^\circ$  dipping thrust that intersects the Wairarapa Fault at  $\sim 4\text{-}5$  km depth, consistent with gravity modelling by McClymont [2000]. Below this depth we assume the Wairarapa fault plane is continuous. Figure 4(d) shows the model configuration. We extend the southern end of the Wharekauhau Thrust to about the location identified by Barnes [2005]. However, none of our data are sensitive to this limit.

The especially large, localised, uplift (up to 6 m) near Turakirae Head cannot be a regional signal, so must arise from motion on a local structure. We model it using a plausible local thrust wedge above the Wharekauhau Thrust, as shown in Figure 4(e). This is a non-unique model with no independent supporting evidence. However, the onshore section of the Wharekauhau Thrust does exhibit similar structures.



**Figure 4.** Cross-sections showing models of 1855 rupture surfaces. WC, EC and WF are the positions of the west and east coasts, and the surface trace of the Wairarapa Fault. (a), (b) and (c) are along line A-A' north of the Wharekauhau Thrust showing, respectively, the listric, steeply dipping and moderately dipping configurations for the Wairarapa Fault. The thin blue line is the plate interface interpreted from seismicity studies [Ansell & Bannister, 1996]. Solid red lines are faults we believe must have slipped in the 1855 earthquake. Dashed red lines are part of the subduction interface that may have slipped during the earthquake (see text). (d) shows the fault configuration along line B-B' through the Wharekauhau Thrust. Slip on the top 4-5 km of the Wairarapa Fault has transferred onto the Wharekauhau Thrust and has become mostly down-dip rather than mostly right-lateral. (e) shows the fault configuration along line C-C' through Turakirae Head. We have added an additional thrust wedge to explain the very high uplifts here. There is no independent evidence for this structure, but similar structures occur along the on-land section of the Wharekauhau Thrust. (d) and (e) are shown for the case corresponding to (c), but the structures shown are also present in the models corresponding to (a) and (b).

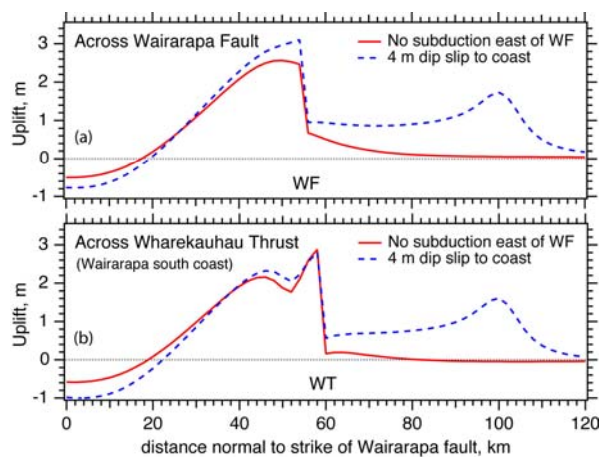


**Figure 5.** Contours of vertical motion in mm from listric Wairarapa Fault model with downdip involvement of the subduction interface. The light coloured rectangle shows the surface projection of the Wairarapa Fault and deeper subduction interface; the smaller rose-coloured rectangle is the surface projection of the model Wharekahu Thrust. Rose lines show onshore active faults. Cross sections A-A', B-B' and C-C' are shown in Figure 4. Note the ~0.5-1 m subsidence in the lower Wairau Valley. Contours are not shown for the northern part of the model as we have no data to constrain them.

## MODELLING RESULTS

A comparison between observations and one of our models is shown in Figure 3, with other modelling results in Figures 5 and 6. In order to fit the uplift in the Wellington region, the listric Wairarapa Fault model must slip to ~30 km depth, to a point where it is no longer distinguishable from the deeper subduction interface. For the planar Wairarapa Fault models, the part of the subduction interface between ~18 and ~30 km depth must have slipped in the earthquake in order to satisfy the observed uplift in the Wellington region.

Once it is recognized that the deeper subduction interface must have slipped, all three Wairarapa Fault models can fit the observed uplift data equally well. There is no way to distinguish from available data between the models of Figures 4(a), (b) and (c).



**Figure 6.** Model uplift profiles (a) along A-A' and (b) south of B-B' (near the observations of Roberts [1855]), for two variations on the steeply-dipping Wairarapa Fault model. In the red curves there is no slip on the subduction interface east of the surface trace of the WF. In the blue dashed curves there is 4 m of dip-slip as far as the east coast. Both models provide adequate fits to the observed uplift data west of the Wairarapa Fault (WF) and Wharekahu Thrust (WT). The magnitudes of the model earthquakes are  $M_w$  8.25 and 8.35, respectively; these are both plausible values.

All our models have the following features: 15 m strike slip and 2-3 m dip slip on the Wairarapa Fault; 6-8 m of predominantly dip slip on the Wharekahu Thrust; 10-15 m of predominantly strike slip on the deep subduction interface (~18-30 km depth); several m of dip slip on the extra thrust to explain the 5-6 m uplifts at Turakirae Head.



We discuss below whether any slip on the shallower subduction interface is allowed by the data.

## DISCUSSION

Darby & Beanland [1992] modelled the supposed 2.7 m uplift near Turakirae Head as part of the regional deformation field. This was a reasonable approach at the time, but it led to difficulties; matching the 2.7 m at Turakirae Head using a regional model tended to lead to mismatches with other data. Now that the Turakirae Head uplift has been reinterpreted as 6 m, it is clear this can only be due to a local source. We therefore do not need to match it with a regional deformation model.

The observations of Roberts [1855] on the south coast near Mukamuka suggest that there was little or no uplift immediately to the east of the fault, but this was an observation of the Wharekauhau Thrust rather than the Wairarapa Fault further north, and the deformation patterns may be different between these two locations (Figure 6). It was the supposed absence of deformation east of the Wairarapa Fault that led Darby & Beanland [1992] to prefer a listric fault model. However, this absence of deformation can also be matched if slip occurs on both a planar fault and the deeper subduction interface (Figure 6, solid red lines).

Figure 6(b) shows the step across the Wharekauhau Thrust and the relatively undisturbed profile immediately east, as observed by Roberts [1855]. If the subduction-interface slip does not extend up dip, the land east of the thrust remains at the same level, as observed by Roberts. In the case where 4 m of interface slip extends to the coast, this region is raised about 0.7 m relative to sea level but is still quite flat lying. Could Roberts have missed uplift of this magnitude? We suspect not, but could he perhaps have missed 0.3 m of uplift, corresponding to ~2 m of slip on the shallow subduction interface? Whatever the answer to this question, slip greater than about 2 m on the shallow subduction interface is difficult to reconcile with Roberts' observations.

The model with 4 m of slip on the shallower interface also predicts up to 2 m of uplift at Cape Palliser and along the east coast. Such uplift was not reported at the time of the earthquake, even though the normal tidal range is only about 1 m, and widening of the coastal platform corresponding to such uplift would be quite noticeable. The coastal route was well frequented at the time by travellers between Wellington and properties on the east coast and as far north as Hawkes Bay. Our conclusion is that dip slip greater than ~2 m on the shallow subduction interface in 1855 is most unlikely. Darby & Beanland [1992] and Grapes & Downes [1997] also reached the conclusion that there was low or no slip on this part of the interface.

That there was no slip on the shallow subduction interface in 1855 remains our favoured interpretation. However, what are the implications if there was in fact up to ~2 m of slip on this area of the fault in 1855? One possibility is that the southern Hikurangi subduction thrust usually fails in earthquakes of only a few metres down-dip slip (though these only rarely occur in conjunction with a Wairarapa Fault earthquake). This would imply subduction earthquakes of magnitude  $M_W \sim 8$  every ~100-200 years, meaning that a subduction earthquake of this size can be expected in the relatively near future. Another possibility is that the Hikurangi subduction thrust usually fails in larger earthquakes, probably involving a longer along-strike length than the ~130 km that

might have failed in 1855. In this case the usual interval between major subduction thrust earthquakes would be substantially longer than 200 years, and any 1855 slip on the shallow interface may have delayed the occurrence of the next such event by about 100 years.

## CONCLUSIONS

Even with updated and newly collected vertical deformation data we are not able to say much more than Darby & Beanland [1992] about fault slip in the 1855 earthquake. In one way, because we no longer consider that the high uplifts close to Turakirae Head can be fit by a regional model, we actually have fewer data available than Darby & Beanland.

Robust conclusions from our modelling are as follows.

- We cannot determine the variation of dip with depth of the Wairarapa Fault from available data.
- If the observed 1855 subsidence in the lower Wairau Valley is accepted as a tectonic signal, at least 10 m of oblique slip occurred near the southern end of the subduction interface, down dip of the Wairarapa fault, to ~30 km depth.
- No more than ~2 m of dip slip could have occurred on the shallow subduction interface above ~15 km depth. This would represent only about 100 years of accumulated slip, so slip associated with Wairarapa Fault earthquakes cannot be a primary mode of slip on the shallow subduction interface.
- 6-8 m of predominantly dip slip occurred on the Wharekauhau Thrust, with additional localised faulting necessary to explain the 6 m of uplift near Turakirae Head.
- The size and timing of the next subduction interface earthquake in the Wellington region remain a matter of speculation.

## ACKNOWLEDGEMENTS

Our thanks to Phil Barnes, Gaye Downes, John Begg, Tim Little and Laura Wallace for useful discussions, to Biljana Lukovic for digitised fault traces, and to Phil for sharing pre-publication results from his side-scan surveys in Cook Strait. Research supported by the Foundation for Research Science and Technology.

## REFERENCES

- Ansell, J. H., and S. C. Bannister (1996), Shallow morphology of the subducted Pacific plate along the Hikurangi margin, New Zealand, *Physics of the Earth and Planetary Interiors*, 93, 3-20.
- Barnes, P. (2005), The southern end of the Wairarapa Fault, and surrounding structures in Cook Strait, this volume.
- Beavan, J., P. Tregoning, M. Bevis, T. Kato, and C. Meertens (2002), Motion and rigidity of the Pacific Plate and implications for plate boundary deformation, *Journal of Geophysical Research*, 107(B10), 2261, doi: 10.1029/2001JB000282.

- Begg, J. G., and M. R. Johnson (2000), *Geology of the Wellington area, 1:250,000 Geological Map 10, 1 sheet + 64 pp.*, Inst. Geol. Nucl. Sci., Lower Hutt, New Zealand.
- Darby, D. J., and S. Beanland (1992), Possible source models for the 1855 Wairarapa earthquake, New Zealand, *J. Geophys. Res.*, 97(B9), 12,375-12,389.
- DeMets, C., R. G. Gordon, D. F. Argus, and S. Stein (1994), Effects of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions, *Geophysical Research Letters*, 21, 2191-2194.
- Downes, G., and R. Grapes (1999), The 1855 Wairarapa, New Zealand, earthquake – historical data, *Inst. Geol. Nucl. Sci. science report*, 99/16, 267 pp.
- Grapes, R., and G. Downes (1997), The 1855 Wairarapa, New Zealand, Earthquake – Analysis of Historical Data, *Bull. N. Z. National Soc. Earthq. Eng.*, 30(4), 271-368.
- Hull, A. G., and M. J. McSaveney (1996), A 7000-year record of great earthquakes at Turakirae Head, Wellington, New Zealand, Client Report 1996/33493B.10 prepared for Earthquake Commission, Inst. Geol. Nucl. Sci., Lower Hutt, New Zealand, 28 pp.
- Little, T. A., and D. W. Rodgers (2004), 1855 Wairarapa Fault earthquake: world record strike-slip displacement now even bigger, In: Manville, V. & Tilyard, D. (eds.) *Programme and Abstracts*, *Geol. Soc. N. Z. Misc. Publ.*, 117A, 64-65.
- McClymont, A. F. (2000), A gravity survey of the Wharekauhau Thrust, Palliser Bay, New Zealand, *N. Z. J. Geol. Geophys.*, 43, 303-306.
- Roberts, E. (1855), See the extensive discussion on Roberts' observations in Grapes & Downes [1997].
- Van Dissen, R., and K. R. Berryman (1996), Surface rupture earthquakes over the last ~1000 years in the Wellington region, New Zealand, and implications for ground shaking hazard, *Journal of Geophysical Research*, 101(B3), 5999-6019.
- Wallace, L. M., J. Beavan, R. McCaffrey, and D. Darby (2004), Subduction Zone Coupling and Tectonic Block Rotations in the North Island, New Zealand, *J. Geophys. Res.*, 109:B12, B12406, doi:10.1029/2004JB003241.

# EARTHQUAKES FROM FAULT RUPTURE: THE SCIENTIFIC IMPACT OF THE 1855 WAIRARAPA EARTHQUAKE

Richard H. Sibson

Department of Geology, University of Otago, PO Box 56, Dunedin.  
(rick.sibson@stonebow.otago.ac.nz)

“A bad earthquake at once destroys our oldest associations: the earth, the very emblem of solidity, has moved beneath our feet like a thin crust over a fluid...”

— Charles Darwin, 1845

## INTRODUCTION

Whether fear is reduced or increased by understanding is debatable. An earthquake as horrific as that responsible for the Indian Ocean tsunami of December 26<sup>th</sup>, 2004, though well understood in terms of its mechanism and effects, still makes us fearful because of the scale and unpredictability of the event, and the vast ensuing destruction and loss of life. Today, no serious seismologist would consider anything other than gigantic shear rupture as the cause of this devastating earthquake, despite the fact that it occurred offshore along an unseen subduction thrust interface. Our faith that a ‘large earthquake’ requires ‘shearing along a large fault rupture’ in fact stems directly from observations of ground deformation made at the time of the 1855 Wairarapa earthquake. My purpose here is to draw together some of the threads that illuminate the pivotal role played by these observations, which generated a ‘quantum leap’ in our understanding of earthquake source mechanics. The history of ideas on earthquakes and their cause is vast (HEAT website). My selection may be criticised as overly anglocentric, but I have sought the roots of the ideas that led Charles Lyell, in the 10<sup>th</sup> edition of his famous ‘Principles of Physical Geology’ (1868), to pronounce: *“In no country, perhaps, where the English language is spoken, have earthquakes, or to speak more correctly, the subterranean causes to which such movements are due, been so active in producing changes of geological interest as in New Zealand”*.

## EARTHQUAKES IN THE CLASSICAL WORLD

Aristotle (384–322 BC) evolved ideas on earthquakes that were decidedly anthropomorphic, attributing them to the confinement of ‘earth breath’ (pneuma) and its occasional violent release. Belief in an ‘earth breath’ of malevolent power was widespread. For centuries, successive oracles at Delphi on the flanks of Parnassus had sat above a ground fissure (along the trace of an active normal fault) to inhale vapours from the earth, before issuing their often inauspicious prophecies. In fact, during Aristotle’s lifetime, a destructive earthquake sequence in 373 BC, centred on the Gulf of Corinth, triggered movement on the same normal fault to offset the very Temple of Apollo where the Pythia had sat (Piccardi 2000). ‘Aristotelian’ views were widespread and enduring. Thus, Epicurus (341–270 BC) writes: *“Earthquakes may be brought about because wind is caught up in the earth so that the earth is dislocated in small masses and is continually shaken, and that causes it to sway”*. Similar ideas are found in translations (Latham 1951) of Lucretius (105–55 BC): *“Learn now the true nature of earthquakes ... the earth in its nether regions... is everywhere full of windy caves...under the earth’s back many buried rivers with torrential force roll their water mingled with sunken rocks ... the earth above trembles with the shock of tumbling*

*masses when huge caverns...have collapsed through age” and “another cause of the same tremendous quaking ... a sudden turbulent squall of wind...has rushed into subterranean hollows ... rages there amongst the vast caverns, swirling and eddying...splitting open the earth from its depths, creates a stupendous chasm”.*

## **EARTHQUAKE UNDERSTANDING IN THE AGE OF ENLIGHTENMENT**

‘Aristotelian’ views on the origin of earthquakes generally held sway well into the mid-18<sup>th</sup> century. But the roots of elasticity theory were enunciated by Robert Hooke (1635–1703) who also attributed the elevation of marine fossils to earthquake activity. The concept of elastic behaviour embodied in Hooke’s Law was progressively developed and applied to earthquakes. John Michell (1724–1793) suggested that earthquakes were elastic waves in strata driven by injection of steam along the bedding planes. Thomas Young (1773–1829) measured the elastic ‘stiffness’ of various materials (Young’s Modulus) and explained earthquake ground motions as oscillatory sound waves. William Hopkins (1793–1866) developed the mathematics of elastic wave propagation in both solids and fluids. This all laid the groundwork for the ‘scientific’ investigations of earthquake shaking by Robert Mallet in the mid-19<sup>th</sup> century (see below).

## **RECOGNITION OF FAULT DISPLACEMENTS**

Faults (fractures along which shear displacements had occurred) had been recognized by miners for centuries (e.g. Agricola 1556), but awareness of the extent and varying character of faulting, with measured displacements ranging up to hundreds or even thousands of metres became widespread with the development of deep coal mines during the industrial revolution. Terminology, however, was bewilderingly non-uniform: commonly, no clear distinction was made between fissures (extension fractures) and faults (shear fractures). In different mining areas, faults were also referred to as ‘dykes’ or, perhaps more tellingly, as ‘slip-dykes’. Thus W.D Conybeare, quoted in Buckland (1836), defines faults as: “fissures traversing the strata, extending often several miles, and penetrating to a depth, in very few instances ascertained... accompanied by a subsidence of the strata on one side of their line... an elevation of them on the other; so that it appears...the same force which has rent the rocks asunder, has caused one side of the fractured mass to rise, and the other to sink”.

Aside from terminology, there was considerable debate as to whether observed large fault displacements occurred catastrophically or by a progression of incremental movements. Charles Lyell argues the point, thus: “there are grooves, it is said, and scratches on the rubbed and polished walls which have often one direction, favouring the theory that the movement was accomplished by a single stroke, and not by a series of interrupted movements” but also notes: “...the last movement must always tend to obliterate the signs of previous trituration, so that neither its instantaneousness nor the uniformity of its direction can be inferred from the parallelism of the striae that have been last produced”. He went on to conclude: “when rocks have been once fractured, and freedom of motion communicated to detached portions of them, these will naturally continue to yield in the same direction, if the process of upheaval or undermining be repeated again and again. The incumbent mass will always give way along the lines of least resistance, and therefore usually in the places where it was formerly rent asunder”. The inference that fault movement was incremental is clear. Further hints of the relationship between faults and earthquakes can be found in the remarkable insights of

the rev. William Buckland (1836) who, in a chapter ‘on the advantageous effects of disturbing forces in giving rise to mineral veins’, states: “a further result attending the disturbances of the surface of the earth has been, to produce rents or fissures in the rocks, which have been subjected to these violent movements, and to convert them into receptacles of metallic ores, accessible by the labours of man. The greater part of metalliferous veins originated in enormous cracks or crevices, penetrating downwards to an unknown depth and resembling the rents and chasms which are produced by modern earthquakes.”

## EARTHQUAKES, GROUND DEFORMATION, AND VOLCANOES

Important earthquakes of the late 18<sup>th</sup> and early 19<sup>th</sup> centuries that were extensively discussed by Lyell and others include the 1755 Lisbon earthquake, the 1783 Calabrian earthquakes, the 1811–1812 earthquakes in New Madrid on the Mississippi River, the 1819 earthquake in the Rann of Kachchh, India, and the great 1835 Chilean earthquake which was directly experienced and described by Charles Darwin. The close association of the Italian and Chilean earthquakes with belts of active volcanoes led many to deduce a common cause (subterranean heat / magmatic intrusion / exothermic sulphur–iron reactions). Thus, Darwin, who with Captain Fitzroy observed coastal uplift in Chile ranging from 1–3 metres over a broad region, noted the penecontemporaneous eruption of several volcanoes, and also observed the elevation to hundreds of metres in the coastal hills of seashells, not dissimilar to those still living (“...it is hardly possible to doubt that these ... elevations had been effected by successive small uprisings”), attributed both earthquakes and volcanoes to the existence of a “subterranean lake of lava”.



Deep fissure, near Polistena, caused by the earthquake of 1783.

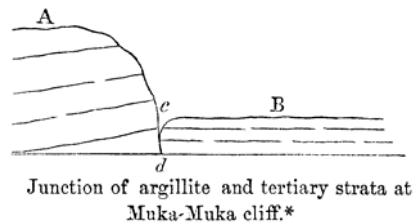
— Lyell (1868 – 10<sup>th</sup> edn.)

Observations of ground deformation for the onshore earthquakes in Calabria with extensive fissuring and landsliding failed to distinguish clear evidence of faulting, though Lyell did note: “the ground was sometimes on the same level on both sides of new ravines and fissures, but sometimes there had been a considerable upheaving of one side, or subsidence of the other.” The 1819 earthquake in the Rann of Kachchh, India, was accompanied by the appearance of a mysterious ridge, the ‘Allah Bund’, that dammed the eastern channel of the Indus and likely represents the scarp of a steep reverse fault (Bilham 1999), but was unrecognised as such at the time.

## ROBERT MALLET'S 'SCIENTIFIC SEISMOLOGY'

Robert Mallet (1810–1881), a practising engineer, is widely regarded as the father of 'scientific seismology'. Among many contributions, he made experimental determinations of seismic velocities in sand and granite, and also coined the terms 'seismology', 'isoseismal', and 'seismic focus'. His investigations and seismological experiments are of particular interest because they were almost contemporary with the 1855 Wairarapa earthquake. He published "*On the Dynamics of Earthquakes*" in 1846, discussing ground motion from elastic waves, and produced his great two-volume analytical treatise "*The Great Neapolitan Earthquake of 1857: the First Principles of Observational Seismology*" in 1862. This report was based on a two-month field investigation through the epicentral area of the earthquake southeast of Naples. In it, he made a quite reasonable determination of the depth of focus (c. 8 km) from surface observations of damage to buildings and structures. However, his preferred mechanism for the 1857 earthquake (appropriate for an engineer in the Victorian industrial era!), was steam-driven extensional fissuring. He argued for the formation of an inclined 'focal cavity' oriented NE–SW, orthogonal to the elongate (near-elliptical) pattern of isoseismals that he had mapped. However, a series of NW–SE normal fault scarps, probably representative of a surface rupture produced by the M~7 earthquake in 1857, have been identified in recent years by investigations combining satellite image analysis with field investigations (Benedetti et al. 1998).

## EARTHQUAKE IN NEW ZEALAND – PERMANENT UPLIFT AND SUBSIDENCE OF THE LAND – A FAULT PRODUCED IN THE ROCKS



— Lyell (1868 – 10<sup>th</sup> edn.)

The great significance of the 1855 M~8.1 Wairarapa earthquake is that it provided the first definitive observations of fault rupture at the Earth's surface accompanying a great earthquake, with ~3 m of vertical offset described at Muka-Muka, based on the uplift of a band of subtidal nullipores on one side of the fault. Based on discussions with Edward Roberts ('Royal Engineers department'), Walter Mantell ('son of the celebrated geologist'), and Frederick Weld ('landed proprietor') in 1856, Charles Lyell in the 10<sup>th</sup> edition of his '*Principles of Geology*' (1868) provided a comprehensive account of the extent of the surface rupture, thus: "*The junction of the older and newer rocks along the line of fault above described is marked in the interior of the country by a continuous escarpment running north and south along the base of the Remutaka Mountains.... The course of the fault along the base of the escarpment was rendered visible by a nearly perpendicular cliff of fresh aspect 9 feet in height and traceable in an inland direction to the extraordinary distance of about 90 miles*". While his observers had failed to recognise the enormous sideways displacement along the rupture (~12 m of dextral strike-slip), attention was drawn to the coastal uplift diminishing towards Wellington, such that a vast tract of country ('4,600 square miles'), notably devoid of adjacent

volcanoes, was tilted to the northwest. These observations led Charles Lyell to conclude: *“The geologist has rarely enjoyed so good an opportunity as that afforded him by this convulsion in New Zealand, of observing one of the steps by which those great displacements of the rocks called ‘faults’ may in the course of ages be brought about. The manner also in which the upward movement increased from north-west to south-east explains the manner in which beds may be made to dip more and more in a given direction by each successive shock”*.

Thus was the association between shallow earthquakes and faulting in the Earth’s crust finally established, but whether faulting was the actual cause of earthquakes or merely a ‘by-product’ of the earthquake process remained unclear. However, it was clear from his writings that Lyell recognised that the earthquake rupture occurred along an existing fault structure, and represented just the last increment of shearing along it. Another scientific aspect of the 1855 earthquake of global interest (though not recognized till much later) was the recognition of the huge strike-slip displacement along the rupture trace. The purported ~12 metres of strike-slip recognized by Harold Wellman for the 1855 earthquake (Grapes & Wellman 1988) was greater than any onshore earthquake displacement observed in California or elsewhere. To my knowledge, it was not until the  $M_w$  7.8 Central Kunlun earthquake of northern Tibet in 2001 that a larger continental earthquake displacement with <16 m of sinistral strike-slip was recognized along parts of a 400 km long rupture (Lin et al. 2002).

## **AFTER 1855**

The association between large earthquakes and fault rupture had previously been noted in New Zealand valley during the 1848  $M \sim 7.4$  earthquake, but again the sense of shear was not noted for the ‘fissure’ that was traced ~100 km along the Awatere Valley (Grapes et al. 1998). Strike-slip (sideways movement) was finally recognised from fence-lines offset by < 2.6 m during the 1888  $M \sim 7.1$  rupture along the Hope Fault (McKay 1888), the first description of such fault motion since Zechariah (14:4).

Physical justification for the existence of such structures was provided by Anderson (1905) who recognised the possibility of three basic stress regimes in the Earth’s crust accompanied by three dominant modes of faulting – thrust, wrench (strike-slip), and normal. The 1906 San Francisco earthquake on the San Andreas Fault provided confirmation that strike-slip faulting could indeed occur on a massive scale (~4 m dextral strike-slip, on average along an ~450 km rupture), with the accompanying distortion of a geodetic triangulation net providing the necessary data for the formulation of Reid’s (1911) hypothesis of ‘elastic rebound’ as the driving force behind crustal earthquakes. It became ever more apparent that big earthquakes involve the ‘reshear’ of part or all of big existing faults with large finite displacements. Frictional ‘stick-slip’ (Brace & Byerlee 1966) provided the instability that leads to elastic rebound. Of late there has also been renewed interest in the role of fluids in earthquake rupturing since Hubbert & Rubey’s (1959) seminal work on reduction of frictional fault strength by overpressured pore-fluids.

## **CONCLUSIONS**

Observations following the 1855 Wairarapa earthquake provided the first clear evidence that the earthquake was accompanied by a substantial increment of shearing



displacement on a major fault structure. The link between fault rupture and earthquakes was established.

## REFERENCES

- Agricola G 1556. *De Re Metallica* (trans. HC Hoover & LH Hoover, New York, Dover).
- Anderson EM 1905. The Dynamics of Faulting. *Transactions Edinburgh Geological Society* 8(3): 387-402.
- Benedetti L, Tapponier P, King GCP, Piccardi L 1998. Surface rupture of the 18587 southern Italy earthquake. *Terra Nova* 10: 206-210.
- Bilham R. 1999. Slip parameters for the Rann of Kachchh, India, 16 June 1819 earthquake quantified from contemporary accounts. In: Stewart, IS, Vita-Finzi, C ed. *Coastal Tectonics*. Geological Society of London Special Publication 146: 295-318.
- Brace WF, Byerlee JD 1966. Stick-slip as a mechanism for earthquakes. *Science* 153: 990-992.
- Buckland W 1836. *Geology and Mineralogy, Considered with Reference to Natural Theology*. London, William Pickering.
- Darwin C 1845. *Journal of Researches into the Natural History and Geology of the Countries Visited during the Voyage of H.M.S. "Beagle" Round the World*. London, Ward, Lock & Bowden Ltd.
- Grapes R, Little T, Downes G 1998. Rupturing of the Awatere Fault during the 1848 October 16 Marlborough earthquake, New Zealand. *New Zealand Journal of Geology and Geophysics* 41: 387-399.
- Grapes R, Wellman HW 1988. *The Wairarapa Fault*. Research School of Earth Sciences, Geology Board of Studies, VUW, Publication 4, 55pp.
- HEAT <<http://www.univie.ac.at/Wissenschaftstheorie/heat/heat.htm>>
- Hubbert MK, Rubey WW 1959. Role of fluid pressure in mechanics of overthrust faulting. *Bulletin of the Geological Society of America* 70:115-166.
- Latham RE 1951. *Lucretius – On the Nature of the Universe*. Harmondsworth, Penguin Books.
- Lin A, Fu B, Guo J, Zeng Q, Dang G, He W, Zhao Y. 2002. Co-seismic strike-slip and rupture length produced by the 2001  $M_s$  8.1 Central Kunlun Earthquake. *Science* 296: 2015-2017.
- Lyell C 1830-1876. *Principles of Physical Geology* (1<sup>st</sup> – 12<sup>th</sup> edn.) London, John Murray.
- McKay A 1888. Remarks on earthquakes in the Amuri District, South Island. *Transactions of the N.Z. Institute* 21: 508-509.
- Mallet R 1862. *The Great Neapolitan Earthquake of 1857 – The First Principles of Observational Seismology*. London, Chapman & Hall.
- Piccardi L 2000. Active faulting at Delphi, Greece: seismotectonic remarks and a hypothesis for the geologic environment of a myth. *Geology* 28:651-654.

Reid HF 1910. The mechanism of the earthquake. In: The California Earthquake of April 18, 1906, Report of the State Earthquake Investigation Commission, Vol. 2. Washington, DC, Carnegie Institution, pp. 1-192.

# ACTIVE FAULTING AND PALEOEARTHQUAKES IN THE WAIRARAPA AND WELLINGTON REGIONS

R.M. Langridge, R.J. Van Dissen, U.A. Cochran, N.J. Litchfield, K.R. Berryman,  
J.G. Begg, P. Villamor, D. Heron, A. Nicol, D. Townsend  
Geological & Nuclear Sciences, PO Box 30-368, Lower Hutt  
(r.vandissen@gns.cri.nz, k.berryman@gns.cri.nz)

## INTRODUCTION

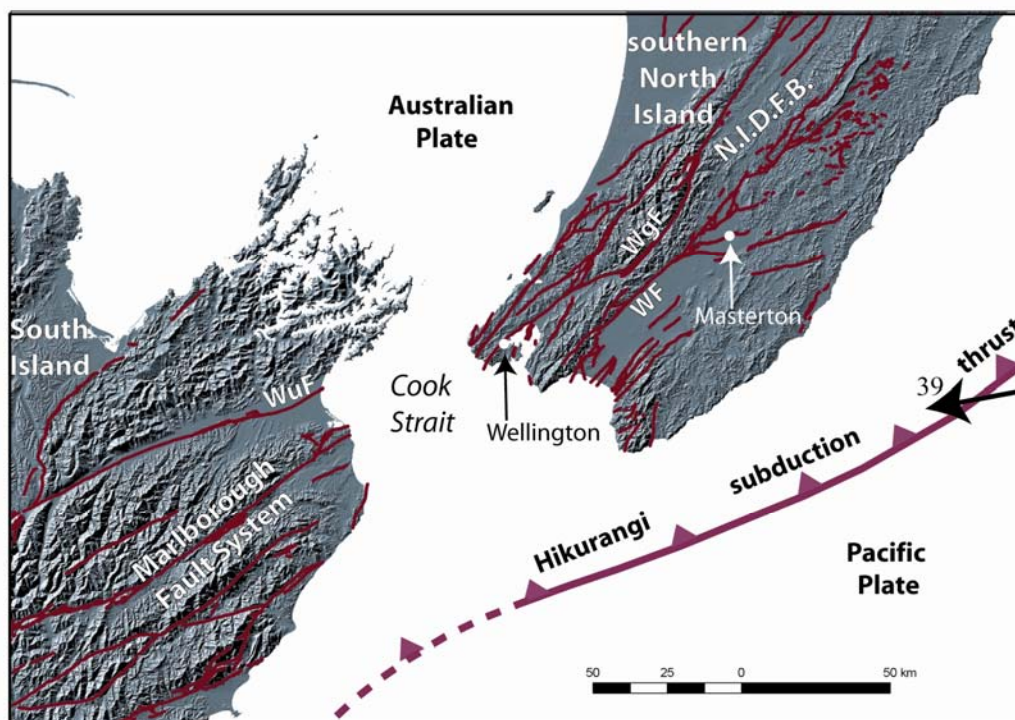
A considerable body of new work has been undertaken to better understand the characteristics, slip rates and earthquake histories of active faults in the Wellington and Wairarapa regions since the last review on this topic (Figs. 1 & 2) (Van Dissen & Berryman 1996). Several faults in the region, e.g. the Akatarawa, Whitemans Valley, Carterton, Masterton, and Huangarua faults have been studied for the first time, while the “principal” or “first-order” faults of the region, e.g. the Wellington and Wairarapa faults, continue to receive attention. Considerable progress has been made in understanding offshore faults around the southern North Island (see Barnes, this volume). However, the Hikurangi subduction thrust that underlies southern North Island remains the least understood major seismic source in the region. Paleoseismic data from active faults is being used extensively in hazard calculations and the National Seismic Hazard Model (Stirling et al. 2002) for forward prediction of levels of ground shaking. In addition, with the advent of the Ministry for the Environment’s guidelines for building on or adjacent to active faults (Kerr et al. 2004; Van Dissen et al. 2003), the importance of understanding the past recurrence behaviour of faults in New Zealand has been brought to the fore. This paper summarises past and current data for many of the onland faults in the southern North Island, and touches on new data for some offshore faults and the Hikurangi subduction zone.

## TECTONIC CONTEXT OF FAULTING IN THE WAIRARAPA & WELLINGTON REGIONS

Surface faulting in southern North Island is a consequence of oblique collision between the Australian and Pacific plates at the Hikurangi Trench and along the dipping plate interface beneath the Wairarapa and Wellington regions (Fig. 1) (Van Dissen & Berryman 1996). Tectonic strain resulting from the plate collision is partitioned between the plate interface and upper plate structures such that earthquakes on the plate interface accommodate motion normal to the trench (Ansell & Bannister 1996; Webb & Anderson 1998), while upper plate structures accommodate both margin-parallel motion at the rear of the deformation zone (Darby and Beavan 2001) and a lesser amount of contraction (margin-normal) at the leading edge in a slip-partitioned fashion (Cashman et al. 1992; Barnes et al. 1998; Nicol & Beavan, 2003). Because the subduction margin is evolving rapidly (see Wallace et al. 2004) there is also a rapid evolution in upper plate faulting. Begg & Mazengarb (1996) & Berryman et al. (2002) suggest no more than c. 10 km of total strike-slip motion on each of the Wellington or Wairarapa faults. This is consistent with the conclusions of Kelsey et al. (1995) who have shown that at the location of the present-day strike-slip faults, reverse faulting occurred in the late Pliocene to early Pleistocene, c. 3-1 million years ago. Kelsey et al. (1995) also showed

that the present-day Wairarapa and Alfredton faults formed by linking sections of suitably oriented reverse faults.

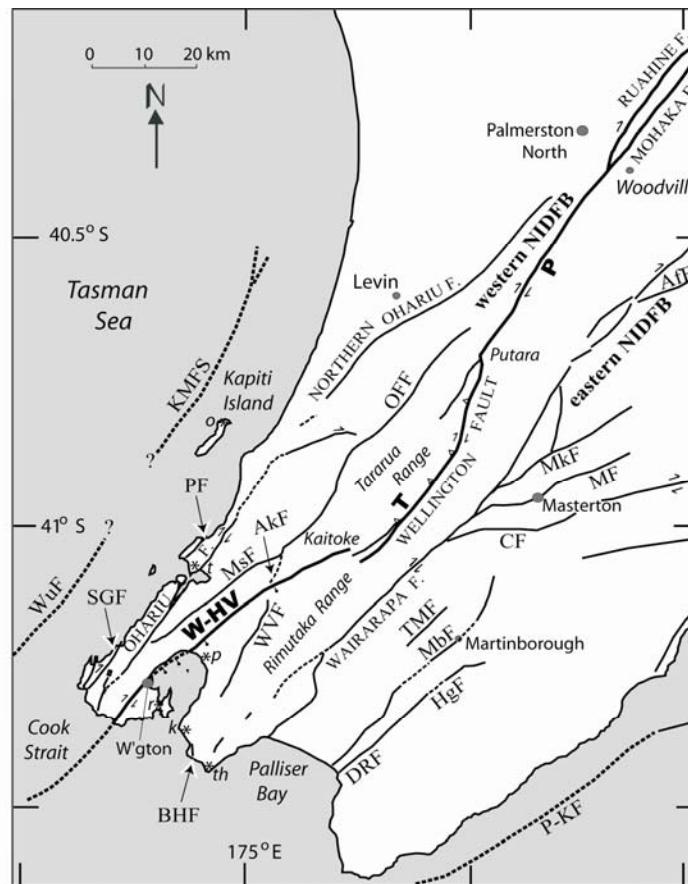
Elsewhere, particularly across the Wellington peninsula, where the cover of Tertiary sediments has been removed by uplift and erosion, an older structural pattern of more north-south striking faults has been mapped (Stevens 1974; Begg & Mazengarb 1996). Some of these structures, such as the Terawhiti, Happy Valley, Terrace, Baring Head, Evans Bay (Ota et al. 1981) and Seatoun faults are possibly still active but their sense and rates of movement are unknown. They may have originally been part of the reverse fault domain prevalent in the late Pliocene and early Pleistocene but now only sporadically active.



**Figure 1.** Digital Elevation Model showing the general physiographic and tectonic setting of central New Zealand. Onland traces of late Quaternary active faults come from the GNS Active Fault Database. The Hikurangi subduction thrust represents the main plate boundary structure with respect to southern North Island, while the Marlborough Fault System accounts for strain release in northern South Island. Upper plate strain is largely released in southern North Island by active faults of the North Island Dextral Fault Belt (NIDFB; Beanland 1995). WuF = onland trace of Wairau Fault; WF = Wairarapa Fault; WgF = Wellington Fault. Plate motion vector of the Pacific plate relative to the Australian plates is shown in mm/yr.

Because much of the margin-parallel motion is accommodated through deformation of the overriding Australian plate, many of the major active structures in the region are aligned in a NE-SW direction and are dextral-slip faults. From east to west, the major active NE-SW striking principal faults that cut the southern North Island and accommodate 60-90% of margin-parallel motion are the Wairarapa, Wellington, Ohariu-Northern Ohariu, Shepherds Gully-Pukerua faults, and the offshore portion Wairau Fault (Fig. 2). In central Wairarapa, the Carterton, Masterton, and Mokonui faults re-distribute significant strike-slip movement from the Wairarapa Fault and should be also considered “first-order” faults (e.g. Zachariassen et al. 2000; Townsend et

al. 2002). A small component of margin-normal motion also occurs on these faults. In addition to these principal faults, there are a host of lower slip rate, “second order” faults that cut the region. The Moonshine, Akatarawa, and Otaki Forks faults strike approximately NE-SW and accommodate a small portion of predominantly margin-parallel motion (Van Dissen et al. 2001). The Whitemans Valley Fault strikes NNE-SSW and accommodates dominantly reverse movement (Van Dissen et al. 1998). In eastern Wairarapa and offshore of the east coast, faults such as the Te Maire, Martinborough, Dry River-Huangarua faults appear to be predominantly reverse faults that accommodate margin-normal contraction.



**Figure 2.** Active fault map of southern North Island. Fault names are: P-KF, Palliser-Kaiwhata; HgF, Huangarua; DRF, Dry River; MbF, Martinborough; TMF, Te Maire; CF, Caterton; MF, Masterton; MkF, Mokonui; AfF, Alfredton; BHF, Baring Head; WVF, Whitemans Valley; AkF, Akatarawa; MsF, Moonshine; SGF, Shepherds Gully; WuF, offshore Wairau Fault; PF, Pukerua; and OFF, Otaki Forks faults. KMFS = Kapiti-Manawatu Fault System. The postulated geomorphic fault segmentation pattern for the Wellington Fault is also shown: the Wellington-Hutt Valley segment (W-HV) extends into Cook Strait; the Taranua section (T) traverses the transpressional Taranua Ranges northward from Kaitoke; the Pahiatua (P) section occurs from Putara to near Woodville (after Beanland 1995). Teeth and ticks on fault sections imply reverse and normal components. Coastal sites (\*, italics) are: *th*, Turakirae Head; *k*, Kohangapiripiri; *r*, Rongotai; *p*, Petone; *t*, Taupo Swamp; and *o*, Okupe.

## THE WAIRARAPA FAULT AND 1855 EARTHQUAKE

The Wairarapa Fault trace lies on the western side of the Wairarapa Valley where it is well defined for about 90 km north of Palliser Bay, and further to the north, it continues into southern Hawkes Bay as a series of subparallel splays (Figs. 1, 2). It also extends south into Cook Strait (see Barnes this volume). In 1855 at least 140 km of this fault ruptured in the c.  $M_w$  8.2 Wairarapa earthquake (e.g. Ongley 1943). This is the only

known historical (post-European) surface faulting event in the Wellington region (c.f. Schermer et al. 2004). Grapes & Wellman (1988) estimated dextral displacement for the 1855 rupture to be in the order of 9-13.5 m (averaging c. 12 m). However, recent re-surveying and dating of offsets suggest that average displacement, at least on the portion of the fault south of Featherston, was much higher (c. 15-16 m), and that maximum surface rupture displacement during 1855 was as high as c. 18 m (Little & Begg 2005, Little & Rogers this volume, 2004). Slip rates calculated from offset terraces along the Wairarapa Fault typically fall within the range of 7-10 mm/yr (see Van Dissen & Berryman 1996 and references cited therein).

Paleoseismic data for the Wairarapa Fault comes via trenching data from the fault and from the record of uplifted beach ridges at Turakirae Head (Figs. 2 & 3). Trenches at Tea Creek reveal the 1855 event, followed in time by rupture events interpreted to have occurred at 1330-1570, 2560-2960, c. 4420-4870 and 6040-6480 cal. yr BP (Fig. 3)(Van Dissen & Berryman 1996). This gives an average inter-event time of 1500-1600 yr. The beach ridge record at Turakirae Head shows evidence for uplift events at 1855 AD, 2060-2380 cal. yr BP, 4710-5350 cal. yr BP and 6610-6920 cal. yr BP (Begg & McSaveney this volume, McSaveney et al. submitted, Hull & McSaveney 1996) yielding an average inter-event time of c. 1900 yr. The event-timing records derived at Tea Creek and at Turakirae do not show a one-to-one correspondence, and the resolution of this discrepancy awaits further research.

## **CARTERTON, MASTERTON AND MOKONUI FAULTS**

The Carterton, Masterton and Mokonui faults are ENE to NE striking splay faults from the Wairarapa Fault in the central Wairarapa area (Fig. 2). In spite of their geometric relation with the Wairarapa Fault, and unlike the Alfredton Fault further north (Schermer et al. 2004), none of them seem to have ruptured in 1855 based on the presence of un-faulted young river terraces (Zachariassen et al. 2000, Begg et al. 2001, Townsend et al. 2002). All three faults are characterised as dextral strike-slip faults with a subordinate dip slip component - normal for the Carterton and Masterton faults (Begg et al. 2001), and possibly reverse for the Mokonui Fault (Langridge et al. 2003).

The vertical component of late Pleistocene slip is well expressed and thus quantifiable along all three faults (i.e. there are clear, measurable fault scarps with a southeast downthrow along all traces). However, the strike-slip component of displacement is mainly inferred from evidence that does not readily provide quantifiable measures of lateral slip, namely the presence of restraining and releasing bends along all three faults (Zachariassen et al. 2000, Townsend et al. 2002), and the mismatch of stratigraphic layer thickness across the Mokonui Fault exposed in trench excavations (Langridge et al. 2003). The presence of a few offset streams along the Carterton Fault (Zachariassen et al. 2000) provide the only quantifiable control on the amount and age of lateral slip and, thus, on lateral slip rate. As such, the Carterton Fault is the best characterised of these faults with dextral and vertical slip rates of 2-4 mm/yr and 0.1-0.5 mm/yr, respectively (Zachariassen et al. 2000). The Masterton and Mokonui Faults both yield vertical slip rates of c. 0.3-0.7 mm/yr and 0.2-0.5 mm/yr, respectively (Zachariassen et al. 2000; Langridge et al. 2003). However, because the ratio of horizontal to vertical slip for the Masterton and Mokonui faults is unknown, it is not possible to estimate their strike-slip and total slip rate. Nevertheless, their strike-slip rate is currently considered to be less than that of the Carterton Fault. Modelling of seismic fault slip and GPS data (Wallace

et al. 2004) predicts a total of c. 5 mm/yr of dextral strike-slip and <1 mm/yr of extension across the area encompassing these faults, implying that the largest portion of the strike-slip deformation for these faults is accommodated by slip on the Carterton Fault.

Paleoseismic data for all three faults is poorly constrained. Langridge et al. (2003) estimated a recurrence interval for the Mokonui Fault of c. 1300-2000 yr and an elapsed time since the most recent rupture of  $\leq 2500$  yr. The most recent event for the Carterton Fault appears to have occurred within the last 3000 yr.

## **WELLINGTON FAULT**

Because of its proximity to urban centres, the Wellington Fault is considered the most significant surface faulting and ground shaking hazard in southern North Island. It extends from Cook Strait in the south (Carter et al. 1988), through the cities of Wellington, Lower Hutt and Upper Hutt, and north to the Manawatu Gorge (Figs. 1, 2). The fault has a long tradition of neotectonic studies including those of the 1990's that defined the fault's key seismic hazard parameters (Berryman 1990; Beanland 1995; Van Dissen et al. 1992; Van Dissen & Berryman 1996). The NE-SW striking, c. 75 km-long Wellington-Hutt Valley segment of the fault is postulated to represent an individual rupture segment, and it has a slip rate of 6-7.6 mm/yr, single-event lateral displacement size of 3.8-4.6 m, and an average recurrence interval in the range of 500-770 yr. Along the Petone foreshore, rupture of the fault is expected to generate c. 1 m of subsidence (Begg et al. 2002, 2004). The Wellington-Hutt Valley segment alone is capable of generating M 7.3-7.9 earthquakes. Paleoseismic data gleaned from trenches and river bank exposures showed that the most recent event (MRE) occurred at 290-440 cal. yr BP (1510-1660 AD) and that the penultimate faulting event occurred at 660-720 cal. yr BP (Fig. 3).

More recently, studies along the Wellington Fault have focused on defining seismic parameters for the two sections of the fault farther north; the Tararua and Pahiatua sections (Beanland 1995; Berryman et al. 2002; Langridge et al. 2005a). Data remains difficult to obtain from the Tararua section. However, recent studies have identified a significant aggradation event in the Waiohine River catchment that buried tree stumps at Totara Flats at 300-500 cal. yr BP, which overlaps in age with the timing of the most recent rupture of the Wellington-Hutt Valley segment of the Wellington Fault (Berryman et al.

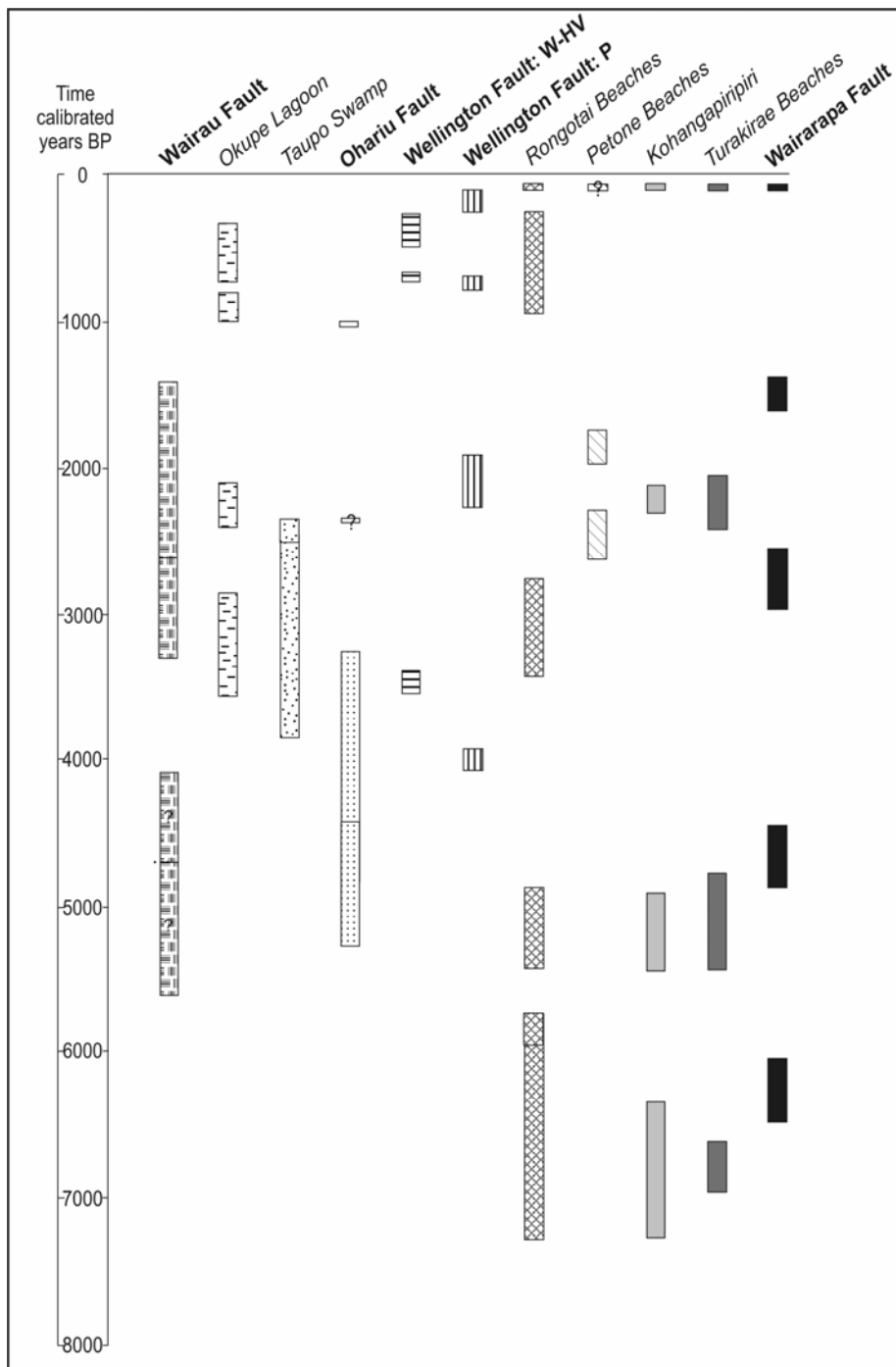


Figure 3. Age estimates for paleoearthquakes in the Wellington region (modified from Cochran 2002). Ages come from trench excavations across major faults, sequences of raised beach ridges and sedimentary records of coastal waterbodies with original publications cited in text. Abbreviations: W-HV, Wellington Hutt Valley segment; P, Pahiatua section.

2002). The longest paleoseismic records for the Wellington Fault currently come from the Pahiatua section of the fault (Berryman et al. 2002; Langridge et al. 2004). These show that at least four surface rupture events have occurred along the Pahiatua section during the last c. 4100 yr. Best estimates for the timing of these four events are c. 110-280 cal. yr BP; 690-790 cal. yr BP; 1900-2350 cal. yr BP and 3910-4090 cal. yr BP, but significant uncertainty still surrounds the timing of most of these events, particularly the



older ones. The four events have individual inter-event times that range between c. 650-2000 yr. When compared to the Wellington-Hutt Valley segment, this is consistent with the Pahiatua section's longer average recurrence interval (560-1080 yr), derived from its lower slip rate (5.1-6.2 mm/yr) and equivalent single-event displacement (3.5-5.5 m) (Langridge et al. 2005a). A new trench site at Putara, near the boundary between the Tararua and Pahiatua sections is serving up the longest paleoearthquake record yet for the Wellington Fault (Langridge et al. 2005b).

## **OHARIU FAULT**

The Ohariu Fault extends northeast from Cook Strait, through Porirua City to Waikanae (Fig. 2). Due to the rapid urbanisation of the Kapiti Coast District and the introduction of Ministry for the Environment's guidelines for building on or near active faults (e.g. Kerr et al. 2004), the Ohariu Fault has become one of a number of national test cases with respect to fault avoidance zonation and fault recurrence interval classification (Van Dissen et al. 2004). Recent paleoseismic studies at Nikau Valley and MacKays Crossing (Litchfield et al. 2004; Litchfield et al. submitted) have augmented the results of previous work (Heron et al. 1998) and have provided constraints on the timing of three surface rupture events in the last 5300 cal. yr BP. The most recent event is now tightly constrained at 1000-1050 cal. yr BP and the timing of two older ruptures is constrained at 3260-4810 cal. yr BP and 4410-5270 cal. yr BP. Heron et al. (1998) present observations from a trench exposure across the fault in Ohariu Valley of buried trees that were killed at c. 2350 cal. yr BP. This burial could have resulted from rupture of the fault, and subsequent aggradation behind the uphill-facing scarp, but this is only one of several plausible explanations. As such, this tentative rupture event was not included in the recurrence interval calculations above, but is depicted in Figure 3 for comparative purposes.

Heron et al. (1998) derive an average dextral slip rate for the fault of 1-2 mm/yr, and an average single event displacement, based on measurements at seven sites, of c. 3.7 m. Using statistical methods incorporating inter-event times, slip rate, single event displacement, and their uncertainties, a best estimate mean recurrence interval of 2200 yrs is calculated for the Ohariu Fault, with minimum and maximum 68% and 95% confidence interval limits of 1300-3800 yrs, and 800-7000 yrs, respectively (Litchfield et al. submitted).

## **NORTHERN OHARIU FAULT**

The Northern Ohariu Fault forms the northern continuation of the Ohariu Fault in the Kapiti/ Horowhenua districts (Fig. 2). The fault strikes NE-SW and comprises one of the western boundary faults of the Tararua Ranges (Van Dissen et al. 1998; 1999). The Northern Ohariu Fault was mapped in detail and scarps are commonly found across Ohakean terrace surfaces over a length of c. 60 km. Based on soils and geomorphic relations, the most recent surface rupture for the Northern Ohariu Fault is believed to be within the last 5000 yr. The lateral slip rate of the fault is in the order of 1-3 mm/yr, and single-event displacement is poorly constrained at c. 3 m (Palmer & Van Dissen 2002). The recurrence interval for earthquakes of M 7.2-7.5 is considered to be in the range of one to several thousand years on average. It is not yet known whether or not the Northern Ohariu Fault ruptures simultaneously with the Ohariu Fault, thereby resulting in larger earthquakes.

## **SHEPHERDS GULLY-PUKERUA FAULTS**

The Shepherds Gully and Pukerua faults appear to be part of the same geologic structure (Fig. 2) (Van Dissen & Berryman 1996). However, the overall geomorphic expression of these two faults is relatively subdued, and laterally continuous fault scarps are not present along the faults, suggesting a relatively low rate of activity. An estimate of displacement of  $20 \pm 5$  m from an offset channel on an Ohakean age (30-18 kyr) surface yields a lateral slip rate of 0.8-1.4 mm/yr for the Pukerua Fault. One single-event displacement measurement on the Shepherds Gully Fault, in combination with this slip rate, yields a tentative, poorly constrained, recurrence interval of 2500-5000 yr. There is no direct data available regarding the timing of surface rupture on either of these faults. However, the poor preservation of scarps along both these faults suggest that they are less active, and have had a longer elapsed time since the most recent event, in comparison with the adjacent Ohariu Fault.

## **THE KAPITI MANAWATU FAULT SYSTEM AND WAIRAU FAULT**

The Kapiti Manawatu Fault System (KMFS) refers to a fold and thrust belt mapped in the region offshore from the Kapiti, Horowhenua and Manawatu coasts (simplified on Fig. 2) (Lamarche et al. 2005). This system of faults is active and may link into the offshore part of the Wairau Fault in Cook Strait. Late Quaternary (0-120 kyr) dip slip rates along the KMFS are up to c.  $1.8 \pm 0.5$  mm/yr (Lamarche et al. 2005). The paleoseismic histories of the KMFS and the offshore part of the Wairau Fault are unknown at this time. The Wairau Fault is a major active dextral strike-slip fault in the northern South Island, and extends offshore of the South Island, through Cook Strait, and passes west of Kapiti Island (Lensen 1968; Barnes et al. 1998). The onshore and offshore proximity of the Wairau Fault to Wellington means that it represents a considerable shaking and possibly tsunami hazard for the Wellington region. Onshore in South Island, the fault has an estimated slip rate of 4-5 mm/yr and a single event horizontal displacement of 5-7 m (Lensen 1968; Zachariassen et al. 2001). Three or four surface rupture earthquakes are inferred to have occurred since about 5600 cal. yr BP with the last and penultimate events occurring between 1400-2600 and 2400-3400 cal. yr BP respectively (Zachariassen et al. 2001). If the large landslide that blocked the Goulter River and formed Lake Chalice was activated by the most recent event on the Wairau Fault, it can be inferred from radiocarbon dates on drowned trees (Adams 1981), that the age of the most recent event for the Wairau Fault is better constrained to 1885-2301 cal yr BP (see Fig. 3).

## **WHITEMANS VALLEY FAULT**

The Whitemans Valley Fault is a “second order” active fault that strikes NNE-SSW to the east of Upper Hutt (Fig. 2), and has a mappable length of c. 20 km (Begg & Van Dissen 1998, Van Dissen et al. 1998). Trenching of the fault has revealed multiple late Pleistocene surface ruptures. The most recent of these ruptures is probably  $\leq 10$  ka in age and has a vertical displacement of c. 2 m (c. 3 m dip-slip reverse). A dextral component of slip may also have occurred. The Whitemans Valley Fault is considered capable of generating M 6.7-7.3 earthquakes, and has an estimated recurrence interval of c. 15-20 ka.

## **AKATARAWA, MOONSHINE AND OTAKI FORKS FAULTS**

The Akatarawa Fault consists of a number of faults that splay from the Wellington Fault near Upper Hutt and strike NNE-SSW (Begg & Van Dissen 2000, Van Dissen et al. 2001). Like the Whitemans Valley Fault, the Akatarawa Fault is an important second order active fault in the Wellington region. Geomorphic mapping and trenching of the fault trace in the Akatarawa valley indicate that the Akatarawa Fault has a minimum dextral slip rate of 0.4 mm/yr, and a maximum average earthquake recurrence interval of c. 9000 yrs. However, given dating and measurement uncertainties, the actual slip rate may be considerably higher, and the recurrence interval may be considerably less. A possible kinematic effect of the Akatarawa Fault is to increase the slip rate and hazard for the Wellington Fault to the south of their junction (Fig. 2).

The Akatarawa Fault merges in the northeast with the Moonshine and Otaki Forks faults, which strike NE-SW and lie between the Ohariu-Northern Ohariu and Wellington faults (Begg & Van Dissen 2000; Van Dissen et al. 1998; 2001). Due to the documented activity of the Akatarawa Fault, the Otaki Forks Fault, and possibly also the Moonshine Fault, should both be regarded as active. This is consistent with the distinct topographic expression of the Otaki Forks Fault, and to a lesser extent, that of the Moonshine Fault. However, there are no direct slip rate or paleoearthquake data available for either the Otaki Forks or Moonshine faults.

## **OTHER FAULTS**

There are numerous other faults in the region for which data is limited. These include many “second order” faults in the Wellington urban area (e.g., the Terrace, Evans Bay, Kaiwharawhara and Seatoun faults), faults in eastern Wairarapa associated with growing folds (e.g., Te Maire, Martinborough and Dry River-Huangarua faults) (Nicol et al. 2002), and offshore structures such as the Booboo and Palliser-Kaiwhata faults (see Barnes et al. 1998; Barnes this volume) (Fig. 2). In most cases, but certainly not all, these faults have relatively low slip rates (<1 mm/yr), and therefore have relatively long recurrence intervals (Van Dissen et al. 2003). However, the notable exceptions are the high-slip rate, strike- to oblique slip Booboo and Palliser-Kaiwhata faults offshore of the southeast coast of North Island. The latter, based on analysis of uplifted Holocene terraces along the south Wairarapa coast, may have a dip-slip rate of c. 3 mm/yr (NZ Tsunami Risk project), and a recurrence interval of <1000 yr (Berryman et al. 1989). Movement on the Palliser-Kaiwhata Fault may in part be responsible for uplift of the Aorangi Range.

## **OTHER EARTHQUAKE RECORDS**

Evidence of past large earthquakes in the Wellington region has also been derived from sequences of raised beach ridges and sedimentary records of coastal waterbodies. Figure 3 provides a timeline of known paleoearthquakes for the Wellington region with ages of earthquakes from trenching studies on faults as described above and from studies of raised beaches and sedimentary records. Cochran (2002) documents evidence for sudden uplift and/or strong shaking at three widely-spaced coastal waterbody sites in the region. Four events were identified at Okupe Lagoon on Kapiti Island (Fig. 3), the timings of which overlap with the timing of known, or inferred, ruptures of the Wellington Fault or Ohariu Fault. At Taupo Swamp near Plimmerton, two uplift events

were identified, and these may relate to ruptures of the Ohariu Fault, or possibly the closer Shepherds Gully-Pukerua Fault. The sedimentary record at Lake Kohangapiripiri on the south coast between Pencarrow and Baring Heads appears to record earthquakes on the Wairarapa Fault. Age estimates of the two oldest events bracket age estimates for Wairarapa Fault ruptures from the Turakirae Head raised beaches and the Tea Creek trenches (Fig. 3). This suggests that all three sites are recording the same earthquakes, and that the apparent differences in the Turakirae and Tea Creek earthquake records are more a consequence of incorrect interpretation of event occurrence and timing rather than real differences in the earthquake records at the two sites.

Pillans & Huber (1995) describe a series of paleoshorelines at Rongotai that provide evidence for the occurrence of multiple (up to eight) earthquakes totalling 7-9 m of uplift in the last 6500 years. The ages of three of these paleoshorelines correlate well with the ages of the uplifted beach ridges at Turakirae Head (Begg & McSaveney this volume, McSaveney et al. in review, Hull & McSaveney 1996) and thus may relate to uplift caused by rupture of the Wairarapa Fault. Rupture of the Wellington Fault may have been responsible for uplift that led to the formation of at least some of the other paleoshorelines, and movement on small local faults may also account for one or two of these abandoned shorelines.

Stranded beaches also occur at Petone (e.g. Stevens 1973, Stirling 1992, Begg et al. 2002). The third beach ridge known as 'The Rise' correlates well in age with the penultimate uplifted beach ridge at Turakirae Head. However, correlation of younger and older beach ridges at Petone with ruptures of the Wairarapa Fault and/or other faults in the district has yet to be established.

## **THE HIKURANGI SUBDUCTION INTERFACE**

The Pacific plate subducts beneath the Australian plate at the Hikurangi trough east of the North Island of New Zealand (Fig. 1). The interface between the two plates dips beneath the Wellington region and part of the interface is thought to be locked, accumulating strain and capable of rupturing in a future large earthquake (Reyners 1998, Darby & Beavan 2001). Estimates of magnitude and frequency for such earthquakes have been postulated. For example, Reyners (1998) suggests  $M_w$  8 earthquakes are possible every 875 yr, but there is no historical or paleoearthquake record with which to substantiate this assessment. During historical times the subduction interface has not ruptured in a large earthquake although it is possible that part of it ruptured at the same time as the Wairarapa Fault in the 1855 Wairarapa earthquake. Dislocation models for the 1855 earthquake can explain the observed vertical deformation with or without partial rupture of the interface (Darby & Beavan 1992, see also Beavan & Darby this volume).

Detection of subduction earthquakes in the geological record of the Wellington region is complicated by the fact that the greatest vertical deformation is likely to take place offshore. Elastic dislocation modelling indicates that rupture of the strongly coupled part of the interface beneath Wellington is likely to result in maximum coseismic subsidence occurring offshore to the west (and beneath Marlborough) and maximum coseismic uplift occurring offshore to the east (Laura

Wallace pers. comm. 2005). The vertical deformation signal is also likely to be confused by simultaneous rupture of one or more of the upper plate faults. There is one interval of time in Wellington's paleoearthquake record (c. 2200 cal. yr BP) when uplift or surface rupture is observed at a number of widely-spaced sites (Fig 3). It is possible that this represents simultaneous rupture of several faults triggered by rupture of the subduction interface (see Robinson et al. 1998). Further investigation and tighter age control would be required to verify this idea.

## **DISCUSSION & CONCLUSIONS**

Almost a decade ago, Van Dissen & Berryman (1996) compiled available active fault and paleoearthquake data for the principal onland faults in the Wellington region. Based on the record of surface rupturing earthquakes derived from these data, they concluded that within the last c. 1000 years, there had not been any temporal clustering of surface rupture earthquakes on adjacent faults in the region. They also demonstrated the important and vital contribution paleoseismic data makes in the estimation of earthquake shaking hazard in the Wellington region. Over the intervening years, much new data has come to light, including paleoearthquake data for many faults in the Wairarapa, faults north of the immediate Wellington region (e.g. Northern Ohariu Fault, and Pahiatua section of the Wellington Fault), offshore faults, and several of Wellington's "second order" faults. Also, longer records of paleoearthquakes are available for some of the principal faults, in particular the Ohariu Fault, and off-fault records of paleoearthquakes have been derived from several coastal sites throughout the region.

Based on the expanded paleoearthquake data set, much of which is summarised in Figure 3, some important observations can be made. The original conclusion of Van Dissen & Berryman (1996) still holds, in that over the last c. 1000 years there does not appear to have been temporally-clustered ruptures of adjacent faults in the region. However, along-strike triggered rupture appears to be a distinct possibility (compare the timing of the last two events on the Wellington-Hutt Valley segment and the Tararua and Pahiatua sections of the fault). Also, at c. 2,200 years ago coastal uplift and surface fault rupture is documented at a number of widely-spaced sites throughout the region, hinting at the possibility of temporal clustering on a grand scale.

Despite the considerable advances made over the last ten years in quantifying the active fault and paleoearthquake history of the Wairarapa and Wellington regions, there still remain some glaring deficiencies in the collective data set. Some of the most important include: 1) the paleoearthquake history and rupture characteristics of the subduction interface beneath Wellington are largely unknown; 2) the paleoearthquake history for the most hazardous section of fault in New Zealand, the Wellington-Hutt Valley segment of the Wellington Fault, is embarrassingly short, extending back in time not even 1000 years; 3) the slip rates and timing of past earthquakes on important offshore faults are, as yet, largely unquantified; 4) the slip rates of several important onland faults are not yet sufficiently well known to provide constraints on kinematic and hazard modelling of the region; 5) earthquake timing data for along-strike sections of faults are typically not constrained enough to test models of simultaneous versus triggered rupture; and 6) the confidence of recurrence interval classification for many faults in the region is low thus hindering thoughtful land use planning and application of the Ministry for the Environment's fault avoidance guidelines.

## ACKNOWLEDGMENTS

We thank Julie Lee and Laura Wallace for their reviews of, and consequent improvements to this paper. We also acknowledge the assistance of countless people during field studies in southern North Island over the last decade. Institute of Geological and Nuclear Sciences contribution number 3409.

## REFERENCES

- Adams, J 1981. Earthquake-dammed lakes in New Zealand. *Geology* 9: 215-219.
- Ansell JH, Bannister SC 1996. Shallow morphology of the subducted Pacific plate along the Hikurangi margin, New Zealand. *Physics of the Earth and Planetary Interiors* 93: 3-20.
- Barnes PM this volume. The southern end of the Wairarapa Fault, and surrounding structures in Cook Strait. 1855 Wairarapa Earthquake Symposium. 8-10 September, 2005.
- Barnes PM, Mercier de Lépinay B, Collot J-Y, Deltiel J, Audru J-C 1988. Strain partitioning in the transition area between oblique subduction and continental collision, Hikurangi margin, New Zealand. *Tectonics* 17: 534-557.
- Beanland S 1995. The North Island Dextral Fault Belt, Hikurangi Subduction Margin, New Zealand. Unpublished PhD thesis, Victoria University of Wellington, New Zealand.
- Beavan J, Darby D this volume. Fault slip in the 1855 Wairarapa earthquake based on new and reassessed vertical motion observations: Did slip occur on the subduction interface? 1855 Wairarapa Earthquake Symposium. 8-10 September, 2005.
- Begg JG, McSaveney MJ 2005. Wairarapa Fault – vertical deformation in 1855 and a history of similar events from Turakirae Head. This Volume.
- Begg JG, Mazengarb C 1996. Geology of the Wellington area, scale 1:50,000. Institute of Geological & Nuclear Sciences geological map 22. 1 sheet + 128 p. Lower Hutt, New Zealand: Institute of Geological & Nuclear Sciences Ltd.
- Begg JG, Van Dissen RJ 1998. The Whitemans Valley fault and the earthquake generating potential of Wellington's second order faults. *New Zealand Journal of Geology and Geophysics* 41: 441-448.
- Begg JG, Van Dissen RJ 2000. Documentation of multiple post-glacial ruptures on the Akatarawa fault, Wellington region, New Zealand. Institute of Geological & Nuclear Sciences Client Report 2000/81 prepared for EQC.
- Begg J, Villamor P, Zachariassen J, Litchfield N 2001. Paleoseismic assessment of the active Masterton and Carterton faults, Wairarapa. Institute of Geological and Nuclear Sciences Client Report 2001/70.
- Begg JG, Van Dissen RJ, Rhoades DA, Lukovic B, Heron DW, Darby DJ, Brown LJ 2002. Coseismic subsidence in the Lower Hutt Valley resulting from rupture of the Wellington

- Fault. Institute of Geological and Nuclear Sciences Client Report 2002/140. (prepared for the EQC Research Foundation).
- Begg JG, Van Dissen RJ, Rhoades DA 2004. Subsidence in the Lower Hutt Valley and the interplay between Wellington and Wairarapa Fault earthquakes. In: Proceedings, New Zealand Society for Earthquake Engineering Technical Conference, Rotorua, New Zealand. Paper No. 43, p 9.
- Berryman, KR, Ota Y, Hull AG 1989. Holocene paleoseismicity in the fold and thrust belt of the Hikurangi subduction zone, eastern North Island, New Zealand. *Tectonophysics* 163: 185-195.
- Berryman K 1990. Late Quaternary movement on the Wellington Fault in the Upper Hutt area, New Zealand. *New Zealand Journal of Geology and Geophysics* 33: 257-270.
- Berryman K, Van Dissen R, Mouslopoulou V 2002. Recent rupture of the Tararua section of the Wellington fault and relationships to other fault sections and rupture segments. Institute of Geological and Nuclear Sciences (EQC Research Report 97/248).
- Carter L, Lewis KB, Davey F 1988. Faults in Cook Strait and their bearing on the structure of central New Zealand. *New Zealand Journal of Geology and Geophysics* 31: 431-446.
- Cashman SM, Kelsey HM, Erdman CF, Cutten HNC, Berryman KR 1992. Strain partitioning between structural domains in the forearc of the Hikurangi subduction zone, New Zealand. *Tectonics* 11: 242-257.
- Darby DJ, Beanland S 1992. Possible source models for the 1855 Wairarapa earthquake, New Zealand. *Journal of Geophysical Research* 97: 12,375-12,389.
- Darby D, Beavan J 2001. Evidence from GPS measurements for contemporary interplate coupling on the southern Hikurangi subduction thrust and for partitioning of strain in the upper plate. *Journal of Geophysical Research* 106: 30881-30891.
- Cochran UA 2002. Detection of large Holocene earthquakes in the sedimentary record of Wellington, New Zealand, using diatom analysis. Unpublished PhD thesis, Victoria University of Wellington.
- DeMets C, Gordon RG, Argus DF, Stein S 1990. Current plate motions. *Geophysical Journal International* 101: 425-478.
- DeMets C, Gordon RG, Argus DF, Stein S 1994. Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions. *Geophysical Research Letters* 21: 2191-2194.
- Grapes R., Wellman H 1988. The Wairarapa Fault. Research School of Earth Sciences Geology Board of Studies Publication No. 4. Victoria University of Wellington.
- Heron D, Van Dissen R, Sawa M 1998. Late Quaternary movement on the Ohariu Fault, Tongue Point to MacKays Crossing, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 41: 419-439.

- Hull AG, McSaveney MJ 1996. A 7000-year record of great earthquakes at Turakirae Head, Wellington, New Zealand. Institute of Geological and Nuclear Sciences client report 33493B.10 prepared for EQC.
- Kelsey HM, Cashman SM, Beanland S, Berryman KR 1995. Structural evolution along the inner forearc of the obliquely convergent Hikurangi margin, New Zealand. *Tectonics* 14: 1-18.
- Kerr J, Nathan S, Van Dissen R, Webb P, Brunson D, King A 2004. Planning for development of land on or close to active faults. Ministry for the Environment, Wellington.
- Lamarche G, Proust J-N, Nodder, SD 2005. Long-term slip rates and fault interactions under low contractional strain, Wanganui Basin, New Zealand. *Tectonics* 24, TC4004, doi:10.129/2004TC001699.
- Langridge RM, Townsend D, Persaud M 2003. Paleoseismic assessment of the active Mokonui Fault, Wairarapa. GNS Client Report 2003/68.
- Langridge RM, Villamor P, Townsend D, Berryman K, Van Dissen R 2004. Paleoseismology of the northern Wellington and southern Mohaka Fault system: How to deal with 16 trenches! In: Manville V, Tilyard D (eds) Programme and abstracts, Geological Society of New Zealand/New Zealand Geophysical Society/26<sup>th</sup> Annual Geothermal Workshop combined conference "GEO<sup>3</sup>, Taupo, New Zealand. Geological Society of New Zealand Miscellaneous Publication 117A: 59-60.
- Langridge RM, Berryman KR, Van Dissen RJ 2005. Defining the geometric segmentation and Holocene slip rate of the Wellington Fault, New Zealand: The Pahiatua section. *New Zealand Journal of Geology and Geophysics* 48 (4): 591-607.
- Langridge RM, Villamor P, Townsend D 2005. Paleoseismicity of the Wellington Fault at Putara: Implications for fault segmentation and earthquake timing. GNS Client Report 2005/ 116, prepared for EQC (in press).
- Lensen GJ 1968: Analysis of progressive fault displacement during downcutting at the Branch River terraces, South Island, New Zealand. *Geological Society of America Bulletin* 79: 545-556.
- Lewis KB 1989. Reversal of throw and change of trend on the Wellington Fault, Wellington Harbour. *New Zealand Journal of Geology and Geophysics* 32: 293-298.
- Litchfield N, Van Dissen R, Langridge R, Heron D, Prentice C 2004. Timing of the most recent surface rupture event on the Ohariu Fault near Paraparaumu, New Zealand. *New Zealand Journal of Geology and Geophysics* 47: 123-127.
- Litchfield N, Van Dissen R, Heron D, Rhoades D, submitted. Constraints on the timing of the three most recent surface rupture events and recurrence interval for the Ohariu Fault: trenching results from MacKays Crossing. *New Zealand Journal of Geology and Geophysics*.



- Little T, Begg J 2005. All-day field-trip to the Wairarapa Fault and 1855 rupture sites. 1855 Wairarapa Earthquake Symposium. 8-10 September, 2005.
- Little TA, Rodgers DW 2004. 1855 Wairarapa Fault earthquake: World record strike-slip displacement now even bigger. In: Manville V, Tilyard D (eds) Programme and abstracts, Geological Society of New Zealand/New Zealand Geophysical Society/26<sup>th</sup> Annual Geothermal Workshop combined conference "GEO<sup>3</sup>, Taupo, New Zealand. Geological Society of New Zealand Miscellaneous Publication 117A: 64-65.
- Little TA, Rogers DW this volume. Co-seismic slip during the 1855 earthquake, southern Wairarapa Fault, New Zealand. 1855 Wairarapa Earthquake Symposium. 8-10 September, 2005.
- McSaveney MJ, Graham IJ, Begg JG, Beu AG, Hull AG, Kim K, Zondervan A submitted. Late Holocene uplift of beach ridges at Turakirae Head, South Wellington coast, New Zealand. *New Zealand Journal of Geology and Geophysics*.
- Nicol A, Beavan J 2003. Shortening of an overriding plate and its implications for slip on a subduction thrust, central Hikurangi Margin, New Zealand. *Tectonics* 22 (6), 1070, doi:10.129/2003TC001521.
- Nicol A, Van Dissen R, Vella P, Alloway B, Melhuish A 2002. Growth of contractional structures during the last 10 m.y. at the southern end of the emergent Hikurangi forearc basin, New Zealand. *New Zealand Journal of Geology and Geophysics* 45: 365-385.
- Ongley M 1943. Surface trace of the 1855 earthquake. *Transactions of the Royal Society of New Zealand* 73: 84-89.
- Ota Y, Williams DN, Berryman KR 1981. Part sheets Q27, R27 and R28 - Wellington (1st Edition). Late Quaternary Tectonic Map of New Zealand 1:50000 (with notes). New Zealand Department of Scientific and Industrial Research
- Palmer A, Van Dissen R 2002. Northern Ohariu Fault: earthquake hazard assessment of a newly discovered active strike-slip fault in Horowhenua. EQC Research Foundation Project 97/263. 52 p.
- Pillans B, Huber P 1995. Interpreting coseismic deformation using Holocene coastal deposits, Wellington, New Zealand. *Quaternary International* 26: 87-95.
- Reyners M 1998. Plate coupling and the hazard of large subduction thrust earthquakes at the Hikurangi subduction zone, New Zealand. *New Zealand Journal of Geology and Geophysics* 41: 343-354.
- Robinson R 1986. Seismicity, structure and tectonics of the Wellington region, New Zealand. *Geophysical Journal of the Royal Astronomical Society* 87: 379-409.
- Robinson R, Benites R, Van Dissen R 1998. Evidence for temporal clustering of large earthquakes in the Wellington region from computer models of seismicity. *Bulletin of the New Zealand National Society for Earthquake Engineering* 31: 24-32.

- Schermer ER, Van Dissen R, Berryman KR, Kelsey HM, Cashman SM 2004. Active faults, paleoseismology and historical fault rupture in the northern Wairarapa, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 47: 101-122.
- Stevens GR 1973. Late Holocene marine features adjacent to Port Nicholson, Wellington, New Zealand. *New Zealand Journal of Geology and Geophysics* 16: 455-484.
- Stevens GR 1974. Rugged landscape: the geology of central New Zealand, including Wellington, Wairarapa, Manawatu and the Marlborough Sounds. AH & AW Reed Ltd., Wellington, New Zealand. Reprinted in 1990 by DSIR Publishing, Wellington, New Zealand. 286 p.
- Stirling MW 1992. Late Holocene beach ridges displaced by the Wellington Fault in the Lower Hutt area, New Zealand. *New Zealand Journal of Geology and Geophysics* 35: 447-453.
- Stirling MW, McVerry GH, Berryman KR 2002. A new seismic hazard model for New Zealand. *Bulletin of the Seismological Society of America* 92: 1878-1903.
- Townsend D, Begg J, Villamor P, Lukovic B 2002. Late Quaternary displacement of the Mokonui Fault, Wairarapa, New Zealand: a preliminary assessment of earthquake generating potential. Institute of Geological and Nuclear Sciences Client Report 2002/58 prepared for Wairarapa Engineering Lifelines Association.
- Van Dissen RJ, Berryman KR 1996. Surface rupture earthquakes over the last c. 1000 years in the Wellington region, New Zealand, and implications for ground shaking hazard. *Journal of Geophysical Research* 101 (B3): 5999-6019.
- Van Dissen RJ, Berryman KR, Pettinga JR, Hill NL, 1992. Paleoseismicity of the Wellington-Hutt Valley segment of the Wellington Fault, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 35: 165-176.
- Van Dissen R, Begg J, Palmer A, Nicol A, Darby D, Reyners M 1998. Newly discovered active faults in the Wellington region, New Zealand. In: *Proceedings, New Zealand NZSEE Technical Conference, Taupo, New Zealand*: 1-7.
- Van Dissen R, Heron D, Palmer A 1999. Ohariu and Northern Ohariu faults: field guide to Late Quaternary active faulting: *Geological Society of New Zealand Miscellaneous Publication 107A*: 29-69.
- Van Dissen RJ, Begg JG, Robinson R 2001. The Akatarawa fault: a newly discovered fault in the Wellington region, and implications for increased hazard on the Wellington fault. In: *Proceedings, New Zealand Society for Earthquake Engineering Technical Conference, Wairakei, New Zealand. Paper No. 4.06.01*, 8 p.
- Van Dissen RJ, Berryman K, Webb T, Stirling M, Villamor P, Wood PR, Nathan S, Nicol A, Begg J, Barrell D, McVerry G, Langridge R, Litchfield N, Pace B, 2003. An interim classification of New Zealand's active faults for the mitigation of surface rupture hazards.

- In proceedings, Pacific Conference on Earthquake Engineering, Christchurch, New Zealand, February, 2003, Paper No.155.
- Van Dissen R, Heron D, Hinton S, Guerin A 2004. Mapping active faults and mitigation surface rupture hazard in the Kapiti Coast District, New Zealand. *in proceedings*, NZSEE Technical Conference, Rotorua, New Zealand. Paper No. 21, 9 p.
- Wallace LM, Beavan J, McCaffrey R, Darby D 2004. Subduction zone coupling and tectonic block rotations in the North Island, New Zealand. *Journal of Geophysical Research* 109: 1-24.
- Webb TH, Anderson H 1998. Focal mechanisms of large earthquakes in the North Island of New Zealand: slip partitioning at an oblique active margin. *Geophysical Journal International* 134: 40-86.
- Zachariassen J, Villamor P, Lee JM, Lukovic B, Begg JG 2000. Late Quaternary faulting of the Masterton and Carterton faults, Wairarapa. *GNS Client Report* 2000/71.
- Zachariassen J, Berryman KR, Prentice C, Langridge R, Stirling M, Villamor P, and Rymer M 2001. Size and Timing of Large Prehistoric Earthquakes on the Wairau Fault, South Island. *GNS Client report* 2001/13. 30 p.

# THE SOUTHERN END OF THE WAIRARAPA FAULT, AND SURROUNDING STRUCTURES IN COOK STRAIT

Philip M. Barnes

National Institute of Water & Atmospheric Research, Private Bag 14-901, Wellington  
(p.barnes@niwa.co.nz)

## INTRODUCTION

The M8.1 1855 Wairarapa Earthquake was associated with rupture of the Wairarapa Fault (Grapes and Wellman, 1988; Grapes and Downes, 1997). The surface rupture on land extended along the eastern edge of the Rimutaka Ranges for at least 75 km from near Alfredton to Cook Strait (Fig. 1), and was associated with right-lateral displacements of more than 12 m, together with widespread regional uplift of south western North Island. Maximum uplift at Turakirae Head, at the south coast of the Rimutaka Ranges, indicates that the rupture extended offshore. Indeed, Darby and Beanland (1992) modelled the dislocation as a west-dipping fault extending southwards for about 40 km into southern Cook Strait.

Interpretations of seismic reflection profiles and mapping of fault structure in Cook Strait by Carter et al. (1988) indicated that the Wharekauhau section of the Wairarapa Fault extends offshore along the Wairarapa Canyon, and several structures were identified on the eastern margin of Nicholson Bank. Barnes and Audru (1999a, b) revised the offshore structure maps using improved coastal bathymetry (Mitchell, 1996), and additional seismic profiles from the eastern Marlborough shelf. They discovered a close co-alignment of the southern end of the Wairarapa Fault with the newly mapped Needles Fault north east of Cape Campbell, and suggested that a relatively youthful strike-slip fault zone has been developing across the strait during the Quaternary (c. < 1.5 Myr).

In 2002 and 2003, the National Institute of Water and Atmospheric Research (NIWA) acquired high-resolution SIMRAD EM300 multibeam bathymetric data from Cook Strait on board RV *Tangaroa*. The data provide unprecedented details of the irregular geomorphology associated with submarine canyons and landslide catchments, and reveal two lineaments that appear to be late Quaternary fault traces in the vicinity of the 1855 earthquake. Whilst interpretation of these traces does not constrain the precise extent of the 1855 rupture, it does enable further re-evaluation of the structure of the southern Wairarapa Fault within the context of the wider plate boundary deformation in the region.

## REGIONAL TECTONIC CONTEXT

The Wairarapa Fault is part of the North Island Dextral Fault Belt, a group of major structures that extend the length of North Island. These strike-slip faults accommodate much of the crustal motion (at least 20 mm/yr) expected parallel to the plate boundary as a result of oblique convergence between the Pacific and Australian plates (e.g., Van Dissen and Berryman, 1996). Beneath these faults is the plate boundary thrust of the Hikurangi subduction zone. This mega-thrust fault dips gently to the northwest, and is about 20 km deep beneath the southern Wairarapa Fault (Darby and Beanland, 1992).

The surface expression of this thrust lies in 2500–3000 m water depth in the Hikurangi Trough east of North Island (e.g., Barnes et al., 1998).

Cook Strait and Marlborough straddle a transition between the Hikurangi subduction zone and very oblique continental collision along the Southern Alps. The Pacific plate has been subducted beneath Marlborough to depths of more than 150 km, but geological studies indicate that at least 80 % of the total 38 mm/yr of relative plate motion is currently being accommodated by strike-slip faults in the Marlborough Fault System (e.g., Holt and Haines, 1995). These northeast-trending faults pass through the Kaikoura Ranges and extend offshore beneath southern Cook Strait and the eastern Marlborough continental margin (Carter et al., 1988, Barnes and Audru, 1999a, b).

The Marlborough Fault System comprises several major strike-slip faults that merge into the southern end of the North Island Dextral Fault Belt and Hikurangi margin. From north to south, the major structures of the Marlborough Fault System on land include the Wairau, Awatere, Clarence, Kekerengu, and Hope Faults. These faults are well expressed in the landscape, and have slip rates reasonably well constrained from the dating and analysis of offset late Quaternary geomorphic features. Individual slip rates generally increase towards the southeast, from about 3–5 mm/yr on the Wairau Fault to as much as 20–35 mm/yr on the Hope Fault (Holt and Haines, 1995). The major faults along the southeastern edge of the system typically strike within about 10° of the azimuth of relative Pacific–Australia plate motion. At a broad scale, these faults progressively step to the left with displacement being transferred from the Hope to the Kekerengu, Chancet, Needles, and Boo Boo faults. To the east, the lower continental margin at the edge of the Hikurangi Trough is underlain by active thrust faults associated with bathymetric relief of > 1 km.

## **STRUCTURE OF THE SOUTHERN WAIRARAPA FAULT**

The surface trace of the Wairarapa Fault north of Lake Wairarapa is linear, and trends about 040–045°. Towards the south, this section has been traced into the upper reaches of the Orongorongo River catchment (Begg and Johnston, 2000). The late Pleistocene slip rate has been estimated at about 6–10 mm/yr. In 1855, this section ruptured together with the approximately parallel Wharekauhau thrust, which intersects the main trace immediately south of Lake Wairarapa and projects offshore into the western side of Palliser Bay (Grapes and Wellman, 1988). The main trace north of the lake is offset to the left with respect to the Wharekauhau thrust, and the step-over width is about 5–6 km. This geometry represents a restraining jog, in which there are space problems created by the fault geometry and sense of displacement, and this contributed to the increased coseismic uplift of the southern Rimutaka Ranges.

Marine seismic reflection data reveals the Wharekauhau thrust beneath the western wall of Palliser Canyon, east of Turakirae Head (Fig. 1; Barnes and Audru, 1999a). The fault bounds the western margin of the Wairarapa sedimentary basin, which extends southwards beneath the continental shelf of Palliser Bay. Basement rocks in the hanging wall (west) are thrust over the late Miocene–Recent section in the Wairarapa Basin, with total vertical separation of the order of 2.0–2.3 km. An absence of thickening growth strata in the footwall indicates that the vertical displacement postdates the deposition of late Miocene sediments. Considering the late Quaternary uplift rate of c. 3

mm/yr at Turakirae Head (McSaveney & Hull 1995), the observed minimum vertical separation of the basement could have been achieved in 0.6–0.8 Myr.

The southwest continuation of this fault may be associated with a subdued lineament crossing Nicholson Canyon and the eastern margin of Nicholson Bank. Reverse displacement on the fault, from many late Quaternary earthquakes, appears to have resulted in a ramp (a subdued scarp down to the south east) about 100 m high across the floor of Nicholson Canyon. Improved seismic reflection coverage and data quality, however, are required to confirm if the lineament on the eastern margin of Nicholson Bank is a continuation of the fault. Based on the length of the submarine lineament (33 km), the entire onshore–offshore Wharekauhau section could be up to 47 km long.

The multibeam bathymetry data reveals a second surface lineament associated with discontinuous scarps lying 5–7 km west of the Wharekauhau section. Although seismic reflection data are required to evaluate the subsurface structure, and no dextral displacements are yet recognised, the linearity of the scarp is typical of active strike-slip faults in the region. This western fault is at least 33 km in length, and has a surface trace crossing Nicholson Canyon, Nicholson Bank, and Cook Strait Canyon. The surface trace trends about 050°, projects directly towards Turakirae Head, and can be traced to within 4 km of the coast. The southern part of the trace lies along strike of, and projects into, the northern end of the Needles Fault on the south side of Cook Strait Canyon.

#### **WHERE IN SOUTHERN COOK STRAIT DID THE 1855 RUPTURE TERMINATE?**

From the 6 m magnitude of 1855 uplift at Turakirae Head, the Wairarapa Fault rupture can be confidently interpreted to have extended into Palliser Bay. It can reasonably be inferred that the entire length of the Wharekauhau section ruptured in the earthquake.

It is questionable whether the 1855 rupture involved the western offshore trace of the Wairarapa Fault or potentially part of the Needles Fault to the southwest. Severe aftershocks reported at Kekerengu on the eastern Marlborough coast two days after the mainshock were possibly associated with earthquakes located to the south of the main shock rupture zone, however the reliability of the felt intensities reported are uncertain (Grapes and Downes, 1997). Where the western trace of the Wairarapa Fault crosses Nicholson and Cook Strait canyons, there is no evidence in the multibeam bathymetry data for a recent displacement of the sediment-fill in the axes of the canyons, nor clear dextral displacements of the canyon walls. However, potential single event dextral displacements of up to a few metres may not be resolvable in the digital elevation model of the seabed surface, which has a resolution determined by the 10 × 10 m cell size. Furthermore, the capacity of currents and storm waves to move sediment in Cook Strait (Carter and Lewis, 1995) is such that a potential 150 year old surface trace in the canyon axis could possibly now be masked by sedimentation and erosional processes, including landslide debris emplaced during the larger aftershocks.

The bathymetry data reveals hundreds of submarine landslide scars on the margins of Nicholson Bank and the adjacent submarine canyons, and high-frequency seismic profiles show that the canyon fill sediments include much landslide debris. Many of the landslide scars appear to be very youthful but there is no data at present to constrain their ages. Whilst many are certain to be pre-1855, it is extremely likely that submarine

landslides would have been triggered in 1855, given the severity and duration of strong ground motion (Grapes and Downes, 1997).

## CONCLUSIONS

New multibeam bathymetric data from Cook Strait reveals two lineaments that appear to be active traces of the southern Wairarapa Fault. Each trace is discontinuous and about 33 km in length. The eastern trace coincides with the offshore continuation of the Wharekauhau thrust, implying a total onshore – offshore length of this structure of about 47 km. The western trace lies 5–7 km to the west, and aligns approximately with Turakirae Head and the Needles Fault northeast of Cape Campbell. Improved multichannel seismic reflection coverage and data quality are required for subsurface structure imaging and confirmation of the active fault traces.

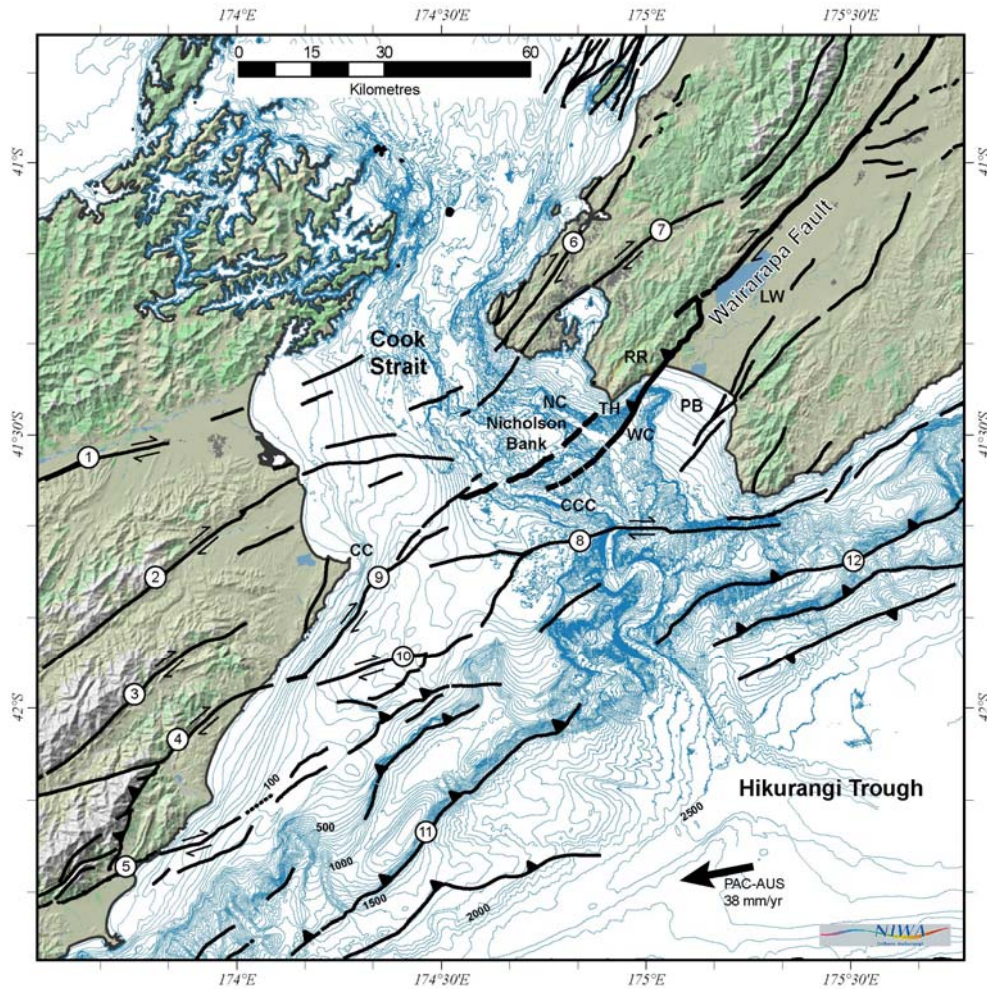
The 1855 Wairarapa Earthquake rupture most likely involved the offshore Wharekauhau section, but it is not known whether the western trace or structures to the southwest were involved. Numerous undated submarine landslide scars are observed in the vicinity, at least some of which were likely triggered in the 1855 earthquake.

## REFERENCES

- Barnes, P. M.; Audru, J-C. 1999a: Quaternary faulting in the offshore Flaxbourne and Wairarapa Basins, southern Cook Strait, New Zealand. *New Zealand Journal of Geology and Geophysics*, 42: 349-367.
- Barnes, P. M.; Audru, J-C. 1999b: Recognition of active strike-slip faulting from high-resolution marine seismic reflection profiles: Eastern Marlborough Fault System, New Zealand. *Geological Society of America Bulletin* 111: 538-559.
- Barnes, P. M.; Mercier de Lépinay, B.; Collot, J-Y.; Delteil, J.; Audru, J-C. 1998: Strain partitioning in the transition area between oblique subduction and continental collision, Hikurangi margin, New Zealand. *Tectonics* 17: 534-557.
- Begg, J.G., Johnston, M.R. (compilers) 2000: Geology of the Wellington area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 10. 1 sheet + 64p. Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited.
- Carter, L.; Lewis, K; Davey, F. 1988: Faults in Cook Strait and their bearing on the structure of central New Zealand. *New Zealand Journal of Geology and Geophysics* 31: 431-446.
- Carter, L.; Lewis, K. 1995: Variability of the modern sand cover on a tide and storm driven inner shelf, south Wellington, New Zealand. *New Zealand Journal of Geology and Geophysics* 38: 451-470.
- Darby, D.J., Beanland, S. 1992: Possible source models for the 1855 Wairarapa Earthquake, New Zealand. *Journal of Geophysical Research* 97: 12,375-12,389.

- Grapes, R., Wellman, H. 1988: The Wairarapa Fault. Publication 4, Research School of Earth Sciences, Geological Board of Studies. Victoria University of Wellington, 55pp, Wellington.
- Grapes, R., Downes, G. 1997: The 1855 Wairarapa, New Zealand, earthquake – Analysis of historical data. *Bulletin of the New Zealand National Society for Earthquake Engineering* 30: 273-367.
- Holt, W. E.; Haines, A. J. 1995. The kinematics of northern South Island, New Zealand, determined from geological strain rates: *Journal of Geophysical Research* 100: 17991-18010.
- McSaveney, M. J.; Hull, A. G. 1995: A 7000-year record of great earthquakes at Turakirae Head, Wellington. in Subduction Systems and Processes in New Zealand, Programme and Abstracts, New Zealand Geophysical Society Symposium 1995.
- Mitchell, J. S. 1996: Cook Strait bathymetry, 3rd Edition. New Zealand Oceanographic Institute Chart, Coastal series, 1:200,000.
- Van Dissen, R.J.; Berryman, K.R. 1996. Surface rupture earthquakes over the last ~1000 years in the Wellington region, New Zealand, and implications for ground shaking hazard. *Journal of Geophysical Research*, 101, 5999–6019.





**Figure 1** Structure map and bathymetry (m) of the southern Cook Strait region showing major active faults. The Wairarapa Fault is shown in bold, and its offshore structure is refined here as part of this study. Numbered faults include: (1) Wairau Fault, (2) Awatere Fault, (3) Clarence Fault, (4) Kekerengu Fault, (5) Hope Fault, (6) Ohariu Fault, (7) Wellington Fault, (8) Boo Boo Fault, (9) Needles Fault, (10) Chancet Fault, (11) Kekerengu Bank thrust, and (12) Opuawe – Uruti Fault. Selected principal sources of data are listed in the reference list. Abbreviations include: CC, Cape Campbell; CCC, Cook Strait Canyon; LW, Lake Wairarapa; NC, Nicholson Canyon; PB, Palliser Bay; RR, Rimutaka Ranges; TH, Turakirae Head; and WC, Wairarapa Canyon.

# WAIRARAPA AND WELLINGTON EARTHQUAKES: PAST, PRESENT, AND FUTURE

Martin Reyners

Institute of Geological and Nuclear Sciences, PO Box 30368, Lower Hutt  
(m.reyners@gns.cri.nz)

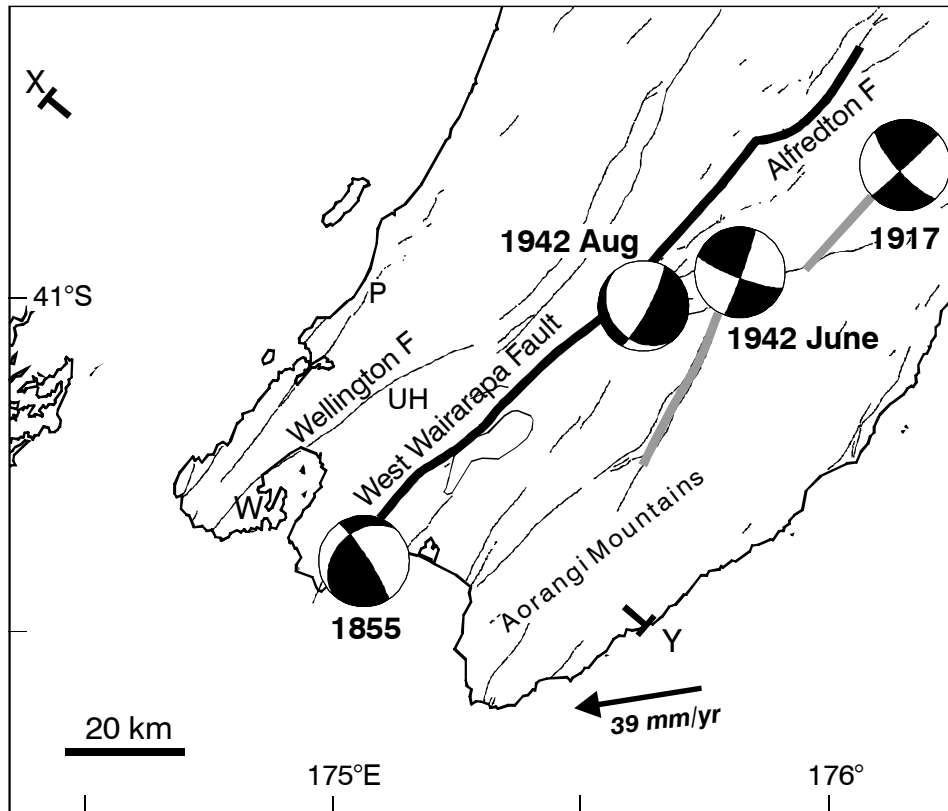
## WHY DID THE 1855 EARTHQUAKE HAPPEN?

Blame it on plate tectonics. In the Wairarapa and Wellington regions, the Pacific and Australian plates are converging at about 39 mm/yr at an azimuth of 261° (Fig. 1). This has resulted in subduction of the Pacific plate and deformation within the overlying Australian plate. However, the subduction zone has a strike of about 045°, oblique to the plate convergence direction. This results in a partitioning of slip at the plate boundary, with the convergent component of the relative plate motion largely taken up with down-dip slip on the plate interface, and the transcurrent component largely taken up with dextral strike-slip on faults within the overlying plate (e.g. Webb & Anderson 1998, Nicol & Beavan 2003).

As described elsewhere in this volume, the 1855 Wairarapa earthquake largely involved dextral motion on the West Wairarapa fault in the overlying plate, consistent with slip partitioning at the plate boundary. Limited uplift data from the event have been modelled as resulting from movement on a listric (spoon-shaped) fault in the overlying plate, together with rupture on 0 to 50 km width of the deeper part of the of the plate interface (Darby & Beanland 1992; see Fig. 2). The shallower part of the plate interface, east of the West Wairarapa fault, apparently did not rupture in 1855. This portion of the plate interface is currently locked and accumulating strain, as indicated by both seismological and GPS data (Reyners, 1998; Wallace et al. 2004). It is likely that similar locking of this part of the plate interface occurred prior to 1855, leading to the build-up of strain in the overlying plate, the transcurrent component of which was released in 1855.

What the 1855 earthquake demonstrated is that the overlying plate in the vicinity of the West Wairarapa fault is sufficiently strong to store enough strain energy to produce a magnitude 8.2 earthquake. This is consistent with what we know about the rheology of the overlying plate. Between the West Wairarapa fault and the west coast of the southern North Island, the overlying plate has a relatively high  $Q_p$  of 300–500 (Fig. 2), suggesting that this part of the crust is strong compared to that further to the southeast. There,  $Q_p$  less than 250, low  $V_p$  and high  $V_p/V_s$  all suggest a much weaker crust, probably due to overpressured fluids within this part of the accretionary wedge (Eberhart-Phillips *et al.* 2005). [ $Q_p$  is the quality factor for  $P$  waves, which is inversely related to attenuation of these waves with distance, while  $V_p$  and  $V_s$  are the seismic velocities of  $P$  and  $S$  waves respectively]. The dextral fault belt, including the West Wairarapa, Wellington and Ohariu faults, is confined to this relatively strong crustal unit, suggesting a first order control of rheology on the mode of deformation.

Eberhart-Phillips *et al.* (2005) have suggested that the strong crust represents a distinct geological terrane (the Haast schist belt), and that the impact of this terrane with the subducted plate may contribute to the strong coupling between the plates seen in this region.



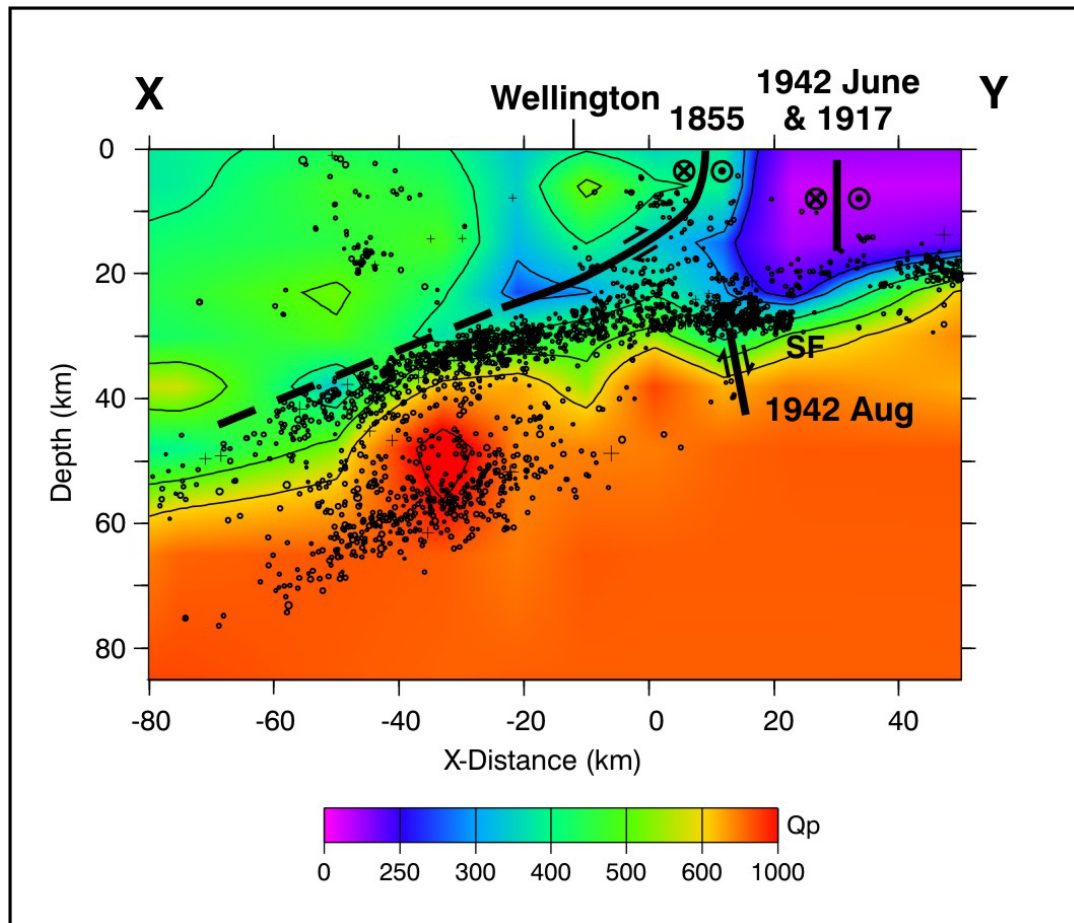
**Figure 1.** Historical seismicity and active surface faults in the southern North Island. Beach balls are lower hemisphere projections of the focal mechanisms of large earthquakes since 1917, with compressional quadrants shaded and inferred fault lengths shown by grey bars (Doser & Webb 2003). The 1855 rupture is shown by the solid line, and the focal mechanism for the southern end of the rupture is denoted by the beach ball at the south coast (Darby & Beanland 1992). X-Y denotes the line of section in Fig. 2, and the arrow shows the velocity of the Pacific plate relative to the Australian plate. Legend: W – Wellington, P – Paekakariki, UH – Upper Hutt.

## WHAT HAS HAPPENED SINCE?

Not much in terms of large earthquakes. In 1917 an event of magnitude  $M_w$  6.8–6.9 occurred east of the northern end of the 1855 rupture (Fig. 1). The focal depth of this earthquake is poorly constrained (18–25 km), but the strike-slip mechanism of the event suggests it ruptured the overlying plate (Doser & Webb 2003). [If it had occurred in the subducted plate, we would have expected a normal-faulting mechanism, which is the ubiquitous mechanism for contemporary smaller events in this region]. Then in 1942 a sequence of earthquakes occurred east of the central part of the 1855 rupture, including a shallow (12–17 km)  $M_w$  6.9–7.2 event on June 24 and a deeper (34–40 km)  $M_w$  6.8 event on August 01. The June mainshock had a strike-slip mechanism, consistent with rupture in the overlying plate, while the August mainshock had a normal-faulting mechanism, consistent with rupture in the subducted plate (Doser & Webb 2003; Fig. 1).

All these larger earthquakes occurred in regions where there is very little contemporary small earthquake activity (Fig. 2). Whether these events were triggered by stress changes following the 1855 earthquake, including viscoelastic relaxation in the mantle of the subducted plate, remains an open question. However, the 1942 June 24

earthquake may have been triggered by the Coulomb failure stress changes following the 1934  $M_w$  7.2-7.4 Pahiataua earthquake, as the 1942 rupture may represent a continuation of that earlier rupture (Doser & Webb 2003). Similarly, the 1942 June 24 earthquake may have triggered the deeper 1942 August 01 earthquake in the subducted plate, as happened (in reverse order) in the two largest events of the 1990 Weber earthquake sequence 100 km further northeast (Robinson 2003).

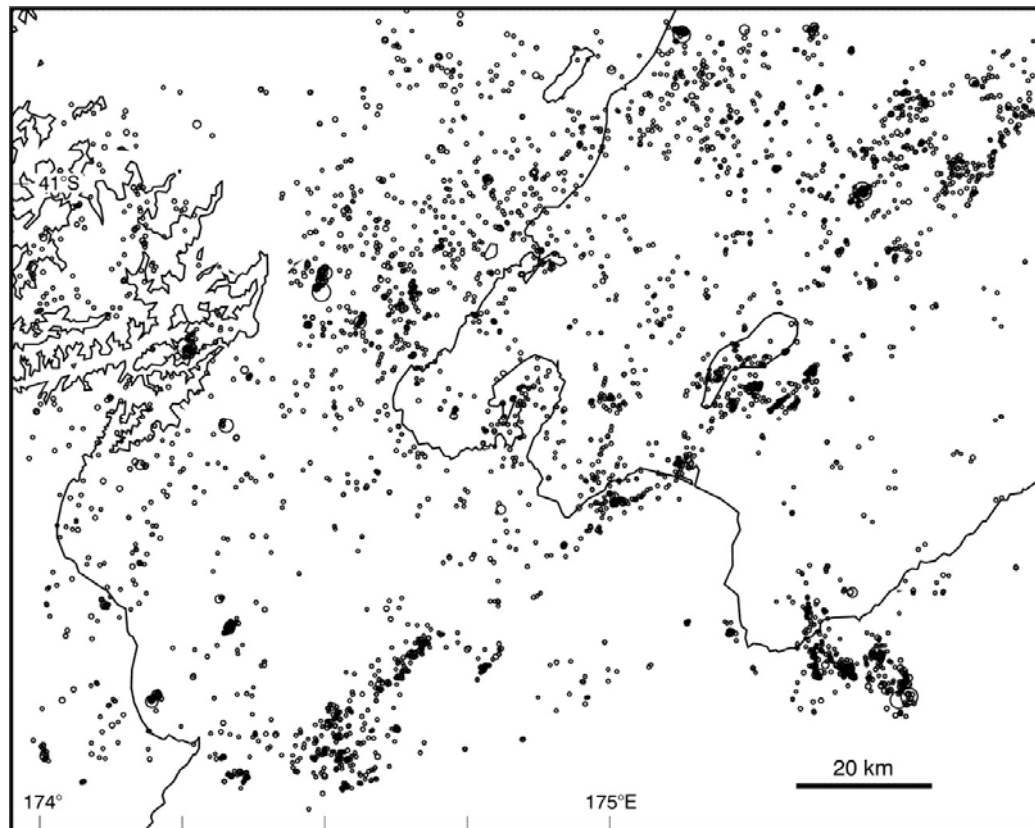


**Figure 2.**  $Q_p$  structure along the line X-Y shown in Fig.1 (Eberhart-Phillips *et al.* 2005), together with double-difference relocations of earthquakes northeast of Cook Strait during 1990–2001 (Du *et al.* 2004). Solid lines (dashed where uncertain) are schematic fault planes of large historical earthquakes. SF denotes the seismic front in the top of the subducted plate.

## WHAT IS HAPPENING NOW?

Seismicity in the Wellington and southern Wairarapa regions recorded by the Wellington Network of seismographs has been described by Robinson (1986) and Du *et al.* (2004). Small earthquakes with epicentres within  $1^\circ$  of Wellington, and with magnitudes 2.3 or more, occur at an average rate of 5.5 per day. The great majority of these small events are concentrated in a dipping seismic zone within the top of the subducted plate (Fig. 2). A notable feature in the spatial distribution of these events is a sharp “seismic front”, behind which the distribution is relatively uniform. Double-difference relocation of earthquakes near this front reveals that they delineate NE-SW striking normal faults in the top of the subducted plate (Fig. 3). This is one of the few places in New Zealand where background seismicity delineates faults, a situation which may indicate high pore pressure on these fault planes. It seems likely that the 1942

August 01 earthquake occurred on one of these faults and/or its extension into the mantle of the subducted plate. The fact that these faults parallel surface faults in the overlying plate further suggests that faults in the top of the subducted plate may control the orientation of faulting seen at the surface.



**Figure 3.** Map view of double-difference relocations of earthquakes in the top of the subducted plate and near the plate interface during 1990–2001.

We still don't fully understand the genesis of the seismic front. It may reflect the onset of a basalt/gabbro phase transition to blueschist and then to eclogite in the crust of the subducted plate, causing embrittlement and high pore pressures due to dehydration. Alternatively, it may represent a marked change in frictional conditions (and hence coupling) at the plate interface, again leading to changes in pore pressure in the top of the subducted plate. This view is supported by recent seismic reflection and refraction studies of the seismic front further northeast in Hawke Bay. Here the seismic front marks a conspicuous kink in the subducted plate, the transition from weak to strong plate coupling, and the base of prominent NW-dipping splay faults that have uplifted the forearc (Henry *et al.* 2005). A similar kink and splay faults at the seismic front in the Wairarapa would explain the enigmatic uplift of the Aorangi Mountains. Also, the onset of strong coupling at the seismic front beneath the eastern edge of the Wairarapa basin is consistent with observations from large circum-Pacific subduction thrust earthquakes that asperities (strongly coupled portions of the plate interface) underlie basins in overlying plate (Wells *et al.* 2003).

## WHAT WILL HAPPEN IN THE FUTURE?

Sooner or later we will have a large thrust earthquake on the plate interface. The magnitude of such an event will scale with the area of the plate interface that ruptures. Assuming that a segment of the plate interface of similar length to the 1855 rupture will fail in a single event, Reyners (1998) has estimated a magnitude of about  $M_w$  8.0 for such an event. Available seismological and GPS data suggests the plate interface is strongly coupled, and the 1855 earthquake demonstrated that the overlying plate is strong — a necessary condition for a large thrust earthquake on the plate interface. Currently the margin-perpendicular slip deficit at the portion of the plate interface that is thought to be strongly coupled averages about 10 mm/yr (Wallace *et al.* 2004) in the southern North Island. If this rate were representative of the average rate over the entire seismic cycle, the recurrence interval for an  $M_w$  8.0 event would be about 400 years. This is similar to the estimated recurrence interval of  $M_w$  7.0 earthquakes on the thrust fault coring the Aorangi Mountains anticline (Stirling *et al.* 1998). These “hidden” faults appear to be the most active in the region.

Modelling of elastic interactions between faults in the Wellington region demonstrates that mutual enhancement most often occurs between the plate interface and the overlying strike-slip faults, and between the northern and southern segments of the Wellington fault (Robinson & Benites 1996). The upshot of this is that events of magnitude 7.2 or more (“characteristic” events in the sense that they rupture most of the fault plane) are likely to be clustered in time, which has implications for seismic hazard. It appears that large events that rupture the plate interface are most likely to “bring the clock forward” or induce large events on the strike-slip faults in the overlying plate, and vice-versa.

## CHALLENGES FOR THE FUTURE

It thus becomes very important to learn more about the seismic potential of the plate interface. Firstly, we need to have a better estimate of which parts of the plate interface are tightly coupled (i.e. asperities), and which parts are slipping more freely. One way of doing this is to map the distribution of small earthquake clusters at the plate interface, which may represent repeated rupture of a small asperity within an otherwise creeping region. A search in the Wellington region by Du *et al.* (2004) has failed to find such events at the plate interface, consistent with GPS data that the interface there is strongly coupled. This search should be extended along the subduction zone to better define the length of a possible interplate earthquake rupture.

Another way of defining the coupled portion of the plate interface is to monitor how the plate boundary responds to perturbations, such as episodes of slow slip both downdip and updip of the coupled region as measured by GPS. An episode of slow slip beneath Paekakariki triggered a swarm of earthquakes in the top of the subducted plate beneath Upper Hutt in April-May 2004. Similarly, an episode of slow slip under Wanganui early in 2005 “lit up” earthquake activity in the southern North Island, with earthquake sequences of magnitude 5 or more in Upper Hutt, Wanganui and off the Wairarapa coast (Reyners *et al.* 2005).

The resulting enhanced understanding of plate coupling should then be fed into three-dimensional finite element models, constrained by rheology, deformation, stress and

seismicity. The development of moderate magnitude seismicity predicted by such models should provide insight into where we are in the cycle of large earthquakes in the southern North Island.

## ACKNOWLEDGEMENT

This paper relies heavily on the work of Russell Robinson, who was instrumental in setting up the Wellington Network of seismographs in 1976 and has been at the forefront of studies of Wellington seismicity since.

## REFERENCES

- Darby, D.J. & Beanland, S., 1992. Possible source models for the 1855 Wairarapa earthquake, New Zealand. *J. Geophys. Res.*, 97, 12,375-12,389.
- Doser, D.I. & Webb, T.H., 2003. Source parameters of large historical (1917-1961) earthquakes, North Island, New Zealand. *Geophys. J. Int.*, 152, 795-832.
- Du, W.X., Thurber, C. H., Reyners, M., Eberhart-Phillips, D. & Zhang, H., 2004. New constraints on seismicity in the Wellington region of New Zealand from relocated earthquake hypocentres. *Geophys. J. Int.*, 158, 1088-1102.
- Eberhart-Phillips, D., Reyners, M., Chadwick, M. & Chiu, J-M., 2005. Crustal heterogeneity and subduction processes: 3-D  $V_p$ ,  $V_p/V_s$  and  $Q$  in the southern North Island, New Zealand. *Geophys. J. Int.*, 162, 270-288.
- Henrys, S., Reyners, M., Pecher, I., Bannister, S., Nishimura, Y. & Maslen, G., 2005. Shallow plate kinking along the central North Island of New Zealand: a subduction escalator. Submitted to *Geology*, June 2005.
- Nicol, A. & Beavan, J., 2003. Shortening of an overriding plate and its implications for slip on a subduction thrust, central Hikurangi Margin, New Zealand. *Tectonics*, 22, No. 6, 1070, doi: 10.1029/2003TC001521.
- Reyners, M., 1998. Plate coupling and the hazard of large subduction thrust earthquakes at the Hikurangi subduction zone, New Zealand. *N.Z. J. Geol. Geophys.*, 41, 343-354.
- Reyners, M., Robinson, R. & Bannister, S., 2005. Definition of the locked zone of the shallow plate interface in the Hikurangi subduction zone using clusters of small earthquakes, *EQC Research Report 03/493*, in preparation.
- Robinson, R., 1986. Seismicity, structure and tectonics of the Wellington region, New Zealand. *Geophys. J. R. astr. Soc.*, 87, 379-409.
- Robinson, R., 2003. Fault interactions and subduction tectonics: a re-examination of the Weber, New Zealand, earthquake sequence of 1990. *Geophys. J. Int.*, 154, 745-753.
- Robinson, R. & Benites, R., 1996. Synthetic seismicity models for the Wellington region, New Zealand: implications for the temporal distribution of large events. *J. Geophys. Res.*, 101, 27,833-27,844.

- Stirling, M.W., Wesnousky, S.G. & Berryman, K.R., 1998. Probabilistic seismic hazard analysis of New Zealand. *N.Z. J. Geol. Geophys.*, 41, 355-375.
- Wallace, L.M., Beavan, J., McCaffrey, R. & Darby, D., 2004. Subduction zone coupling and tectonic rotations in the North Island, New Zealand. *J. Geophys. Res.*, 109, B12406, doi: 10.1029/2004JB003241.
- Webb, T.H. & Anderson, H., 1998. Focal mechanisms of large earthquakes in the North Island of New Zealand: slip partitioning at an oblique active margin. *Geophys. J. Int.*, 134, 40-86.
- Wells, R.E., Blakely, R.J., Sugiyama, Y., Scholl, D.W. & Dinterman, P.A., 2003. Basin-centred asperities in great subduction zone earthquakes: a link between slip, subsidence, and subduction erosion? *J. Geophys. Res.*, 108, B10, 2507, doi: 10.1029/2002JB002072.



# **STRONG GROUND SHAKING IN THE 1855 WAIRARAPA EARTHQUAKE**

David J. Dowrick

Institute of Geological & Nuclear Sciences, 21 Kotare Crescent, Tauranga  
(d.dowrick@gns.cri.nz)

## **INTRODUCTION**

The Mw 8.2 1855 Wairarapa earthquake is the largest earthquake to have occurred in New Zealand in historical times. The maximum intensity that occurred was Modified Mercalli X (MM10). This is the strongest intensity known to have occurred in New Zealand. MM10 has also occurred in three other earthquakes, namely the 1929 Buller earthquake (Mw 7.7), the 1931 Hawke's Bay earthquake (Mw 7.8) and the 1968 Inangahua earthquake (Mw 7.2).

From the attenuation modelling of Dowrick & Rhoades (in press), it appears that the threshold event for producing intensity MM10 is a surface rupturing earthquake with a magnitude of  $M_w \approx 7.2$ . Although there were no indicators in existence in the respective near source regions for MM10, ground shaking of similar strength is likely to have occurred in up to four other large, shallow New Zealand earthquakes, such as those of 1848 Marlborough ( $M_w \geq 7.5$ ), 1934 Pahiatua (Mw 7.4), and possibly 1843 Wanganui (Mw 7.5?) and 1863 Central Hawke's Bay (Mw 7.5?). This means that the average return period of shaking of intensity MM10 in this country since 1840 could be as short as 20 years.

## **NEAR SOURCE INTENSITIES IN 1855**

The isoseismal map for the Wairarapa earthquake presented in Figure 1 is part of that of Grapes & Downes (1997), with the addition of the fault rupture the MM10 isoseismal derived by Hancox et al (1998) in their extensive study of earthquake-induced landslides. Widespread landsliding occurred in the Rimutaka and Tararua ranges, which rise immediately to the west of the southern end of the causative Wairarapa fault.

As seen in Figure 1, central Wellington lies approximately 22 km west of the surface trace of the fault. Over this distance, the attenuation of the earthquake waves was enough to reduce the intensity from MM10 near the source to MM9 in central Wellington. This intensity represents very strong ground shaking that caused severe damage to most structures in Wellington, all of which, of course, were not designed to resist earthquake shaking.

## **STRONG GROUND MOTION MODELLING OF THE 1855 EARTHQUAKE**

In the absence of instrumental data of ground motions produced by the 1855 earthquake, we resort to attenuation modelling in order to obtain estimates of the strength of ground shaking that occurred in the near source region. For the sake of simplicity we restrict ourselves to considering peak ground acceleration (pga), and confine that to identifying locations where the mean pga would be 0.5g (that is, the mean pga associated with intensity mm9) and to estimating the likely mean pga that would have occurred in central Wellington.

The geometry of the isopga line is estimated using two New Zealand predictive models, one using a strong motion (acceleration) model (McCrery pers. comm.), and the other using the isoseismal model of Dowrick & Rhoades (in press) for intensity mm9 ( $\approx 0.5g$ ). Pga is estimated from mm intensity using the relationship given in Dowrick & Rhoades (2005). It is seen in Figure 2 that the “acceleration” model has a similar area inside the 0.5g pga line to the “isoseismal” model.

The strength of ground shaking in central Wellington is indicated from the actual mm9 and mm10 isoseismals to have a mean pga of  $\approx 0.57g$ , while that estimated from the “acceleration” model is 35% lower at 0.38g.

The “acceleration” model is overly narrow, an error that has recently been shown (Dowrick & Rhoades 2005) to be an artefact of an unrealistic modelling assumption (the source-to-site distance) that is common to all such attenuation models worldwide.

### **NEAR SOURCE INTENSITIES IN THE 1934 PAHIATUA EARTHQUAKE**

Seventy-nine years after the Wairarapa earthquake, the Mw 7.4 earthquake occurred, centred in the Wairarapa region to the northeast of the 1855 event. As seen in Figure 3, the strongest observed intensities were MM9, but as noted in the introduction the 1934 event was sufficiently large and shallow to have caused shaking intensity of MM10 in the near source region. The attenuation model of Dowrick & Rhoades (in press) suggests that the MM10 isoseismal would have been about 20 km long and 10 km wide.

The difference in magnitude (0.8 units) between the 1855 and 1934 earthquakes is seen in Figure 4 to have caused a large difference in the areas enclosed by their MM8 isoseismals.

As seen in Figure 4, the surface trace of the fault rupture of the 1934 earthquake is about 10 km long, while the subsurface rupture had a length estimated as 60 km (Dowrick & Rhoades 2004). The difference between the strike of the surface trace and that estimated by Doser & Webb (2003) suggests that the 1934 fault rupture may not be linear in plan (Doser & Webb, pers. comm.), as shown somewhat speculatively with Figure 4. The proximity of the adjacent ends of the two fault ruptures makes it likely that 1855 event brought forward the rupture that occurred in 1934 (R. Robinson, pers. comm.).

### **CONCLUSIONS**

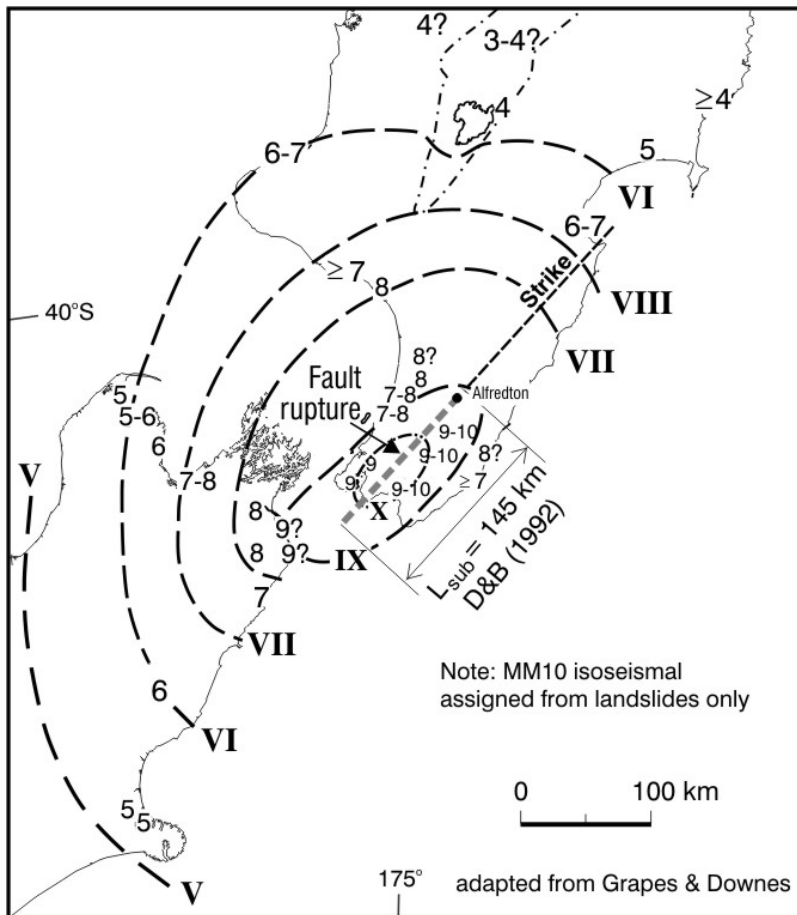
The following conclusions have been drawn:

1. The strongest shaking in the 1855 Mw 8.2 Wairarapa earthquake is known to have been of intensity MM10 in the near source region, while in central Wellington the intensity was midway between the MM9 and MM10 isoseismals (PGA  $\approx 0.57g$ ), suggesting that the mean PGA there would have been about 0.57g.
2. The mean PGA in Wellington predicted by the New Zealand strong motion attenuation model considerably underestimates the strength of shaking.

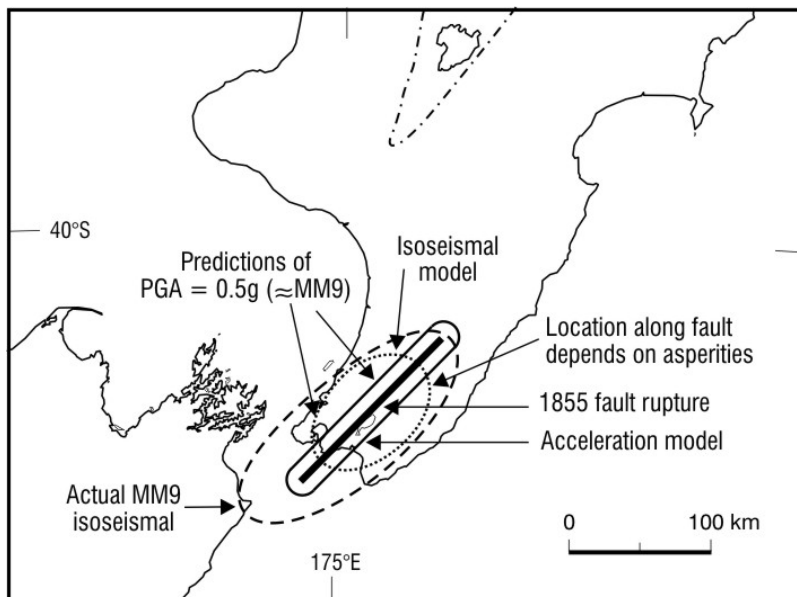
3. Although there were no indicators available for it, the 1934 Mw 7.4 Pahiataua earthquake was strong enough to have caused intensity MM10 in a near source area about 20 km long and 10 km wide.
4. The fault ruptures of the 1855 and 1934 earthquakes lie in an almost continuous northeast-trending line from Cook Strait to southern Hawke's Bay, possibly with an offset between them. The 1855 event thus may have brought forward in time the 1934 event.

## REFERENCES

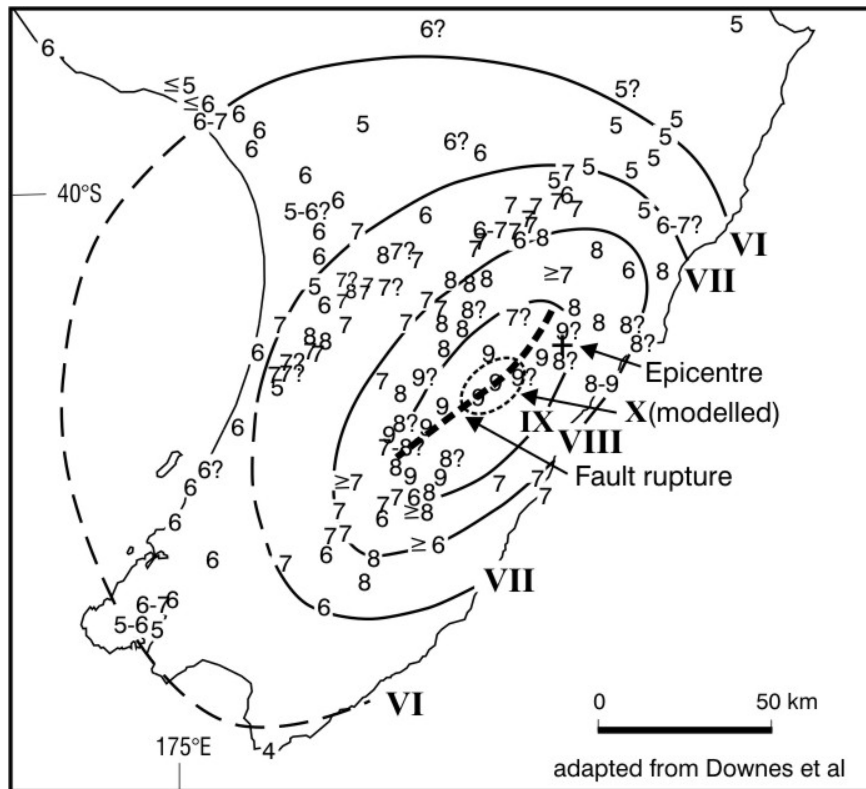
- Downes G, Dowrick D, Smith E, Berryman K 1999. The 1934 Pahiataua earthquake sequence: analysis of observational and instrumental data. *Bulletin of the New Zealand Society of Earthquake Engineering* 34(4): 221-245.
- Doser DL, Webb TH 2003. Source parameters of large historic (1917-1961) earthquakes, New Zealand. *Geophysical Journal International* 152: 795-832.
- Dowrick DJ, Rhoades DA 2005. Spatial distribution of ground shaking. Planning and engineering for performance in earthquakes, *Proceedings of the New Zealand Society of Earthquake Engineering, Wairakei*.
- Dowrick DJ, Rhoades DA 2004. Relations between earthquake magnitude and fault rupture dimensions: how regionally variable are they? *Bulletin of the Seismological Society of America* 94(3): 776-788.
- Dowrick DJ, Rhoades DA (in press). Attenuation of Modified Mercalli intensity in New Zealand earthquakes (II). *Bulletin of the New Zealand Society of Earthquake Engineering*.
- Grapes R, Downes G 1997. The 1855 Wairarapa earthquake: analysis of historical data. *Bulletin of the New Zealand National Society of Earthquake Engineering* 30(4): 271-369.
- Hancox GT, Perrin ND, Dellow GD 1998. Earthquake induced landsliding in New Zealand and implications for Modified Mercalli intensity and seismic hazard assessment. *Earthquake Commission Project 95/196, Institute of Geological & Nuclear Sciences, Lower Hutt*.



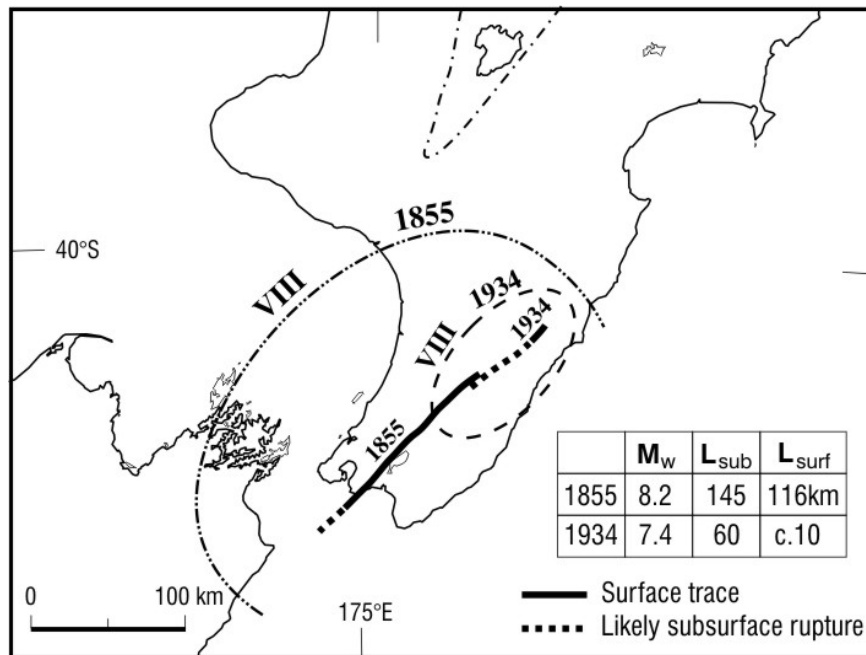
**Figure 1.** Isoseismal map of the 1855 Mw 8.2 Wairarapa earthquake (adapted from Grapes and Downes 1997).



**Figure 2** Two models of the iso lines for PGA of 0.5g in the 1855 Mw 8.2 Wairarapa earthquake, together with its MM9 isoseismal (equivalent to PGA 0.5g).



**Figure 3** Isoseismal map of the 1934 Mw 7.4 Pahiataua earthquake (adapted from Downes et al. 1999).



**Figure 4** Fault ruptures and MM8 isoseismals of the 1855 Wairarapa and 1934 Pahiataua earthquakes.

# LANDSLIDES AND LIQUEFACTION EFFECTS CAUSED BY THE 1855 WAIRARAPA EARTHQUAKE: THEN AND NOW

G.T. Hancox

Institute of Geological and Nuclear Sciences Ltd., PO Box 30 368, Lower Hutt  
(g.hancox@gns.cri.nz)

## INTRODUCTION

The Wairarapa earthquake of 23 January 1855 is the strongest earthquake that has occurred in New Zealand in the last 150 years. It was centred c. 25 km below Palliser Bay, possibly about 5 km off the south Wairarapa coast (Fig. 1), and had an estimated magnitude of  $M_w$  8.2 based on reported shaking that was felt over the whole country (Eiby 1968; Downes 1995; Grapes and Downes 1997). The earthquake was accompanied by ground surface rupture on the Wairarapa Fault, which extended from the coast for about 100 km northeast up the Wairarapa valley. Land on the western side of the fault moved right-laterally (north) between 9 and 13 m, and was uplifted and tilted westward. Uplift of 6 m occurred at Turakirae Head, between 1 and 2 m in Wellington Harbour (Port Nicholson), and decreased northeast along the fault to about 0.5 m near Masterton (Grapes and Downes 1997). The earthquake also caused landsliding over a large area, especially in the southern Rimutaka Range. Severe ground damage due to soil liquefaction occurred in areas underlain by saturated alluvium and fine-grained sediments (loose fine sands and silts) in river valleys and coastal plains (Hancox et al. 1994, 1997; Grapes and Downes 1997).

This paper describes the landslides and liquefaction effects caused by the 1855 earthquake and discusses what the effects might be, and what damage would result, if a similar earthquake ( $M_8$  on the Wairarapa Fault or  $M$  7.5 on the Wellington Fault) occurred today. The paper is based mainly on earthquake-induced landslide studies that the author has participated in over the last 12 years (Hancox et al. 1994; 1997; Brabhakaran et al. 1994), but also draws on other data sources. Information on the landslides and liquefaction damage is derived from historical accounts in journals, letters, books, and newspapers in which descriptions are generally vague. There are no known photos of any landslides caused by the earthquake, but in a few cases landslides are shown in sketches and paintings. Despite the limitations of the historical data, many of the landslides identified are visible today, and photos of some are included to illustrate this paper.

## DEFINITIONS AND DAMAGE

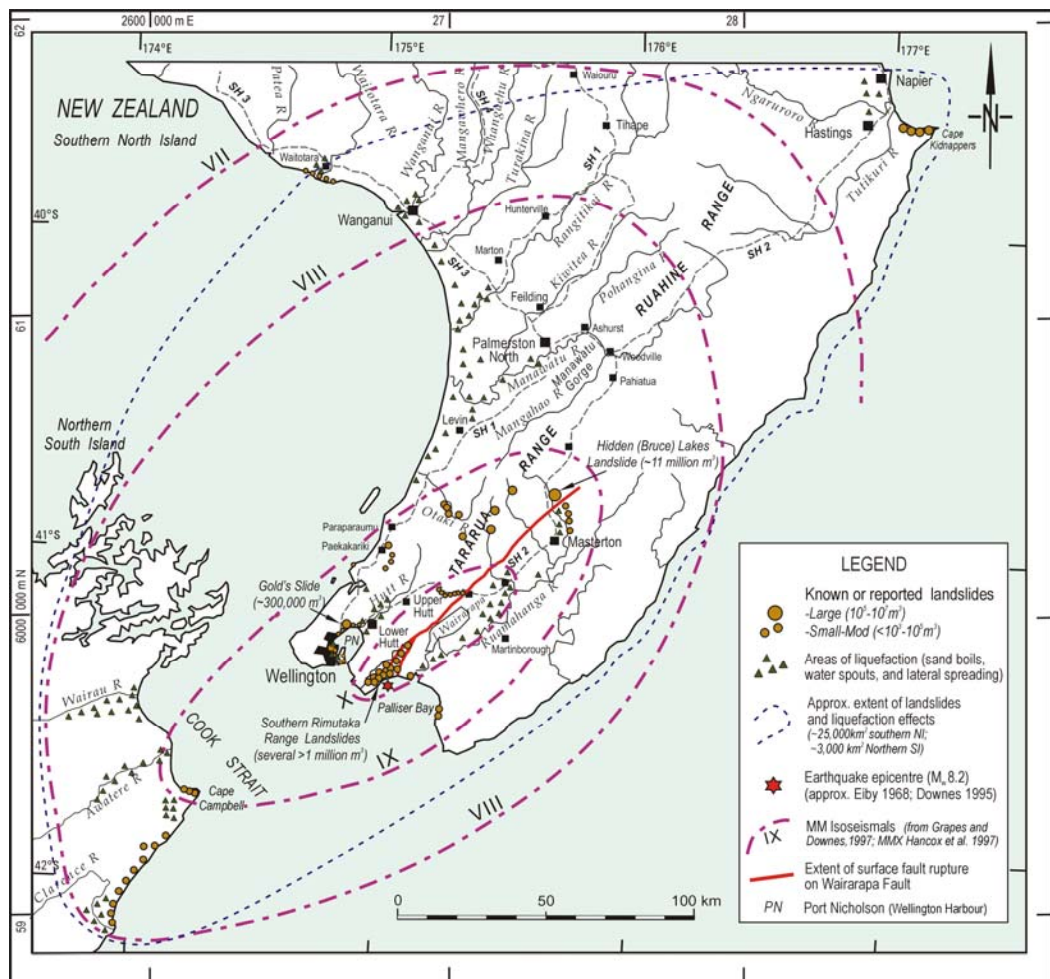
The following definitions are provided to explain terms and issues discussed in the paper:

*Landslide* is a general term for gravitational movements of *rock* or *soil* down a slope. In this context, the term *soil* includes both *earth* (material smaller than 2 mm) and *debris* (material larger than 2 mm); *rock* is a hard or firm intact mass and in its natural place before movement (*slope failure*). Landslides can occur spontaneously, but are most often triggered by heavy rainfall or by earthquakes. Shaking of Modified Mercalli

intensity MM VII can cause small failures ( $<10^3 \text{ m}^3$ ), but MM VIII or greater is generally required for larger landslides ( $\geq 10^3\text{--}10^6 \text{ m}^3$ ).

*Landslides* are usually classified or described in terms of: (a) the type of material involved (rock, earth, debris, or sometimes sand, mud etc.), and (b) the type of movement — fall, topple, slide, flow, spread, which are kinematically-distinct modes of movement. Combining these two terms gives a range of landslide types such as: *rock fall, rock slide, rock topple, debris fall, debris slide, debris flow, earth flow* etc. Landslides involving soils and bedrock are often called *slips* or *landslips*, while small failures with rotational slide surfaces are generally referred to as *slumps*.

Small landslides of a few tens of cubic metres often do little damage, but very large failures of thousands or millions of cubic metres moving bodily downslope can overrun and bury buildings and roads, or cause foundation collapse at the tops of slopes. Effects of landslides can range from minor deformation of foundations and structural failures to total destruction of sites and all buildings, lifelines and infrastructure above or below slopes.



**Figure 1.** Map showing the distribution of known or reported landslides and areas of soil liquefaction caused by the 1855 Wairarapa earthquake (after Hancox et al. 1997).

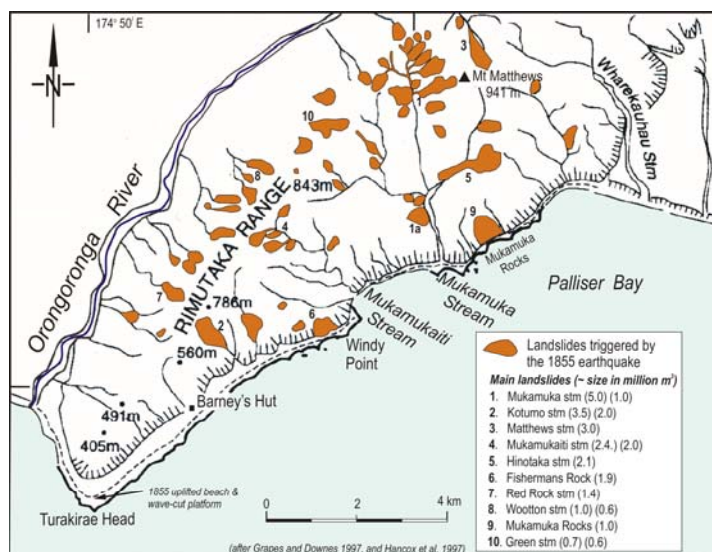
*Liquefaction* is a process that occurs when saturated fine sands and silts temporarily lose strength and behave like a fluid during strong earthquake shaking (generally MM

VII or greater). Such soils may be up to 10 m below the ground surface. Liquefaction effects can include *sand boils or sand volcanoes* (ejections of sand and water from a central point) and *lateral spreading* (ground fissuring, spreading settlements, accompanied by sand and water ejections), especially adjacent to rivers and streams, or along roads, embankments and reclaimed areas in low-lying alluvial and coastal areas. Sand boils in alluvium are often non-damaging, but lateral spreading can result in severe ground damage, causing buildings to tilt or deform, buried tanks and pipes to float disrupting underground services, and deforming and closing roads and railway lines

## LANDSLIDES AND LIQUEFACTION CAUSED BY THE EARTHQUAKE

Landslides and liquefaction effects known or inferred to have been caused by the 1855 earthquake are shown in Fig. 1. The main area of landsliding extended over about 5000 km<sup>2</sup> in the Wairarapa and Wellington area, especially in the southern Rimutaka Range east of Wellington Harbour. The total area affected by landslides and liquefaction damage covered c. 25,000 km<sup>2</sup> in the southern North Island, extending northwest to the Wanganui River and northeast to Cape Kidnappers. About 3000 km<sup>2</sup> of the northern South Island was also affected by smaller landslides, especially along coastal cliffs from Cape Campbell to the Clarence River. Small landslides also occurred in more distant parts of the central North Island. Ground subsidence and liquefaction effects (sand boils, lateral spreading) occurred as far north as Wanganui, Waitotara, and Napier in the North Island, and Marlborough in the South Island.

The most severe landslide damage and most of the largest slides were in the southern Rimutaka Range (within c. 10 km of the fault rupture zone), where numerous rock and debris slides and avalanches occurred on steep ridges and sides of gullies. Historical reports described these slides as visible from Wellington. They include many large debris slides and avalanches, including several in Greens (c. 0.6 million m<sup>3</sup>), Matthews (c. 0.3 million m<sup>3</sup>) and Mukamuka (c. 1–5 million m<sup>3</sup>) streams (Fig. 2). Many of these landslides remain obvious today (Fig. 3).



**Figure 2.** Map showing landslides in the southern Rimutaka Range thought to have been triggered by the 1855 Wairarapa earthquake. (after Grapes and Downes 1997; and Hancox et al.1997)





**Figure 3.** Photo looking south down Mukamuka Stream showing scars of 1855 landslides extending from ridge crests to valley bottoms. Some are partly revegetated, but others (grey scars) were reactivated by a severe rainstorm on 30 March 2005. Similar reactivations in the last 150 years have caused ongoing erosion and sedimentation effects in the area. (Photo: GT Hancox, April 2005)

Many landslides in the southern Rimutaka Range extend from the crest of the range (c. 800 m) to valley bottoms near sea level (Figs. 2, 3). Landsliding was particularly intense in the area because of the sheared greywacke rock and very steep slopes, and its location close to and on the upthrown side of the Wairarapa fault zone. Some of the smaller landslides in the area are now partly revegetated. However, many larger slides were recently reactivated by a rainstorm on 30 March 2005, with several slides in Boulder Creek forming a debris flow fan that dammed the Orongorongo River for 4 weeks. Other storm-induced landslide reactivations over the last 150 years (e.g. Cunningham & Arnott 1964) have continued the ongoing erosion and sedimentation processes in the southern Rimutaka Range, building large fans in rivers, streams, and coastal plains, and maintaining its vulnerability to future earthquake damage.

Landslides were also reported in the northern Rimutaka and Tararua ranges, and along the coast on the east side of Palliser Bay. The old coach road across the Rimutaka range was almost completely destroyed by landslides (Fig. 1). These slides were on a much smaller scale than the extensive slides to the south, and few are visible today. Significant landsliding is also likely to have occurred in the eastern Wairarapa ranges, but apart from ridge-top cracking at Castlepoint, few were reported because of the sparse population in that area at the time of the earthquake.

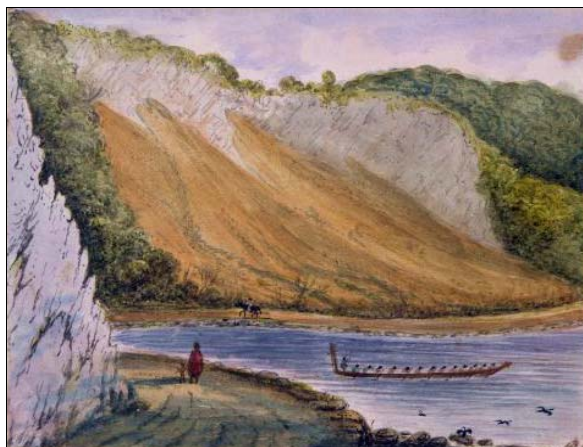
The largest landslide reported during the 1855 earthquake was the Hidden (Bruce) Lakes Landslide at Kopuaranga, 14 km north of Masterton and 1 km northwest of the Wairarapa Fault (Fig. 4). This very large (c. 11 million m<sup>3</sup>) rotational slide in Tertiary mudstone temporarily dammed the Ruamahanga River and formed the 'lakes' (landslide ponds). When the dam broke, Maoris living in pas downstream had to climb trees to escape the flood (Grapes 1988). A similar old (prehistoric based on its subdued topography). very large landslide east of Martinborough may have been triggered during an earlier large earthquake, possibly also on the Wairarapa Fault.



**Figure 4.** Hidden (Bruce) Lakes Landslide was the largest landslide triggered by the 1855 earthquake. This very large (c. 11 million m<sup>3</sup>) rotational slide, 1 km north of the Wairarapa Fault (F), temporarily dammed the Ruamahanga River. The photo (looking south) shows the lakes (L) and the remains of the landslide dam which has been considerably eroded (ed) in the last 150 years.

(Photo: DL Homer, Jan 2002)

There were also numerous small to moderate-size rock falls and slides from steep greywacke slopes around Wellington. These damaged roads and tracks, and scarred the cliffs around Worser Bay near the entrance to Port Nicholson. There was only one slide of significance in the area. A large landslide (c. 300,000 m<sup>3</sup>) from the harbour cliff c. 3 km north of Ngauranga Gorge fell into Port Nicholson, blocking the Wellington to Hutt valley road. This slide is well known from the painting by Charles Gold (Fig. 5a) and can be recognised today just north of the BP Station on the Hutt motorway (Fig. 5b). Other slides damaged the Paekakariki Hill road, and a ‘heavy’ (large) slide occurred on the cliffs at Paekakariki, possibly near the present railway station (Fig. 1).



(a)



(b)

**Figure 5.** (a) Painting by Charles Gold of the large landslip into Port Nicholson during the 1855 earthquake (Alexander Turnbull Library). (b) Recent photo of ‘Gold’s Slide’ on the Hutt road in which the slide debris cone (sd) and head scarp (sc) are still clearly recognisable. Despite its cover of scrub, this high coastal cliff is oversteepened and susceptible to future earthquake-induced slope failures. The Hutt motorway is built on fill here and is at risk from liquefaction-induced spreading and collapse.

Contemporary accounts of the 1855 earthquake suggest that building damage around Wellington was very much less than during the 1848 earthquake, apparently because there were fewer brick and more wooden houses. However, the effects of the 1855 shocks were about 10 times worse on the land than in 1848 (Ward 1928). Observations of landslide damage decreased away from the epicentre, and most reports of far-field

damage are generally sketchy and vague. Because of the sparse population there are few reports of landslides in steep mountainous areas where many failures are likely to have occurred. Landslides were widely reported from coastal cliffs, such as between the Wairau and Clarence rivers in the South Island, and the Wanganui and Cape Kidnappers areas of the North Island, where falls from near-vertical conglomerate cliffs occurred (Fig. 1). There were also vague reports of landslides on Mt Taranaki, Mt Tongariro, and just south of Cambridge, but the accuracy of these reports is uncertain.

## **LIQUEFACTION EFFECTS**

Following the 1855 earthquake, liquefaction effects were widely reported from the Wellington, Hutt Valley, and Wairarapa areas. More distant parts of the North Island from Paraparaumu to the Manawatu and Wanganui rivers, and around Napier were also affected, as were the lower Wairau, Awatere, and Clarence valleys in the South Island (Fig. 1). While there are many historical accounts of the ground damage that occurred, there are no known photos or sketches that show it, and the locations are somewhat unclear. However, the descriptions of what occurred are generally typical of liquefaction-induced ground damage.

In the Wellington urban area there were several reports of extrusions of grey mud from fissures up to c. 25 m long in the Thorndon, Government House, Willis, and Manners Street areas adjacent to Lambton Harbour and the former Te Aro swamp (Grapes and Downes 1997), but no large subsidences are known to have occurred. The Hutt Valley suffered more extensive ground damage due to liquefaction than Wellington. Large fissures were formed along banks of rivers and streams, and the bridge across the Hutt River was destroyed when the abutments sank. In southern areas of the Hutt valley numerous 'hillocks of sand' (sand boils) up to 1.2 m high were formed, along with deep long fissures and areas of subsidence. Liquefaction effects appear to have been most extensive on alluvial plains of the Wairarapa valley, with some areas of fissuring and subsidence about 300 m long and cracks up to 1 m wide and 3–4 m deep. The worst affected areas appear to have been on the Ruamahanga River plains north and south Masterton, and also east and south of Lake Wairarapa (Fig. 1).

## **SIGNIFICANCE OF 1855 LANDSLIDING AND LIQUEFACTION EFFECTS**

The 1855 Wairarapa earthquake is the largest earthquake in New Zealand in the last 150 years, and the size of the area affected by landslides and liquefaction damage (about 28,000 km<sup>2</sup>) reflects this distinction. However, the size and number of landslides formed generally does not. For example, the  $M_w$  7.8 Murchison earthquake in 1929 caused landsliding over a smaller area (only about 7,000 km<sup>2</sup>), but the landslides formed were larger and more numerous. This difference may partly be due to under-reporting of landslides caused by 1855 earthquake because of the sparse population at that time, but is more probably related to the steep, formerly-glaciated mountainous terrain and geology of the area where the 1929 earthquake was centred.

Nevertheless, the 1855 earthquake caused the largest and most extensive landslides and liquefaction effects in the Wellington area in the last 150 years. The resulting ground damage was much more extensive than what occurred during other earthquakes that have been strongly felt in the Wellington region, including: the 1848 Marlborough earthquake (MM VIII in Wellington); 1929 Murchison earthquake (MM VI in

Wellington); and the June 1942 Masterton earthquake (MM VI-VII Wellington, MM IX near Masterton, Downes et al. 2001).

Figure 1 shows some landsliding in the MMVII and MM VIII zones, but the most extensive landsliding occurred in the MM IX and MM X isoseismals, with the latter centred on the heavily damaged southern Rimutaka Range. Although an MM X isoseismal was not identified by Grapes and Downes (1997) on the basis of building damage, Hancox et al. (1997) recognised an MM X zone based on the numerous landslides that occurred in the Rimutaka Range, and widespread liquefaction effects in the Wairarapa valley. The greater landslide damage in that area is attributed not only to steep topography, poor rock, and close proximity to the fault rupture zone, but also to possibly stronger ground accelerations on the upthrown side of the fault. The MM X zone excludes Wellington city, however, and is somewhat smaller than that drawn by Eiby (1968).

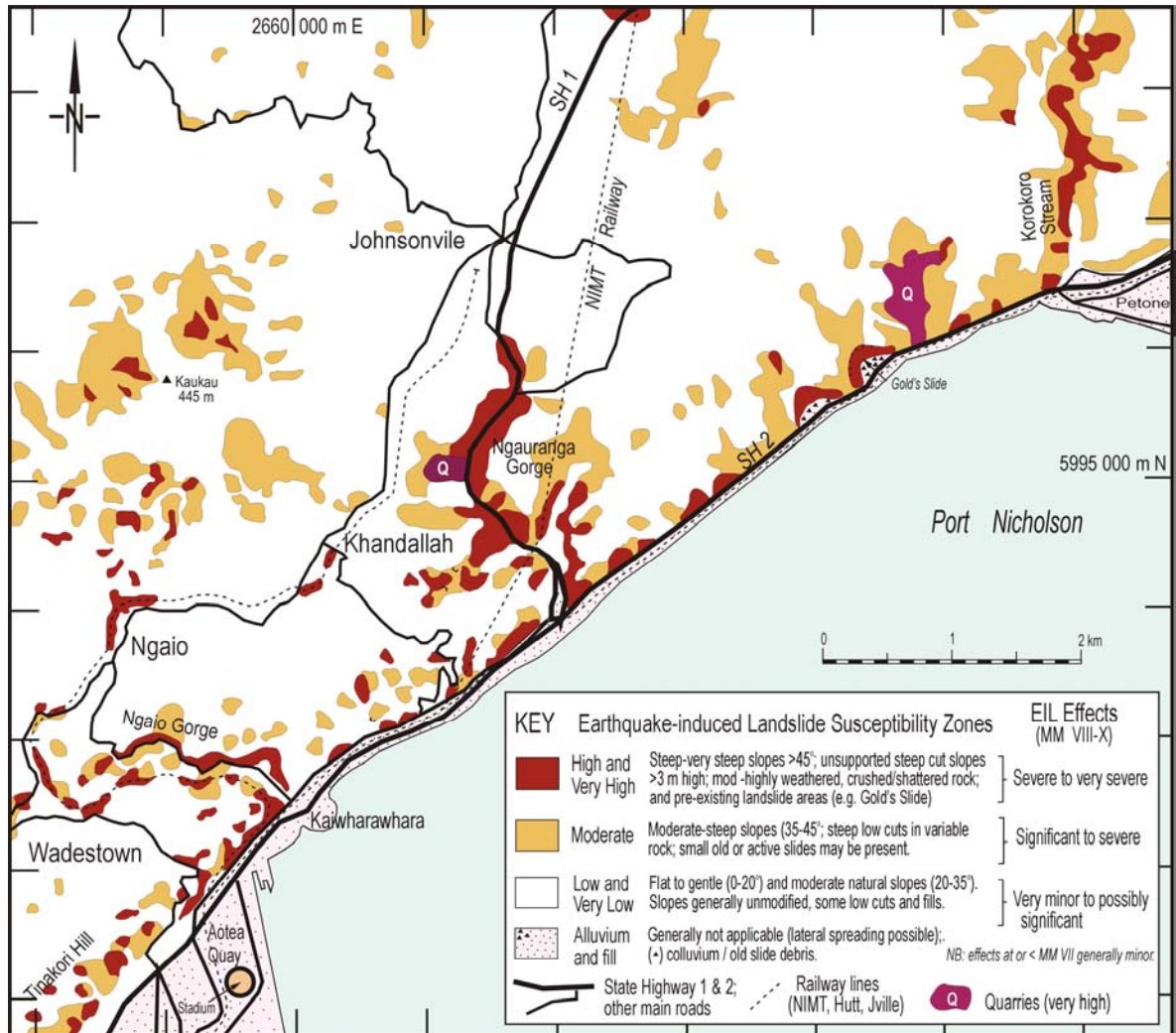
Rock slides and falls triggered by the 1855 earthquake caused extensive damage to narrow roads and tracks throughout the Wellington area, and liquefaction effects on alluvial plains in the Hutt Valley, Wairarapa, and Otaki to Manawatu area damaged many roads and bridges. There were no reports of landslide damage to buildings during the 1855 earthquake, but damage to the rudimentary network of roads and tracks was more severe than has occurred during other historical earthquakes in the Wellington region.

## **WHAT COULD HAPPEN IN THE FUTURE?**

Landslide and liquefaction damage in the Wellington region will probably be much worse when the next large earthquake occurs. This could be another M 8 earthquake on the Wairarapa Fault, an M 7.5 earthquake on the Wellington Fault, or a large (>M 7) subduction zone earthquake. The resulting damage is likely to be greater because urbanisation and infrastructure development in the Wellington region over the last 150 years has significantly changed the landscape, making it more vulnerable to landslide and liquefaction damage during strong earthquakes (MM VIII–X). Construction of steep unsupported cuts for buildings, roads, and railway lines along the Hutt motorway, Ngauranga gorge, and elsewhere has increased earthquake-induced landslide (EIL) susceptibility in the region. Embankments for roads and extensive reclamation fills extending into Wellington Harbour along Aotea Quay and the Hutt motorway are vulnerable to liquefaction ground damage. In recognition of this hazard potential, the Wellington Regional Council commissioned a series of studies in the early 1990s to assess seismic hazards in the region, including those resulting from earthquake-induced slope failure (Brabhakaran et al. 1994) and ground liquefaction (Brabhakaran et al. 1993), as shown in Figures 6, 7, and 8.

Figure 6 shows earthquake-induced landslide susceptibility zones in the Wellington to Petone area (based on slope angle, geology, slope modification, and existing landslides), and predicted severity of EIL effects under strong earthquake shaking (MMVIII to MMX). On most hill slopes around Wellington EIL susceptibility is low to very low. However, on steeper slopes (>35°) in gorges or on coastal cliffs along the Wellington Fault scarp bordering Port Nicholson (Fig. 7), landslide susceptibility is high to very high. Slopes modified by steep cuts for quarries, railway lines, and main roads such as

the Hutt motorway (SH2) and Ngauranga Gorge (SH1) are most vulnerable. Steep cuts for buildings >2–3 m high are also vulnerable to failure unless supported.

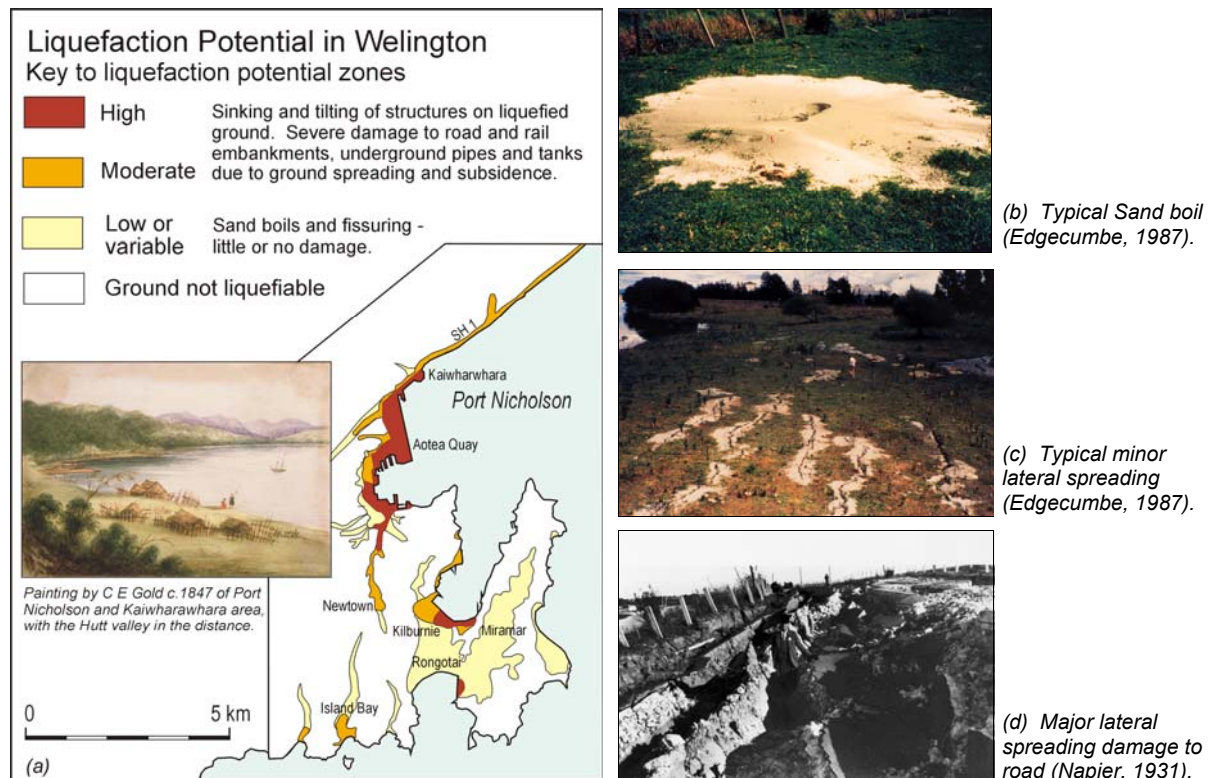


**Figure 6.** Earthquake-induced slope failure (landslide) hazard map of the northern Wellington to Petone area at a regional scale, and expected severity of EIL effects (after Brabbaharan et al. 1994).

Steep high rock cuts in the Wellington area did not exist in 1855 (see inset Fig. 8a), and have never been tested by strong earthquake shaking. Most cuts (those steeper than c. 45°) have not been designed to withstand strong earthquake shaking, and numerous large rock falls and slides are expected when a large earthquake (c. M 7.5 or greater) strikes the region. Slope failures will severely damage and close roads and railway lines out of Wellington, isolating the city. Other main roads assessed as having high EIL susceptibility, such as Centennial Highway from Pukerua Bay to Paekakariki, and the Rimutaka Hill road (Brabbaharan et al. 1994), are likely to be severely damaged by landslides and rock falls. The road through the Manawatu Gorge may be closed by landslides. Significant slope failures could also occur along the Wellington Fault scarp in the Hutt Valley, especially adjacent to the large landslide (c. 300,000 m<sup>3</sup>) that dammed the Hutt River at Te Marua during the February 2004 rainstorm (Hancox and Wright 2005).



**Figure 7.** Recent photo showing steep slopes and cuts (covered by vegetation) along the Wellington Fault scarp and Hutt motorway (SH1). Many of these slopes have high EIL susceptibility. Large areas of reclamation fill on which the railway yards, wharves, and Westpac Stadium (foreground) are located have high to very high liquefaction susceptibility. Extensive ground improvement costing \$1.3 million was carried out under the stadium to prevent ground deformation damage during strong earthquakes



**Figure 8.** (a) Map showing liquefaction potential zones in Wellington (after Brabhaharan et al. 1993); (b, c, and d) photos illustrating typical liquefaction effects during previous NZ earthquakes.

The consequences of liquefaction-induced ground damage (especially lateral spreading) will be more severe during future large earthquakes than it was in 1855. There are now more roads and rail embankments which will be damaged by ground spreading and collapse throughout the Wellington region. Liquefaction damage will occur mainly in areas of saturated soft sediments and fills with high and moderate liquefaction potential in Wellington city (see Figs. 5, 6, 7, 8). In these areas, both buildings and lifelines (water supply, drainage, electricity, gas pipelines, telecommunications, railways and roads) are likely to suffer severe damage due to liquefaction. The Wellington airport at Rongotai could also suffer some liquefaction damage.

The Westpac Stadium on Aotea Quay (Fig. 7) was constructed on potentially liquefiable reclamation fill in the late 1990s. To prevent ground liquefaction foundation failure during earthquakes, stone columns were installed over the entire site to depths of up to 9.5 m. These measures cost \$1.3 million (1% of the total cost), but were necessary to protect the structure from damage or possibly destruction during the next ‘big’ earthquake to hit Wellington.

## CONCLUSIONS

The 1855 Wairarapa earthquake caused the most extensive and severe landslide and liquefaction damage that has occurred in the Wellington region in the last 150 years. Many large landslides occurred in the southern Rimutaka Range, Wairarapa, and Wellington area, causing extensive damage to roads and tracks. Rock slides made the Rimutaka coach road impassable, and the Wellington–Petone road was blocked by a large slip into Port Nicholson. Roads and bridges on alluvium in the region were significantly damaged by liquefaction-induced lateral spreading and subsidence, especially in the Hutt Valley and Wairarapa, and as far north as Manawatu, Wanganui, and Napier. The northern South Island was also affected.

Urbanisation and infrastructure development in the Wellington region over the last 150 years has changed the landscape and made it more vulnerable to landslides and liquefaction effects during strong earthquake shaking (MM VIII–X). The consequences of these effects would be much more damaging today than in 1855. Large slope failures of steep unsupported cuts are expected to close many roads, and railway lines in the region. Liquefaction-induced lateral spreading and ground subsidence will cause severe damage to buildings on soft sediments and reclamation fills, and road and rail embankments throughout the greater Wellington area. Planning and designs for roads and structures in the region must take this risk into account.

## REFERENCES

- Brabhaharan P, Jennings DN, McMinn JA 1993. Liquefaction hazard study, Wellington Region: Reports and maps covering six study areas. *Prepared for Wellington Regional Council by Works Consultancy Services Limited.*
- Brabhaharan P, Hancox GT, Perrin ND, Dellow GD 1994. Earthquake-induced slope failure hazard study, Wellington Region: Reports and maps covering six study areas. *Prepared*

- for Wellington Regional Council by Works Consultancy Services Ltd and Institute of Geological & Nuclear Sciences.*
- Cunningham A, Arnott WB 1964. Observations following a heavy rainfall on the Rimutaka Range. *Journal of Hydrology* 3(2): 15–24.
- Downes GL, Dowrick DJ, Van Dissen RJ, Taber JJ, Hancox GT, Smith, EGC 2001. The 1942 Wairarapa, New Zealand, earthquakes: Analysis of observational and instrumental data. *Bulletin of the NZ Society for Earthquake Engineering* 34: (2) 125–157.
- Downes GL 1995. Atlas of isoseismal maps for some New Zealand earthquakes. *Institute of Geological and Nuclear Sciences monograph 11*, 304 p.
- Eiby GA 1968. An annotated list of New Zealand earthquakes 1460–1965. *New Zealand Journal of Geology and Geophysics* 11: 630–647.
- Grapes RH 1988. Geology and revegetation of an 1855 landslide, Ruamahanga River, Kopuaranga, Wairarapa. *Tuatara* 30: 77–83.
- Grapes RH, Downes G 1997. The 1855 Wairarapa earthquake: analysis of historic data. *Bulletin of the N Z National Society for Earthquake Engineering* 30(4): 273-368.
- Hancox GT, Perrin ND, Dellow GD 1994. Earthquake-induced Slope Failure Hazard Study, Wellington Region: Review of historical records of earthquake-induced slope failures. *Works Consultancy Services Limited Report (prepared for Wellington Regional Council).*
- Hancox GT, Perrin ND, Dellow GD 1997. Earthquake-induced landslides in New Zealand and implications for MM intensity and seismic hazard assessment. *Institute of Geological & Nuclear Sciences Client Report 43601B (prepared for EQC).*
- Hancox GT, Wright K 2005. Landslides caused by the February 2004 rainstorms and floods in southern North Island, New Zealand, New Zealand. *Institute of Geological & Nuclear Sciences science report 2004/10*. 33p.
- Ward WT 1928. Early Wellington. *Wellington, NZ. Whitcomb and Tombs Ltd.*



# TSUNAMI: CURIOSITY OR CALAMITY?

R.G. Bell<sup>1</sup>, J.R. Goff<sup>2</sup>, R.A. Walters<sup>2</sup>, and G. Downes<sup>3</sup>

<sup>1</sup>NIWA, PO Box 11115, Hamilton, New Zealand

<sup>2</sup>NIWA, PO Box 8602, Christchurch, New Zealand

<sup>3</sup>GNS, PO Box 30368, Lower Hutt, New Zealand

(r.bell@niwa.co.nz)

## INTRODUCTION

Up until Boxing Day of 2004, New Zealanders by and large viewed tsunamis as a curiosity — a phenomenon that occasionally reached our shores that provided interesting viewing down at the beach. Indeed, this viewpoint is supported by the results from a National Coastal Community Survey of 3500 people in 42 different coastal localities throughout New Zealand in 2003 (Johnston et al., 2003). In listing the two natural hazards most likely to affect their community, coastal erosion was the most popular choice (68% nationwide) followed by storms and floods, while tsunami was ranked further down. More to the point, when asked “Over what time period is a tsunami likely to affect your community?”, 56% nationwide responded with “not within my lifetime” (the longest period on offer out of “within the next year”; “within the next 10 years”; within your lifetime” and “not within my lifetime”). This public perception of the tsunami threat to New Zealand (which undoubtedly has been re-shaped somewhat by the Sumatra mega-tsunami) is at odds with recent findings of tsunami researchers from GNS, NIWA and universities that the risk of a tsunami calamity in our coastal communities has been substantially under-rated, particularly in the context of our escalating coastal development (real estate values and population). There are far more lives and property at stake now compared to when historic tsunami events struck some of our sparsely-developed coasts. If such tsunami had occurred in our present era, they would have inflicted substantially more damage and some loss of life.

## TSUNAMI EXPOSURE AND RISK

New Zealand faces potential tsunami threats from several different types of sources, with the main ones being large submarine or coastal earthquakes, submarine landslides, large landslides into coastal waters or lakes, volcanic eruptions (above or below the sea or lake surface) or a rare bolide (meteor) splashdown. Further, the threat from these source mechanisms can occur: a) locally at hotspots around New Zealand’s continental shelf (defined as being within 1 hour travel time to the coast); b) in our region, such as the Kermadec Ridge volcanoes or Macquarie Ridge fault zone (within 1–3 hours travel time to the coast); and c) distant sources more than 3 hours travel time to New Zealand e.g. tsunamis generated along South American subduction zones. Research proceeds on essentially two fronts: i) fundamental geophysical and geological investigations on discovering, typing and determining upper limits and recurrence intervals on the tsunami hazard exposure; and ii) through a mix of geophysics, oceanography, numerical modelling, statistical-probability and engineering disciplines, determining the tsunami risk (consequences) for New Zealand’s coastal communities.

## NEW ZEALAND'S PAST RECORD

A succinct summary of the New Zealand's historical record of tsunami is given by de Lange (2003), while Chagué-Goff & Goff (2003) and Walters & Goff (2003) outline some of the palaeo-records of tsunami deposits preserved in coastal wetlands and dune systems. Tsunamis of 30 m or more run-up height have been found in the geological (pre-historical) record of the last 6,000 years (e.g., Henderson Bay, Northland).

A New Zealand historical tsunami database (GNS, unpublished data) now has records of impacts from over 40 tsunami in the past 165 years of European settlement. Half were from distant or regional sources and the other half from local sources. At least three of these historic tsunami events resulted in run-up heights of 10 m (similar heights to those experienced on the Andaman Coast, Thailand during 26 December event). Two of these events were local sources — 1855 Wairarapa and 1947 Pouawa (Gisborne) — the other was from a large earthquake off northern Chile/southern Peru on 13 August 1868, which caused the only recorded tsunami death so far in the post-European era. Fortunately, the largest waves in the three biggest South American tsunami events have also coincided with low tides at the most-affected locations. This low-tide coincidence has limited the impacts despite their extensive occurrence along the entire east coast from Cape Reinga to Stewart Island. This “pattern” is entirely fortuitous, as there is an equal chance of tsunami waves striking the coast at their peak around high tide. The calamity along Thailand's Andaman Coast on 26 December 2004 was exacerbated by the largest waves arriving at high tide (tide range of 2 m that day).

Of particular relevance to this Symposium, is the tsunami that was generated on the Wairarapa Fault by a M8.1–8.2 earthquake on 23 January 1855. Reports at the time indicate the highest wave run-up occurred at Te Kopi in Palliser Bay reaching over 10 m (Grapes & Downes, 1997; de Lange & Healy, 1986), and confirmatory geological evidence has been found nearby to the east of Lake Ferry (Goff et al., 1998). A complex response was also recorded in Wellington Harbour. An almost immediate sequence of waves (slosh) was generated by the differential uplift and deformation of the Wellington Harbour basin, followed later by the tsunami generated in Cook Strait along the fault rupture, propagating in through the Entrance. Run-up heights reached between 3–4 m in and around Wellington Harbour, with the highest waves occurring at Evans Bay and Lyall Bay (Gilmour & Stanton, 1990). Substantial wave run-up heights were also observed in Wairau River mouth and northern Marlborough. The tsunami was noticed as far south as the Clarence River mouth and up through the South Taranaki Bight on the west coast (e.g., Otaki and New Plymouth). There is also geological evidence for an impact in Abel Tasman National Park as well (Goff and Chagué-Goff, 1999).

## TSUNAMI RISK AND PREPAREDNESS

Substantial progress was already underway in New Zealand prior to the landmark Boxing Day event on a number of fronts to improve the awareness of the tsunami risk to our coastal communities and the appropriate response/warnings required. A few examples of recent projects or programmes are instructive on how far we have come in recent years:

- Discussions and planning to bolster up the national tsunami warning system including signage (Ministry of Civil Defence and Emergency Management-MCDEM and territorial/regional emergency management groups);

- Creation of the first CDEM Group Plans for each region under the new CDEM Act;
- Compilation of a consistent and verified set of records on historic tsunami events in a database held by GNS (compiled by GNS and Earth Sciences-University of Waikato);
- Major advances in equipment and techniques to image the seafloor at high resolution, which have resulted in the discovery or much improved definition of offshore faulting, submarine volcanoes and submarine landslides (NIWA);
- Ongoing search and confirmation of palaeo-tsunami signatures in coastal areas (NIWA, GNS, GeoEnvironmental Consultants; University of Auckland, University of Waikato);
- Vastly improved understanding of underwater landslide sources and mechanisms (NIWA, Earth Sciences-University of Waikato, University of Canterbury)
- An interactive Tsunami Display at the National Aquarium in Napier (development coordinated by Hawkes Bay Regional Council with input from NIWA and GNS);
- An interactive Tsunami Display at Te Papa Museum of New Zealand (Te Papa, GNS, NIWA)
- Development and application of tsunami propagation/inundation models to assist in quantifying the risk of local and distant source tsunami (NIWA, GNS, University of Waikato);
- Clearer understanding of the hot-spot areas in the Pacific Rim that pose the most risk to New Zealand from distant sources through tsunami modelling in collaboration with US (NOAA) scientists developing a near real-time wave-height forecasting system (GNS);
- Emergence of regional studies to determine the tsunami risk e.g. Kaikoura Lifelines Project (Environment Canterbury and NIWA) and the Bay of Plenty/Coromandel tsunami study funded jointly by Environment BOP and Environment Waikato (NIWA, GNS and GeoEnvironmental Consultants);
- Momentum gathering through regional and territorial authorities for undertaking high-resolution aerial surveys (e.g., photogrammetry and LIDAR) to vastly improve the available digital terrain topography of our coastal margins;
- National Coastal Community Survey of 2003 (developed by GNS, NIWA and Environment Waikato);
- Two tsunami symposia held in New Zealand — TSUNZ 2002 (Paraparaumu) and the jointly organised IUGG–ICG/ITSU International Tsunami Symposium in Wellington in 2003 (NIWA, GNS, MCDEM);
- Significant shift in FRST research funding from causes and frequency of hazards to assessing the risk (consequences) of hazards in casualties and dollars through the creation of the Regional Riskscape Model project being undertaken by a joint venture between NIWA and GNS (Riskscape NZ).

However, much more impetus has been focussed on New Zealand's risk exposure to tsunamis since the Boxing Day event plus there is much we can learn from the calamity suffered by several countries surrounding the Indian Ocean. Some of the lessons that can be gleaned from post-event reconnaissance surveys in Thailand and Sri Lanka (sponsored by Earthquake Commission) are (Liu et al., 2005; Bell et al., in prep):

- Saving lives must always be the key objective in managing tsunami risk;
- To achieve this goal, no singular approach will work. Instead it must be a balance of several approaches that transcend the physical sciences, engineering, social sciences, emergency management, education, policy and planning, socio-economic and

political sectors in order to achieve resilient coastal communities understanding and managing their hazards including the elusive tsunami threat. These approaches needs to include at least:

- Robust and timely earthquake and tsunami detection and confirmation systems;
  - Clear and nationally consistent systems for producing and disseminating appropriate warnings, while at the same time minimising false alarms;
  - Clear evacuation and/or refuge systems that are practiced (in part anyway);
  - Improved public knowledge building on the tremendous platform laid by the media coverage of the Boxing Day event — however the knowledge needs to also be institutionalised to retain “corporate memory”;
  - Timely response and recovery operations during and after the event;
  - Reduction in the risk (or at least holding the status quo) through strong policy and planning provisions (e.g. managed retreat, set-back zones), through working together with real-estate, insurance, engineering and local/regional government sectors and local communities;
  - More encouragement for community-based coastal dune and beach care rather than hardening coastlines—dunes and coastal vegetation provide a natural tsunami mitigation measure as evidenced in Thailand and Sri Lanka. (It is recognised that developed urban shorelines may need protection works, although sustainability of such works in the long-term with climate-change effects looming will be an increasing issue to grapple with.)
- Need for a consistent approach nationally to warnings and evacuations (including informing tourists);
  - Infrequent, large tsunami can cause total catastrophic damage to timber and masonry buildings at the coast. There is little that can be done economically to improve the tsunami-resistance of existing buildings and infrastructure. However, some tsunami proofing may be possible for new developments e.g., more open ground-floor spaces, improved tie-downs to foundations. However, the key objective in mitigating the impacts of such large damaging events must remain the saving of lives.

Following the Boxing Day event, Cabinet have instigated two major initiatives. The first is a review of New Zealand’s overall exposure to the tsunami hazard and our preparedness to deal with a damaging tsunami. This review is being undertaken for the Ministry for Civil Defence and Emergency Management by Geological and Nuclear Sciences (GNS) and various sub-contractors. The Review is due out later this year. The second initiative is the development and operation of a purpose-built tsunami detection and warning system for New Zealand. This project is being coordinated by Land Information NZ (LINZ) for the sea-level network component in cooperation with the GeoNet system run by GNS on behalf of the Earthquake Commission. A system, where seismic and sea-level monitoring are combined in near-real time, will substantially improve the robustness and timely service than the present piece-meal system. However, it still means tsunami from local sources within an hour’s travel time of the coast difficult to provide adequate warnings for evacuation other than confirmation for any “downstream” sites.

## **SUMMARY**

Significant progress has occurred in the past 3–5 years in terms of advancing the tsunami hazard beyond the realm of a curiosity to consideration of tsunami as a

potential calamity. This has occurred despite the fact that the last damaging tsunami hit our shores in 1960 from the M9.4–9.5 Chile earthquake, some two generations ago. The recent calamity in the Indian Ocean has heightened people’s awareness of the hazard and has re-focussed attention again on our own exposure to tsunamis, particularly against the backdrop escalating coastal development and attendant rising property prices and summer populations including tourists.

## REFERENCES:

- Bell, R.; Cowan, H.; Dalziell, E.; Evans, N.; O’Leary, M.; Rush, B.; Yule, L. (in prep). The December 26, 2004 Sumatra Earthquake and Indian Ocean Tsunami: Post-Event Survey of Impacts on the Andaman Coast, southern Thailand. Invited paper, Bulletin of the New Zealand Society for Earthquake Engineering.
- Chagué-Goff, C. and Goff, J.R. (2003). Long- and short-term environmental changes in coastal wetlands. Chapter 10, p. 215–236. In: *The New Zealand Coast: Te Tai O Aotearoa*, (Ed.) Goff, J.R.; Nichol, S.L.; Rouse, H.L. Dunmore Press, Palmerston North with Whitireia Publishing and Daphne Brasell Associates Ltd., New Zealand.
- de Lange, W.P. (2003). Tsunami and storm-surge hazard in New Zealand, Chapter 4, p. 79–95. In: *The New Zealand Coast: Te Tai O Aotearoa*, (Ed.) Goff, J.R.; Nichol, S.L.; Rouse, H.L. Dunmore Press, Palmerston North with Whitireia Publishing and Daphne Brasell Associates Ltd., New Zealand.
- de Lange, W.P.; Healy, T.R. (1986). New Zealand tsunamis 1840–1982. *NZ Journal of Geology and Geophysics* 29: 115–134.
- Gilmour, A.; Stanton, B. (1990). Tsunami hazard in the Wellington region. Report to Wellington Regional Council by NZ Oceanographic Institute (DSIR) and NZ Geological Survey (DSIR). May 1990. 116 p.
- Goff, J.R., Crozier, M., Sutherland, V., Cochran, U. and Shane, P. (1998) Possible tsunami deposits of the 1855 earthquake, North Island, New Zealand. In: Stewart, I.S. and Vita-Finzi, C. (eds) *Coastal Tectonics*. Geological Society Special Publication No. 133, 353-374.
- Goff, J.R. and Chagué-Goff, C. (1999) A Late Holocene record of environmental changes from coastal wetlands: Abel Tasman National Park, New Zealand. *Quaternary International*, 56, 39-51.
- Goff, J.R.; Walters, R.A. (2003). Assessing tsunami hazard along the New Zealand coast. *Science of Tsunami Hazards* 21(3): 137–153.

- Grapes, R.; Downes, G. (1997). The 1855 Wairarapa, New Zealand, earthquake,— Analysis of historical data. *Bulletin of the New Zealand Society for Earthquake Engineering* 30: 271–369.
- Johnston, D.; Bell, R.G.; Stewart, C.; Hickman, M.; Thompson, J.; Kerr, J.; Glassey, P. (2003). The 2003 national coastal survey: Assessing community understanding and participation in coastal management in New Zealand. In: Kench, P.; Hume, T. (Eds) *Proceedings of the Coasts and Ports Australasian Conference 2003*, Auckland, CD-ROM.
- Liu, P., L.-F., Lynett, P., Fernando, J., Jaffe, B.E., Fritz, H., Higman, B., Morton, R., Goff, J. and Synolakis, C. (2005). Observations by the International Tsunami team in Sri Lanka. *Science* 308: 1595.

# POST-EARTHQUAKE FIRE AND THE 1855 WAIRARAPA EARTHQUAKE

G.C. Thomas<sup>1</sup>, W.J. Cousins<sup>2</sup> and D.W. Heron<sup>2</sup>

<sup>1</sup>Victoria University, Wellington, New Zealand

<sup>2</sup>Institute of Geological & Nuclear Sciences, Lower Hutt, New Zealand

(geoff.thomas@vuw.ac.nz)

## INTRODUCTION

Fire following earthquake is an extremely variable phenomenon. Most earthquakes are not accompanied by fire, but sometimes fire losses are light (e.g. Izmit Earthquake, Turkey, 1999; ChiChi Earthquake, Taiwan, 1999), occasionally they are moderate (Northridge Earthquake, USA, 1994; Hyogo-ken Nanbu (Kobe) Earthquake, Japan, 1995), and very rarely, they are disastrous (San Francisco, USA, 1906; Kanto (Tokyo), Japan, 1923). New Zealand's rather limited experience mirrors that seen world-wide (Table 1).

Event Name	Date	Magnitude	Main Locality Affected	Fire Losses
Marlborough	16 <sup>th</sup> Oct 1848	7.8	Wellington [MM8]	None
Wairarapa	23 <sup>rd</sup> Jan 1855	8.1	Wellington [MM9]	None
Murchison	16 <sup>th</sup> Jun 1929	7.7	Murchison [MM9]	None
Hawke's Bay	3 <sup>rd</sup> Feb 1931	7.8	Napier [MM10]	Conflagration
Pahiatua	5 <sup>th</sup> Feb 1934	7.4	Pahiatua [MM8]	None
Wairarapa	24 <sup>th</sup> Jun 1942	7.2	Masterton [MM8]	Minor
Inangahua	23 <sup>rd</sup> May 1968	7.2	Inangahua [MM10]	None
Edgecumbe	2 <sup>nd</sup> Mar 1987	6.5	Edgecumbe [MM9]	None

**Table 1:** New Zealand's experience of fire losses following major earthquakes. In most cases, we found no reports of post-earthquake fires. In one case, one house was destroyed and there was minor damage to a few others, and in one other case, Hawke's Bay 1931, there was a conflagration that destroyed most of the business district of Napier. The Modified Mercalli (MM) intensities of shaking in the main localities are also given.

There are two main reasons why major earthquakes can cause fires that sometimes may spread and turn into urban conflagrations. First, there may be multiple ignitions after earthquakes due to damaged power and gas supplies, and damaged heating and cooking appliances. Second, after an earthquake the water supplies are often disrupted, streets may be blocked and fire service personnel may be busy undertaking rescue operations, with the result that the potential for fire spread is greater than usual. Examples of major earthquakes that have been followed by devastating fires include the 1906 San Francisco Earthquake, the 1923 Kanto (Tokyo) Earthquake and closer to home, the 1931 Hawke's Bay earthquake. There were no reported fires after the 1855 Wairarapa earthquake, which may have been due to the timing of the earthquake and good fortune. This paper describes what has happened in other relevant earthquakes in New Zealand

and what we would predict to happen if a similar earthquake happened now. Possible mitigation measures are discussed.

### **WHAT HAPPENED THEN?**

No fires were reported after the 1855 Wairarapa earthquake (Grapes and Downes 1997). There is a possibility of fires that were too small to be noted that went unreported. Likely sources of fires due to earthquakes at that time would have been open fire places and solid fuel cooking appliances. The earthquake occurred on 23 January, in the height of summer and so open fire places would not have been in use for heating. The earthquake occurred at 9:15 pm, when most people would have finished cooking and eating dinner and when cooking fires and appliances would have been put out. Candles and oil lamps may well have been in use.

### **WHAT HAS HAPPENED SINCE?**

After the Wairarapa earthquake of 1942, one farmhouse at Waihakeke near Carterton was destroyed by fire thought to have been caused by damaged electrical wiring. Presumably being a farmhouse it would have been isolated from other buildings so that the fire could not spread to other buildings, and as it was the middle of winter the risk of fire spread via vegetation would have been extremely low. There was minor fire damage to a few other houses (Downes et al 2001) even though there were an estimated 4,700 chimneys down in Wairarapa (over 1,000 in Masterton alone) and throughout the region 20,000 chimneys were estimated to have fallen. There were only two chimney fires in Wellington, but these and several other minor fires attributed to earthquake damage were extinguished before a major fire developed. The low number of fires has been attributed to the lateness of the time of the earthquake of 11:16 pm when many open fires would have been out for the night (Downes et al 2001).

Within the MM8 isoseismal there were 6,000 houses. Assuming a floor area of 100 m<sup>2</sup> for each house and allowing for some non-domestic buildings there would have been approximately 600,000-700,000 square metres of building stock. In an MM8 isoseismal the expected number of ignitions would be about 0.24 per 1000 single family equivalent dwellings, with a single family equivalent dwelling being approximately 140 m<sup>2</sup> (Scawthorne 1987). Thus the expected number of ignitions in this earthquake within the MM8 isoseismal would about one, as did occur.

After the Napier earthquake of 1931 there was a large conflagration that destroyed most of the centre of town (Conly 1980). The earthquake occurred in mid-morning on February 3. This again is a time of year when open fires would not be used for heating and a time of day when little cooking would be done. The ignitions that started the conflagration were in commercial premises and not in domestic dwellings. If this earthquake had occurred in winter or when people were cooking, there may have been more fires.

### **WHAT COULD HAPPEN NOW?**

If an earthquake of a similar size occurred on the Wairarapa fault today what sort of fire losses would we expect? The fire losses from such an earthquake have been modelled



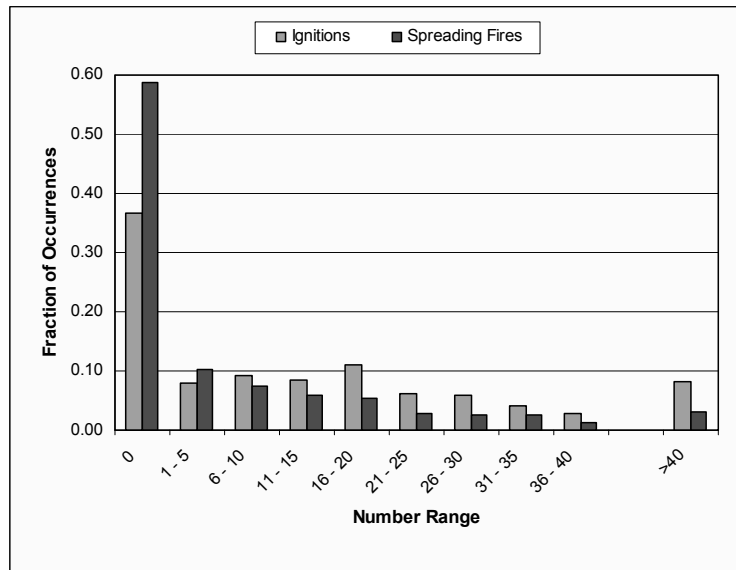
using a fire spread model developed previously by GNS and Victoria University (Cousins et al 2002, 2003a, 2003b, Thomas et al 2002). Because natural variability and hence uncertainty are always present when earthquake losses are being modelled, we carried out the simulation 1000 times, each time varying the parameters involved. In most cases, the procedure involved generating a random number at the point of uncertainty and using it to select from a distribution of values. The forms of distribution used were either normal, for ground motion parameters, lognormal, for damage ratios, or based on recorded data, for wind speeds. The parameters handled in this manner were as follows: characteristic magnitudes and locations of earthquakes, shaking attenuation (including both between-earthquake and within-earthquake variability), damage ratio (using a standard deviation of 0.3 in the logarithm to base 10 of the mean damage ratio), numbers of ignitions, wind speed, and placement of ignition points.

The main steps of the methodology (described in more detail in Cousins and Smith 2004) were to:

- estimate the shaking intensity throughout the region,
- estimate the shaking loss (following methodology of Cousins and Smith 2004),
- estimate the number (N) of ignitions using a largely speculative relationship between the shaking intensity and the number,
- allow for active suppression of some of the fires by the Fire Service,
- select a wind speed using recorded wind run data as a guide,
- given the selected wind speed, specify the maximum distance a fire can jump, then
- select a set of “burn-out” areas from multiple sets previously generated within a Geographic Information System and based on a building-by-building footprint map of Wellington City, extrapolated to cover the regional urban area — the particular set being determined by the maximum jump distance,
- randomly distribute the N ignitions amongst the buildings of the “burn-out” areas as a way of choosing the areas to be “burned”, and
- accumulate the losses for the chosen areas.

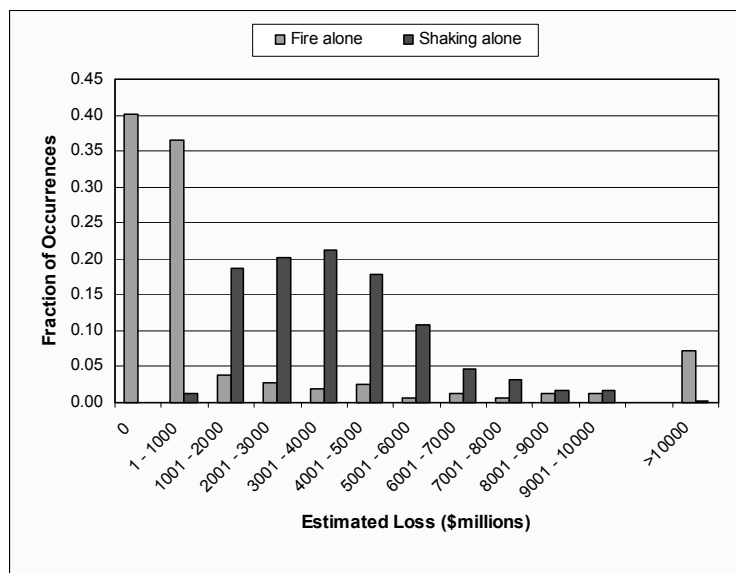
The magnitude of the earthquake was varied from 7.8 to 8.4 with a mean of 8.1. The epicentral location was also varied along the fault so it ranged from 22 to 86 km from the Wellington Central Business District (CBD) with a mean of 48 km. Consequently the Modified Mercalli Intensity varied from 7.1 to 10.6 in the Wellington CBD with the highest intensity at any of the asset locations in the region ranging from 8.4 to 11.0.

Numbers of ignitions and spreading fires were tabulated for main urban parts of the affected area, i.e. for the cities of Wellington, Hutt, Upper Hutt and Porirua. The outer and smaller towns such as Masterton, Nelson and Blenheim were excluded from the modeling because there the intensities and numbers of ignitions are expected to be relatively low, water is likely to remain available, and so spreading fires are much less likely than in the main urban areas. The expected numbers of ignitions and ignitions causing spreading fires are summarized in Figure 1. The mean number of ignitions is 14 and the mean number of expected spreading fires is 7. This can be compared with 30 ignitions that would be expected within Wellington City itself given a characteristic (magnitude 7.5) earthquake on the Wellington fault (Cousins et al 2003a).



**Figure 1.** Estimated numbers of ignitions and ignitions causing spreading fires, from 1000 simulations of present-day repeats of the 1855 Wairarapa Earthquake.

For most of the 1000 simulations, 85%, the estimated fire loss was smaller than the estimated loss due directly to shaking. In fact, for 70% of the simulations the fire loss was relatively very small, i.e. less than 10% of the shaking loss. This is further emphasised by the distributions of the estimated losses as shown in Figure 2. There is a nearly 80% probability of the shaking loss being in the range \$1 billion to \$5 billion, compared with nearly 80% probability of the fire loss being below \$1 billion. In fact the most likely fire loss is zero.



**Figure 2.** Estimated losses from fire and shaking from 1000 simulations of a present-day repeat of the 1855 Wairarapa Earthquake.

An apparently curious result, however, is that the average fire loss of \$2.2 billion is not remarkably smaller than the average shaking loss of \$3.7 billion. This arises because there is significant probability of very high fire losses, which would be caused by

unfortunate coincidences of some or all of the following factors — above average earthquake magnitude, strongest shaking at the southern end of the Wairarapa Fault, below average attenuation of shaking, above average numbers of ignitions, below average Fire Service capability, and high wind speed.

## **WHAT CAN WE DO NOW?**

The potential fire losses from a repeat of the 1855 Wairarapa Earthquake could be substantial, but are not the worst that could be experienced in New Zealand. Both fire and shaking losses would almost certainly be greater for a Wellington Fault Earthquake. On average each spreading fire in Wellington City could, according to Cousins and Smith (2004), cost about \$150 million. Hence mitigation of post-earthquake fire is clearly important.

Losses can be reduced by reducing the number of ignitions. Many fires were caused by gas leaks after the Northridge (Todd et al 1994)<sup>and</sup> Kobe (Hokugo 1997) earthquakes. The possibility of ignitions could be reduced by ensuring houses and other buildings with gas reticulation have good connections at the foundations to reduce differential movement, and gas connections should have some degree of flexibility. Seismic shut-off valves could also be installed. Improving foundations and foundation connections would also reduce shaking losses.

The second major cause of ignitions was electrical fires after the power was turned back on. Better coordination between emergency management and the power companies and processes to isolate damaged buildings would minimize these fires.

Many fires, particularly after the Kobe earthquake, were put out by the public before they were able to spread. The Building Code no longer requires hand-held fire-fighting appliances in most types of building. The provision of fire extinguishers would aid the public in fighting fires. At present people are advised to leave buildings as soon as it is safely possible once the shaking has subsided. Perhaps we should modify this advice to say that before leaving a building quickly check for fires and, if it can be done safely, extinguish them.

There are a number of buildings that do not comply with the Building Act in terms of spread of fire to other property. These buildings should be identified and upgraded.

Water supplies need to be upgraded in order to supply water for fire-fighting. Even if it is not possible to deal with a worst case event, there should be the resources and planning in place to deal with lesser events, which are more likely. Upgrading water supplies to having enough water to be able to fight fires would also result in emergency water supplies being more readily available to the public for drinking.

The post earthquake fire model needs to be developed further to include some factors that at present are not adequately modeled. These include the effects of vegetation, slope, and to some degree the claddings of the buildings. Some of the component models, in particular the relationship between the number of ignitions and the intensity of shaking, do not have sufficient underpinning data. It is possible to develop this model for use in real time to fight fires. It is a useful tool in determining the effect of various mitigation measures in order to justify their costs.

## CONCLUSION

No fires were reported after the 1855 Wairarapa earthquake, but if a similar earthquake were to happen today then we would expect significant fire losses. Our simulations indicate that the most likely outcome is for losses due to fire to be smaller than the losses due directly to earthquake shaking.

These potential losses can be mitigated against by preventing ignitions, enhancing water supplies and upgrading buildings to prevent spread of fire from building to building. Most ignitions are from gas, which can be minimised by installing seismic shut-off valves, providing flexibility in connections and ensuring foundations, and foundation connections are robust enough to minimise differential movement between the buildings and ground where gas connections come in. Electrical fires can be minimised by isolating the power in damaged buildings before the power supplies are switched back on and good liaison between emergency management and the power companies. Fire extinguishers should be readily available in buildings so occupants can fight fires before they grow.

## ACKNOWLEDGEMENTS

We thank the New Zealand Fire Service Commission and the Foundation for Research Science and Technology (FRST Contracts C05X0006 and C05X0209) for funding the research and Wellington City Council for providing buildings data.

## REFERENCES

- Conly G 1980. The shock of '31. The Hawke's Bay earthquake. A.H. & A.W. Reed Ltd, Wellington, Sydney, London, Auckland Christchurch, 234 p.
- Cousins WJ 2004. Towards a first-order earthquake loss model for New Zealand. Proceedings, 2004 Conference of the New Zealand Society for Earthquake Engineering, 19-21 March 2004, Rotorua. New Zealand Society for Earthquake Engineering, Paper No. 029.
- Cousins WJ, Smith WD 2004. Estimating losses due to post-earthquake fire in three New Zealand cities. Proceedings, 2004 Technical Conference and AGM, New Zealand Society for Earthquake Engineering, 19-21 March 2004, Rotorua, Paper No. 28.
- Cousins WJ, Thomas GC, Heron DW, Mazzoni S, Lloyd D 2002. Estimating risks from fire following earthquake. Institute of Geological and Nuclear Sciences Client Report 2002/60, Lower Hutt, New Zealand, 43 p. [see [http://www.fire.org.nz/research/reports/reports/Report\\_27.htm](http://www.fire.org.nz/research/reports/reports/Report_27.htm)]
- Cousins WJ, Thomas, GC, Heron DW, Mazzoni S, Lloyd D 2003a. Modelling the spread of post-earthquake fire. Proceedings, 2003 Pacific Conference on Earthquake Engineering, Paper No. 001. New Zealand Society for Earthquake Engineering. 8p (CD-ROM).
- Cousins WJ, Thomas GC, Heron DW, Lukovic B, Schmid R 2003b. Fire Following Earthquake-Napier 1931 Revisited. Institute of Geological and Nuclear Sciences Client Report 2003/95, Lower Hutt, New Zealand, 32p.

- Downes, GL, Dowrick DJ, Van Dissen RJ, Taber JJ, Hancox GT, Smith EGC 2001. The 1942 Wairarapa, New Zealand, earthquakes: analysis of observational and instrumental data. *Bulletin of the New Zealand Society for Earthquake Engineering*, 34(2):125-157.
- Grapes R, Downes G 1997. The 1855 Wairarapa, New Zealand, Earthquakes: Analysis of Historical Data. *Bulletin of the New Zealand Society for Earthquake Engineering*, 30(4):271-368.
- Hokugo A 1997. The Performance of Fire Protection of Buildings against the Fires Following the Great Hanshin-Awaji Earthquake. *Fire Safety Science—Proceedings of the Fifth International Fire Safety Symposium*, Melbourne, 1997, pp 947-958.
- Scawthorn C 1987. Fire Following Earthquake. Estimates of the Conflagration Risk to Insured Property in Greater Los Angeles and San Francisco. All Industries Research Advisory Council. Oak Brook, Ill. USA.
- Thomas GC, Cousins WJ, Lloyd D, Heron DW, Mazzoni S 2002. Post-earthquake fire spread between buildings – Estimating and costing extent in Wellington. *Seventh International Symposium on Fire Safety Science*, Massachusetts, USA, 16<sup>th</sup> – 22<sup>nd</sup> June 2002. International Association for Fire Safety Science.
- Todd D et al, 1994. 1994 Northridge Earthquake, Performance of Structures, Lifelines and Fire Protection Systems. National Institute of Standards and Testing, NIST SP 862, Gaithersburg, MD, 186 p.

# **EARTHQUAKES: THEIR STRATEGIC IMPORTANCE IN CIVIL DEFENCE AND EMERGENCY MANAGEMENT GROUP PLANS**

Peter Kingsbury

Ministry of Civil Defence and Emergency Management, PO Box 13-766, Christchurch  
(peter.kingsbury@dia.govt.nz)

## **INTRODUCTION**

The inevitability of further major earthquakes and recognition of other natural and man-made hazards in New Zealand, together with our better appreciation of the likely potential impacts and consequences, has made effective emergency management a high priority.

Under the Civil Defence Emergency Management Act 2002 (CDEM Act) sixteen Civil Defence and Emergency Management Groups (CDEM Groups) have been established in New Zealand. The groups are an alliance of local authorities, key infrastructure providers, health and welfare agencies, and emergency services.

Each CDEM Group has a statutory plan that identifies and assesses natural and man-made hazards, the risks they create, and how the risks are currently being managed. The group plans also record agreed arrangements for readiness, response and recovery co-ordination, as well as identifying targets and actions for improving the management of hazards.

Earthquakes, as natural events, feature prominently in all the group plans. Of more importance in the plans is the recognition of potential earthquake impacts and ensuing consequences. Functions to address the consequences are, along with lead agency, mandate, process and resource, key elements of the plans operational arrangements.

## **SINCE 1855: EARTHQUAKES GIVEN HIGH PRIORITY BY CDEM GROUPS**

Predictably, most of the sixteen CDEM Groups have identified earthquakes, in their group plan, as a significant threat or *high priority hazard* in their region. The threat posed by earthquakes, relative to other hazards, was initially determined by all CDEM Groups from a qualitative assessment of earthquake likelihood and consequence.

A more quantitative assessment was used by most CDEM Groups and included consideration of *seriousness* (impacts, including human, economic, social, infrastructure and environmental), *manageability* (the ability to reduce risk), *urgency* (the importance of addressing risk) and *growth* (the rate at which the risk will increase). All organisations associated with the CDEM Groups were consulted as part of this process.

In addition to the relatively high probability of occurrence, earthquakes are generally classified by most CDEM Groups as a *high priority hazard* because they:

- have the potential to affect a large part of the groups' region (whilst recognising that some effects will be localised)
- have the potential for considerable impact across all aspects of community life
- will require, at least, a regional co-ordinated response
- require significant input across all four key areas of emergency management - reduction, readiness, response and recovery.

In evaluating their full range of hazards, but more importantly the consequences of those hazard events, earthquakes have also been identified by most CDEM Groups as an issue of *national significance*. Issues of national significance are where national response and/or recovery assistance and/or co-ordination would be required. However, the nature and scope of these requirements is generally poorly explained in most of the group plans. This is partly because determining national significance (in terms of response and recovery) has been qualitative not quantitative. It may also be attributed to the fact that New Zealand has not experienced a highly destructive earthquake in a heavily populated area in recent time. Some CDEM Groups have identified in their group plan the need for further work to better define their issues of national significance.

### **FUTURE FOCUS: EARTHQUAKE PROBABILITIES AND IMPACTS, AND POLICIES AND STRATEGIES**

As part of the development of group plans and the definition of specific earthquake scenarios, and from earlier work by CDEM Group members, most CDEM Groups have a reasonably sound understanding of the general nature of the earthquake hazard for their region.

Information on probability/likelihood of occurrence and impacts/consequences is however, at best, vague for many CDEM Groups. A thorough understanding of both these components of earthquake hazards is essential for developing effective reduction, readiness, response and recovery strategies and work programmes. Key targets (measurable outcomes) and actions (agency specific), to achieve specific earthquake reduction objectives, have been defined in some group plans to address these matters. Notwithstanding this, considerably more effort is required in defining community vulnerability or pre-event potential impact.

Although existing group plans go some way to addressing earthquake hazard response and recovery matters, wider local government policies and strategies for long-term mitigation, and particularly for land use planning, are rare. Research is needed to find ways in which land use planning and development decisions can better take into account a thorough understanding of earthquake hazards including surface fault rupture, ground shaking and ground failure. A pertinent example of this is the difficulties of the use and application of detailed liquefaction hazard information in Christchurch.

Furthermore, the development of methods to encourage local government organisations to include hazard mitigation as an integral part of their core activities is required. Too often the consideration of *the* earthquake hazard is a thoughtless reaction to development pressures. Some progress is being made, for example through the Ministry for the Environment's *Urban Design Protocol* project and Christchurch City Council's *Greater Christchurch Urban Development Strategy*, but regrettably, issues of economic development and personal choice remain firmly set in many politicians minds. It is fair to say that earthquake hazard reduction principles are generally widely accepted, but practice often falls short of stated values.

## CONCLUSIONS

The existence of earthquake hazards in New Zealand has been known for a long time. However, parts of the country are still vulnerable to a level of risk that is undoubtedly undesirable, and probably unacceptable.

CDEM Group plans provide another useful “hook” for promoting and advocating earthquake hazard mitigation through the full range of emergency management reduction, readiness, response and recovery initiatives.

The level of attention given to earthquake hazard mitigation in local government has, in the past, often depended on the existence of an advocate or “champion”. Given the CDEM Group structure, the process of group plan development, the wide range of stakeholders and contributors, and the plans’ statutory basis, it would be disappointing if CDEM Group plans do not stimulate broader involvement, and more importantly, tangible actions and achievements.

Having robust and defensible probability/likelihood and impact/consequence information is fundamental to understanding risk. A poor understanding of these two risk factors means it is hard to identify ways of reducing risk and setting priorities is difficult.



# EARTHQUAKE RISK: HOW BAD AND HOW OFTEN?

Warwick Smith<sup>1</sup>

<sup>1</sup>Institute of Geological & Nuclear Sciences, PO Box 30-368, Lower Hutt  
(w.smith@gns.cri.nz)

## INTRODUCTION

If decisions in earthquake risk management are to be well-founded, they must rest on knowledge of the peril, by which we mean estimates of the likely consequences of large earthquakes and of the probability that they will occur. The 1855 Wairarapa earthquake was the largest to affect New Zealand in historical times, and if it were to occur today it would wreak more havoc than it did in 1855 when Wellington was a small town. But are there other earthquakes that could cause more damage? How likely are they to occur? Can we assign some sort of measure to the severity of the risk? How does that measure vary from place to place in New Zealand? How strong do we need to make our buildings? Is it absolutely safe anywhere? What information is needed by planners so that they can make decisions that reflect (a) the hazard as it varies throughout the country, (b) the best use of financial resources, and (c) minimum risk to people and infrastructure? Hazard and risk analysis can provide some of these answers.

## DEFINITION OF TERMS: HAZARD AND RISK

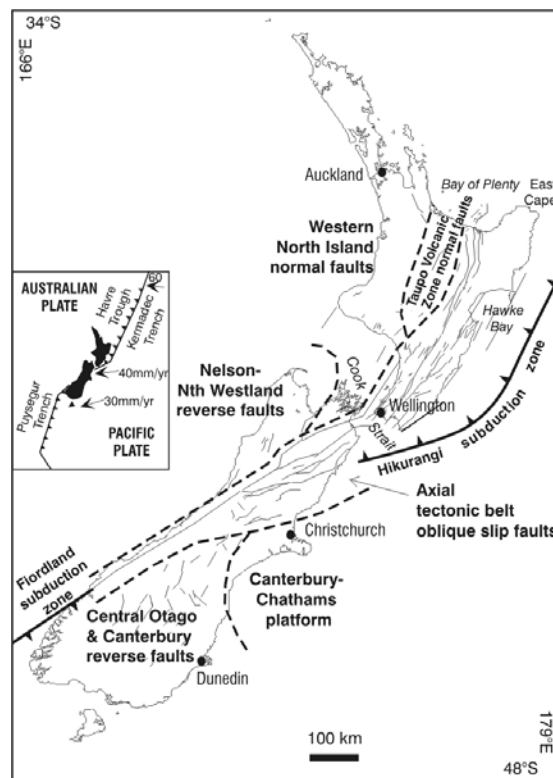
By *earthquake hazard* at any particular locality, we mean the probability that there will be strong ground shaking there. So if you live near a major active fault the hazard is quite high, but further away the hazard is less because the shaking is less severe at greater distances. *Earthquake risk* goes a little further by estimating the likely effects of earthquake damage, and how often they can be expected. So while the hazard is high in Fiordland, because of the very frequent earthquakes there, the risk to property there is not great because there are no large cities there. Hazard analysis is done for individual localities, while risk analysis is done for specific assets, and assesses not only the hazard but also how vulnerable these assets are to the shaking that is likely to occur.

## SEISMICITY MODEL

Hazard and risk modelling involve combining the findings of three areas of research, and the first of these addresses the earthquakes that are likely to occur. Our historical record is too short to be a reliable indicator of geological processes, so an examination of the active faults is called for. How often does each one rupture? With earthquakes of what magnitude? Current thinking considers that major faults rupture with approximately the same characteristic magnitude on each occasion (e.g. Wells & Coppersmith 1994). Paleoseismological investigation of active faults yields information on past ruptures, and in particular the direction and amount of displacement. Stirling et al (2002) have published a detailed *catalogue of active faults*. This catalogue is under ongoing revision; it currently documents more than 300 active faults, and for each one estimates the likely mechanism, characteristic magnitude and recurrence interval. These last two parameters are drawn from relationships among fault length, area, amount and frequency of rupture.

In addition, the earthquakes that occur away from known active faults are accounted for in a *background seismicity* model, which assigns occurrence rate parameters at each of a grid of sites that cover the country. This is particularly important for locations such as Auckland, from which the nearest active fault is many kilometres away and whose seismic hazard derives mainly from the background earthquakes. In assigning the seismicity parameters to each grid point (rate, b-value and maximum magnitude), some spatial smoothing is necessary in order to account for low data rates and achieve a realistically smooth variation throughout the country.

Figure 1 shows the plate tectonic setting of New Zealand, with many features that are implemented in the fault and background seismicity models.

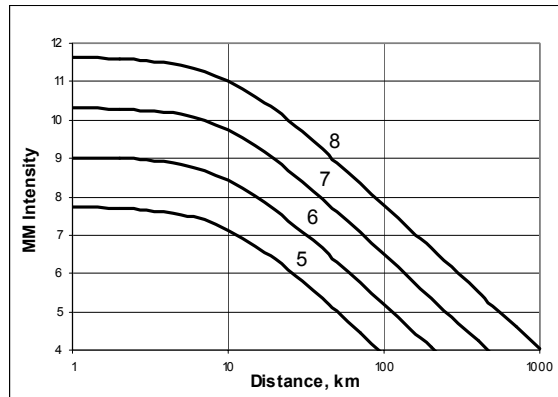


**Figure 1.** Tectonic setting of New Zealand

## ATTENUATION OF STRONG GROUND MOTION

Because the hazard measures the probability that strong ground motion will occur at a particular place, the rate at which the severity of ground motion decays with increasing distance is very important. Dowrick & Rhoades (2002) have developed an attenuation relation for MM intensity, which estimates the intensity as a function of earthquake magnitude and mechanism, and the location of the observing site with respect to the earthquake. A simple measure of distance is eschewed in favour of an elliptical pattern of strong motion excited by a long rupture on a fault, and by the regional characteristics of strong motion propagation, which tend to be anisotropic. Figure 2 shows likely intensities as a function of magnitude and epicentral distance, for one particular class of earthquakes.

McVerry et al (2000) have developed an attenuation function that expresses acceleration as a function of natural period, as well as magnitude and distance from the source. This is particularly important for engineering applications, because acceleration as a measure of ground motion can be readily incorporated into building design and into building codes.



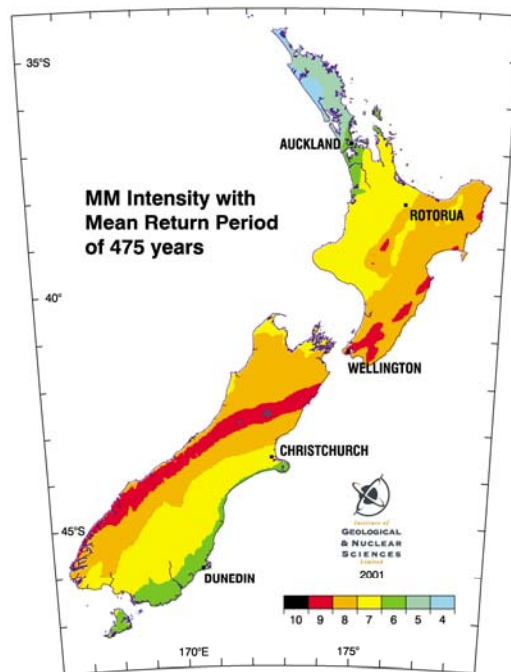
**Figure 2.** Intensity of ground motion decreases with distance from the epicentre. Shown for magnitudes 5 to 9, as modelled by Dowrick & Rhoades (1999)

## HAZARD ANALYSIS

Hazard analysis comes from combining the earthquake source model with the attenuation function. Hazard is expressed in terms of the probability that ground motion of a particular natural period will exceed any given threshold. It represents the total effects all the earthquake sources that can affect a particular locality: fault sources and background seismicity. Such hazard estimates are essential for engineering design. Stirling et al (2002) present maps of the ground motion level that is likely for a set of return periods. The earthquake hazard in New Zealand is greatest along a broad zone that extends from Fiordland to East Cape. But there is much detail in the maps, because of the detail in the model of active faults. The hazard in Auckland and Dunedin is much less than in the more active parts of the country because of their locations away from the active margins.

The term *return period* may need clarification. Earthquake hazard and risk should ideally be expressed in terms of probability. Thus, we evaluate the probability that an event of a particular severity will occur in any one year. The problem with this is that the numbers expressing the probability are quite small. It is more convenient to define the return period as the average time between occurrences, which (except for probabilities approaching 1.0) can be taken to be equal to the reciprocal of the annual probability. Thus, an event with an annual probability of 0.01 has a mean return period of 100 years. This means that such events occur about every 100 years, on average but not on schedule. Two commonly held misconceptions about return periods are that this event is the biggest that will occur during that period, and that it can be expected to occur in that time. *Neither of these is true.* It turns out that the probability that such an event will occur within a 100-year period is about 0.63. For a ground motion that has a return period of 475 years it is equivalent to say that it has a 10% probability of occurring within 50 years. Figure 3 shows these data for New Zealand.

Hazard is usually expressed as the return period for a given severity of ground motion *or greater*. This is a practical aspect of the analysis: it makes no sense to talk about the probability that an acceleration of 0.5g will be experienced, because it will never be exactly that value. By using the cumulative measure we can provide a probability for 0.5g or greater.



**Figure 3.** MM intensities with a 10% probability of occurring within 50 years. This is equivalent to a mean return period of 475 years.

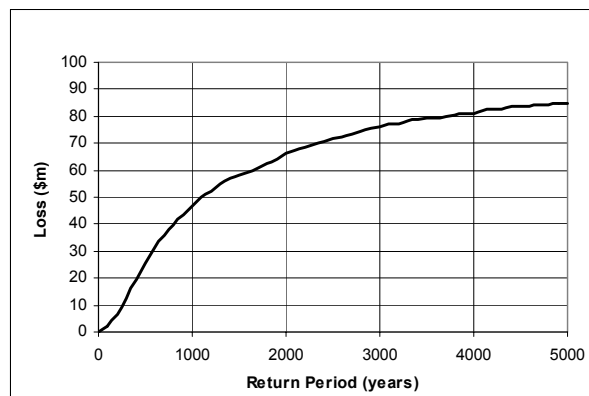
## RISK ASSESSMENT

While hazard analysis is very useful for engineering design and safety considerations, progression to risk assessment by incorporating the likely damage to assets has other applications. For insurance purposes it is useful to know the likely amount of damage due to earthquakes that may occur. Other risk management exercises may want to compare earthquake risk with those of other hazards, such as flood. The risk manager wants to know what is the most cost-effective way to use scarce resources.

Dowrick & Rhoades (1993, 1997a,b and other papers) have evaluated damage ratios as a function of MM intensity in New Zealand earthquakes. The damage ratio is the ratio of the amount of damage to the value of the asset, so it varies between zero (no damage) and 1.0 (total writeoff). So, if we can estimate the likely intensity and we know the value of a building and its structural characteristics, it is possible to estimate the amount of damage. In an alternative approach, the HAZUS software package (FEMA 1997) uses the spectral content of the ground motion, together with the structural properties of the building to calculate a deformation state and hence the damage cost.

Risk studies in New Zealand have so far implemented only the intensity-based approach (Smith 2003), because of the availability of insurance-derived data on damage costs, although work is progressing on developing methods of assessment using spectral

acceleration. This work has had considerable application in the insurance industry, where owners of large assets can obtain assessments of the probability of damage. The results are in the form of a loss curve (Figure 4), which shows the probability that any given level of loss is likely to be exceeded. Decisions such as the level of excess (deductible) and how the insurance package is to be structured can be taken using this information. When done for an insurance company that is seeking to purchase reinsurance, it is possible to include insurance conditions such as excess and cap, in order to estimate the losses the company might face, and against which it wishes to reinsure.



**Figure 4.** Loss curve showing the loss likely to be equalled or exceeded, as a function of return period, for a hypothetical portfolio of commercial buildings near Wellington. The total replacement value of the buildings is \$350 million.

## RISK MANAGEMENT

Insurance is but one form of risk management. Another important aspect is the use of mitigation measures to reduce the risk. Questions arise immediately: what will the mitigation measures cost? Does the benefit justify this? Would the money be spent more effectively on other projects? One way to approach this is to “discretise” the loss curve as short-term, medium-term and long-term losses, and to note how these losses reduce with the proposed mitigation measures. Some hazards, such as flood, tend to cause losses more frequently than earthquake, so it is important that comparison across different hazards be done at the three different time scales. Decision-making will no doubt be somewhat subjective, and based on many different criteria: social and political as well as economic. But a well-founded risk assessment should be the first step.

## REFERENCES

- Dowrick DJ, Rhoades DA 1993. Damage costs for commercial and industrial property as a function of intensity in the 1987 Edgecumbe earthquake. *Earthquake Engineering and Structural Dynamics* 22: 869-844.
- Dowrick DJ, Rhoades DA 1997. Vulnerability of different classes of low-rise buildings in the 1987 Edgecumbe, New Zealand, earthquake. *Bulletin of the New Zealand National Society for Earthquake Engineering* 30(3): 227-241.

- Dowrick DJ, Rhoades DA 1997. Damage ratios for plant, equipment and stock in the 1987 Edgecumbe, New Zealand, earthquake. *Bulletin of the New Zealand National Society for Earthquake Engineering* 28(4): 265-278.
- FEMA 1997. *HAZUS*. National Institute of Building Services Documents 5200 to 5203, Federal Emergency Management Agency, USA.
- Smith WD 2003. Earthquake hazard and risk assessment in New Zealand by Monte Carlo methods. *Seismological Research Letters*, 74, 298-304.
- Stirling MW, McVerry GH, Berryman KR 2002. A new seismic hazard model for New Zealand. *Bulletin of the Seismological Society of America*, 92(5): 1878-1903.
- Wells DL, Coppersmith KJ 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. *Bulletin of the Seismological Society of America* 84, 974-1002.

## REGIONAL RISKScape MODEL: PROGRESS ON DEVELOPING A MULTI-HAZARD RISK TOOLBOX

Robert Bell<sup>1</sup> and Andrew King<sup>2</sup>

<sup>1</sup>NIWA, PO Box 11115, Hamilton

<sup>2</sup>GNS, PO Box 30368, Lower Hutt

(r.bell@niwa.co.nz)

New Zealanders are exposed to a wide variety of natural hazards and within historic time (last 200 years), have experienced community damage from almost every conceivable natural hazard. The past two years have seen three damaging floods with associated landslides and some sizeable earthquake events such as that in Fiordland in August 2003. The risks need to be managed, but first the phenomena itself must be understood. Much of hazards research has been historically targeted at the latter, but increasingly emergency managers and planners are demanding more quantitative information of the risks associated with different hazards and to be in a position to compare the impacts across the different hazards.

Once the zone of influence of a particular hazard has been ascertained and its recurrence interval established, then the impact of events of various intensity can be calculated by overlaying the hazard exposure for each event over built-environment inventories and people exposed to that event. Then, by reference to the fragility of each inventory or people class to that exposure, the losses, casualties and disruption (i.e. consequences) resulting from these events can be quantified. Conceptually, this process is relatively straight forward, but application to real-world situations with inherent difficulties in obtaining and linking good-quality inventory and demographic datasets and comparing hazards with vastly different recurrence intervals and source mechanisms is problematic, but nevertheless is achievable. In June 2004, the New Zealand Foundation for Research, Science and Technology (FRST) directed funding to the development of a Regional Riskscape Model to accomplish the above. The business approach preferred was a joint venture comprising Geological Risk Ltd. (a subsidiary of the Institute of Geological & Nuclear Sciences, GNS), which focuses on geological hazards, and the National Institute of Water & Atmospheric Research (NIWA), which focuses primarily on weather-related hazards.

The main goal of the project is to produce a decision-support tool that converts existing hazard knowledge into likely consequences for a region, such as damage and replacement costs, casualties, disruption and number of people that could be affected. Consequences for each region presented in a common platform across all natural hazards can then form the basis of prudent planning and prioritised risk-mitigation measures that link directly to the severity of the risks. A working prototype of the system is being developed for three areas in ascending size of population base: Westport, Napier/Hastings and Christchurch. Progress to date will be outlined with examples. Without a good assessment of the overall risk profile (“riskscape”), efforts to manage natural hazards may be futile, so the Regional Riskscape Model offers future socio-economic benefits in this regard.

## **REFERENCE**

King, A.; Bell, R.G. (2005). Riskscape New Zealand: A multihazard loss modelling tool. Paper at International Conference on Earthquake Engineering "Earthquake Engineering in the 21st Century – IZIS 40 EE-21C", Skopje/Ohrid, Macedonia, 27 Aug-1 Sept 20.



# THE 1855 EARTHQUAKE: SOCIETAL IMPACT AND RESPONSE IN WELLINGTON

Rodney Grapes<sup>1</sup> and Hamish Campbell<sup>2</sup>

<sup>1</sup>Albert-Ludwigs Universität-Freiburg, D-79104, Freiburg, Germany

<sup>2</sup>Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand  
(rodney.grapes@minpet.uni-freiburg.de, h.campbell@gns.cri.nz)

## INTRODUCTION

The 1855 earthquake of January 23<sup>rd</sup> with its numerous and protracted aftershocks occurred at a time of important social and political tensions in New Zealand, and particularly in Wellington where the greatest damage was sustained. Evidence from mostly contemporary accounts shows that many people, particularly politicians, were acutely aware of the negative effect that a second large earthquake in seven years would have on prospective immigrants and also on Wellington's aspirations of becoming the seat of Government. The damaging effects of the earthquake had to be downplayed — the future of the settlement depended on it.

## EFFECTS AND CONSEQUENCES

By 1855 the European population of Wellington had reached 3,200. It was a busy, thriving commercial centre of incoming goods and outgoing produce from surrounding areas, the Wairarapa, Horowhenua and Marlborough. The future looked optimistic. And then, on the evening of January 23<sup>rd</sup>, to mark Wellington's 15<sup>th</sup> Anniversary, a large earthquake centered in Cook Strait about 40 km SW of Wellington shook almost the whole of New Zealand and caused substantial damage in Wellington.

The immediate impact of an earthquake of this magnitude was one of terror, despair, and despondency, although there is little commentary on these symptoms in contemporary sources. Remarkably, there was only one life lost — that of Baron von Alzendorf, the proprietor of the largest brick hotel who died from exhaustion and bleeding after being severely cut by a mirror that broke when a chimney collapsed into his living room.

The time of the earthquake at 9.17 p.m. was fortuitous and “favourable to the escape of adults, who seized the children from beneath tottering chimneys, themselves not generally retired to bed”<sup>1</sup>. Apart from a few references to minor injuries, most accounts describe the experience of the earthquake, — the shaking, jolting and swaying, feelings of nausea, immediate damage to buildings, particularly the falling of chimneys and the lucky escapes from injury or worse. The widespread havoc and panic caused by the first and greatest shock continued with numerous aftershocks that were “so nerve wrecking ... that many people believing that the end of all things was near, were quite indifferent to the ruin of their goods”<sup>2</sup>.

Once the initial and greatest shocks were over (human as well as those of the earthquake), damage control was set in motion. At a public meeting a few days after the earthquake, Jerningham Wakefield “felt sure that the people of Wellington did possess those qualities of prudence and endurance: that as they had struggled through far more

grievous afflictions [possibly the voyage to New Zealand!], so they would cheerfully meet this, and even be prepared to triumph over difficulties”<sup>3</sup>. Indeed, “the very day after the awful night”, writes Charles Carter “...repairs were affected, business was resumed, the newspapers were published as usual, and what was more noticeable and strange, the virulence of politics – mitigated for a night – resumed its sway”<sup>4</sup>. Needless to say — both of these men were strong advocates of emigration.

Many of the Wellington’s inhabitants still remembered the cluster of earthquakes in October 1848 that caused considerable destruction and the loss of three lives. But the town had recovered and although a good number of inhabitants left most remained to rebuild. They had staked their future on creating a new life in a far-away undeveloped land and were resolved to remain, undeterred by such natural setbacks.

Immigration had continued through active promotion of the New Zealand Company and it was clear that a prosperous future lay ahead for Wellington, and all the settlements — Wanganui established in 1840, Nelson in 1841, New Plymouth in 1841, Dunedin in 1848, Christchurch in 1853, and Auckland in 1840, the seat of British Administration. There was vigorous competition for immigrants between all the settlements and in Wellington an earthquake, however destructive, could not be allowed to stem the flow.

Naturally, there are some accounts that record a loss of confidence in staying in New Zealand. Writing of her father, the Hon. Henry William Petre of Lower Hutt, his daughter relates that the earthquake “upset all Father’s plans; he lost confidence in New Zealand and made up his mind to return to England”<sup>5</sup>. Another, talks of William Bennett, a civil engineer in Wellington who had “come to the conclusion that men of his profession will never be wanted in such a country so he has decided to return to England at the first opportunity”<sup>6</sup>. For several months after the earthquake, people were continuing to leave Wellington.

The immediate impact of the earthquake brought local animosities and rivalries to the surface. The editors of the two Wellington newspapers — the *Independent* and the *Spectator*, were bitter opponents, missing no opportunity to undermine each other.

The first report on January 24<sup>th</sup> in the *Independent* created the impression that the earthquake was a trifling affair: “On Tuesday evening a little before ten o’clock, the community was alarmed by a smart shock of earthquake, which lasted several seconds, and was succeeded at intervals by tremors of less violence.... At the time of going to press, there is the appearance of all commotion having ceased”.

On January 27<sup>th</sup> the *Spectator* strongly rebuked the report, “We cannot help noticing in terms of strong reprobation, the short paragraph in Wednesday’s *Independent* referring to this visitation, the falsehood and flippancy of which has excited very general disgust. Possibly the writer of it thought by this manner of treating this subject, to do away with any unfavourable impression out of the colony which such news was likely to produce; if so, like most cunning but shallow persons, he has overshot his mark, and will, we think, create the very opposite feeling, and utter want of confidence in anything the *Independent* may say”.

The February 10<sup>th</sup> issue of the *Independent* relates a somewhat more realistic and detailed story, but accuses the *Spectator* (and other provincial newspapers) of

exaggerating the effects of the earthquake. The general belief was that the Wellington politicians who supported the *Independent* were quite happy for the earthquake to be described in terms of a short smart shock for obvious reasons.

Not so easy to dismiss was the largely first-hand account of the earthquake written by Byron Drury, commander of the survey ship *Pandora* anchored in Wellington Harbour at the time of the earthquake. First published in the Nelson newspaper it appeared in the 7th February issue of the *Spectator* to the dismay of Wellington's politicians. One, Jerningham Wakefield, thought that "Captain Drury's hasty account would convey false impressions to distant readers (i.e. those in England)" although "he felt sure from the high character of that officer that he intended to give a true account, but had been betrayed by haste into expressions which he would probably have modified on further examination and reflection.

Captain Drury's actual words were correct in most instances, but it was the absence of explanation which produced false impressions<sup>7</sup>. Another, William Fox went so far as to suggest that on reflection, Drury was ashamed of it<sup>8</sup>. To the contrary, in a letter to the British Admiralty in mid February Drury states that his impression was that the report appeared "to be acknowledged as the most accurate account yet in Wellington"<sup>9</sup>.

The "civil defence" unit operating in Wellington at the time of the earthquake was the 65<sup>th</sup> Regiment. They acted swiftly in clearing debris and pulling down buildings left in a dangerous condition, mindful after their experience during the 1848 earthquakes that strong aftershocks had the potential to cause further damage to household goods, weakened buildings and loosened masonry that could inflict injury or loss of life.

A supply of tents was issued as many people required shelter, either because they had been rendered homeless, or they preferred the relative safety of sleeping under canvas rather than venturing back into their damaged houses. The Maori headed for the hills as they had traditionally done during such events.

Unfortunately, the supply of tents, together with the question of the use of Government House became the spark that ignited an argument between the military and the Provincial Government<sup>10</sup>. The Colonial Secretary had requested some tents and the temporary use of Government House for holding Council meetings because the Council Chambers had collapsed. This request was refused by the military commander on the grounds that the available tents were needed to protect military property and that Government House needed to be inspected and declared safe before anyone could use it. The refusal only increased the semi-autonomous Provincial Government's frustration and anger with the presence of a regiment who took their orders from the administration in Auckland. Despite these concerns, the efforts of the 65<sup>th</sup> Regiment were greatly appreciated and highly praised by the general populace.

As to the question of the future seat of Government, those in Christchurch were guardedly jubilant. "Everyone has given up the idea of Wellington," wrote Charles Bowen in Lyttelton<sup>11</sup>. For Henry Sewell, future Prime Minister, in Christchurch - "There will be no Government House in Wellington, and nobody will propose building one there... It is beyond doubt a calamity to that place and I'm afraid to New Zealand generally. The damage to Wellington is two-fold: loss of property and loss of good repute. The loss of property is considerable, buildings destroyed, and goods damaged.

More than that: the whole place has undergone a depreciation of marketable value.... A septennial calamity of this sort is of course utter condemnation to a place of residence”<sup>12</sup>.

Ten years later, both predictions were proved wrong when Wellington became the seat of Government.

## UPSIDE AND FUTURE

Despite the damage, alarm, and depreciation of marketable value caused by the earthquake, its one benefit was soon recognised — namely the uplift of about one metre. Commander Drury, whose boats sounded Lambton Harbour after the earthquake, congratulated Wellington’s inhabitants in now being able to “redeem a large tract of building ground”<sup>13</sup>. It did not take long for plans drawn up for reclamation in Lambton Harbour before the earthquake to be implemented. This and the determination of the Provincial Government and citizens to put the earthquake and its effects behind them as quickly as possible ensured the survival and continued development of the settlement. Quite simply, there was no alternative. The future of Wellington, as its church and political leaders realised, depended solely on the individual and collective response of its citizens to such uncontrollable setbacks. Will it be so again?

## REFERENCES

- <sup>1</sup> *Spectator* February 7 1855. Extracts from Commander Drury’s Remarks.
- <sup>2</sup> Hollard, Elizabeth, ca.1930? Reminiscences [1842–1930]. QMS-0989–0990. Alexander Turnbull Library, NLNZ.
- <sup>3</sup> *Spectator* February 10 1855.
- <sup>4</sup> Carter, C.R. 1866. *Life and recollections of a New Zealand Colonist*. R. Madley, London, England.
- <sup>5</sup> Colley, Mrs. Lucy (nee Petre), 1907. *The life of the Hon. Henry W. Petre and Eleanor Walmsley, his wife, written by the eldest daughter, Mrs Phillip Wellesley Colley (Lucy Petre) with notes on their children and grand children from authentic sources and family papers*. Privately printed. MS-0593. Alexander Turnbull Library, NLNZ.
- <sup>6</sup> Anon 1855. Great ‘quake’ – over seventy years ago – a contemporary account. *In: The Northlander*, April 18, 1928.
- <sup>7</sup> *Spectator* February 10 1855.
- <sup>8</sup> Fox, William, 1855. Letter from J. Fox dated February 26 1855. In: J.R.Godley Papers, Typescripts, v.II, p.678–9. Canterbury Museum, Christchurch, New Zealand.
- <sup>9</sup> Drury, Byron, 1855. Letter dated February 13 1855 from Commander Drury to Captain Washington, Hydrographer, British Admiralty. Letter held at Ministry of Defence, Taunton, Somerset, England.
- <sup>10</sup> *Spectator* February 10 1855; Provincial Council Papers, March 1855.

- <sup>11</sup>Bowen, C.C. 1855. Letter from Charles C. Bowen dated February 16, 1855. In: J.R.Godley Papers, Typescripts v.II: 564–4, Canterbury Museum, Christchurch, New Zealand.
- <sup>12</sup>McIntyre, W.D.(ed.) 1980. *The Journals of Henry Sewell 1853–7*. v.II. W. Whitcoulls Publishers, Christchurch, New Zealand.
- <sup>13</sup>*Spectator* February 24 1855.

# INDIVIDUALS' RESPONSE TO NATURAL HAZARD EVENTS

J.L. McClure<sup>1</sup>, D.M. Johnston<sup>2</sup>, and D. Paton<sup>3</sup>

<sup>1</sup>School of Psychology, Victoria University of Wellington, Wellington, New Zealand

<sup>2</sup>Institute of Geological & Nuclear Sciences, Lower Hutt, New Zealand

<sup>3</sup>School of Psychology, University of Tasmania, Launceston, Australia

(john.mcclure@vuw.ac.nz, d.johnston@gns.cri.nz, douglas.paton@utas.edu.au).

## INTRODUCTION

New Zealand is exposed to a wide range of potentially devastating impacts from a range of natural hazards. Although New Zealanders have been subject to significant earthquakes in the past (e.g., 1931 Napier earthquake), we have had a relatively calm period over the past 75 years. The fact that few New Zealanders have experienced disastrous earthquakes is a good thing, in terms of their survival. The downside, however, is the resulting complacency and limited understanding of earthquake risk. This risk has been compounded by the relatively frequent exposure of New Zealanders to minor seismic activity, increasing the likelihood that people normalize (see below) to this level of experience rather than anticipating what could occur. Our level of experience at an individual, community and national level in dealing with significant earthquakes needs to be better understood if we are to develop effective risk management measures. The benefits of a better understanding of earthquake risk are found in increased support for risk reduction activities, increased readiness and response capability, and an understanding of how to recover from events in an efficient manner. The adoption of protective measures (e.g. storing food & water, securing fixtures and furniture, preparing a household earthquake emergency plan) reduces the risk of damage and injury and facilitates a capability for coping with the temporary disruption associated with hazard activity. In building these capabilities we will reduce our economic exposure to future earthquakes (and to other natural hazards).

Earthquakes are uncontrollable events however; the effects of earthquakes can be partly controlled in the sense that they are mitigated by preparedness. The difference between the huge losses caused by some recent earthquakes in Asia and the relatively low fatalities in San Francisco in 1989 or Northridge in 1995 is not due to the magnitude of the earthquakes, but to the level of preparedness. Some preparedness takes the form of building regulations and other legislation, but regulations need to be complemented by citizens' own preparation. Yet despite the risk of huge losses from earthquakes, many citizens and businesses do not take the trouble to prepare. It is therefore useful to clarify psychological and social factors that contribute to a failure to prepare for earthquakes, and to show how best we can overcome these obstacles.

## RISK PERCEPTION

Expert estimates of risk are based on objective analyses of the likelihood of hazard activity and its consequences within a specific area. It is common to find considerable disparity between these expert assessments and the manner in which they are interpreted and acted on by the public and other groups (including some councils) (Adams, 1995; Paton et al., 2005). This discrepancy sometimes remains even when people are presented with scientific information. People's understanding of risk and response to risk are determined not only by scientific information or direct physical consequences,

but also by the interaction of psychological, social, cultural, institutional and political processes (Burns et al., 1993; Sjoberg, 2000). Factors affecting risk perception are usually not independent, and can vary between different hazards.

Beliefs about risk and risk reduction behaviour are also influenced by attributional processes (explanations about the causation of events) and intentional processes. Processes relevant here are unrealistic optimism and normalisation bias (Paton, Smith, & Johnston, 2001). Unrealistic optimism, sometimes referred to as the “illusion of invulnerability”, is seen where people underestimate the risk to themselves and overestimate the risk to others (Weinstein & Klein, 1996). Thus, while people may acknowledge objective risk in their community, they are more likely to attribute its negative implications to others rather than themselves. This bias leads people to take risky options, and applies to judgments about earthquakes, in that citizens in the USA and New Zealand think they are better prepared than others, which leads them to think that they will be safe (Helweg-Larsen, 1999; Spittal, McClure, Walkey, & Siegert, 2005). This bias is difficult to change, but it can be affected by showing people lists of earthquake precautions that have been carried out by others (Weinstein & Klein, 1996). Other strategies are also effective.

The normalisation bias results when people extrapolate a capability to deal with major hazards from a minor (objective) but rarely occurring hazard experience. Like the optimistic bias, this process results in people underestimating risk (relative to scientific and planning estimates) and acting in ways that, from an objective perspective, are counterintuitive and counterproductive.

Denial of risk is a related bias that inhibits positive actions. Furthermore, denial is greatest among people who are most at risk, partly because denial serves to reduce anxiety. Lehman and Taylor (1987) showed that students living in dormitory buildings with poor seismic resistance in Los Angeles denied the seriousness of earthquake risk more than those who lived in sound buildings. Denial can be reduced by people seeing that they have some control over a hazard.

The communication of risk information can have a distorting effect, particularly in regard to the risks with minor biophysical consequences eliciting extreme concern or significant risks being underestimated by communities and organisations. This phenomenon has been termed “the social amplification of risk” (Kasperson et al. 1988). Accusations of “irresponsible media”, “organisational incompetence”, and “public hysteria” are common (Rip, 1988). The problem arises when sources, such as the media, overemphasise adverse or catastrophic aspects of a problem and fail to provide a balanced view. It can also arise in situations where there is a lack of trust in information sources, particularly when these sources dismiss the concerns, needs, and interests of the community.

An additional bias is a tendency to overestimate the capacity of hazard mitigation strategies to eliminate a threat through the operation of an interpretive bias known as risk compensation (Adams, 1995). This phenomenon has also been known as the levee syndrome. This construct describes how people maintain a balance between the perceived level of safety proffered by their environment and the level of risk manifest in their actions and attitudes. Thus, a perceived increase in extrinsic safety (e.g., hazard monitoring, structural mitigation) can decrease perceived risk (as perceived by an

individual or group), reducing the perceived need for action. This becomes problematic because planners, in the process of engineering structural mitigation or disseminating information on their response role, assume that people's risk estimates, and thus their behaviour, remains constant. This assumption is unfounded. The dissemination of information on structural mitigation has been found to lead to a reduction in levels of household and personal preparedness, and a transfer of responsibility for safety to civic authorities (Paton et al., 2000).

## **CHANGING OUTCOME EXPECTANCY AND FATALISM**

People differ in their outcome expectancy about the value of preparedness actions. A key factor affecting outcome expectancy is fatalism, the attitude that "nothing that I do will make any difference, so there is no point in trying." In regard to earthquakes, fatalism is the attitude that earthquakes are so powerful that there is no use preparing. When the 'big one' comes, it will be so powerful that the best of efforts will be laid to waste. This fatalism often reflects a failure to distinguish between the uncontrollable force of earthquakes and the relative controllability of their effects. Damage from earthquakes can be attributed to the power of the earthquake not the structure of the buildings that collapse and kill people. Fatalistic people acknowledge only one of these causes, the earthquake's force, whereas other people, including people who know a lot about earthquakes, attribute damage to the combined effects of the earthquake and building design. These people are less fatalistic about outcomes.

Research has shown that there are ways of reducing earthquake fatalism. One strategy is to show people that the damage that occurs in earthquakes is often distinctive in terms of the buildings that collapse (McClure, Allen, & Walkey, 2001). An example is where one house in a street collapses and all the other houses stand firm. When people see that damage in earthquakes is often distinctive, they attribute the damage more to building design.

News reports of earthquakes usually take the opposite tack, and focus on widespread damage rather than buildings that stood firm. An American reporter arriving at Kobe two days after the earthquake in 1995 said he expected to see the city devastated but he was amazed that all around him there were buildings in good shape (Cowan, McClure, & Wilson, 2001). News reports immediately after an earthquake focus on the greatest damage, with headlines like "Kobe devastated". By contrast, later reports such as anniversary reports are more analytic and focus on the characteristics of the buildings that collapsed, and on lessons that can be learned. People who read these more analytic reports about the Kobe earthquake were less fatalistic about the damage than people who read the immediate news reports about the same earthquake (Cowan, McClure, & Wilson, 2001). So the information that citizens are exposed to can alter their fatalism and understanding.

Taking this strategy one step further, spelling out the specific features of building design that reduces damage helps people to see that something can be done (McClure, Sutton, & Wilson, 2005). Of course, some aspects of building design that affect resilience are expensive, which is a disincentive to action, but they are not all so. The use of simple computer locks was a leading predictor of business survival after the 1989 San Francisco earthquake, yet this precaution costs only a few dollars. Turner, Nigg

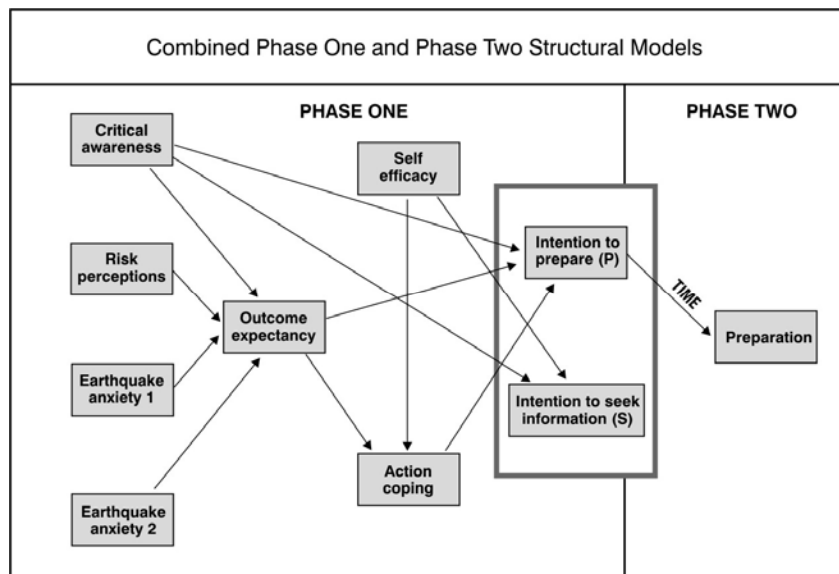


and Paz (1986) noted that focusing people on specific preventive actions helps them to be less fatalistic about earthquake outcomes.

## MOTIVATION

Changing risk perceptions alone will not necessarily bring about behaviour change or increased action to address a particular risk. Rather, the latter reflects social cognitive processes that mediate between perceived risk and risk reduction actions. People may not be motivated to prepare if they do not accept their risk status or perceive hazards as salient. Irrespective of the level of risk, action is constrained if people see hazard effects as insurmountable (low outcome expectancy), see themselves as lacking the competence to act (low self efficacy), or are not disposed to action (low action coping). Risk perception may not guide actions if people lack resources for implementation (low response efficacy), transfer responsibility for their safety to others (low perceived responsibility), lack trust in information sources, or stress uncertainty regarding the likely timing of hazard occurrence (Paton, 2003).

To understand the processes involved in improving preparedness for earthquakes, research has been directed towards examining the utility of social cognitive models of protective behaviour. Recent work by Paton and others (Paton 2003, Paton et al. 2004, Paton et al. 2005) proposes a model (figure 1) that begins with motivational factors and progresses through forming relevant intentions to decisions to prepare or not. Motivational factors in the model include critical awareness and earthquake anxiety. Critical awareness is the extent to which people talk and think about a hazard (i.e., how important or salient it is in their lives) on a regular basis and represents a primary motivator or precursor. Anxiety about future earthquakes can be both good and bad. Paton et al. (2005) separate anxiety into two categories, one having a positive impact of outcome expectancy (referred to as earthquake anxiety 1), the other having a negative impact (referred to as earthquake anxiety 2). High levels of negative anxiety increase avoidance of earthquake preparedness advice and reduce the adoption of preparedness measures.



**Figure 1** Combined phase one and two models, modified from Paton et al. 2005.

Some people take no action no matter what information you give them, but the realization that preparedness may make a difference to earthquake outcomes is a prerequisite to voluntary action, and it is likely to enhance action among those who act prudently. However, it may be necessary to have more assertive strategies that enhance motivation. For example, there could be an “earthquake warrant of fitness” for houses in the way that laws require a warrant of fitness for cars. We already have such a rating system for commercial buildings in Wellington, and owners of unsafe buildings are required to strengthen them within a given time frame. There is no inherent reason why a related strategy could not be extended to private dwellings.

## CONCLUSIONS

Perceptions of risk and safety are social and psychological products, not absolutes. Perceived risk can be amplified or attenuated through personal, social psychological and community factors, and ends up being interpreted in a manner that differs substantially from the objective, scientifically-derived index of risk used with the planning process. Risk management must address the wide spectrum of social factors that determine levels of acceptable risk, and that govern mitigating action. It is important that risk management be seen as a multi-disciplinary activity using models to reflect the dynamic nature of risk phenomena. The models and processes discussed here can be used to formulate more effective risk reduction and communication strategies that can serve to assist people in making decisions about protective actions in relation to the hazardous aspects of their environment.

The National Civil Defence Emergency Management Strategy has a vision for a “Resilient New Zealand – strong communities understanding and managing their hazards”, and calls for increased community awareness, understanding and participation in emergency management; reduced risk from hazards; and an enhanced national capability to manage emergencies and recover from disasters. For New Zealand to achieve these goals, the CDEM sector requires a sound research base that addresses the spectrum ranging from the physical phenomena of natural hazards through to the impacts of these hazards from a psychological, social and cultural perspective.

## REFERENCES

- Adams J 1995. Risk. London, UCL press.
- Burns WJ, Slovic P, Kasperson RE, Kasperson, JX, Renn O, Emani S 1993. Incorporating structural models into research on social amplification of risk; implications for theory construction and decision making. *Risk Analysis* 13: 611-623.
- Cowan J, McClure J, Wilson M 2002. What a difference a year makes: how immediate and anniversary media reports influence judgments about earthquakes. *Asian Journal of Social Psychology* 5: 169-185.
- Helweg-Larsen M 1999. (The lack of) optimistic bias in response to the Northridge earthquake: The role of personal experience. *Basic and Applied Social Psychology* 21: 1119-129
- Kasperson RE, Renn O, Slovic P, Brown HS, Emel J, Goble R, Kasperson JX, Ratick S 1988. The social amplification of risk: a conceptual framework. *Risk Analysis* 8: 177-187.

- Lehman DR, Taylor SE 1987. Date with an earthquake: Coping with a probable, unpredictable disaster. *Personality and Social Psychology Bulletin* 13: 546-555.
- Lindell MK 1994. Perceived characteristics of environmental hazards. *International Journal of Mass Emergencies and Disasters* 12: 303-326.
- McClure JL, Allen M, Walkey FH 2001. Countering fatalism: causal information in news reports affects judgments about earthquake damage. *Basic and Applied Social Psychology* 23: 109-121.
- McClure J, Sutton RM, Sibley C. 2005. Listening to reporters or engineers? How different messages about building design affect earthquake fatalism. Manuscript under review, Victoria University of Wellington.
- Paton D 2003. Disaster Preparedness: A social-cognitive perspective. *Disaster prevention and Management* 12: 210-216.
- Paton D, Smith LM, Johnston D 2000. Volcanic hazards: Risk Perception and Preparedness. *New Zealand Journal of Psychology* 29: 84-88.
- Paton D, Smith L, Johnston DM, Johnston M, Ronan K 2004. Developing a model to predict the adoption of natural hazard risk reduction and preparatory adjustments. Wellington: Earthquake Commission Research Project No. 01-479, 58 p.
- Paton D, Smith LM, Johnston D 2005. When good intentions turn bad: Promoting natural hazard preparedness. *Australian Journal of Emergency Management* 20: 25-30.
- Rip A 1988. Should social amplification of risk be counteracted? *Risk Analysis* 8: 193-197.
- Spittal MJ, McClure J, Siegert RJ, Walkey FH 2005. Optimistic bias in relation to preparedness for earthquakes. *Australasian Journal of Disaster and Trauma Studies*, 2005-01: 1-10.
- Turner RH, Nigg JM, Paz, DH 1986. *Waiting\_for disaster: Earthquake watch in California*. Los Angeles: University of California Press.
- Weinstein ND, Klein WM 1996. Unrealistic optimism: Present and future. *Journal of Social & Clinical Psychology* 15: 1-8.

# UNDERSTANDING THE VULNERABILITY OF ORGANISATIONS

E.P. Dalziell

Dept. of Civil Engineering, University of Canterbury, Private Bag 4800, Christchurch  
([erica.dalziell@canterbury.ac.nz](mailto:erica.dalziell@canterbury.ac.nz))

## INTRODUCTION

The 1855 Wairarapa Earthquake was a significant event in the lives of the people affected. For many of them, it would have had a 360 degree impact; concern for the safety of family and friends; damage to homes and possessions; and disruption to shops and businesses affecting both livelihoods, and access to essential goods and services. It is the impact of major events, such as the 1855 Earthquake, on businesses that is the focus of this paper.

Businesses, or more generically organisations, play key roles within our society. They have the responsibility for managing, maintaining and operating our infrastructure, creating our economy, and providing employment and essential goods and services for our communities.

The ability of key organisations to continue to function in the face of sudden crises, such as that presented by earthquakes, will have a large influence on the length of time that essential services are unavailable, and on the suffering and duration of recovery for the community as a whole.

## HOW ARE ORGANISATIONS IMPACTED?

Total damages to buildings and contents (including merchandise and household effects) from the 1855 Wairarapa Earthquake was estimated at around £15,000 (Grapes 2000). Included in this estimate would be significant damage to business premises, stock and machinery.

One of the few accounts of business impacts from the 1855 Earthquake concerns the delayed reopening of the Union Bank. The bank was closed until the safe could be righted and the building made safe against future aftershocks. It is interesting to note that even 150 years ago, staff quickly recognised that the re-opening of the bank was important to the recovery of other businesses and the community:

“...(an) enquiry by a ‘cool customer’ of the Bank, whether it would be open at the usual hour; I told him it was impossible as we had not yet got at the safe: I saw at once, however, that it was my duty to open the Bank as soon as I possibly could.” Mr Raymond, manager of the Union Bank (Grapes 2000 p155).

By early March 1855 (two months after the earthquake) most businesses were reopened and operating much as before, although some repairs were not completed till months later (Grapes 2000).

In today's closely networked world, the impact of a magnitude eight earthquake in downtown Wellington is likely to cause far greater economic consequences than it did in 1855. After the 1989 San Francisco Bay Earthquake it is estimated that 50% of small businesses directly affected were permanently disabled, with the resulting job losses significantly impacting the economy of the area (EPICC, 2003).

The economic imperative to build businesses and organisations that are more resilient to hazards was again clearly illustrated by the September 11th attacks, where business interruption losses far exceeded the sum of all property losses (Munich Re 2001). These types of events have the potential to impact on nearly all facets of an organisation. The breadth of potential impacts includes:

- **Direct physical impact:** Organisations may suffer partial or even total damage to their facilities, or the facility may become off-limits, even where it is not directly damaged, if contamination is suspected. Organisations should consider where and how they would relocate if needed, and have off-site back-ups of all critical information and equipment needed for initial response and recovery activities.
- **Human impact:** Loss of key staff including those in positions of leadership or who have specialist knowledge, or the absence of large numbers of staff has the potential to severely impact the ability of an organisation to respond and recover from a hazard event.
- Organisations need to factor into their planning that key staff may not be available: because of death, injury or illness; their need to care for family or friends at home; or if they are unable or unwilling to come to work, for example because of transport disruptions, fear of terrorist attack or contagious illness. Organisations need to recognise that the first priority of staff will be the safety of family and friends. Staff are unlikely to be available or productive until this need has been met. Where organisations require staff to be available and productive in times of crisis, provision should be made for their welfare, in terms of food and water, monitoring stress levels, rotation of staff etc.
- **Interruption to lifeline services:** Lifeline services are those critical services on which a community relies, including water, electricity, gas, sewage and transportation. Without these services, many organisations would be unable to function, even if the rest of their facility were unaffected. Buildings without water and hence sewage, quickly become unusable because of health concerns. IT, communication systems and a myriad of other equipment rely on electricity. A safe and efficient transportation system is necessary for the movement of goods, staff and customers. Particularly with the prevalence of just-in-time delivery systems, a functioning and reliable transportation system is critical for many businesses. Organisations need to recognise these vulnerabilities, and where appropriate put strategies in place for managing them.
- **Delays and increased costs for repairs:** Anyone trying to find builders or trades people at present will quickly recognise the potential shortages there are likely to be after a major event such as an earthquake. A majority of people will want to rebuild as quickly as possible. This is likely to cause labour and resource shortages, inflate prices for reconstruction, and place significant pressures on regulatory authorities for approving plans and checking the quality of work.
- There is also likely to be a shortage of basic resources. Particularly in the case of regional events, it will not just be your organisation that requires replacement desks, chairs, filing cabinets, computers etc ASAP! Many organisations underestimate the

time it takes to source and replace equipment, particularly where suppliers make-to-order and do not carry large amounts of stock other than what is on the shop-floor.

- **Reduced delivery performance from suppliers:** Organisations need to consider that although their organisations may be well prepared for times of crisis; other organisations on which they depend may not be so well prepared. Distress of a key supplier or even competitor can have major knock-on impacts throughout the business sector. Organisations need to identify these impacts quickly whilst there is still time to respond.
- Where critical business services are provided by contractors or suppliers, organisations should think carefully about how to manage the risks that this imposes on their operation. Performance expectations and required capabilities in times of crisis need to become a criterion for supplier selection, and capabilities should be tested to verify that expectations are both realistic and being met.
- **Potential changes in customer purchasing behaviour:** During and after a major crisis, it is quite possible that customers and clients may scale back their investment in non-essential goods and services, until market volatility and uncertainty is reduced. Business owners and operators need to quickly recognise these changes, and adapt their recovery strategies accordingly. This aspect is further discussed in a later section “What does ‘recovery’ mean for an organisation.”

As well as thinking about the broader scope of ways an event can impact, organisations also need to think beyond the typical ‘disaster’ scenarios. In New Zealand, quite understandably, focus tends to concentrate on natural hazards such as earthquakes or flooding. The next major disaster to strike New Zealand though may well be quite different, such as an influenza pandemic or computer virus.

The impact of major hazard events on organisations is the subject of a six-year research programme underway in New Zealand (Resilient Organisations 2005). To challenge organisations to start thinking more broadly about the hazards that might affect them, this programme uses four different consequence scenarios to explore resilience:

- **Regional Event:** Significant *physical damage to buildings, contents, and resources* coupled with severe disruptions to *lifeline services* such as transportation, electricity, water and telecommunications. An example of this type of event may be a major earthquake or flood.
- **Societal Event:** A nationwide event resulting in *extended staffing absences*. In this event all physical infrastructure is intact, but staff are either unable or unwilling to be at work. Examples may be an influenza or Sars pandemic.
- **Localised Event:** An *organisation specific incident* resulting in loss of life, severe disruption to normal operations and *reputation impacts*. The intense focus of media and regulatory agencies requires the organisation to focus on managing stakeholder perception as well as the physical response and recovery from the event. Examples may be a fire or explosion in a key building, or a hazardous spill affecting the immediate locality.
- **Distal Event:** Impacts *business flow* through key suppliers or customers. This consequence scenario is designed to explore the ways an organisation may be impacted through its networks of *inter-organisational relationships*. Examples may be failure of a key supplier, major disaster of another large urban centre, or an international shortage of key resources.

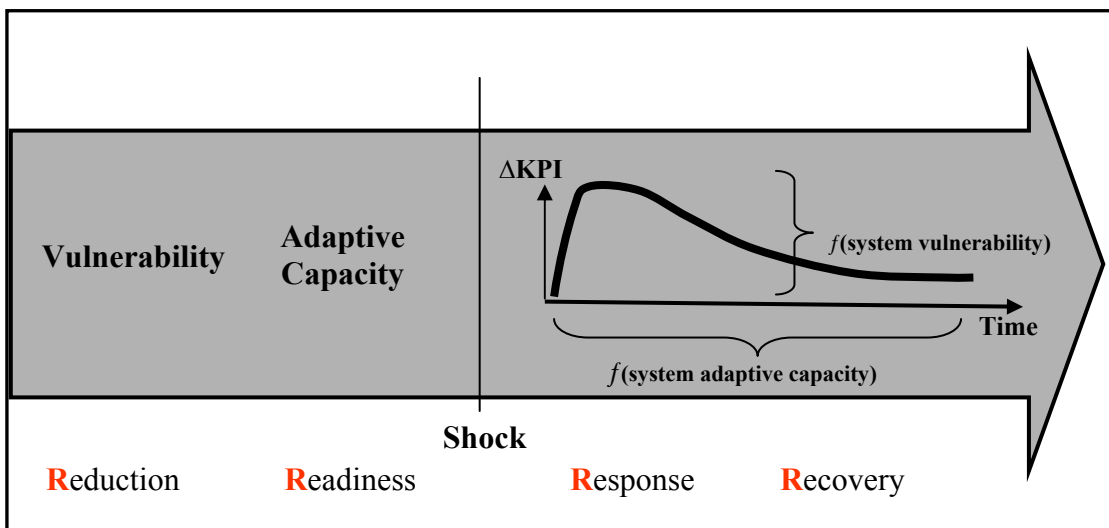
The above discussion highlights the challenges for organisations wishing to become more resilient. The variety of hazards and their potential impacts are multifaceted and complex. They are challenges, however, that need to be addressed now.

### CAN WE MAKE OUR ORGANISATIONS MORE RESILIENT?

The economic implications of organisations being unprepared for high impact events are significant. Consequences go beyond the zone of physical damage, affecting businesses right along the supply chain. Having more resilient organisations is a key component towards achieving more resilient communities because it is organisations that deliver essential services and provide employment for a large proportion of the community.

An organisation's ability to survive a major event depends on their organisational structure, the management and operational systems they have in place, and the resilience of these. So what is a Resilient Organisation? Resilience may be broken down into two key components: vulnerability and adaptive capacity. Vulnerability reflects the degree to which the organisation may be affected by an event, and adaptive capacity relates to the ability of the organisation to respond and recover from those effects.

Figure 1 illustrates this point. The ease with which the key performance indicators (KPIs) of an organisation can be moved away from their desired levels by a crisis event will be a function of the organisation's vulnerability. The time it takes for the organisation's performance to recover will be a function of the organisation's adaptive capacity. The overall resilience of the organisation will be a function of the area under the curve (Dalziell & McManus 2004), which is the total impact on performance over the response and recovery period.



**Figure 1:** Severity and duration of impact on performance as a measure of an organisation's resilience, where resilience is a function of the area under the curve.

Resilience Management brings together existing risk management and business continuity planning into a common framework; combining a strategy of managing identified risks with an ability to respond effectively when a crisis actually happens; irrespective of whether or not that event has been previously identified as a risk.

## WHAT DOES 'RECOVERY' MEAN FOR AN ORGANISATION?

A key concept within resilience is the ability of an organisation to respond and recover from an event. A question for business owners however, is '*recover to what?*' In highly dynamic environments, such as the business world, an organisation is never a static entity. Some sectors will be more stable than others, but nevertheless, an organisation that remains exactly the same over time will eventually erode its potential to achieve its purpose. In an ever-changing environment, a system must change in response to that environment in order to retain its advantage.

This has interesting implications for an organisation hit by disaster. It implies that the organisation should not aim to recover and rebuild itself to be the same as it was before disaster struck, but should recover to a new equilibrium, where it will regain synergy with its external environment. Its' post-disaster condition may lead to a very different organisational structure than before the disaster event.

This concept is also supported by disaster research, which indicates that that strongest indicator of a small to medium sized enterprise surviving a major hazard event is the extent to which the owner/operator recognises that the post disaster business environment is different, and adapts their strategies appropriately (Alesch et al 2001).

Disasters can wipe out literally years of economic progress in small economies. At this time however, relatively few organisations (public or private) in New Zealand are making appropriate levels of commitment and investment in the vital element of 'readiness' to respond to and recover from major emergency events (Brunsdon & Dalziell 2005).

Whilst risk management is being used more extensively in New Zealand today, there are few organisations that apply risk management at a strategic level across the organisation. Uptake of business continuity/emergency planning is increasing, but still only a small proportion of organisations have any planning in place (Ewing-Jarvie 2004), and those organisations that have plans in place, often lack the depth required to sustain a prolonged emergency response capability. This needs to change if we as a community are going to become more resilient.

## CONCLUSIONS

Organisations deal with uncertainties and unexpected events all the time. Some organisations, such as the emergency services are designed to manage them as part of normal operations. For a majority of others it is just part of normal business, where uncertainty presents both opportunities and risks.

There is an operating envelope, within which certain scale events are part of normal business. However, once an event moves beyond this scale, there is greater uncertainty about the organisations ability to respond, and the scale of potential impacts.

During and after a major disaster is a time when communities are least capable of absorbing service disruptions – hospitals, emergency services and response and recovery teams rely on water, power, communications and access to minimise risks to



life and property. In New Zealand, this criticality is reflected in Civil Defence and Emergency Management legislation (CDEM Act 2002), which places a statutory requirement on all lifeline service providers to be able to function to the fullest possible extent during and after an emergency, and to have plans for such continuity that can be reviewed by the Director of Civil Defence on request.

There is also a case for non-lifeline organisations to become more resilient to hazard events, as they also play a key role in the fabric of a community. After the initial response is over, communities will expect that normal services resume and require access to food, medicines, building materials, household goods, recreation and entertainment facilities etc. Organisations should not only consider what goods and services they need to continue operating after an event, but also to think about what goods and services they provide to a community, and how quickly the community will want and need these to be available again.

Encouraging organisations to become more resilient however is difficult in the private sector, where planning for greater resilience is not a concept that can be regulated. It requires individual business owner and operators to recognise the need for greater resilience, be aware of strategies available for increasing resilience, and be prepared to invest to achieve this resilience. In essence, there is a need to develop and promote in New Zealand a persuasive business case for investing in more resilient organisations.

## REFERENCES

- Alesch, D. J., Holly J. N., Mittler, E., Nagy, R. 2001. Organisations at Risk: what happens when small businesses and not-for-profits encounter natural disasters? Fairfax, Public Entity Risk Institute.
- Brunsdon, D. B., Dalziell, E. P. 2005. Making Organisations Resilient: Understanding the Reality of the Challenge. Resilient Infrastructure Conference. Rotorua 8<sup>th</sup>-9<sup>th</sup> August 2005.
- Dalziell, E. P., McManus, S. T. 2004. Resilience, Vulnerability and Adaptive Capacity: Implications for Systems Performance. International Forum for Engineering Decision Making (IFED); Switzerland. December 2004
- Ewing-Jarvie, S. 2004. Organisational Disruption in New Zealand: Planning, perceptions and human resource implications. Awesome Kiwi New Zealand Limited.
- EPICC, 2003. Earthquake Planning for Businesses: A guide for businesses in British Columbia. Emergency Preparedness for Industry and Commerce Council.
- Grapes R, 2000. Magnitude Eight Plus: New Zealand's biggest earthquake. Victoria University Press, Wellington.
- Munich Re, 2001. 11<sup>th</sup> September 2001. Munich Re Reinsurance Company, Germany.
- Resilient Organisations, 2005. [www.resorgs.org.nz](http://www.resorgs.org.nz)

# **THE PROMISE OF DESTRUCTION — URBAN DESIGN IN RESPONSE TO PAST AND FUTURE EARTHQUAKES**

Chris McDonald  
School of Architecture & Design, Victoria Univ. Of Wellington,  
PO Box 600, Wellington  
(chris.mcdonald@vuw.ac.nz)

## **INTRODUCTION**

Natural disasters seem to provide unique opportunities for correcting planning problems and accelerating urban design initiatives. With its overnight raising of beaches and draining of swamps, Wellington's 1855 earthquake was no exception. Many of those who witnessed the quake remarked on the appearance of valuable new waterfront land and the possibility of improved communication around the harbour. Some commentators even suggested that the long-term benefits of the disaster outweighed the immediate cost of rebuilding. Writing in *Life and recollections of a New Zealand colonist*, building contractor Charles R. Carter recorded: "I am of opinion...that the whole damage to public and private property in town and country, was much more than compensated for by the upheaval of the shores of Wellington harbour, to the extent of two feet...prior to the earthquake of 1855, the road from Wellington to the Hutt was, in many places, liable to be washed away; now it is high and dry. The drainage on the beach in the city of Wellington was attended with difficulties, it can now be easily effected [sic]." (quoted in Downes & Grapes, 1999, p.44).

Even if one allows for a certain amount of 'spin' in these accounts, such determined optimism is impressive and raises an interesting question for the present-day citizens of Wellington. As we wait for the next 'Big One,' is the awful prospect of destruction tempered by the promise of a better city rising from the ruins? History suggests this prospect is an illusion. The 1855 'quake may have helped the early colonists to reclaim land and connect Wellington with its hinterland. However, as the examples of San Francisco in 1905 and Napier in 1931 demonstrate, a natural disaster creates few new opportunities for re-configuring established cities.

## **SAN FRANCISCO — DANIEL BURNHAM'S FAILED PLAN FOR A "PARIS" ON THE PACIFIC**

By a remarkable coincidence, Daniel Burnham's master plan for a new San Francisco arrived at City Hall just days before the great 1906 earthquake. Eighteen months earlier, America's most eminent city planner had been engaged by a group of wealthy citizens to redesign the city's uniform street grid and recreate California's principal metropolis as a new Paris or Vienna. Burnham was so enamoured of San Francisco's peninsula location and picturesque terrain that he offered his services at no cost (Baker, 1973, p.49). Along with his associate Edward H. Bennett, he took up residence in a purpose-built cottage near the summit of Twin Peaks overlooking the city. From this vantage point, he composed a network of radial and concentric streets, artfully adapted to the peculiarities of the site and the existing pattern of settlement (Hines, 1974, pp.181-187).

Burnham was well aware of the difficulty of implementing such a proposal in an established city, albeit one that was little more than 60 years old. He stressed that the design would need to be built incrementally and opportunistically over many decades. He even implied that the whole plan might never be realised. But, he argued that a bold comprehensive design provided better preparation for the future than a more modest proposal constrained from the start by practicalities (Baker, 1973, p.49).

Then, on 18 April 1906, America's greatest urban catastrophe changed these prospects dramatically. All Burnham's original drawings and most copies of his plan were destroyed in the fires which followed the earthquake. Yet, the destruction promised to accelerate San Francisco's transformation into a model of Beaux Arts urbanism. San Francisco's mayor and reconstruction committee adopted Burnham's proposal as a ready-made blueprint for the city's recovery. After the initial reactions of shock and grief had passed, the whole nation followed the plan's progress with eager anticipation. Burnham himself cut short a vacation in Europe and travelled to San Francisco to survey the destruction and promote his timely design (Moore, 1921, p.2). These events caused one commentator to confidently predict:

The execution of what was to have been a slow and gradual improvement and metamorphosis, necessarily made difficult by existing limitations, will now be rendered simple and direct through the ruthless and complete ravages of earthquake and fire. (Sheffauer, 1906, p.94)

Before long, this optimism seemed ill-founded. Some of San Francisco's more pragmatic citizens argued that attempts to build a "Paris" on the Pacific would only delay recovery (Hines, 1974, p.190). In their view, the fastest way to rebuild the city and restart businesses was to retain the existing layout of streets and lots. As one prominent supporter of the plan wrote: "It was the worst time to talk about beautification" (Moore, 1921, p.3). In the face of mounting opposition to the plan, City and State officials pleaded with Burnham to return permanently to San Francisco to supervise reconstruction and sell his vision to an increasingly sceptical public. However, despite the apparent opportunity which fate presented to him, Burnham declined these requests. He claimed that his professional commitments tied him to Chicago (Hines, 1974, p.193). But he may also have sensed that the devastating earthquake and the imperative to rebuild quickly actually *reduced* the likelihood of his master plan ever being realised.

## **NAPIER — THE MOST MODERN CITY IN THE WORLD**

Napier had no ready made master plan when disaster struck on 3 February 1931. At the time, the city's main civic improvement initiative was a modest street widening scheme designed to adapt the town centre's tight nineteenth-century grid for use by motor traffic (Conly, 1980, p.172). But Napier did have a compelling precedent. Six years earlier, another California city had suffered a devastating earthquake. Santa Barbara used this opportunity to adopt a spurious yet romantic "Spanish" identity. The town's make-over was far more successful than San Francisco's (Staats, 1990, pp.ix-x). Within a decade, Santa Barbara became the most celebrated example of the emerging "Californian" style of architecture.

For many people in Hawke's Bay, Santa Barbara provided the ideal model for Napier's reconstruction. Some proponents of this approach sought direct imitation: a simple transference of the Californian style to a superficially similar environment on the East Coast of New Zealand. But those who studied this precedent in more detail might have noticed two important underlying features of Santa Barbara's recovery strategy. First, the town's renaissance did not involve dramatic alterations to its street pattern. The principal instrument of change was a "Board of Review" equipped with architectural guidelines based on a loose formulation of the Californian style (Staats, 1990, p.v). In this way, Santa Barbara's new identity emerged not from monumental public works but from an early form of design review applied incrementally on a case-by-case basis to many private reconstruction projects. The second salient feature of Santa Barbara's recovery was the fact that the post-earthquake Board continued a well-established campaign for aesthetic control. As early as 1901, a group of well-healed residents called the Plans and Planning Committee were actively promoting an invented version of "Spanish colonial" architecture as an agreeable style for Santa Barbara. Prior to the earthquake, the group had most effect among like-minded property owners in the town's wealthy hillside suburbs. After 1925, the style received official sanction, and the design review process ensured that it was much more widely adopted (Staats, 1990, p.x).

Santa Barbara's experiment with aesthetic controls persuaded a group of Napier architects to work in a similarly uniform style. Assisted by the cooperative spirit which accompanied early reconstruction efforts, and encouraged by the town's Reconstruction Committee, many of Napier's architects adopted the plain flattened surfaces and horizontal emphasis now loosely defined as "Art Deco" (Wright, 2001, pp.119-121). The style was modern but not revolutionary. In fact, the visual coherence of the new-look Napier resulted partly from a continuation of existing trends. Spanish colonial and art moderne motifs were already fashionable in pre-earthquake Hawke's Bay and, by 1931, a number of recently built structures displayed the hallmarks of Californian Architecture.

Napier also had visionaries who saw the earthquake as an opportunity for fundamental changes to urban structure, not just an updated architectural vocabulary. Several plans were prepared for modern, comprehensively planned building complexes. One of these occupied an entire city block, and included a continuous first-floor terrace planted with lush vegetation. Another proposal showed a new entertainment centre spanning the city's Marine Parade (Wright, 2001, p.120). Soon after the disaster, some citizens even suggested abandoning the town centre and building a completely new commercial and cultural district on the opposite side of Bluff Hill (Wright, 2001, p.119). This idea might have exploited the broad expanse of flat land that was raised by the earthquake from the Ahuriri lagoon. Here, an ideal city could be laid out without regard for Napier's nineteenth-century origins.

None of these ambitious plans came to fruition. Rubble from the town centre was used to extend a building platform along the seaward edge of Marine Parade. In time, this became the site for a chain of foreshore amenities. However, the city's famous esplanade began with the Municipal Baths and a band rotunda, both constructed well before the earthquake (Conly, 1980, p.173). Otherwise, the city's core was rebuilt largely on its existing footprint. Reconstruction accelerated the town's street widening programme. Property owners along Tennyson Street agreed to sacrifice three metres from their frontages to accommodate a more generous carriageway. Three other streets

were enlarged in similar fashion, and 23 corners were splayed to improve motorists' sight lines at intersections. Several central city blocks acquired service lanes (Conly, 1980, pp.172-173, 184). These new alleys provide a fascinating example of urban "retro-fitting" which could never have occurred without widespread destruction and rebuilding. But, taken together, the changes to the city's plan were pragmatic, localised and superficial. By the early 1940s, "before" and "after" photographs depicted dramatic changes in Napier's appearance. For a time, local boosters called it the world's most modern city (McGregor, 1989, p.67). However, most transformations can be attributed to a world-wide shift in architectural fashions, and to the appearance of whole new residential or industrial suburbs on reclaimed land near the outskirts of the city.

## **THE ETERNAL CITY VS. THE IDEAL CITY**

San Francisco and Napier illustrate the contradictory human impulses which accompany recovery from natural disasters. On the one hand, city dwellers look to their built environments for signs of stability. This need is heightened in the aftermath of a catastrophe, when survivors demand a quick return to normality. By and large, cities answer this need. Visitors to Napier and San Francisco marvelled at how quickly these cities resumed day-to-day functions, albeit in make-shift accommodation. Their capacity to survive destruction resulted from great size, massive infrastructure and a high degree of redundancy and autonomy among their parts. However, the persistence of urban forms also expresses the human quest for continuity. For this reason, images of destroyed or abandoned cities are shocking. They create the prospect that, individually and collectively, we will one day vanish without trace. So, a ruined city presents a compelling invitation to rebuild on the foundations of the old. This urge to replicate what has been lost is prompted partly by economic imperatives, but it also reflects people's desire for tangible links with their past and their future.

However, there is a second image deeply embedded in most urban cultures. Confronting the eternal city is the ideal city, the future city: utopian, visionary and critical. When the histories of cities on fault lines are written, the awful prospect of destruction is tempered by the promise of renewal. This prospect is always seductive because there are many urban form models to choose from. Cities have been devised as cosmological diagrams, machines, organisms and even texts. More recently the city has been viewed as an information system or even a giant theme park. None of these conventions are static. Ideas mutate and sometimes become their opposites. For example, over a thousand years, the place of nature in the city has been reversed from a chaotic, menacing "outside" to a benign refuge for natural order. Another fluctuating image is the machine. Once it represented dynamism, modernity and material welfare. Now, it has become a symbol of alienation and control. These transformations remind us that the city is constantly being reinterpreted. A calamity is an opportunity to start over again by reinventing the city in accordance with the latest prescription for well-being or the most persuasive explanation of contemporary urban culture.

There are two more reasons why Burnham's plan for San Francisco stood little chance of being implemented. Even if the will to create a better city exists, a natural disaster reveals that urban form is remarkably resistant to change. Regardless of the extent of the damage, attempts to reinvent cities following catastrophes are likely to be frustrated. This is because two of the most significant determinants of urban form, topography and property lines, survive natural disasters intact. As San Francisco and Napier illustrate, terrain

predetermines much of the character of earthquake-prone cities. In Napier, the 1931 quake triggered landslides, raised beaches and helped to drain swamps. In some localities these changes were pronounced. Yet, on a macro scale, the city's natural setting changed little. Napier's subdivision pattern proved equally robust. In the central city, changes to rights-of-way and private lots were superficial. Indeed, the destruction of Lands and Survey Department records and the displacement of boundary markers meant that owners had every incentive but to rebuild on existing sites so as to avoid protracted surveys and negotiations (Conly, 1980, pp.188-189). Property lines and public rights-of-way endured because they had an abstract existence as well as a physical one. While many constructed boundaries collapsed and paper records burned, the legal titles to land persisted and were painstakingly recreated following the earthquake.

## **PLANNING FOR THE “BIG ONE” – EARTHQUAKES AND URBAN DESIGN IN WELLINGTON**

The remainder of this paper focuses on informed speculation rather than historical fact. Using Wellington as an example, it investigates whether a major earthquake could help a city to realise its urban design aspirations. Wellington has not suffered the kind of devastation experienced by San Francisco or Napier, but it faces a well-recognised seismic risk. When the “Big One” comes, is it likely to clear the way for a radical redesign of the central city?

Before one can answer this question, it necessary is to consider how the current generation of Wellingtonians would like their city to look in 20, 30 or even 50 years. Given the lessons of San Francisco and Napier, it would be pointless to suggest replacing existing street patterns with a whole new network of monuments and public spaces. History indicates that the plans most likely to be implemented during the recovery period are those formulated long before disaster strikes. Wellington has a number of major urban design projects in the pipeline. If the City Council's initiatives are combined with the author's wishful thinking, it is possible to predict substantial changes to the area within the Town Belt:

- The existing Lambton Harbour redevelopment is joined by two new urban villages on redundant port and rail land.
- The notorious “motorway” extension is superseded by a “triple bypass” which disperses east-west traffic through the previously impervious Te Aro street grid.
- On Cable Street, the New World supermarket yields its site to a larger Waitangi Park that preserves an uninterrupted view shaft down the landscaped axis of Kent and Cambridge Terraces.
- Te Papa is embedded within a matrix of pedestrian-scaled city blocks, while canals convert the Herd Street Post Office and the Overseas Passenger Terminal sites into a small island.
- The imposing but unloved New Zealand Post Headquarters disappears to allow a broad swath of open space between Parliament and Glasgow Wharf.

- A new city park appears mid-way along Cuba Street, and apartment developments repair the eroded southern and western edges of the Te Aro grid.

Would any of these projects be accelerated by some vigorous shaking along the city's main fault? Clearly, none of the plans are predicated on a "doomsday scenario" in which large tracts of the city are razed and made available for urban renewal. Whether or not an earthquake provides a useful catalyst for realising these improvements depends partly on the location of damage. According to the Wellington Regional Council's 1996 *Combined Earthquake Hazard Map*, central city buildings and infrastructure are most at risk in areas of soft natural sediments and poorly compacted reclamations. These zones account for most of the land between the city's natural shoreline and the present waterfront. They also include an ancient waterway which skirts the western slope of Mt Victoria. Given the Council's present focus on waterfront developments, there is an intriguing degree of congruence between probable extent of destruction and the sites of major urban design initiatives.

Around the edge of Lambton Harbour, the magnitude of the damage may cause the present waterfront redevelopment plan to become obsolete. Since it has taken 20 years to reach a consensus on the current design, such radical change may hamper the development rather than hasten it. Nevertheless, an earthquake might introduce some attractive new opportunities. Finger wharves and old warehouses may be lost, but the threshold between city and sea could become more indented and more varied. Waterloo, Jervois and Customhouse Quays will almost certainly be destroyed. However, they would soon be rebuilt either as wide tree-lined boulevards or as a new esplanade, depending on prevailing attitudes to pedestrians and traffic. The Post Office Headquarters sits on shaky ground, and may be damaged beyond repair. Its demolition would permit Parliament Grounds to be extended to new boat harbour and an artificial beach where wakas could land on ceremonial occasions.

Further north, between Thorndon and Kaiwharawhara, the implications of earthquake damage are even more profound. Here, a disaster could trigger positive changes to the city's transport infrastructure. If the container terminal is severely damaged, port operations may move to Seaview or to other more competitive North Island locations. This would release what remains of the Thorndon reclamation for a new inner-city district which rivals Te Aro in terms of size and proximity to the CBD. However, the most unstable areas of reclaimed land would likely be transformed into parks and wetlands. Wellington's rail system would also be rationalised. With no shipping to serve, freight lines could disappear, creating room for light rail and high-density housing. Damaged culverts, water mains and other underground services would be rebuilt at great expense. But this repair work could tip cost-benefit equations in favour of a Britomart-style tunnel bringing passenger trains to the northern end of Lambton Quay. Thorndon Quay could become a prime retail address. If offices and apartments replace the present rail sidings, this gracefully curving street could be perceived as a natural extension to the so-called Golden Mile. Along its eastern frontage, a grid of new streets could provide frequent connections with the harbour, causing Thorndon to become a waterfront suburb once again.

In other parts of the city, the areas of greatest risk do not coincide so closely with the locations of planned civic improvements. Te Aro appears to offer least opportunity in this regard. This district has one of Wellington's highest concentrations of unreinforced

masonry buildings. But better subsoil conditions mean reduced hazards for modern or light-weight construction. A tongue of loose sediment between Courtenay Place and College Street might produce a large enough pocket of damage to allow an eastward extension of Ghuznee Street. Another hazard area could become the nucleus for much needed redevelopment around the ragged intersection of Victoria Street and the proposed Bypass. Sadly, there are fewer prospects for rebuilding elsewhere along the erratic edges of these two arterial roads. In the centre of Te Aro, no single location presents itself as the obvious site for a new neighbourhood park. But some of Wellington's ancient stream beds might reappear: first as trails of destruction, then as a series of canals or leafy linear reserves.

## CONCLUSION

The process of urban development is most often an empirical one. Expedient, fragmentary and incremental: city form frequently responds to circumstance rather than a perfect idea or a predetermined plan. Natural disasters seem to offer a different kind of growth. They promise to deliver an urban *tabula rasa*: effectively a new civic foundation without context or compromise; a blank slate on which a contemporary vision of the ideal city can be mapped out. Yet the real possibilities for recovery are more limited. While it is rare for a ruined city to be restored exactly to its former state, it is equally unusual for natural disasters to generate grand new urban designs. In the absence of a despotic ruler or a totalitarian government, a city survives catastrophe by building a likeness of its previous form. Ambitious plans may be realised more quickly as the result of an earthquake, but only if the projects have wide public acceptance before disaster strikes. Even then, the fate of these improvements will depend on the distribution of damage. In Wellington, major design initiatives coincide with the areas of greatest seismic risk. However, this in itself provides no guarantee of implementation. Like all city development, the recovery process is shaped by many competing factors, and the outcome is difficult to predict at an urban or architectural scale.

## REFERENCES

- Baker, Michael, 1973, The Little-Known Plan that Burnham Proposed, *American Institute of Architects Journal*, Vol. 59, No.4, pp.48-51.
- Conly, Geoff, 1980, *The Shock of '31, the Hawke's Bay Earthquake*, Reed, Wellington.
- Hines, Thomas S., 1974, *Burnham of Chicago, Architect and Planner*, Oxford University Press, New York.
- McGregor, Robert, 1989, *The Great Quake*, Regional Publications Limited, Napier.
- Moore, Charles, 1921, *Daniel H. Burnham, Architect, and Planner of cities Vol. 2*, Houghton Mifflin, New York.
- Scheffauer, Herman, 1906, The City Beautiful – San Francisco Rebuilt – II, *Architectural Review*, Vol. 20, No.117, pp.86-94.
- Staats, H. Philip (ed.), 1990, *Californian Architecture in Santa Barbara*, Architectural Book Publishing Company, Stamford, Connecticut.



Wellington Regional Council, 1996, *Combined Earthquake Hazard Map Sheet 1*, WRC, Wellington.

Wright, Matthew, 2001, *Quake, Hawke's Bay 1931*, Reed, Auckland.

# THE EARTHQUAKE'S IMPACT ON PROPERTY BOUNDARIES

Graeme Blick and Anselm Haanen  
Land Information New Zealand, Private Box 5501, Wellington  
(gblick@linz.govt.nz, ahaanen@linz.govt.nz)

## ABSTRACT

New Zealand has a modern, well-developed cadastre (public register showing the details and extent of land ownership). Legal precedence has established a hierarchy of evidence for re-establishing property boundaries. The best evidence of property boundaries is provided by the presence of reliable cadastral boundary marks. In the absence of these marks, or where they are proved unreliable, boundary positions may be re-established by using previous survey observations from control and witness marks. Boundaries may also be re-established by long-standing occupation, i.e. fences, walls, etc.

A major earthquake such as the 1855 Wairarapa Earthquake can have a significant impact on property boundaries and ownership, particularly where they cross the fault rapture, or are close to the rupture where significant deformation has occurred. There is very little formal precedence in New Zealand for the re-establishment of property boundaries following a major earthquake in an urban area. Research from overseas also reveals little guidance.

This presentation examines the issues in re-establishing property boundaries following a major earthquake and shows that the normal hierarchy of evidence for re-establishing property boundaries will not be appropriate in all cases, and that other factors will need to be considered.

## WHAT IS THE CADASTRE?

New Zealanders enjoy a title system that provides certainty of title. This includes certainty as to the location of boundaries, typically to within a few centimetres in urban areas, as prescribed by standards set by the Surveyor-General.

Primary evidence of a boundary corner is provided by the existence of an undisturbed peg, typically recorded on an approved survey plan. The survey plan records the dimensions of the boundaries as well as measurements to nearby witness marks. These are usually iron marks placed to ensure their long term survival and are usually connected by some survey to more permanent control marks. When a landowner seeks to relocate a boundary corner (eg. in order to subdivide) and the original peg cannot be located, a surveyor can re-establish the position by locating a witness mark and “adopting” the earlier dimensions to the relevant point.

Where a boundary was last pegged a very long time ago, boundary pegs and witness marks are unlikely to be found at all. In these cases, long-standing “occupation” plays a key role in determining the position. This might consist of very old fence posts, hedges, or similar. Occasionally such occupation proves to be in conflict with measurements from other marks, in which case the surveyor must make a professional judgement on the best location.

Finally, not all cadastral boundaries are “fixed”. “Natural” boundaries, typically following the banks of a river or lake, or Mean High Water Mark (MHWM) of the sea, are “moveable.” This means that they wander with slow and imperceptible movement of the relevant feature. Re-establishment of the original position of these boundaries is not normally required – in these cases the position at the time of survey is the main concern.

The cadastral survey plans, including the historical record, are held by Land Information New Zealand (LINZ). Much of the data from urban plans has been captured so that most boundary corners are now digitally coordinated to within a few centimetres of their true position in terms of the local geodetic framework. In rural areas the boundary positions are typically not coordinated to “cadastral survey accuracy” and may be many metres from their true position. Where the positions are sufficiently accurate, they are used to support the validation of new surveys – e.g. “Do the new measurements fit the existing coordinates and dimensions within acceptable tolerances?” However although they support validation, relocating boundary positions by using existing coordinates is not currently acceptable.



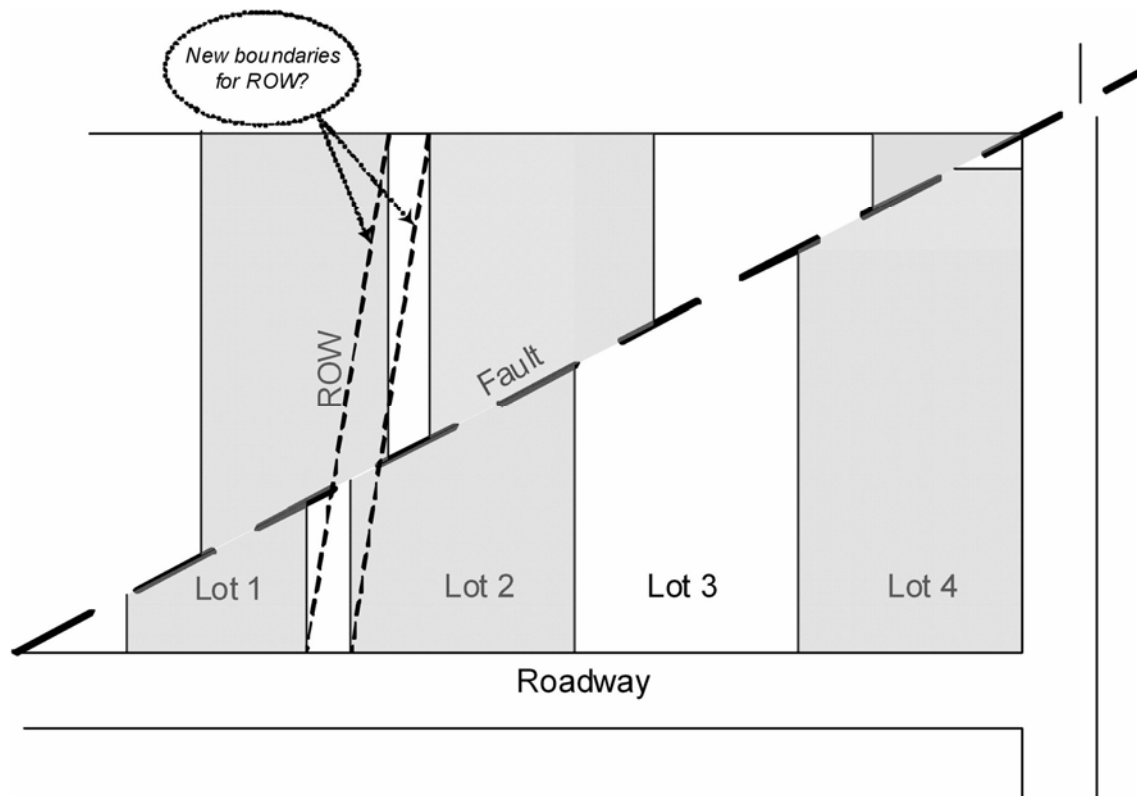
**Figure 1** Cadastral property boundaries overlaid on an aerial photograph. The approximate location of the West Wairarapa fault is shown by the thick line.

## WHAT IS THE IMPACT OF AN EARTHQUAKE ON THE CADASTRE?

The 1855 West Wairarapa earthquake occurred at a time of little settlement and in a predominantly rural area. Even today, the West Wairarapa fault traverses generally rural properties and bypasses significant urban settlement (Fig. 1). Were such an event to occur today in an urban environment the effect on the cadastre could be calamitous.

Such events that have an effect on the cadastre take several forms including fault rupture (whether lateral, compression, or extension), crustal deformation away from the fault, liquefaction, slumping and land sliding. These phenomena may cause horizontal movement and vertical movement in the land.

A surface rupture of anything more than a few decimetres horizontally across an urban lot will have a major impact on the shape and area of the lot as well as the form of the boundary line itself. What was once a rectangular lot can become highly distorted and in extreme cases could be almost split into two (see Fig. 2). The diagram also shows how fault movement across a right-of-way appears to have cut off legal access from the road.



**Figure 2** A series of lots and a right-of-way subject to a fault rupture.

Deformation away from the fault rupture can also be extreme, particularly in areas affected by liquefaction and slipping. In these areas deformation may not be uniform and affect some boundaries more than others. Once again lot shape and area, and the form of the boundary line can be affected.

If the earthquake has a significant vertical component, it may affect a moveable natural boundary such as determined by MHW. Given the gentle slopes that typically occur

on beaches, a small vertical movement of the land can easily translate into a horizontal movement of the line of MHW in the order of 10 or 20 times as much. In some cases, large areas that were previously under water may become dry land (and vice versa). Who owns such new land – the adjoining owners? If so, how would it be apportioned?

In terms of the role of the cadastre, the most startling effect is likely to be that landowners can no longer be certain of the location of their boundaries. This could mean that they would be unable to sell their land and not be permitted to develop their land (including rebuilding). Also, banks may be unwilling to lend money for development because of inadequate collateral for a mortgage.

In order to re-establish “quiet” title in such scenarios, the new positions of boundaries would need to be established. The question for the surveyor in this scenario could be less about the normal “re-establishing” the earlier position of boundaries, but in establishing fresh practical and reasonable boundaries. The splitting of lots into two and cutting off access are simple illustrations of this need.

The extent to which the cadastre would need to be re-defined is dependant on several factors including:

- The size of the movement;
- The size of lot, particularly in proportion to the movement (eg. several metres on a 30 hectare rural lot may cause less concern than a few decimetres on a residential lot);
- The relationship between any physical structures (especially buildings) in relation to the boundaries;
- The value of land affected (eg. Lambton Quay, compared to Featherston).
- Whether the purpose to which the land can be used has changed because of the earthquake, eg. Is it still habitable?

### **WHAT PRINCIPLES COULD BE APPLIED IN ESTABLISHING NEW BOUNDARIES FOLLOWING AN EARTHQUAKE?**

A number of principles for boundary establishment have been identified from international literature:

<ul style="list-style-type: none"> <li>• In the event of sudden earth movement, the same rule should apply as for a sudden change in a rivers course: the same land belong to the same owner;</li> </ul>	<p>In the examples in Figure 2, this would suggest that some parcels are split in two, or their shape could render them unusable.</p>
<ul style="list-style-type: none"> <li>• If the land is distorted (eg. enlarged, shrunk), then the new boundary should be proportioned between stable points (eg. geodetic control, or survey marks clear of the deformation);</li> </ul>	<p>This will normally work, but it can be difficult to determine which marks are stable, and which have moved, particularly where the distortion is extensive.</p>
<ul style="list-style-type: none"> <li>• If the entire lot has moved en masse, then it should be defined where it rests, rather than back in its absolute</li> </ul>	<p>Seems sensible.</p>

(original) position;	
<ul style="list-style-type: none"> <li>If landslides occur because of an act of nature, then the owners undoubtedly own where their bedrock is located - boundaries cannot flow with the surface material.</li> </ul>	This appears reasonable for cataclysmic movement, but may not be practical for slow movement.

In practice, the principles may conflict with each other, so judgement is required as to their relevance or appropriateness. If a lot were subject to deformation such as in the simple lateral rupture shown in Figure 2, the normal evidence for re-establishment (as described earlier) would still need to be gathered, but applied independently on each side of the fault. However, this task would be significantly more complex because the deformation would have affected the marks in the ground. A surveyor normally establishes mark “reliability” by measuring between three marks and confirming agreement with previous surveys – this could prove extremely difficult.

Then the above principles could be applied as considered appropriate. However this may still leave the land impractical to use – for example (see Fig 2), should the boundary simply follow a straight line between the points, or should it include a step to enable access?

Clearly a number of complex issues that are not normally encountered will have to be resolved in establishing boundaries subject to deformation.

### WHAT ABOUT THE PROCESS?

Normally a landowner would commission a surveyor to locate their boundary. In undertaking this work, a surveyor is required to consider surrounding title dimensions and not just those of his client. Where an earthquake has caused large fault movement or distortion, this surveyor could effectively be required to take into consideration all boundaries in the immediate locality. The cost of this work might be unfairly burdened on the first owner to commission a survey, even though it would benefit other subsequent surveys in the locality.

Some framework of geodetic and cadastral surveys may be required within which individual surveys could subsequently be undertaken. This could ensure that any distribution is undertaken in an equitable manner. In a Californian example, shortages were mainly placed in public lands such as roads and reserves, using special legislation to establish the determination process. Another consideration could be a large-scale “consolidation survey”, which, in consultation with landowners, could be used to set the boundaries in an area. Such processes have been used in developing countries or ex-communist states migrating to private ownership.

## **SUMMARY**

A large-scale earthquake will have a major impact on the cadastre and cast significant doubt over the location of property boundaries. This uncertainty will need to be resolved to enable properties to be re-developed and to enable the property market to operate.

Although New Zealand has experienced many earthquakes, there have been very few which have caused major deformation like the 1855 Wairarapa earthquake. The impact of such an earthquake on a modern city or town would have a dramatic effect on the cadastre.

The survey principles and processes that would need to be applied in re-establishing boundaries are not well known and require further investigation and analysis.

## KEY DEVELOPMENTS: SEISMIC ISOLATION

W.H. Robinson  
Robinson Seismic Ltd, PO Box 33093, Petone  
(whr@robinsonseismic.com)

### INTRODUCTION

Due to the high seismicity of the Wellington Region and because of the excellent interaction between the engineers of the NZ Dept of Scientific and Industrial Research (DSIR) and the engineers in the Ministry of Works and Development (MoWD) the concept of Seismic Isolation was able to be developed and applied to real structures.<sup>1</sup> In passing, it is worthwhile noting that DSIR and MoWD were old established innovative government institutions able to react rapidly with Directors able to make and support decisions changing circumstances.

The late 1970s were a very productive time with the design and building of test rigs, test procedures, testing fullsize LRBs to determine the design parameters for LRBs plus the MoWD developing the engineering design procedures for the application of the LRB to bridges and buildings and at the same time proving the viability of the LRBs. So we, within the DSIR and MoWD worked very closely together ensuring the rapid build up of the necessary infrastructure thereby resulting in the successful application of this new technology to real structures.

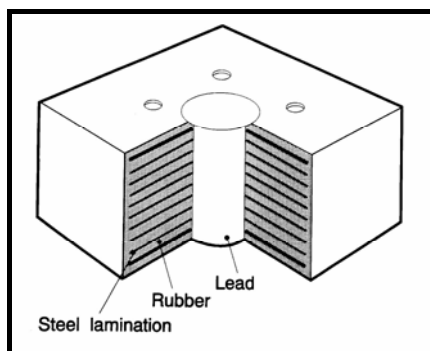
This revolutionary approach was helped by the invention in 1975, within DSIR, of the Lead Rubber Bearing<sup>1,2</sup> with the first application of seismic isolation using the Lead Rubber Bearing (LRB) occurring under the Toe Toe Bridge in 1978 at Utiku on the main highway between Auckland and Wellington, while the first building to be isolated using Lead Rubber Bearings was the William Clayton Building in Wellington, completed in 1981.

### WHAT IS SEISMIC ISOLATION AND WHAT IS THE LRB?

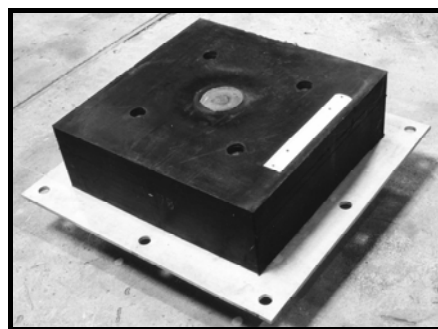
Seismic isolation is similar to the suspension on a motor vehicle in that it provides an elastic support (spring), plus a damping system. For seismic isolation — or as it is often called, ‘base isolation’ — a relatively simple technique is to use Lead Rubber Bearings which support the structure providing a flexible base, ‘a spring’, plus the ‘damping’ via the plastic deformation of lead.

Ideally, each seismic isolator should consist of two components, an elastic restoring force component plus a damping term. This is similar to the suspension on a motor vehicle with ‘springs’ and ‘dampers’. A good example is the Lead Rubber Bearing (LRB) where the rubber/steel layers provide the elastic restoring force (spring) and supports the structure while the lead plug produces the required damping (dampers). In addition the LRB has an estimated lifetime of more than 100 years and excellent fire resistance (see Figures 1a and 1b).





**Figure 1a:** Lead Rubber Bearing which consists of a lead plug inserted into a vulcanized laminated rubber bearing.



**Figure 1b:** Lead Rubber Bearing used in the William Clayton Building.

Seismic isolation of new and existing structures continues to be considered in NZ as a means to reduce the damage to structures and their contents caused by the shaking due to earthquakes. Since its invention in 1975, the most favoured isolation system has been the Lead Rubber Bearing, often in conjunction with slider bearings with over 2000 bridges and buildings worldwide being seismically isolated. Examples of the application of seismic isolation in the Wellington region are contained in Table 1 and Figures 2a and 2b.

**Table 1:** Structures seismically isolated in the Wellington area

STRUCTURE	SEISMIC ISOLATION SYSTEM	CONSTRUCTION METHOD
Bolton Street Overpass	Lead Extrusion Damper	New
Aurora Terrace Overpass	Lead Extrusion Damper	New
Wellington Central Police Station	Lead Extrusion Damper	New
William Clayton Building	Lead Rubber Bearing	New
Petone Printing Press	Lead Rubber Bearing	Retrofit
Haywards Substation	Rubber Bearings and Steel Hysteretic Dampers	Retrofit
Parliament Buildings	Lead Rubber Bearing	Retrofit
General Assembly Library	Lead Rubber Bearing	Retrofit
Museum of City & Sea	Lead Rubber Bearing	Retrofit
Old Bank Arcade	Lead Rubber Bearing	Retrofit
Te Papa Museum of NZ	Lead Rubber Bearing	New
Wellington Hospital Emergency Dept	Lead Rubber Bearing	New
Moonshine Bridge	Lead Rubber Bearing	New
Rankine Brown Building, Victoria University	Lead Rubber Bearing	Retrofit

STRUCTURE	SEISMIC ISOLATION SYSTEM	CONSTRUCTION METHOD
New Regional Hospital, Wellington	Lead Rubber Bearing & Slider Bearings	New

At present, the new Wellington Regional Hospital is being constructed using seismic isolation technology. This hospital is seismically isolated with 135 lead rubber bearings and 135 slider bearings. It is now accepted practise by the New Zealand authorities for bridges and critical facilities in earthquake areas to be seismically isolated.

The earthquake engineering expertise of a number of countries including India, Nepal, Taiwan, South Korea and Turkey is being actively aided by members of the 'New Zealand Earthquake Engineering Technology Business Cluster' ([www.earthquakeengineering.com](http://www.earthquakeengineering.com)). This Cluster along with its companion organisation 'Natural Hazards New Zealand' ([www.naturalhazards.co.nz](http://www.naturalhazards.co.nz)), is aiding the recovery of the many countries damaged by the 26 December 2004 tsunami disaster.

### DOES SEISMIC ISOLATION WORK?

Very strong support for the principles of seismic isolation is given by the results of the January 1994 Los Angeles earthquake and the fact that of the ten hospitals affected by the Los Angeles earthquake, only the hospital seismically isolated by a lead rubber bearing system was able to continue to operate. This seven-storey hospital (the University of Southern California Teaching Hospital) underwent ground accelerations of 0.49g, while the rooftop acceleration was 0.21g; that is, by an attenuation by a factor of 1.8. The Olive View Hospital, nearer to the epicentre of the earthquake, underwent a top floor acceleration of 2.31g compared with its base acceleration of 0.82g, magnification by a factor of 2.8. The Olive View Hospital, designed to strength criteria, suffered no structural damage but had to be closed temporarily because the high acceleration caused a water pipe to burst on the top floor. One kilometre closer to the epicentre than the University Teaching Hospital, the Los Angeles Country Hospital suffered severe damage causing the closure of a number of wings. Repair of this damage is estimated to have cost US\$400 million.

In the January 1995 Great Hanshin Earthquake a building isolated with a lead rubber bearing system in the affected zone survived with no damage or disruption to services. For this building, a Computer Centre of the Ministry of Post and Telecommunications, preliminary results indicate a maximum ground acceleration of 0.40g while the sixth floor acceleration had a maximum 0.13g, that is an attenuation by a factor of 3.

The experience of these two earthquakes provides strong support for the application of seismic isolation.

We have continued to develop new seismic isolation devices. The research on a number of new approaches to seismic isolation continues with the manufacture of a prototype RoGlider<sup>3</sup> capable of supporting both light and high vertical loads with an effective coefficient of friction of 11%. Preliminary tests on the prototype RoGlider have been promising. A number of videos illustrating the application of the LRB to structures and the testing of the RoGlider will be shown.

## DESCRIPTION AND PRELIMINARY TESTS OF THE ROGLIDER

Our aim is to develop the RoGlider™ so that it can be considered as an alternative to the LRB and also be used for light loads and large displacements where it often becomes very difficult to use the LRB. We are continuing to develop other isolators such as the RoBall™ which is suitable for very light loads<sup>7</sup>



**Figure 2a:** NZ Parliament Buildings seismically isolated using Lead Rubber Bearings



**Figure 2b:** William Clayton Building, the first building to be seismically isolated using Lead Rubber Bearings

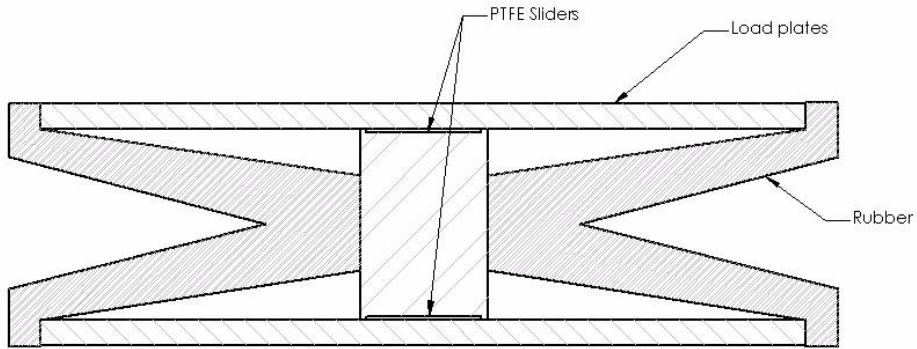
The RoGlider™ is a sliding bearing which includes an elastic restoring force. The actual configuration is dependant on the details of the structure being isolated and the expected earthquake. The RoGlider we present is a double acting unit with the restoring force provided by two rubber membranes (Fig. 3).

This double acting RoGlider™ consists of two stainless steel plates with a PTFE ended puck sitting between the plates. Two rubber membranes are attached to the puck with each being joined to the top or bottom plates. When the top and bottom plates slide sideways with respect to each other, diagonally opposite parts of the membrane undergo tension or compression.

The tension components provide the restoring force between the plates while the compression parts buckle (Figs. 4–6) and provide little or no restoring force.

The particular double acting RoGlider we have tested has a maximum displacement of  $\pm 600$  mm, a maximum vertical load of 1 MN, with an outside diameter of  $\sim 900$  mm and a coefficient of friction at  $\sim 0.5$  m/s of  $\sim 11\%$ . Following this particular membrane approach we expect to be able to increase the elastic stiffness by a factor four or more times using our latest designs.

The RoGlider was tested in our test rig capable of providing a vertical force of up to 6 MN, horizontal force of up to 700 kN and maximum displacement of 600 mm.



**Figure 3:** RoGlider Section

The effect of vertical force on the force displacement curves is illustrated in Figure 7, at 850 kN, and Figure 8, where the vertical load is 110 kN. For both of these vertical forces the horizontal stiffness is  $\sim 100$  kN/m.



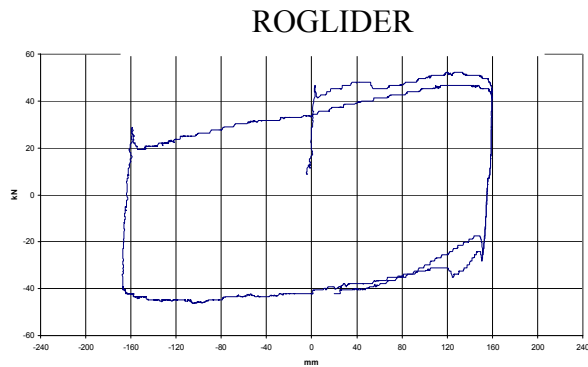
**Figure 4:** RoGlider ready for testing Displacement 0mm, vertical force of 850 kN



**Figure 5:** RoGlider during Test Displacement -150 mm, vertical force of 850 kN

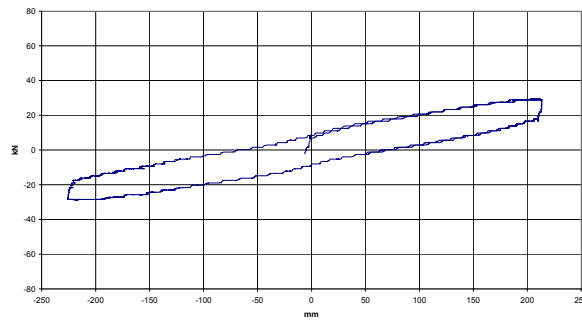


**Figure 6:** RoGlider during Test Displacement +575 mm, vertical force of 110 kN



**Figure 7:** RoGlider Force Displacement Curve - Vertical Force of 850 kN

## ROGLIDER



**Figure 8:** RoGlider Force Displacement Curve – Vertical force of 110 kN Note that the stepped nature of the loops is due to the resolution of the load-cell and is not a characteristic of the RoGlider.

## CONCLUSIONS

Internationally, ‘Seismic Isolation’ is now an accepted method for reducing the forces transmitted to a structure during an earthquake as illustrated by ASSISi (Anti-Seismic Systems International Society) conferences held every two years and is applicable to both old and new structures. ‘Seismic Isolation’ reduces the forces transmitted to the structure by first increasing the flexibility of the support thereby increasing the structures natural period beyond the peak of the earthquake and secondly by adding damping thus reducing the energy transmitted to the structure<sup>1,4</sup>.

The RoGlider which we have presented represents one of many possible configurations we are developing. At this stage this version of the double acting RoGlider is a promising candidate for a commercially viable seismic isolator for both high and low vertical loads.

## ACKNOWLEDGEMENTS

Our original research and development was conducted within the Physics and Engineering Laboratory (PEL), DSIR and as such had tremendous support from the director Dr Mervyn Probine and all PEL staff. Of particular importance was the part played by my friend and colleague Dr Ivan Skinner who introduced me to the concept of Seismic Isolation in 1970.

As previously mentioned in our original book ‘An Introduction to Seismic Isolation’, we thank the huge support of the MoWD and in particular the late Otto Glogau who was Chief Structural Engineer, MoWD, in the 1970s taking our developments to real applications.

Our latest research is supported by Foundation for Research Science and Technology of New Zealand, Contract No.C05X0301 via GNS.

## REFERENCES

1. Skinner, R.I., Robinson, W.H. and McVerry, G.H. (1993). An Introduction to Seismic Isolation (Updated and modified in both Chinese and Japanese, 1998). *John Wiley and Sons Ltd, West Sussex, England.*

2. Robinson, W.H. (1982). “Lead-Rubber Hysteretic Bearings Suitable for Protecting Structures during Earthquakes”. *Earthquake Engineering and Structural Dynamics, Vol. 10, 593-604 (1982)*.
3. Robinson W, H., Gannon, C.R., Meyer, J.M., (2005). The RoGlider – a Sliding Bearing with an Elastic Restoring Force. *Bulletin of the New Zealand Society for Earthquake Engineering (in press)*.
4. Kelly, J.M., Naeim Farzad, (1999). Design of Seismic Isolated Structures – From Theory to Practice. *John Wiley and Sons Inc., New York, USA*.

# ISSUES ASSOCIATED WITH MAKING EXISTING BUILDINGS SAFE

R.D. Jury  
Beca, PO Box 3942, Wellington  
(rob.jury@beca.com)

## INTRODUCTION

The 1855 Wairarapa Earthquake would have been traumatic for early settlers including those setting up new lives in Wellington and the Hutt Valley. Many buildings suffered significant damage and a number collapsed. However, it was apparent, even in these early days, that well built structures, even of un-reinforced masonry, could survive the estimated MMIX to MMX shaking without collapse and in many instances without any obvious structural damage (Grapes and Downes 1997).

Picking which buildings have potential for collapse, and therefore present the greatest risk, and under what level of shaking, remains one of the greatest issues when considering the likely safety of existing buildings. It is also the issue that has seen significant development over the last couple of decades both in New Zealand and overseas (particularly in North America).

The public are becoming much better informed on what constitutes an at-risk building and are demanding to know how well the buildings they inhabit are likely to perform during a severe earthquake. The science (engineering) involved (as any engineer working in this field will attest) is not precise and there is a need for engineers to be able to explain the issues in ways that the general public can understand.

In this paper, some of the recent issues that have arisen relating to the assessment of existing buildings are discussed. Some recent developments in the methodology of building assessment for earthquakes are also given.

The opinions expressed in this paper are those of the author.

## HISTORY

Before discussing the issues, it is useful to review the history of the developments that have influenced how existing buildings in New Zealand are assessed and how they are likely to perform in earthquakes.

In 1939, following the experience of the Hawkes Bay earthquake, the first loadings code (NZSS 95) to include provisions for earthquake was published. The defined lateral load was 0.08g applied uniformly over the height of the building. A triangular loading option was also defined which led to the same overturning moment as the uniform load distribution.

In 1965 a new loadings standard was issued (NZS 1900). The lateral load now varied with structural period, location (seismicity) and whether the building had a public or

private use. Requirements for “adequate” ductility were introduced but no detail was included on how this was to be achieved.

Amendment 301A of the Local Municipal Corporations Act was enacted in 1968. This Act gave Local Authorities the power to declare unreinforced masonry buildings that had insufficient strength to resist 50% of the load defined in the 1965 Standard as “potentially dangerous in earthquake” and provided the ability to require the danger to be removed by securing or removal. The standard that should be used for retrofitted buildings was not defined. These same provisions were carried into Section 624 of the Local Government Act 1974.

In 1969, the New Zealand Society for Earthquake Engineering (NZSEE) published the “brown” book (NZSEE 1969) providing guidance on how to meet the requirements of the Local Government Act.

A new generation of ultimate limit state earthquake loadings standards was launched with the publishing of NZS 4203 in 1976. In this standard, design earthquake loads were a function of building period, available ductility (defined by the structural form and material), soil type, location (seismicity), the risk presented and the importance of the building. The lateral loads for ductile structures were similar to those defined for all buildings in the 1965 standard. The lateral load requirements for non ductile (elastic) buildings were set in an amendment issued in 1984 at a level in the order of 4 times those defined in 1965.

The NZSEE updated its Brown Book and published the updated provisions as the “red” book in 1985 (NZSEE 1985). This document gave guidance to Local Authorities on timescales for dealing with earthquake risk buildings. Two levels of retrofit were defined; securing and strengthening. The suggested lateral load for securing was between 50 and 65% of the loads defined in the 1965 standard. Lateral loads for strengthening of normal buildings were set at approximately 2/3rds of those defined for new buildings in the 1976 standard. The strengthening load levels were varied based on the density of occupation.

The Building Act was introduced in 1991. Section 66 of this Act introduced the concept of an “earthquake prone building (EPB)”. An EPB was defined as an unreinforced masonry or predominantly unreinforced concrete building which would have its ultimate capacity exceeded in an earthquake resulting in earthquake loads 50% of those defined in the 1965 standard. Local Authorities had the same powers as prescribed in earlier Acts.

In 1992, NZS 4203 was fully revised. Earthquake loads were now assessed using a uniform risk approach and the available displacement ductility. Specified loads for non-ductile structures were now much higher than previous standards.

The NZSEE revised its Red Book in 1995 (NZSEE 1995) to bring it in line with the limit state format of NZS 4203:1992 and in 1996 issued a draft study group report on the assessment of earthquake risk buildings of other than unreinforced masonry or concrete (NZSEE 1996). The recommended level of loading for retrofitting was set at approximately 2/3rds of that specified in NZS 4203:1992.



The latest earthquake loadings standard, NZS 1170.5:2004, was issued in December 2004. The loadings are now based on the latest seismicity model for New Zealand. Some significant changes (up and down) result in some parts of New Zealand. Additional penalties are imposed on non-ductile buildings.

In 2004, the New Zealand Building Act was revised extending the definition of earthquake prone buildings to cover all potentially at-risk buildings. A target level for earthquake risk buildings was set, in the Regulations, at an ultimate capacity of 33% of the current earthquake standard. A retrofitting standard has not been defined. The Act requires Territorial Authorities to develop a policy covering earthquake risk buildings and have this in place by March 2006.

### **AND FOR THE FUTURE?**

The NZSEE is working with the Department of Building and Housing to produce a technical guideline for the assessment and retrofitting of earthquake risk buildings. This document will be presented in draft in October 2005 and is likely to recommend that any building not meeting a standard 2/3rds of that required for a new building should be considered potentially at-risk and that earthquake risk buildings should be retrofitted to achieve a standard *as near as is reasonably practicable to that of a new building*. The recommended minimum level for retrofitting is likely to be 2/3rds of that specified in the current standard. It is expected that this document will be issued as a compliance document under the Building Act following public consultation.

### **OVERALL TRENDS IN RETROFITTING STANDARD**

Public expectation regarding what constitutes acceptable building performance has been steadily increasing over the years and the engineering design standards have been increasing in line with this. This trend can be seen, for example in the way design loads have been increasing with time. Table 1 shows the lateral design load that would be applicable for a typical low rise building in Wellington as determined from each of the design standards that have been in force since 1939. The increase has been three fold over 65 years although the largest jump occurred in 1976 with the requirement for explicit allowance for the available ductility.

**Table 1:** Lateral Design Coefficients for a Typical\* Building in Wellington

NZSS 95:1939	NZS 1900:1965	NZS 4203:1976	NZS 4203:1992	NZS 1170.5:2004
0.09	0.18	0.24	0.28	0.31

\* Typical is defined as a low rise limited ductile building located on ground class (c) as defined in NZS 1170.5:2004. Coefficients have been factored to provide equivalent limit state values based on a triangular load distribution.

Securing, i.e. maximising the existing strength of a building by tying otherwise discontinuous bits together and removing hazardous items, without necessarily increasing the overall strength of the building, has long been recognised as providing a cost effective way of, in some cases, achieving a dramatic increase in the earthquake performance of a building. It is unlikely, however, that securing alone would meet the stated objectives of the guidelines that are currently being put together as the potential benefits of securing are difficult to quantify using standard assessment techniques. The

question raised here is whether it is appropriate to rely solely on quantitative methods of assessment or whether there is also a place for qualitative assessment based on experience?

## **ISSUES WITH THE BUILDING ACT 2004**

The changes relating to the performance of existing buildings promulgated in The Building Act 2004 are generally welcomed. However, several issues have come to light since the Act was passed into legislation. Some of these issues and the changes are discussed below:

**Definition of an Earthquake Prone Building:** The definition of an earthquake-prone building is now expressed in terms of the current standard for new buildings. This is a significant improvement on the past when the definition was expressed in terms of a much out-of-date standard, NZS 1900.

Two concepts are used to define an earthquake prone building; one relates to the expected performance in a moderate earthquake and the other to likelihood of collapse. The point of collapse is almost impossible to predict. To get over this problem engineers design buildings to achieve an ultimate limit state (ULS). This is a somewhat arbitrary state based on a combination of loads and a level of stress/deformation that from experience has been found to produce buildings that should have a reasonable earthquake performance. At the ULS most buildings should be a long way from collapse. It is the authors' view that reference to collapse adds unnecessary confusion to the definition.

Reference to ultimate capacity also leads to confusion. The NZSEE guideline document under preparation is likely to define ultimate capacity as the Ultimate Limit State as defined in current standards. Hopefully this document will have widespread credibility as an authoritative industry document but it would be better if the legislation could refer to this directly.

**Target Levels:** The target level for an earthquake prone building is effectively set at an ultimate capacity of  $1/3^{\text{rd}}$  of the load level defined in the current earthquake standard for a similar new building on the same site. It must be kept in mind that this represents a very low level of performance and is intended to identify the worst of the building stock. If a building just exceeds this threshold, it may not be classed as an earthquake prone building in accordance with the Act but it will still represent an unacceptable earthquake risk based on current public expectations/perceptions.

**Retrofitting Standard:** The Act makes no reference to the standard that earthquake risk buildings (including earthquake prone buildings) should be strengthened to. As already discussed, the NZSEE guideline document still under preparation is likely to recommend that buildings should be strengthened to *as near as is reasonably practicable to the standard required of a new building*. This is the same concept that is required currently for change of use. The NZSEE document is likely to also indicate that a standard approximately  $2/3^{\text{rds}}$  of that for a new building will be an acceptable standard for an existing building. In other words, an existing building meeting the  $2/3^{\text{rds}}$  standard should not be classified as an earthquake risk.

**Change of Use:** Change of use would in the past invoke the ability of the Territorial Authority to require retrofitting of below-standard buildings. However, the linking of change of use to the change in risk based on fire safety considerations will frustrate this process for earthquake risk buildings. This is because a change in risk category for earthquake will not necessarily be the same as for fire.

## **DISPLACEMENT BASED ASSESSMENT PROCEDURES**

While force based proceeds have obvious deficiencies and displacement based analysis procedures do provide a better insight into the likely performance of structures in earthquakes, the actual difference in the analysis procedures employing these approaches is not all that great. Figure 1 shows an assessment process flowchart proposed to be included in the latest NZSEE guidelines, which are currently under preparation.

It is apparent that many of the initial steps in two processes are identical, only separating in the later stages.

A major issue with the displacement-based approach, however, is in the assessment of the properties of the equivalent single degree of freedom oscillator, particularly an appropriate value for the equivalent viscous damping. The results of the displacement-based approach are very sensitive to the values chosen for this parameter and at present the assessment of this parameter relies heavily on judgement.

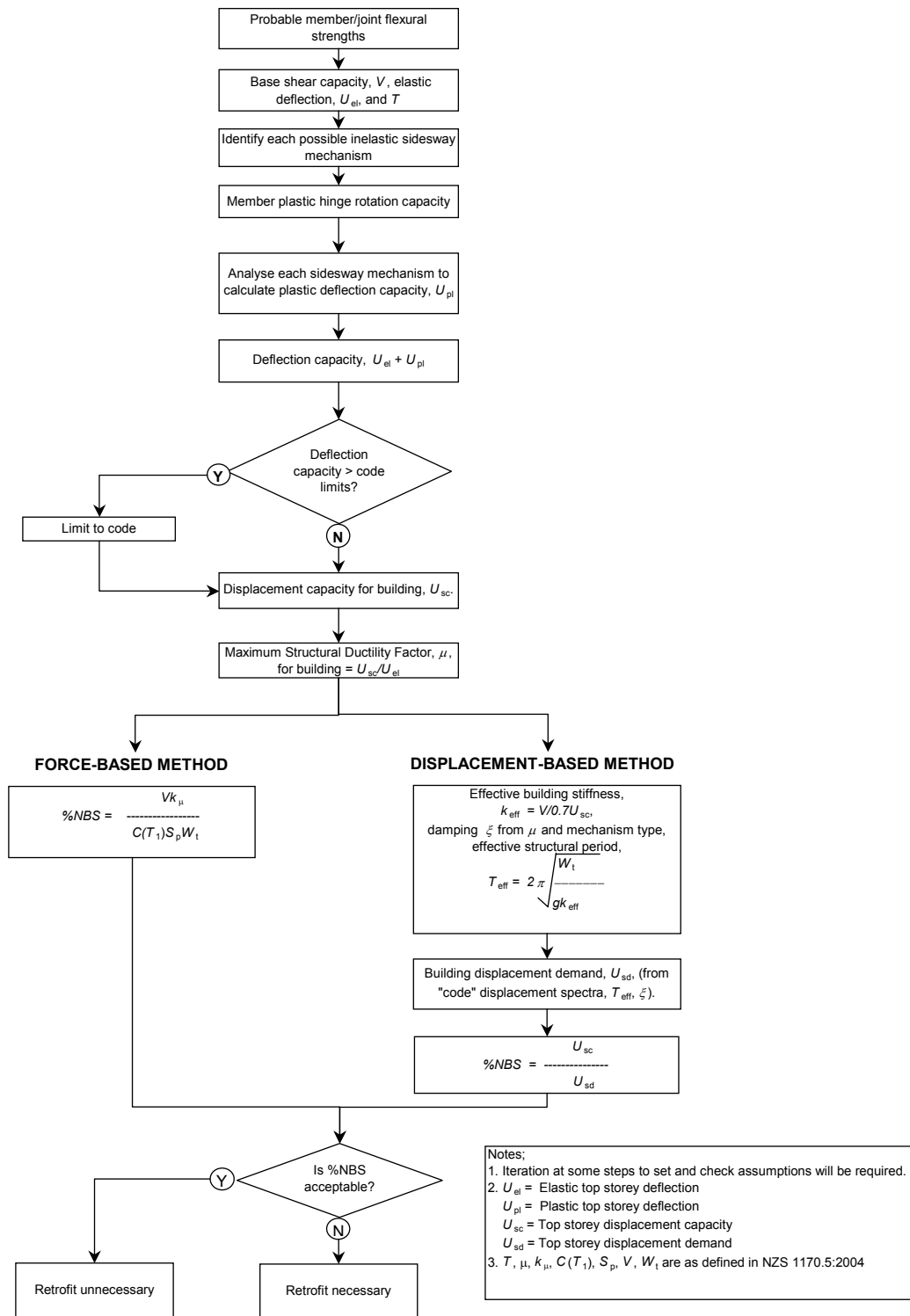
Further work is required to provide practical provisions for designers/assessors.

## **CONCLUSIONS**

There are still significant issues relating to the definition, assessment and retrofitting of earthquake risk buildings.

Problems with interpretation of the relevant sections of The Building Act 2004 have the potential to cause unnecessary confusion and disputes.

There are issues with displacement-based assessment that require further investigation.



**Figure 1** Flowchart Outlining Proposed Assessment Process in Guidelines Under Development.

## REFERENCES

- Grapes R, Downes G 1997. The 1855 Wairarapa, New Zealand, Earthquake – Analysis of Historical Data. Bulletin of the New Zealand National Society for Earthquake Engineering, Vol. 30, No. 4, December 1997.
- NZSS 95:1939 – New Zealand Standard Code of Building By-Laws Parts I – IV, New Zealand Standard
- NZSS 1900 Chapter 8:1965 – Chapter 8 - Basic Design Loads, New Zealand Standard Model Building By-Law.
- Amendment 301A Local Municipal Corporations Act 1968. New Zealand Statute.
- Local Government Act 1974. New Zealand Statute.
- Recommendations for the classification of high earthquake risk buildings. A study group report of the New Zealand Society for Earthquake Engineering, “The Brown Book”, Bulletin of the New Zealand National Society for Earthquake Engineering, Vol. 5, No. 2, June 1972.
- Earthquake Risk Buildings – Recommendations and guidelines for classifying and strengthening earthquake risk buildings, “The Red Book”, A study group report of the New Zealand Society for Earthquake Engineering, December 1985.
- Building Act 1991. New Zealand Statute.
- NZS 4203:1992, - Code of Practice for General Structural Design and Design Loadings for Buildings, New Zealand Standard of Practice.
- Draft Guidelines for Assessing and Strengthening Earthquake Risk Buildings, A study group report of the New Zealand Society for Earthquake Engineering, 1995.
- The Assessment and Improvement of the Structural Performance of Earthquake Risk Buildings, a draft study group report of the New Zealand Society for Earthquake Engineering, 1996.
- NZS 1170.5:2004 – Structural Design Actions, Part 5: Earthquake actions – New Zealand, New Zealand Standard.
- New Zealand Building Act 2004. New Zealand Statute.

# ISSUES ASSOCIATED WITH THE DESIGN AND CONSTRUCTION OF NEW BUILDINGS

D.K. Bull<sup>1</sup> and A.B. King<sup>2</sup>

<sup>1</sup>Dept of Civil Engineering, University of Canterbury, Christchurch and  
Holmes Consulting Group Ltd, Christchurch

<sup>2</sup>Institute of Geological & Nuclear Sciences, Wellington  
(des.bull@canterbury.ac.nz)

## INTRODUCTION

Earthquakes have been and will continue to be one of the most frightening threats to society. The thought of a major quake and its aftermath has filled many minds for a long time, but the general perception by the public and to some extent, the law makers, that we (construction industry) are geared up to provide structures and infrastructure that will survive the event AND be functional afterwards, that is, being “earthquake proof”.

This is the age old chestnut of a structural engineer’s interpretation of “earthquake resistant” compared to that of the “Public’s”.

As researchers, designers, and constructors, we will bear the brunt of Society’s dissatisfaction with the performance of “modern” structures (post-1975 approximately) in the event of the major earthquake that must inevitably happen in a built-up area of New Zealand.

Modern technology has not yet fulfilled its promise for our construction industry. Computer technology has not revolutionised the construction industry the way it has others such as in medicine and in telecommunications. The research has not always led us to improved design or construction. We have seen this in recent years: consider the leaky buildings issue. Because we have had no major urban earthquakes in recent times, we still do not really know how our buildings will behave.

One colleague posed this question and comment:

*“Why can't our analysis tools match “Playstation”?”*

*The laws of physics formulated by Isaac Newton can be solved quickly on desktop computers, as shown by game software. Yet we still approximate the dynamic effects of earthquakes using equivalent static or quasi-dynamic effects and ignore the change in properties as damage occurs. Our software is still based on 1970's mainframe codes...”*

So, what do these observations mean for the design and construction of new buildings?

## **WHAT “SOCIETY” EXPECTS FROM NEW BUILDINGS AND WHAT IT WILL GET...**

There is a concern amongst structural engineers that much of the Public believes that current design Codes of Practice and Standards will provide “earthquake proof” structures.

“Modern” design philosophy (post-1975 or there about) uses structural detailing that will permit controlled “damage” – plasticity or ductility (= “deformation” or “yielding”) – in key parts of the building. As part of the design process using this controlled permanent damage is the principal of “Capacity Design”. This involves the structural designer organising the strengths of the beams, columns, walls, bracing etc in such a way that predictable zones of yielding will occur within these elements (sometimes called “plastic hinge zones”). The rest of the parts of the structural elements remain largely undamaged.

This methodology was pioneered by a number of research and practising engineers in New Zealand through the 1970s and 1980s, initially in concrete and steel structures and later in timber buildings. Eminent leaders in these developments, particularly in the field of concrete structures resisting earthquakes are Professor Bob Park and Professor Tom Paulay, University of Canterbury. Therefore NZ trained engineers (Universities of Canterbury and Auckland) will currently design structures to have some reasonable resistance to earthquakes by sustaining damage in a controlled way; thereby dissipating seismic energy and keeping the forces generated by the earthquake to a manageable level. This damage will vary in extent across the region affected by the earthquake and from structure to structure (even if identical). Such damage will involve the structure, the fit out and the contents. The designer’s aim is to maintain the gravity support within the building during and immediately after the main event. This will allow the occupants to evacuate to safety. The cost of reinstatement of the buildings may be large and in some cases a building may require demolition, becoming a complete economic loss.

Is the general public, including property owners/investors, aware of this design philosophy for our moderate and high seismicity regions?

Buildings of the future will in the majority continue to be built using this philosophy of controlled damage – is this actually what the Public expects?

However, there are new (and not so new) structural systems available and continuing to be developed that are aimed at very little to zero damage; both in structure and in fit out and contents. These structures would remain operational and should require very little expenditure on any resulting damage. Some of the structural systems that can achieve this are:

- Base Isolation, where the buildings are mounted on supports (isolation bearings) that “isolate” the building from the motion of the ground (Skinner et al. 1993).
- Tuned mass dampers: large mass pendulums mounted near the top of structures typically, that move counter to the building motion, effectively cancelling out a lot of the earthquake induced motion (Chopra 1995).

- “Hybrid” precast concrete post-tensioned, prestressed frames and wall buildings (Priestley et al. 1999, Pampanin et al. 2001, *fib* 2003).

At this point in time, these and other “high tech” solutions come at some cost. Future development will continue to focus on these systems, but before they gain acceptance, Society must indicate a willingness to pay for them. Since Base Isolation (BI) was developed first in NZ, there have been 14 buildings built. Holmes Consulting Group have designed six of these and advised on a seventh. It is expected that these BI buildings will out-perform most other buildings. The principle reason we don’t always use BI is that most developers are not willing to pay the premium. This is not simply a developer issue – it springs from Society, which does not yet fully appreciate the perseveration of life, minimisation of economic impact and the protection of operational functions that these alternative systems offer over conventional design and construction.

### **DESIGN STANDARDS AND REGULATIONS — Are current buildings Standards fit for purpose?**

Codes of Practice and Standards for the design and construction of buildings are full of requirements are typically *minima*. However, these requirements are typically seen by many inside and outside the construction industry as *maxima* in terms of quality.

This is quite *false*. In many cases the resulting structures built to the minima standards will not be fit for the purpose that the end-users had anticipated, even though these structures are “code complying”. As a result of the Public being effectively being satisfied with the perceived acceptable performance of structures built to the current *minima* Standards, the construction industry will be hogtied to the “lowest price wins the project”.

A point to ponder knowing what we know today: the *NASA Space Shuttle*: would we consider as a good strategy the creation the world’s most complex vehicle based on 100's of subcontractors, all chosen on the basis of lowest cost?

In other words, **Society gets what it pays for.**

The drivers for putting up buildings are normally, speed, lowest costs for construction and professional services. The areas where the biggest savings in time and cost can be made are during the scheme design (up front) and in site supervision. Investment in these areas will produce savings overall. Further, consider future maintenance in the scheme and recognise that a cheap building may cost them “millions” later in maintenance. So, the Public/investors should be prepared to move away from the lump sum lowest fees to pay for good initial design concepts which will include looking at "sustainable" buildings.

To be fair to Society, it is generally not that naïve to assume that buildings following Standard minima will be “prestige” or “quality” structures. Institutional property owners or public serving structures, such as hospitals, will have design briefs that describe the performance that is wanted from the building (little damage to building and contents; maintain operation as a recovery centre, post a major disaster etc). Typically this will be well above that provided by strictly code complying buildings and will be at a cost premium.



New Zealand has fallen into a trap of designing for what will bring the building down in a few seconds - **big** earthquake, **big** wind or **big** flood. Not much focus is placed on normal serviceability issues (i.e. the day to day functionality). Though modern Codes recognise this “serviceability limit state” offering some guidance, it is often assumed that designing for the “big one” will cover the in-service behaviour – though largely true for strength and life safety – it may not hold for continued function of the building after a service level or moderate event nor avoiding repair costs. This in-service aspect needs to be possibly emphasised more in design.

Other issues with Standards and Regulations include:

- The current legislative and compliance environment is highly prescriptive and does not encourage good design and quality.
- Compliance and review are probably less effective now than they were 20 years ago, although it is suspected that costs have increased – why?
- Codes and Standards are now “20 times the volume”, but the quality of our building work has not improved in step. The burden of compliance is far greater, for little reward.
  - “Simplified” Standards catering for ordinary, typical (possibly “commodity”) structural design may be one way of easing design effort. These already exist for low-rise housing: timber and masonry. It would be possible to develop such Standards or guidelines for low-rise commercial and industrial buildings. If these were produced, the underpinning engineering science will still need to be up to date and comprehensive. The range of buildings that these “simplified” standards would be applied to would be very restrictive. It may be a change in the attitude of designers and contractors simply to be better at the uptake of new technologies and become more efficient with increased use and familiarity.
- There is frustration with excessive time to process building consents (e.g. 50 days plus in some cases). Therefore we need a review process that operates in a timely and consistent manner.
- It highly desirable to have a review process that provides focussed reviews, not simply avoidance of liability (by the Territorial Authorities – is that fair?). The Profession would welcome scrutiny, provided that it is applied evenly, fairly, and is done by people that are in a position to understand what is being reviewed.
- In the future, we would like to see changes of design/construction philosophy from what appears today as satisfying “lowest first up cost”; though life cycle costs are coming to the fore in some areas (generally not). Therefore consider:
  - “Performance Based Design”: there are many definitions of PBD – one of the simplest is: *produce a structure that is designed and built “fit for purpose”*. That is, in service and under extreme loading conditions (wind, earthquake etc) the building functions structurally and operationally in accordance with the expectations of the users of the building.

Technically (structurally, mechanical services etc) this concept is not new – though typically abandon for the sake of satisfying, literally, the Code requirements.

One way of satisfying Performance Based Design objectives, dealing with the technical complexity of PBD, is utilising the computing power available to us today.

- A major issue on what performance criteria should be used (strength overload “Ultimate Limit State” or avoidance of collapse)
  - What is “...a low probability of rupturing, becoming unstable, losing equilibrium, or collapsing during *construction* or *alteration* and throughout their lives”?
    - There are many interpretations of the Regulations. What is needed is that the DBH, all the TA's and consultants should agree on the performance criteria for new designs and EQ prone buildings so that a consistent approach around the country could be adopted.

## DELIVERY OF BUILDINGS

The process of delivering a building to the client is impacted negatively upon by:

- A lack of skilled labour in key areas eroding the quality of construction (trades, engineers, architects, the drafting personnel associated with these professional services and project managers) - marketing and education issues.
- In general, our forms of contract are designed more to punish failure rather than to reward initiative.
- The information flow in the construction industry from start to finish is disjointed, and often fails to deliver the end result that is desired.
- Lack of integration of design, documentation and construction – the process is divided in to respective fields (structural, architectural, services etc), with co-ordination being undertaken with variable degrees of success. Overarching this sectoring is contract law and its ramifications – which tends to produce entrenchment in each sector – hampering dialogue and transfer of information, thereby negatively impacting on the economies that could have resulted.
- Our design methods are no different from 30 years ago, although our computing/analytical capabilities should be much improved.
  - This is in part due to the focus of the education of designers. However, that is largely driven by the expectations of the end-users (employers) for the capabilities of the “education product” – that being the students. Essentially the request is for much the same knowledge base as it was 30 years ago.
- Increased reliance on technology with inappropriate controls, effectively a “black box” mentality being employed with latest software – understanding of the science behind the software and the appropriate interpretation of outputs appear to be inadequate in some instances – an education issue?

- A continued focus in New Zealand on cost control (lowest cost) at the expense of quality.
  - It would be easy to counter that this issue is at the control of the industry. However, it is that Society in general must take a large share of the responsibility for this choice. Expectations of quality come at a cost. Unfortunately, industry has been obliged by the clients (or clients' advisors) to focus on the "lowest cost". The reaction is for industry to be focused on simplification and repetition of stock standard solutions, aiming for economy and efficiency, to too great an extent. The result is buildings and the operation of buildings that reflect the dollars paid for them.

## EDUCATION AND RESEARCH

- As above, a lot of the educational content is the same as it was 30 years ago. This is acceptable to some extent because the "basics" are the same – however, the introduction of advanced and emerging structural engineering techniques is possibly stifled.
- We are constantly being challenged by owners/developers/architects to design more and more irregular or hybrid structures. This is the nature of progress, but it is now a big jump from the typical Engineering school project to one of these designs. There isn't time in a BE course to get into this detail so the reliance on learning on the job is greater than ever.

*Possible solutions to the observations above are an additional year to the Bachelor of Engineering – making it a 5 year degree or making a Masters Degree essentially obligatory?*

- Anecdotally, there appears to be reduced education standards, sacrificing depth for breadth in respect of structural engineering.
- Competing careers choices diverting some of our best potential engineering talent to other industries.
- Reduced research into what is seen as a 'mature' science (structural engineering).
- Continuing Professional Development (CPD) – often gets lip service:
  - Though IPENZ has a programme where proof of an active personal CPD is necessary to maintain the Charter Professional Engineer's status.

## CONCLUSIONS

In order to achieve the better performing buildings, "fit for purpose", satisfying the expectations of the Public, we need:

- An education system that offers encouragement to the right people to advance into professions in the industry that reflect their abilities and aptitudes.

- A framework of Codes and Standards that encourages designers to design for quality, not compliance with the minima set up in the current Codes and Standards.
- Integration of design, documentation and construction – all building professionals working together in a collaborative open mode, not fearful of liability and contractual issues. There are example sin New Zealand of common drafting software platforms being using by all the service providers in a project, so coordination of design changes etc. was far better managed. This ha been built upon by the use of very sophisticated 3-D drafting systems.
- A society (the public) that places reasonable expectations on the industry and is prepared to participate in open and constructive discussion as to what that may consist of and realise that their expectations may not be satisfied by Code *minima* nor by the “lowest price” – we get what we pay for.
- There is a general attitude within the construction industry that engineers are the silent profession – they like it best when they are invisible and just doing their job. We like to think that structural engineering is black and white, “straight forward – nothing new”, but it is not. Occasionally something will shake those beliefs – Cave Creek, the “John Scarry report”, leaky buildings to name some.

Another event on the Wairarapa fault would do that, why wait to change things?

In short, structural engineers as a profession need to remind themselves that new technical developments coupled with changing societal expectations (a desire for better quality and performance) will always occur and that we are bound to stay aware of these changes and adapt our practices accordingly.

## REFERENCES

- Skinner R. I., Robinson W. H. and McVerry G. H. 1993. An Introduction to Seismic Isolation. Wiley.
- Chopra A. K. 1995. Dynamics of Structures. Prentice Hill.
- Priestley M.J.N., Sritharan S., Conley J.R. and Pampanin S. 1999. Preliminary Results and Conclusions from the PRESSS Five-storey Precast Concrete Test Building, PCI Journal , Vol 44, No.6 pp 42-67
- Pampanin S., Priestley M.J.N. and Sritharan S. 2001. Analytical modelling of the seismic behaviour of precast concrete frames designed with ductile connections, Journal of Earthquake Engineering, Vol. 5, No.3, pp.329-367.
- fib*, International Federation of Structural Concrete 2003. Seismic design of precast concrete building structures, Bulletin 27, Lausanne, 254 pp.

## AS SAFE AS HOUSES?

S.J. Thurston and G.J. Beattie  
BRANZ, PO Box 50908, Porirua  
(stuartthurston@branz.co.nz)

### NZS 3604

Most new houses in New Zealand are designed to the “Timber-framed Buildings” standard, NZS 3604. Sections 1–16 of this standard are invoked by the New Zealand Building Code (NZBC) as an “Approved Document” for clauses B1, B2 and E2, meaning that it is deemed to be an acceptable solution for the structural, durability and external moisture aspects of timber-framed buildings.

NZS 3604 is a “cook book” type of standard which enables builders to design timber-framed houses without having to use specific engineering design. The size of every timber member in the house — from rafters in the roof, purlins, ceiling joists, wall plates and studs, and lintels to floor joists bearers and piles — is selected from tables given in the standard as a function of member spacing, span, wind zone, roof and cladding weight (and perhaps snow loading, floor live load or whatever is relevant to the loading of the member). The standard also stipulates connection fixings, often as a function of these parameters.

The tables were prepared using spreadsheets using all the relevant load cases from NZS 4203 and the material strengths specified in NZS 3603, although account was sometimes taken of redundancies, additional strength and other favourable factors known to be present in these buildings, even though such factors cannot normally be taken into account in specific design. Territorial Authority inspectors check the construction. Timber must comply with strength, stiffness and durability requirements. All cladding must have a durability of 15 years and all structural material a durability of 50 years. Thus, provided the standards are complied with, failure under gravity or wind loading is expected to be rare. Houses generally have alternative load paths, and the total composite strength is greater than the sum of individual elements. Thus, life risk from structural failure is small.

### HOUSE EARTHQUAKE RESISTANCE

NZS 3604 tabulates the earthquake and wind demand forces based on the loadings from NZS 4203, building weights, geometry and location. The earthquake forces assume the building has a ductility of 3. Manufacturers test their wall systems to the BRANZ P21 test method which assigns the walls a bracing rating, and then publish these strength results. Designers use this data to ensure the actual wind and earthquake strengths exceed the demand forces. A similar process is used for pile foundation systems.

NZS 3604 ensures all building elements are fixed together, which greatly enhances earthquake resistance. Well-constructed houses have tended to perform well in these extreme events. This is partially due to the box-like shape of houses with good horizontal diaphragms; elements adding strength, but usually ignored in the design process and the multitude of load paths and redundancies present in typical houses. However, the modern trend to larger, more open, houses of complex shapes and vertical

and horizontal irregularities makes them susceptible to torsional forces and increases their vulnerability.

## **DAMAGE IN WINDSTORMS**

New Zealand generally gets one or two major wind storms a year — although the wind speeds reached rarely exceed the design wind speed. Roofing iron and even tiles are often lifted (particularly on older buildings where the roof fixing strengths have deteriorated or were inadequate in the first place). Sometimes the entire roof is lifted if the roof to wall fixing is inadequate. This connection should be high on the Territorial Authority inspector's checklist.

Where windows or sliding doors blow in or are smashed by flying debris, the interior of the house will be pressurised, which tends to lift the roof off. If the roof goes, lack of roof diaphragm can result in collapse of walls under face load pressures. Loss of wall cladding under wind suction may also occur. Racking failure of walls without roof failure, or failure of foundations or lintels in wind storms, has been rare. However, we should not forget the increased risk of wind storm severity associated with global warming.

Apparently some people in Fiji open leeward doors and windows of houses when experiencing cyclones. This reduces the air pressure in the interior of the house and thus decreases the tendency of roofs to blow off. Of course the reduced interior air pressure increases the differential pressure across the doors and windows of the windward side of the house which can lead to failure — and so there is a drawback.

## **LIFE RISK IN HOUSE FIRES**

The majority of fire fatalities occur as a result of fires in the home. There are approximately 5,000 domestic fires a year in New Zealand, and over the last five years there has been an average of 19 deaths per year. Worldwide the mortality rate is decreasing with the passage of time, which may be due to better fire services and rapid uptake in the use of smoke detectors. Most deaths in house fires are from smoke inhalation. BRANZ has been promoting the use of stand-alone battery powered smoke detectors that have been shown (Wade and Duncan) to be cost-effective. More than 50% of New Zealand homes have smoke detectors installed. Domestic water sprinklers are becoming more cost-effective.

## **THE INTERACTION OF RESIDENTIAL DAMAGE FROM NEW ZEALAND EARTHQUAKES AND THE BUILDING REGULATIONS**

Since 1855, New Zealand houses have not been severely tested by earthquakes — particularly modern construction. However,... it is only a matter of time. An exception was possibly the 1931 Napier earthquake, where the major damage was caused by fire rather than ground shaking, and to a lesser extent the 1987 Edgecumbe earthquake.

I will discuss the major earthquakes and their interaction with the New Zealand regulations. With his permission, I have borrowed heavily from Russell Cooney's 1979 and 1987 papers, which are still the authoritative documents on this subject.

- Most of the 4,800 inhabitants of the 1848 Wellington earthquake lived in masonry houses which were severely damaged. The timber-framed houses performed well. Consequently, the majority of houses were rebuilt in timber. The 1855 earthquake felled 80% of the chimneys and masonry houses were again severely hit. Damage to wooden houses was slight.
- A 1929 earthquake near Murchison severely damaged houses.
- New Zealand's greatest earthquake disaster occurred in 1931 at Napier. However, apart from falling chimneys, 90% of the wooden framed buildings were not damaged by the ground shaking in the earthquake. The two main causes of damage were inadequate anchorage of the superstructure to the foundations and lack of sub-floor bracing. Further, insufficient lower storey wall bracing resulted in damage and permanent distortion.
- The 1942 Wairarapa earthquake and subsequent aftershock resulted in more than 5,000 houses being damaged and 22,000 chimneys falling.
- Reports on the 1966 Seddon earthquake attributed damage to lack of bracing in heavy roofs, inadequate veneer ties and house shape irregularity including large openings ... and of course chimneys.
- Eighty houses experienced the heavy shaking of the 1968 Inangahua earthquake, most being timber-framed. It was concluded that performance was good, and the damage mainly occurred in buildings where diagonal wall and/or roof bracing was omitted and attachment to the foundations was inadequate. The few unreinforced masonry buildings in the area apparently disintegrated. Cooney notes buildings on piled foundations often have the superstructure protected by what is effectively base isolation. He observed that the only house founded on a slab-on-ground construction that experienced strong shaking in the 1968 earthquake appeared to have suffered greater superstructure seismic forces than those on timber piled foundations.
- Housner's report of the 1971 San Fernando earthquake (where the houses were similar to those in New Zealand) came to similar conclusions — namely the damage was due to (a) inadequate sub-floor bracing, (b) inadequate lower storey wall bracing particularly where there was a large garage opening, and (c) inadequate roof bracing ... and of course chimneys! After this earthquake, Yanev (1974) stated "... the same type of buildings that failed in the 1906 San Francisco earthquake failed in the 1933 Long Beach, the 1952 Bakersfield, the 1964 Alaska and the 1971 San Fernando earthquake. The same types of building will continue to fail until the building codes pay some heed to history and the principles of physics.

Before the 1931 earthquake there were few New Zealand regulations for residential building construction and it was based on "experience and trade practice". The lessons from previous earthquakes had apparently not been heeded. A model bylaw (NZSS 95) was published in 1935, but was still largely inadequate — except perhaps for bracing of walls between storeys. Houses were permitted to be built on free-standing piles up to 760 mm long. Some parts were vague — such as the requirement that roof framing must be effectively braced without specifying criteria. The far-sighted recommendations by Dixon (1929) on subfloor, wall and roof bracing were largely ignored. Adoption of the bylaws by local government was voluntary.

Later, the 1936 State house specification required continuous reinforced concrete foundation walls. Twenty-eight years later (1964), NZSS 1900 replaced NZSS 95, but the provisions added little seismic strength enhancement to houses.

The introduction of NZS 3604 in 1978 was a major step forward, as it did not rely on good trade practice and tradition, but was instead based on sound engineering principles and calculations. Bracing demand depended on construction weights. A number of wall and foundation bracing systems were offered. The standard placed particular emphasis on piled foundations, as these had such a poor history of seismic performance.

NZS 3604:1978 aimed at minimising damage to houses in major earthquakes to ensure they were habitable after the design earthquake event.

Cooney 1981 predicted large damage to “a significant number” of pre-1978 houses in a major earthquake, with many houses being required to be evacuated while being repaired. Cooney’s predictions of the type of earthquake damage were largely borne out by the outcome of the 1987 Edgecumbe earthquake. He predicts far less damage to houses built to NZS 3604:1978 except for masonry veneer and chimneys. He highlights the importance of building inspections during construction to ensure compliance with NZS 3604. He emphasises that careful study of earthquake damage is the best way to learn how to refine future codes.

### **1987 EDGECUMBE EARTHQUAKE, ML 6.3, MM IX OR PGA 0.33G**

Two-thirds of the Edgecumbe area houses were built in the 1950–1979 era when awareness of earthquake resistant construction was not high. Several hundred houses experienced minor structural damage, but less than 50 buildings were substantially structurally damaged. None of those which complied with the 1978 NZS 3604 standard were damaged by the shaking, with the exception of those on concrete slabs discussed later.

Permanent ground deformation through rupture or subsidence caused much of the damage to houses, especially to concrete and masonry foundations and walls and masonry veneers. Modern houses are still expected to be vulnerable to such differential movement, although probably not to the same degree. The highly variable soil conditions resulted in many examples of almost identical buildings in close proximity having widely different levels of damage.

Most damage involved the foundations — mainly in houses with unbraced piles and jack studs. Approximately 20 foundations collapsed (damaging their superstructure as well) and 100 were laterally displaced at foundation level. Much of the resistance of these houses was due to cast-in porches/chimneys etc. Those on continuous or corner foundation walls performed very well. The construction on slab-on-ground also performed well, except where the slab sat on a perimeter foundation wall and there was no connection between the two. In this instance, the slabs moved up to 300 mm relative to the walls and caused significant damage. Such construction is not permitted in the current NZS 3604.

Although no collapse of timber-framed walls occurred, and none had significant permanent racking deformations, plasterboard cracking was often severe, particularly where external walls had large openings. Houses designed to the current revision of NZS 3604 are expected to have significantly less damage for the same shaking.



Torsion-induced damage in houses with vertical and horizontal irregularity was noted. Damage occurred at junctions of wings of a house, particularly where the different wings had different foundation types. Inadequate bracing of houses under construction resulted in severe damage.

The largest monetary loss was to house contents such as whiteware overturned, electrical appliances such as TVs falling, and shelves emptied. A number of solid fuel stoves moved on their hearths and became disconnected from their flues creating a fire danger.

This is unlikely to change for contents in the lower ground floor of modern construction. Better wall bracing may reduce the shaking in the upper floors, but the more open modern construction will exacerbate it.

Most concrete or masonry chimneys in areas of high shaking were extensively damaged — mainly due to non-compliance with the bylaw requiring them to be tied to the house. If the chimneys had had an open fire, this failure would have posed a fire risk. Few modern houses have concrete or masonry chimneys, and these must now be constructed according to the NZBC Acceptable Solutions and are expected to perform better. Existing chimneys in older houses will remain vulnerable, although many have been strengthened or “topped” on the owner’s initiative.

Over 100 of the 600 houses with brick veneer in Kawerau had damage to the veneer other than slight cracking. Most of this was attributed to the type of tie used, the manner in which the tie was fixed to the wall framing and the spacing of the ties. Damage included portions of the veneer being shed, diagonal cracks originating at openings and re-entrant corners and mortar cracks. Movement between the flexible timber frame behind and the brick veneer sometimes resulted in glass breakage at windows.

## **SUMMARY OF DAMAGE FROM THE EDGE CUMBE EARTHQUAKE**

The damage in this moderate (less than design level earthquake) was largely attributable to inadequate bylaws for earthquake resistance in past decades, non-compliance, and poor construction practices.

## **BRACING WALLS**

Prior to the 1930’s, most houses were lined with horizontal boarding with 150 x 25 mm checked in braces. Fibrous plaster sheets and paper faced gypsum boards then started to be introduced and the brace size reduced to 100 x 25 mm. The sheet bracing is far more effective as a bracing element than the diagonal braces. This was not recognised or provided for in the provisions up to and including NZSS 1900 (1964). However, the concept of bracing walls of tested strength to meet design bracing demand used in NZS 3604 has rationalised the problem and a more reliable wall bracing performance is now expected.

## **FOUNDATIONS**

Early foundations consisted solely of timber piles or stone blocks without any form of lateral support or embedment in the ground.

Slab-on-ground and continuous concrete wall foundations have performed well in earthquakes. Apart from chimneys, no other single element of construction has resulted in so many failures in earthquakes as piled foundations. However, the piles may have provided some base isolation protection to the superstructure. Many of the older style free-standing piled foundations were woefully inadequate.

NZS 3604 now permits specifically detailed braced piles, cantilevered piles with substantial footings and driven timber piles — each with assigned strength based on tests. Proprietary or bolted connections between pile to bearer and bearer to joists must have an even greater proven strength and 50 year durability. Thus better seismic performance is expected. NZS 3604:1979 only allowed single storey buildings to be founded on piles, but subsequent revisions extended this to two storeys.

## **MASONRY VENEERS**

Masonry veneers have had poor performance in past earthquakes. This is largely due to the incompatibility of fixing the stiff veneers to the more flexible timber framed walls. Veneer ties are intended to allow the timber framed walls to move vertically as the timber dries, to rack by  $\pm 20$  mm relative to the stiff veneer and then to prevent large portions of veneer from falling out under seismic face load.

Shelton (1995) found that many brick ties were inadequately held in the mortar. This was caused by nailing of the tie to the stud during construction, causing the stud to vibrate and thereby loosen the tie fixings in the still soft mortar of the layers below. The NZS 4210:2001 requirement for ties to be screwed to studs and the test method (AS/NZS 2699.1:2000) for brick ties is expected to give a much improved seismic performance as evidenced by BRANZ shake table tests. Cracking in the veneer in modern construction is still likely, particularly at veneer corners and window openings (Beattie 2005), although this is expected to be repairable if the brick ties are in sound condition. Inadequate tie fixing was noted as being a major factor in the 1989 Newcastle earthquake.

## **RECENT CODE/STANDARD CHANGES**

Based on the lessons learnt from the Newcastle earthquake and testing by Shelton (1995), an amendment to the NZBC required brick ties in house veneers to be fixed by screwing or other non-impact means. The spacing, tie embedment and tie testing method and criteria have been upgraded. The durability requirements for ties have increased. Better seismic performance of veneers built since the 1990s is now expected. The NZBC also specifies seismic restraint of chimneys and hot water cylinders.

Major revisions to NZS 3604 occurred in 1990 and 1999. These resulted in a significant increase in bracing demand based on NZS 4203:1992. There were changes in piled foundation design and greater emphasis was placed on the connections between the foundations and the superstructure. Large decks must be braced and wings of a house

must be separately braced. Roofs must be braced both within the roof plane and in the roof space depending on roof shape, area and weight. However, on the negative side, many modern houses have complex shapes, large rooms, large window and garage/sliding door openings and few load-bearing internal walls (as trussed-roof construction is now prevalent).

## CONCLUSION

Houses compliant with NZS 3604, especially the more recent revisions, are expected to have greater earthquake resilience than they have shown in the past. Use of sheet wall bracing (rather than let-in timber braces), strong superstructure to foundation connections, and strong sub-floor bracing will each improve the performance. Heavy chimneys are rarer and where used are better reinforced and well tied back to the house. Heavy roofs are also less common. Plasterboard ceilings with fully taped and stopped joints and particle board floors will provide better horizontal diaphragms than historic construction. The modern fixing method for masonry veneers is a major advance and will result in better performance, but veneer cracking near openings and corners is still likely, stepped diagonal cracks may occur and in some instances portions of the veneer will fall. Few roof tiles in modern houses are expected to dislodge as they are now fixed to the framing. Roof bracing provisions are expected to result in few examples of major roof damage.

Non-compliant houses, those with reduced strength from material degradation such as from leaks or floods, corroded tile ties, and those with bracing systems removed as part of renovations, will not fare as well.

Damage to house contents in a seismic event will still be high as there has been generally little effort to brace these items, despite efforts by the EQC to encourage home owners to secure the contents. Significant cracking of plasterboard wall linings can be expected in regions of high shaking, particularly in lower storeys of houses which have few internal walls and large exterior wall openings, such as garages and sliding doors. These walls may be left out-of-plumb. Damage near the junctions of wings of heavy buildings is expected. Large, complex shaped houses, especially those with large openings, are expected to have proportionally more damage. However, life risk due to shaking will be low. Houses built on/by steep slopes may be at risk from landslides. Where houses are sited in ground experiencing distortion and rupture there will still be severe structural damage. Modern water/sewerage and electrical/communication services are relatively flexible and are not expected to be damaged above the ground, but services below the ground may be vulnerable to large ground differential movements.

Houses built to pre-1978 standards will suffer the same damage as noted in past earthquakes. Chimneys will fall, heavy roofs of gable ended houses will be damaged, roof tiles with corroded wire fixings and broken mortar bond at ridge and hip capping tiles will dislodge often falling into roof spaces and perhaps penetrating these, lower storey walls will rack, masonry veneers will crack and fall and piles foundations collapse. Older style brittle clay pipe services, with fully cemented joints, are likely to be ruptured. Hot water cylinders, if not secured, will be dislodged and their valuable post earthquake water supply lost.

## ACKNOWLEDGEMENTS

Funding for writing this paper was provided by the BRANZ Building Research Levy.

## REFERENCES

- Beattie, G.J. 2005. Repair and reinstatement of earthquake damaged houses. *BRANZ Study Report 123*. Judgeford, New Zealand.
- Cooney, R.C. 1979. The structural performance of houses in earthquakes. *Bulletin of the NZNSEE*, 12:3.
- Cooney, R.C. 1981. New Zealand Houses in Earthquakes – what will happen. *BRANZ reprint series, No 21*. Judgeford, New Zealand.
- Cooney, R.C. 1987. Edgecumbe earthquake. Reconnaissance report. Section 4.1 Structural performance – Houses. *Bulletin of the NZNSEE*, 20:3.
- Dixon, C.E. 1931. Earthquake proves superiority of wooden buildings. *NZ National Review*.
- Shelton, R.H. 1995. Seismic performance of masonry veneers and ties. *BRANZ Study Report 53*. Judgeford, New Zealand.
- Wade, C.A. and Duncan, C.R. 2000. Cost-effective fire safety measures for residential buildings in New Zealand. *BRANZ Study Report 93*. Judgeford, New Zealand.
- Yanev, P. 1974. Peace of mind in earthquake country. Chronicle Books, San Francisco.

# TAKING NATURAL DISASTER EVENTS INTO ACCOUNT FOR TRANSPORTATION PLANNING: TIME FOR A NEW APPROACH

W.A. Walbran and D.R. Brunsdon  
Wellington Lifelines Group, PO Box 5050, Wellington.  
([wwcl@paradise.net.nz](mailto:wwcl@paradise.net.nz), [db@kestrel.co.nz](mailto:db@kestrel.co.nz))

## INTRODUCTION

Transposing the sheer physical geological effects caused across the Wellington region by the 1855 Wairarapa earthquake onto the present day built environment creates an instant sense of the likely damage and disruption such an event would occur to our transportation and utility networks.

The Wairarapa fault is one of seven active faults within 40 km of Wellington City, including the plate subduction zone beneath the region, that are each capable of causing appreciable damage to the geological and built environments. With individual recurrence intervals for rupturing of these faults of upwards of 500 years, the impression of their being “low probability” events is easily obtained. However there is a probability approaching 50% of an earthquake between magnitude 6.0 and 6.5 occurring within a circle of 40 km radius around central Wellington within the next 50 years (Wellington Lifelines Group 1993). Earthquakes of this order of magnitude in urban areas are very much in the “high impact” category.

For all the excellent progress made in earthquake engineering during the twentieth century, there remains a pressing need to develop standard techniques for evaluating transportation and utility network improvement projects that adequately account for major natural disaster events, and to use these techniques as a matter of routine.

This discussion paper advocates the need for a different evaluation approach to conventional economic measures. It is clear from the many studies undertaken over the past two decades that the physical impacts of such a regional scale event on transportation infrastructure will have a prolonged disruption effect on the community. The Wellington Lifelines Group believes the corresponding ‘shock’ economic effects from a major natural disaster are not taken into account appropriately using conventional economic measures and methods of analysis.

## UNDERSTANDING THE IMPACTS

Lack of (or restricted) access in the days and weeks following a major disaster greatly magnifies the direct damage effects. The characteristic *operational* or *functional* impacts that could result from a regional scale earthquake in relation to lack of access include:

- Utility services take considerably longer than expected to restore a basic level of service (lack of access to undertake basic repairs)
- Businesses and government agencies close for an extended period (lack of access for owners/ leaders and workers, in addition to direct damage, no reticulated water or wastewater disposal)

- Schools close for an extended period (direct damage, no reticulated water or wastewater disposal, other community functions, limited access)
- Airport unable to function initially due to direct damage (e.g. settlement of sections of runway) and uncertain utility services followed by difficulty of road access for inward and outward resources
- Port affected by lateral movement of sea walls and mis-alignment of crane rails, followed by difficulty of road access for inward and outward resources

Note that the effects from a more extreme event such as a rupture of the Wellington Fault on the communities and facilities of the metropolitan area would be more pronounced.

The combination of a probability approaching 50% in the next 50 years and the extreme effects suggest that these events deserve serious and specific consideration in the region's (and the nation's) transport planning activities.

Established measures of damage to capital stock focus on 'physical' damage rather than human effects. The various forms of consequential inconvenience are not measured in standard economic accounts, and fall into the intangible category of 'welfare losses' (Savage 1997).

Alternative approaches to move towards a regionally based economic analysis framework have previously been initiated by the Wellington Lifelines Group. A first stage report yielded a generic framework to assist lifeline organisations to justify mitigation projects by placing more emphasis on intangible and non-economic factors (Savage et al 1998). There was however insufficient interest in progressing this to the intended subsequent stages where regional benefits could be more systematically quantified.

### **ACTIVITY BASED ANALYSIS VERSUS REGIONAL (OR NATIONAL) BASED ANALYSIS**

In New Zealand the commitment of public funds to land transport capital projects is justified by the objectives of the Land Transport Management Act (LTMA). A key component of the analysis required for justification is economic analysis.

Economic analysis has developed to quantify the imperceptible (or barely perceptible) effects of individual capital improvements (activities) on the national economy. Clearly it would not be possible to measure directly the effect of improving the geometric alignment on a section of rural road on the national economy because the "noise" in the measures of national economic performance greatly exceeds the magnitude of the incremental change attributable to the relatively minor road improvement. Even at the scale of the largest land transport projects (such as Auckland's North Shore Busway) it is unlikely that project effects could be identified at the level of national economic performance measures.

However, a regional scale seismic event is likely to result in major land transport links to Wellington, Hutt Valley and Porirua being cut. As an indicative quantification, some land transport links could be:

- totally cut for *days to weeks*

- open for emergency vehicles only in *weeks*
- open for general usage albeit at severely reduced capacity for *months*; and
- it may take *years* to restore full (or normal) capacity.

Intuitively, disruption at this scale would have a clearly discernable effect at the level of national economic performance measures.

The Wellington Lifelines Group considers that the analysis undertaken for land transport capital expenditure does not adequately capture the scale of economic disruption that would result from a major natural disaster event.

An alternative way of thinking about this is to consider an individual manufacturing plant. A small reduction in the transport costs of the plant has a benefit to the plant that relates to the scale of the transport cost reduction and their proportion of total business costs. However a *total absence* of transport services for an extended period of time may prevent the plant from operating, hence having an impact on the plant that is on a much larger scale than the *cost* of the transport services that are no longer available. The plant will need more than just transport infrastructure to operate effectively. Other short-term infrastructure needs include acceptable power, telephone and water supplies. However, an operational transport infrastructure will be critical to the recovery period for all other network infrastructure.

### **TRAVEL TIME, VEHICLE OPERATING COSTS ETC. VERSUS REGIONAL ECONOMIC IMPACT**

The economic analysis usually undertaken for land transport capital projects is based around vehicle effects (travel time, vehicle operating costs etc.). The value of the individual parameters is set to take account of the effect on the national economy (i.e. they are *economic* values, not *financial* values).

The values are understood to be appropriate for evaluating incremental effects that are miniscule in comparison to the size of the regional (or national) economy. They are a proxy for effect on the national economy; and they are used because it is not possible to model or measure the effect on the national economy directly.

However, for a regional scale event, the effects on the regional (and hence national) economy can be modelled and would be directly measurable. Regional input/output tables have been developed which model the change in regional economic output. The expected land transport effects of a regional scale event could be fed into the regional input/output tables and the effect on the regional economy estimated. There are some limitations to this estimation as demonstrated by the manufacturing plant example above, but it may be much more direct and realistic than estimating economic effects based on changes in vehicle operating parameters.

The analysis of an individual land transport activity, group of activities or even a transport corridor cannot identify, quantify and take appropriate account of the effects of major natural disaster events the effect of which extend far beyond the activity, group of activities or transport corridor being considered. While an argument could be made that current analysis techniques make allowance for consideration of wider issues (as National Strategic Factors) these are rarely used and the authors are not aware of them

ever having been used to attempt to quantify the effects of a major natural disaster event.

## **IS ECONOMIC ANALYSIS APPROPRIATE FOR A REGIONALLY CATASTROPHIC EVENT?**

Economic analysis is appropriate for events that have *marginal* effects. It is not clear that it is appropriate for the evaluation of events that have *potentially catastrophic* outcomes. This may require some explanation. Economic analysis is appropriate where the possible outcome being considered is a comparatively small change in total economic output and where there are other similar options for the resources required to instigate the change. However, it is not clear that it is the appropriate tool to evaluate the prevention of potentially catastrophic outcomes.

Does prevention of the catastrophic outcome justify the investment of more of society's resources than the conventional economic analysis would indicate? There may be some merit in focusing intelligent thought on this question. Game theory, willingness to pay or military strategy theory may be avenues of investigation worth pursuing.

## **PROPOSED APPROACH TO FUNDING BODIES**

Land Transport New Zealand is the distributor of central government's roading funds. They also distribute central government funds for rail, public transport operations and to a much smaller extent for rail freight operations. The Ministry of Transport has recently been allocated responsibility for distributing central government funds for rail infrastructure. The Ministry is currently developing its funding allocation framework.

Land Transport New Zealand allocates funding for research proposals annually. The investigation of a possible change in funding allocation to appropriately address Lifelines issues would be most effectively investigated with the co-operation and preferably active participation of these two bodies.

The Wellington Lifelines Group is proposing a two-pronged approach:

1. Discussions are to be held with Land Transport New Zealand in order to gauge their attitude to a potential research project to consider alternative evaluation approaches for major natural disaster events.
2. A direct approach is to be made to the Ministry of Transport with a request to consider major natural disaster events in the development of their rail infrastructure funding allocation framework.

If these approaches meet with a positive response, suitably experienced researchers will be sought to take this work further.

## **CONCLUDING OBSERVATIONS**

The Wellington Lifelines Group has previously endeavoured to promote a more regionally-based economic analysis framework to better reflect the widespread impacts of a natural disaster event. It is hoped that a fresh approach which takes more account



of the true 'shock' effects of such an event on our technologically and access dependent society will prove more effective.

The key element of this new approach is to look beyond the traditional forms of economic analysis, which are based on marginal effects. If the proposed work in relation to transportation planning bears fruit, it is likely to be directly applicable to other lifeline utility services.

Looking back on the immense regional impacts of the 1855 earthquake reminds us of the importance of progressing this work with some urgency towards a more practical and universally acceptable project evaluation solution.

## **REFERENCES**

- Savage J 1997. Economic Effects of a Major Earthquake, Report for EQC, NZIER Contract No. 1008, NZ Institute for Economic Research
- Savage J, Briggs P and Hassan M 1998. Assessing the Economic Benefits of Lifeline Mitigation Investments (Stage 1 Report), Report to the Wellington Lifelines Group
- WELG 1993. Wellington Earthquake Lifelines Group 1993 Report, Wellington Regional Council ISBN 0-909016-09-7

# THE ROLE OF COMMUNICATIONS IN EARTHQUAKES

Brian Potter  
Telecom NZ Ltd  
(brian.potter@telecom.co.nz)

## INTRODUCTION

This paper examines the use of communications to manage response and recovery from Earthquake damage, while also touching on individuals need to communicate during these events. The subject is covered within two boundaries:

1. From a telecommunications viewpoint, noting that the word “communications” can infer many other methods of conveying information e.g. meetings, written text, press statements etc.
2. Presenting the situation from a Telecom NZ viewpoint i.e. the paper does not attempt to present a telecommunications sector view.

## BACKGROUND

Telecommunications is fundamentally about people keeping in touch. In that definition “people” could be businesses, individuals, communities and so on. The methods by which we “keep in touch” have grown enormously; voice, fax, internet, video, conferencing are a few examples.

Given that telecommunications is about people it follows that communications networks extend to where people choose to live, play, and do business. Noting New Zealanders’ propensity to live in risky places in the NZ Hazardscape, such as volcanic fields, flood plains, and great earthquake sites it means that the natural hazard risk profile of telecommunications looks somewhat like the risks that we as a population choose to live with, or in risk management terms, to accept. These risks, given their low likelihood, may not feature in the risks of highest size if conventional risk ranking techniques are used; but they are significant nevertheless.

No-one would deny that our reliance on telecommunications, for the things we have come to believe are essential, has increased massively since 1855. Indeed the whole Utility sector underpins our modern way of life to such an extent that we have come to term the Utilities of Transport, Power, Gas, Oil, Water, Wastewater and Telecommunications as Lifeline Utilities. This aspect has led to the formation of a number of regionally based Engineering Lifelines Groups.

## WHAT HAPPENED IN 1855?

Telecommunications had not yet made its way to New Zealand, although the Morse Code (and earlier versions) had been in use in Europe and the US since the 1830s. The electric telegraph was not to be used in New Zealand until the 1860s. Telephone followed in the early 1880s.

The 1855 event was widely detected across New Zealand i.e. it was clear that something had big happened. It would have been left to a combination of on foot travellers, and ship borne communications (HMS Pandora was in Wellington Harbour at the time) to

carry the message out of the affected area with letters, newspapers and verbal accounts carrying the situation to international audiences.

However we can draw from the 1855 event some important telecommunications-related observations about impact on a Utility on which Telecommunications is still critically dependent for response and recovery; transport.

- The track across the Rimutaka Ranges was severely disrupted — perhaps today's road would similarly suffer
- The Hutt Road was disrupted by two events: landslip and uplift. It was observed that the 1.5m uplift actually provided a better road, although one would expect that a modern road surface would be considerably disrupted by similar uplift/subsidence
- The area of today's Wellington Airport was swept by a tsunami from Lyall Bay to Evans Bay and back. Clearly there would be implications for use of Wellington Airport if a similar event occurred today
- The Tory St–Courtenay Place area was uplifted from being swamp to usable land and the roading across this area today provides a key “cross town” link
- The harbour bed was altered in depth necessitating rebuild of a number of the wharves

These events, or equivalents, could be expected to have significant impact on response and recovery for telecommunications today. A possible scenario, in a repeat of the 1855 earthquake, emerges of isolation of the Wellington area in a road, airport and shipping sense, with implications for transport of resources (people, equipment) into the area for recovery.

We should also note the devastation in infant Wellington caused by a great earthquake some kilometres distant and ponder what damage an equivalent event on the Wellington Fault would do.

## **HOW HAS TELECOMMUNICATIONS BEEN DEVELOPED/USED FOR EMERGENCIES SINCE 1855?**

The use of telecommunications in large earthquakes since 1855 is a mainly undiscovered story. We find a reported use of telegraph in the 1931 Hawkes Bay earthquake, and can assume the use of telephone since say 1900, and cellular since 1987, for managing events.

The development of telecommunications over the past 150 years is characterised by increasing spread of telecommunications, and an ever-growing number of services. In parallel our society has become ever more dependent on telecommunication services for everyday life and business. Even the most basic habits have been altered – for example, we tend to no longer just drop in to visit people without phoning first. Also, our modern economy is dependent on telecommunications.

Date	Area	Size	Telecommunications Use
Jan 1855	Wairarapa	8.1	
Feb 1863	Hawkes Bay	7.5	
Oct 1863	Cape Farewell	7.5	
Sept 1888	North Canterbury	7.3	
Feb 1893	Nelson	6.9	Unknown
Mar 1929	Arthurs Pass	7.1	Unknown
Jun 1929	Murchison	7.8	Unknown
Feb 1931	Hawkes Bay	7.8 & 7.3	Telegraph
Mar 1934	Pahiatua	7.6	Unknown
Jun / Aug 1942	Wairarapa	7.2 & 7.0	Unknown – large component of military assistance
May 1968	Inangahua	7.1	Unknown
Feb 1995	East Cape	7.0	Unknown
Aug 2003	Fiordland	7.1	Unknown
Nov 2004	Puysegur Trench	7.2	Unknown

(earthquake data sourced from IGNS - <http://www.gns.cri.nz/what/earthact/earthquakes/historic.html>)

These factors have driven the requirement for more resilience in telecommunication networks. Where a single open wire toll route may have sufficed between say Wellington and Levin in 1955, with accompanying acceptance that this line would suffer periods of outages, our customers now have an “always on” expectancy of telecommunications. Additionally dependence on the telecommunications network for the management of emergency situations has grown steadily. As an example in 1958 the 111 Emergency Service was introduced in Masterton with the then NZ Post Office committing to answer the calls on a priority basis. Today Telecom answers approximately 2 million calls annually with an underlying customer expectation that every call will connect and be answered.

Other uses for the telecommunications network in an emergency include:

- Voice calling over landlines and cellular
- Text messaging via cellular
- Photo messaging over cellular
- Audio and Video Conferencing

To achieve greater telecommunications network resilience a number of important measures are taken:

- Selection of exchange sites generally known to be clear of land instability, flood, fault line
- Progressive upgrading of seismic standards at exchange sites, particularly as the building codes change, including seismic bracing in equipment rooms
- Choice of fibre cable routes generally clear (as can be in the hazard prone country) of earthquake fault lines
- Installation of back up power systems at our larger sites
- Installation of fibre cable on diverse routes to interconnect the larger centres. e.g. Levin to Nelson Cook Strait cable with progressive “hardening” as investment allows.

## WHAT IS HAPPENING NOW? — NEW DEVELOPMENTS

### Customer

The communications in a geographic-based emergency come from generally predictable sources:

Source	Related to
Civil Defence, Emergency Services	Management of event
Public, Emergency Services	Casualties
Civil Defence, Lifeline Utilities	Utility infrastructure recovery
Businesses in affected area	Business Recovery
Businesses outside affected area <sup>#</sup>	Business Recovery assistance
Communities in affected area	Response/recovery
Individuals in affected area	Response, recovery, checks on friends/family / neighbours
Individuals outside affected area <sup>#</sup>	Checks on friends/family
News media outside affected area <sup>#</sup>	Seeking stories/updates

<sup>#</sup> *including international*

Call volumes following a great earthquake could impede the carriage of emergency calls as our network, in common with other telecommunications networks, is designed for the busy hour of the busy day of the busy season; not to enable everyone one to call simultaneously. The volumes would be very large and the pressure of calling into the affected area would, most likely, require restrictions to be implemented in the network.

### Network

Telecom has a fibre optic “ladder network” extending over much of the North and South Islands, basically two “poles” with intersecting “rungs”, to give us resilience. In Wellington’s case that network enters the region via the Rimutakas and the West Coast. In addition, we have laid a trans-harbour fibre cable from Point Halswell to Eastbourne.

Telecom is adding additional rings/rungs to our core fibre network to further enhance resilience by reducing the consequence of an earthquake (or other significant event) to telecommunications by, for example, isolating the area.

Telecom has a Crisis Management Plan that we exercise against with the most recent exercise being in February this year with approximately 140 participants.

That said, our work to reduce the consequence of, and to enhance our recovery from, a great earthquake cannot cover off all of the risk of disruption to telecommunications services in a reoccurrence of the great earthquake. Based on 1855 there are residual possibilities of disruption due to:

- copper local access cables being severed as ground liquefies, and by abutment movement at bridge crossings
- fibre cable breakage, due to ground dislocation

- fire following earthquake, and as previously mentioned
- damage to transport facilities delaying our recovery efforts

Other factors — Our legislative environment offers some challenges to recovery after a major disaster:

Health and Safety Act — Telecom understands that there is no relief from the provisions of this act for response activities following a disaster. While this is consistent with our valued approach to people one can foresee delays while buildings are inspected for seismic integrity etc.

Resource Management Act, Emergency Works provision — S.330(c), S.331 of RMA makes provision for a Network Utility operator, under certain circumstances to carry out emergency preventive or remedial work. The Utility Operator is required to advise the consent authority within 7 days and apply for resource consent within 20 working days. In a major earthquake, these time limits may be challenging.

## **WHERE DO WE NEED TO FOCUS FUTURE EFFORTS?**

There needs to be recognition that, as telecommunications is an end-to-end business, the role of mitigating the risk in a great earthquake is shared between Telecom and its customers. We see it as important for:

- Customers with mission critical services running on national telecommunications infrastructure to be prepared for service interruptions, albeit infrequent
- Customers with particularly demanding network availability requirements to carefully consider the physical location at which their systems are based and interconnected with our network
- Telecom to continue upgrading our national network over time to progressively increase capacity, performance and resilience
- All engaged in emergency management to carry a consistent message to our communities about staying off the telecommunications networks post a disaster, except in life and limb situations.

Although not strictly a “future effort” we need to continue to grow the “peacetime linkages” between Telecom and Civil Defence, including the work of the Wellington Engineering Lifelines Group (WELG) and Wairarapa Engineering Lifelines Association (WELA).

## **CONCLUSIONS**

Our telecommunications developments have been, from an 1855 perspective, simply astonishing. We can now communicate instantaneously across a building, city, nation, or world. One of our challenges in the aftermath of a future great earthquake will be to be able to adjust to using the remaining infrastructure and prioritise our use of it for the best outcome.

## **REFERENCE**

Grapes R 2000. Magnitude Eight Plus – New Zealand’s Biggest Earthquake.

# **THE VULNERABILITY OF LIFELINES TO LIQUEFACTION: A WAIRARAPA PERSPECTIVE**

G.W. Butcher

Wairarapa Engineering Lifelines Association, PO Box 41, Masterton  
(fernleigh@xtra.co.nz)

## **INTRODUCTION**

The Wairarapa, as part of the Greater Wellington Region, extends from Palliser Bay some 130 km north to Mount Bruce and some 75 km east from the crest line of the Tararua and Rimutaka Ranges to the Pacific Ocean coast (Figure 1). Included in the area are three district councils, South Wairarapa, Carterton and Masterton covering 6,010 square kilometres and with a combined population of about 38,000. The Wairarapa is predominantly rural in character and covers almost three-quarters of the GWRC land area but contains only nine per cent of the region's population. It consists of three distinct landscapes that strongly influence the climate and land use of the region. These landscapes include the Tararua and Rimutaka Ranges in the west, the Wairarapa Valley in which the five main towns are situated, and the eastern hills and coast. Most of the Wairarapa's infrastructure and productive land is located on the valley floor.

## **LIQUEFACTION IN THE WAIRARAPA**

Since early European settlement there have been a number of earthquake reports containing accounts of liquefaction at a number of sites throughout the Wairarapa. A summary of these accounts is given in Table 1

## **THE VULNERABILITY OF LIFELINES TO LIQUEFACTION**

Liquefaction was one of the natural hazards identified as a potential lifelines risk in the WELA Project. A report on the project was published in 2003 (WELA 2003). At the commencement of the project in 1997 very little information on soil strengths and potential liquefaction was available for Wairarapa soils apart from a 1993 report covering only a limited area of the Valley floor (Brabhakaran 1993). The study area related mainly to the five main townships located there. The 1993 report is discussed later. Most of the soils information available at the time was from logs of water wells for which the soil descriptions were inadequate and there was no soil testing.

In the absence of detailed information on liquefaction and soils susceptible to liquefaction, a soft sediment soils map was prepared for the WELA hazards task group by the GWRC based on the New Zealand Land Resource Inventory, the type of sediment, and the depth to the watertable. The map (Figure 1) provides an indication of areas with a liquefaction potential for use in the vulnerability, damage and level of risk assessments of lifelines used in the WELA Project. The map has limitations as it gives only general conditions and not all areas of soft sediments shown are susceptible to liquefaction. In addition, as Wick points out, the map is not conclusive of the expected site conditions and does not allow for small pockets of liquefiable material (Wick 2000).

**Table 1.** Accounts of Liquefaction Occurring in Major Earthquakes. Wairarapa Region

Date	Earthquake	Magnitude MMI	Depth (km)	Liquefaction	
				Location	Effects
1848 15 Oct	Marlborough	7.1 MM 7-8	40	Pahautea	Sand ejection
1855 23 Jan	Wairarapa	8.1 MM 9-10	25	Pahautea	Fissures, blue mud ejection
				Waihakeke near junction of Waiohine and Ruamahanga Rivers (Papawai)	Fissures, water ejection
				Wairarapa Coast	Fissures
1904 08 Aug	Cape Turnagain	6.7 MM 6-8	Lower Crustal	Gladstone	Fissures, blue mud and sand ejection. Fissures in bridge approaches.
1934 05 Mar	Pahiatua	7.6 MM 6-9	Lower Crustal	Bagshot	Fissures in flat ground
				Longbush	Fissures
				Kahutara	Extensive damage to stopbanks
1942 24 Jun	Wairarapa I	7.2 MM 7-8 (Some 9)	20	Opaki	Sand and water ejected over almost one km square
				Waihakeke (Papawai)	Sand ejection to a height which covered the lower branches of full grown willow trees.
				Lower Valley Bridge (Tauhitarata)	Approaches to bridge settled 600- 900mm. Piers to approach spans of bridge displaced up to 330mm at pile caps due to lateral spreading. (Figure 2) Repairs to tops of piers still evident. (Figure 3)
				Gladstone	Sand ejection. Bridge approaches damaged (Gladstone and Blackwater Bridges)
				Tauweru River Bridge Masterton–Stronvar Rd	Bridge approaches settled about 1 m
				Tauweru	Bridge approaches settled 600mm Abutment damaged
				SH2 Waiohine River	Subsidence and cracking at both ends of bridge
				Dalefield	Sand and water ejection
				Lake Ferry	Sand and water ejection
				Mangapeka	Cracking and settlement of road pavements
1942 01 Aug	Wairarapa II	7.0 MM 6-7 (Some 8)	43	Martinborough East to coast	Cracks and subsidence on all roads

The probabilistic earthquake ground motion study by Berryman *et al* (1998), commissioned by WELA, indicated the following levels of shaking on average to firm ground:

- 142 yr return period event (10% exceedance in 15 years) MMI 8-8.5, PGA 0.33-0.35g.
- 475 yr return period event (10% exceedance in 50 years) MMI 9-9.5, PGA 0.5 – 0.7g.
- On soft soils, the shaking is likely to be one or two MMI steps higher and the PGA 0.1g higher.
- Scenario events for earthquakes in the Wairarapa are those occurring on the Wellington Fault and will produce the following levels of shaking on average to firm ground:
- For central and northern Wairarapa. Tararua segment. MMI 9 (10 on soft soils), PGA 0.6g.
- For southern Wairarapa. Hutt Valley segment. MMI 9 (10 on soft soils), PGA 0.6g.



The assessment of vulnerability and impact of damage of lifeline networks and elements to liquefaction is detailed in WELA 2003 but in general terms is as follows:

### **LIFELINES IN THE TOWNS OF CARTERTON, FEATHERSTON, GREYTOWN, MARTINBOROUGH, AND MASTERTON**

All five urban areas are predominantly underlain by dense sandy, silty and clayey gravels and liquefiable layers are only present in relatively small areas (Brabhaharan 1993). Liquefaction is only likely to occur to a limited extent in such small areas. Some fringe areas of Carterton, Featherston, and Greytown border on soft sediment areas.

#### **Water supply**

*Masterton* Three pipelines of 250 mm, 300 mm, and 450 mm diameter cross the Upper Plain soft sediment areas to the west of Masterton. Several very small alternative supply schemes.

*Carterton* The 380 mm asbestos cement pipeline crosses the soft sediment area at Dalefield where historic liquefaction has been experienced. An alternative (existing supplementary) supply from pumped wells is available.

*Greytown* A 300 mm asbestos cement pipeline 7 km long supplies the town. Crosses some bands of soft sediments No alternative local supply.

*Featherston* A 200 mm PVC pipeline 4 km long links to a main from an alternative supply source. Crosses several bands of soft sediments.

*Martinborough* Water is pumped from two bores in a groundwater aquifer of the Ruamahanga River at Waihenga via 200 mm and 300 mm diameter PVC pipelines to the township. Wick has confirmed Waihenga has a moderate to high liquefaction potential (Wick 2000).

Damage is likely to be fracture of pipes particularly at anchor blocks and hard points, failures at joints, collapse of pipes particularly asbestos cement pipes.

#### **Sewage**

The five main towns have treatment plants consisting of primary oxidation ponds and in most cases tertiary ponds. All the plants are located on the soft sediment areas shown on the map in Figure 1. The aerial photograph in Figure 4 is of the Masterton ponds which are located adjacent to the Ruamahanga River. Elements at risk of damage from liquefaction are trunk sewers to the ponds, flumes, screens and other structures, pond connection pipes, pond walls, berms, embankments, and outlet structures. Damage outcome would be the discharge of untreated sewage to waterways for considerable periods of time after an event.

#### **Flood protection structures**

The GWRC administers a number of flood protection and drainage schemes within the Wairarapa Valley. The major flood protection scheme is the Lower Wairarapa Valley Development Scheme (LWVDS), which was constructed from the mid-1960s to the mid-1980s. The scheme protects 40,000 hectares of highly productive farmland and has a current asset value of \$70M. A critical component of the LWVDS is the Blundell Barrage, a multi-purpose structure that controls the levels of Lake Wairarapa, the Ruamahanga River and Lake Onoke, and provides detention storage during major

floods. It also provides east-west road access. Figure 5 is an aerial view of the barrage looking south from above the outlet channel of Lake Wairarapa towards Palliser Bay. The replacement cost of this structure is estimated at \$10M. Its importance to the scheme was demonstrated again during the February and August floods of 2004. There are also flood protection schemes on the Waiohine, Waingawa, Waipoua, and upper Ruamahanga rivers. Unlike the latter schemes, the LWVDS does not provide protection to urban areas. All schemes however protect rural areas, priority emergency routes, SH 2 and SH 53, and other routes. The total length of stopbanks involved in all the schemes is 295 kilometres. An estimated 214 kilometres or 73% are located on soft sediments and are at risk from potential liquefaction. There are also some 160 drainage outfall culverts with floodgates which are also at risk.

Within the Wairarapa Valley, there are 16 drainage schemes with a total drain length of 160 kilometres protecting an area of 6,600 hectares of highly productive farmland. Five of the schemes are pumped. The total asset value of flood protection and drainage schemes is about \$80M.

Damage to stopbanks resulting from liquefaction is likely to consist of settlement, transverse and longitudinal cracking, single wide longitudinal cracking, berm cracking, slumping, and collapse. Figure 6 is a view of typical liquefaction damage to a stopbank which occurred during the 1987 Edgecumbe Earthquake. The mean damage ratio is likely to vary from about 0.001 to 0.3. In the case of culvert structures, settlement and cracking, fracture, separation, and collapse of pipes.

Damage to drainage schemes is likely to be blockage due to bank slumping or lateral spreading, changes or reversal of drain gradients, cracking or fracture of inlet and outfall pipes at pump stations and headwall junctions, damage to pumps, and settlement or rotation of pump house structures.

The Blundell Barrage, which is constructed on a raft foundation, is particularly vulnerable to liquefaction. Figure 7 is a typical cross section of the barrage. Studies by Wick (Wick 2000) and Kaiser (Kaiser 2005) have shown that the barrage site has a high liquefaction potential. Even minor settlement and particularly differential settlement, or rotation, could prevent the barrage from operating properly and limit the operational effectiveness of the LWVD flood protection scheme. The Wick and Kaiser studies are discussed later.

### **Transportation**

The roading network, SH 2 and SH 53, and priority emergency routes on the valley floor, in some of the river and stream valleys to the east and parts of the coast are located on or cross areas of soft soils with an earthquake history of liquefaction or are likely to be susceptible to liquefaction.

The Wellington to Woodville railway line through the Wairarapa traverses soft sediments with a history of liquefaction at Dalefield and Opaki. There are also soft sediments in the valley systems the line follows north of Mauriceville.

Damage is likely to be pavement damage due to settlement, slumping and block type transverse and longitudinal cracking, slumping and settlement of fills and embankments

and bridge approaches, single wide longitudinal cracking where road and rail formations run parallel to rivers, streams and drainage ditches, and damage to bridge abutments.

### **Electrical**

Parts of the 33kV sub-transmission network and the 11kV distribution network cross soft sediment areas. Sections of the Upper Hutt to Masterton 110 kV double circuit tower line and the Mangamaire to Masterton 110 kV pole line also cross soft sediment areas. All are potentially prone to liquefaction damage. Damage is likely to be at changes in angle of pole lines at anchor stays and struts, and of tower lines. Individual poles subject to normal lateral loads are also at risk.

### **Telecommunications**

A national toll and exchange link fibre optic cable runs from the Rimutaka Tunnel to Mt Bruce. Local reticulation in and between the five main urban areas is mainly by underground cable using copper conductors. Most cables cross soft sediment areas with a liquefaction potential. Users in the eastern hill country and the coastal area down to Palliser bay are fed via multi-access radio and country-set radio sets via Rangitumau Radio and the network is unlikely to be affected.

Little damage is likely to occur to fibre optic cables except where settlement occurs at bridge approaches. On the other hand, copper cables affected by liquefaction are likely to be severely damaged particularly at bridge approaches.

## **LIQUEFACTION STUDIES IN THE WAIRARAPA**

Three reports have been commissioned to study liquefaction in the Wairarapa and there is a further study currently in progress.

### *Works Consultancy Report 1993 (Brabhakaran 1993)*

Works Consultancy were commissioned by the Wellington Regional Council to carry out a limited study of basically a triangular area covering the five main townships on the Wairarapa Valley floor. The two earthquake scenarios chosen were both from outside the Wairarapa area. One was a large, distant, shallow earthquake and the other was an event on the Hutt Valley segment of the Wellington Fault. Ground shaking intensities in gravels and sands were expected to be MMVI-VII for Scenario 1 and MMVII-IX for Scenario 2 events.

Two models were used for the assessment of liquefaction potential.

The report concluded that in general, the Wairarapa Study Area is underlain predominantly by dense sandy, silty and clayey gravels which are resistant to liquefaction.

### **Hadley Wick: Liquefaction Susceptibility of Selected Lifeline Sites in the Wairarapa Region (Wick 2000)**

The aim of the study carried out for WELA was to investigate the liquefaction susceptibility of selected key engineering lifeline sites. The investigation was more a broad screening of the sites than a detailed study. A small number of the selected sites were those where liquefaction had occurred in historic earthquakes. The liquefaction potential of a site was assessed mainly from cone penetrometer testing. Data from the

CPT was analysed with the use of a computer program developed at the University of Canterbury. The program assesses the site liquefaction potential according to the critical cone resistance defined by four models for estimating the earthquake liquefaction potential of a deposit of soil. Five levels of liquefaction potential (high, moderate to high, some degree, possible, and little) were defined in the study, and additional inputs were also used including water table level, grain size distribution, plasticity index, and historical records of liquefaction.

In all, 19 CPT tests were carried out on 17 sites. The sites are marked on the map Figure 1. Of these 17 sites, 5 were classified as having high liquefaction potential and 3 as having moderate to high potential. The 8 sites are listed in Table 2.

In the analysis of each test site, the New Zealand Geologic Survey (NZGS) classification was noted. The data from the study reported a strong relationship between the NZGS classification and liquefaction potential. It was observed that of the 7 sites classified as “Hawera Terrace” gravels, none were found to have High or Moderate to High liquefaction potential. However, of the 11 sites classified as undifferentiated alluvium, 5 had a High liquefaction potential, and 3 had Medium to High potential. Further examination of the relationship between lithology and liquefaction potential would be helpful for most studies looking at site liquefaction.

**Table 2.** Sites with High or High to Moderate Liquefaction Potential

<b>High liquefaction potential</b>	<b>Remarks</b>
5 Tinui Bridge	Silts appear non-plastic, hence liquefiable  Liquefaction observed in 1904 and 1942 Sand boils observed in 1855 and 1942 Degree and effect of cohesion unknown Lateral spreading in 1942
9 Gladstone Bridge	
10 Waihakeke	
13,14 Blundell Barrage	
15,16 Lower Valley Bridge, (Tuhitarata)	
<b>Moderate to high liquefaction potential</b>	Liquefiable deposits 2 to 7m 3 of 4 models predict liquefaction to 6m Susceptible in times of high water table
3 Goodlans Bridge	
11 Ruamahanga River, Martinborough	
18 Pukio	

### **Kaiser and Smith: Surface Wave Dispersion Testing of Three Wairarapa Sites (Kaiser 2005)**

Three sites were selected for further study based upon the earlier work by Wick. The study was carried out for WELA by Kaiser and Smith of the School of Earth Sciences, Victoria University of Wellington and used the ReMi™ surface wave dispersion method to determine shallow shear wave velocities. Surface waves were generated by explosive charges or by sledgehammer blows and recorded on seismic refraction equipment. The three sites are:

- Site 1. Blundell Barrage. Wick - High potential.
- Site 2. Lower Valley Bridge (Tuhitarata). Wick – High potential.
- Site 3. Ruamahanga River, Martinborough (Wairenga). Wick – Moderate to High potential.

The sites are marked on the map Figure 1. The shear wave velocity profiles for each of the sites are shown in Figure 8. At Site 1 the shear wave velocities are very low with the average at 30m being only  $135 \pm 10$ m/s indicating very soft sediments. Site 2 also has low velocities with an average of  $220 \pm 40$ m/s down to 30 m. Site 3 has softer soils from below the water table at 2.5m to about 7m with velocities of 150 – 250 m/s and in the gravels below  $> 250$ m/s.

The results from the three sites are in close agreement with the CPT investigations by Wick and in addition, at Site 1 relate to the bore logs from the 1969 site investigation carried out prior to construction of the barrage.

### **Blundell Barrage Liquefaction Study (Berrill 2005)**

The previous studies above of the Blundell Barrage site have found that the loose, poorly consolidated, generally cohesionless sediments first probed by Wick to a depth of 17m by CPT and investigated later by Kaiser, extend to at least 60m with no sign of rock. While this is not unexpected given the geology of the Wairarapa Valley, the large depth of poorly consolidated material may amplify incoming seismic motion significantly. If this were the case, then liquefaction would occur in the upper layers under smaller magnitude or more distant earthquakes than in more normal circumstances. In other words, the likelihood of liquefaction might be greater than expected, and more severe in its effects due to amplification by the deep deposit of loose sediment beneath the barrage site.

To address these questions and to investigate likely effects on the barrage the following items of work are being undertaken in the current study for the GWRC:

1. Definition of the soil profile to a greater depth by carrying out a seismic reflection survey in the vicinity of the barrage. This part of the study was completed several weeks ago and the results are expected to be available soon.
2. Carry out a one dimensional site response analysis of the profile determined by the seismic reflection study, and estimate modified ground surface motions corresponding to the scenario earthquakes determined in the previous investigations.
3. Revisit the original assessment of liquefaction hazard if it is found that significant liquefaction is expected.
4. Estimate the response of the barrage on the liquefied site.

Items 2 and 3 and possibly item 4 of the study will be carried out by Callum Streeter, a final year engineering student from the University of Canterbury, under the supervision of Dr John Berrill.

### **CONCLUSIONS**

1. There are large areas of the Wairarapa that have soft sediments and high watertables with a significant liquefaction and ground amplification potential. By far the largest area of susceptible soft sediments is in the southern part of the Wairarapa Valley. There are also areas in the eastern valleys and parts of the coastal strip.
2. Reports of historic earthquakes, including the 1855 Wairarapa event, contain accounts of ground damage in the Wairarapa due to liquefaction but the 1942 events in addition caused damage to bridges and roads including damage to the piled piers of the approach spans of a bridge caused by lateral spreading.

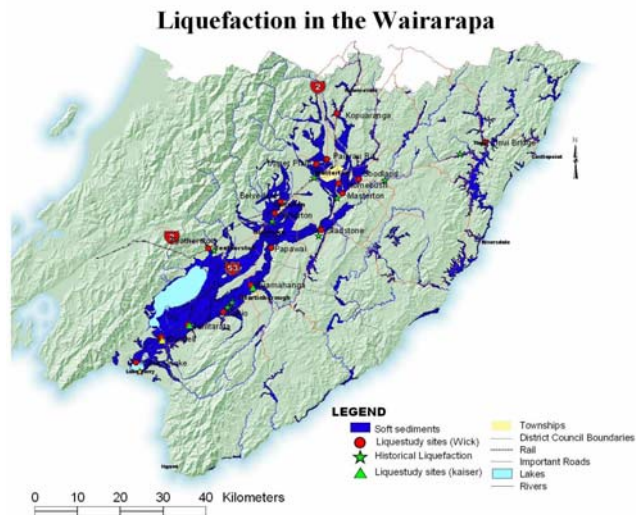
3. The five major towns on the Valley floor are situated on firm to stiff alluvium with little or no liquefaction potential.
4. Over a significant part of the Wairarapa, engineering lifelines outside the five urban areas are potentially at risk from the liquefaction hazard including: roads and bridges, water mains, sewer mains, sewage treatment ponds, parts of the power and telecommunication networks, flood protection structures, SH2 and SH35 and the Wellington - Woodville railway line. The extent and nature of the damage is dependent on the intensity and length of shaking
5. The single most important structure at risk from liquefaction is the Blundell Barrage a key structure in the Lower Wairarapa Valley Development Scheme and controls the levels of the Ruamahanga River and Lakes Wairarapa and Onoke and has the capacity to safely handle major floods. A further study to quantify the liquefaction hazard at the barrage site is currently in progress.

## **ACKNOWLEDGEMENTS**

The assistance of the staff of the Greater Wellington Regional Council, Wairarapa Division in the supply of data on the flood protection and drainage schemes, drawings and photographs is gratefully acknowledged. Thanks are due also to Jeff Jones CEO Environment Bay of Plenty for supplying the photograph of typical liquefaction damage to stopbanks in the 1987 Edgecumbe earthquake.

## **REFERENCES**

- Berrill JB, 2005. Pers. Comm.
- Berryman K, Villamor P, Cheriton M, 1998. Probabilistic earthquake ground motion study of the Wairarapa Region.
- Brabhaharan P, Jennings DN, 1993. Liquefaction hazard study Wellington Region study area 5 – Wairarapa. Wellington Regional Council.
- Kaiser AE, Smith EG, 2005. Shallow shear wave velocity from ReMi™ surface wave dispersion: method and case study. NZSEE Conference 2005 Technical Papers, 11-13 March 2005 Wairakei, New Zealand, Paper Number 10.
- WELA, 2003. Risk to lifelines from natural hazards a Wairarapa engineering lifelines project. Wairarapa Engineering Lifelines Association, Masterton.
- Wick H, 2000. Liquefaction susceptibility of selected sites in the Wairarapa Region. Department of Civil Engineering, University of Canterbury, New Zealand. Research Report 2000-11



**Figure 1:** Map of the Wairarapa showing areas of soft sediments, historic liquefaction sites, and liquefaction study sites by Wick and Kaiser



**Figure 2.** Out of plumb pier to the approach spans of the Lower Valley Bridge (Tuhitarata) due to lateral spreading during the 1942 Wairarapa earthquakes of June or August. (Most likely June)



**Figure 3.** Repairs to the crack at the hinge point at the top of the piers are still obvious.



**Figure 4.** View of the Masterton Sewage Treatment Ponds looking south. The Ruamahanga River is in the foreground and to the left of the ponds. The ponds are partly sited on an old river meander. Masterton is to the right of the photograph.

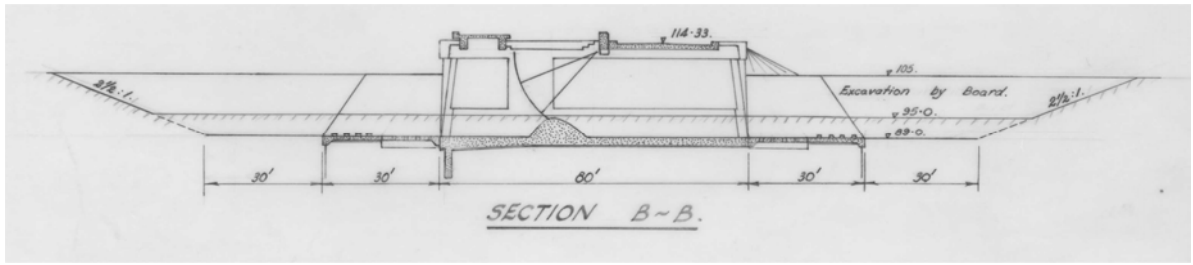


**Figure 5.** View looking south towards Palliser Bay. Outlet channel of Lake Wairarapa in the foreground, the Blundell Barrage and Ruamahanga River in the middle and Lake Onoke and Lake Ferry village in the distance.

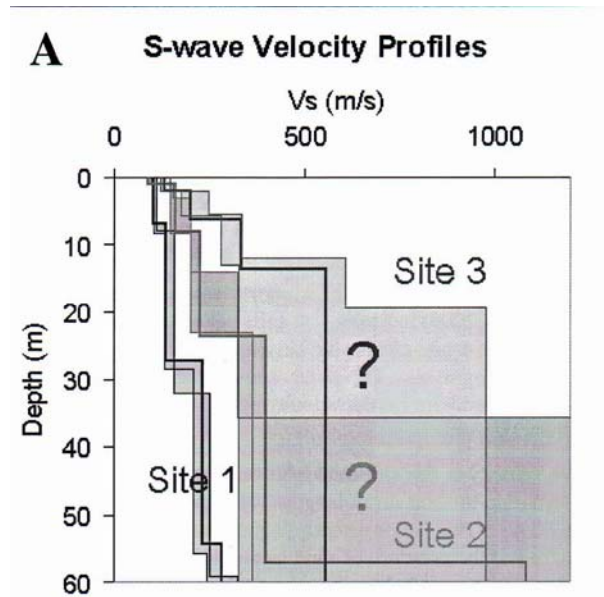


**Figure 6.** Liquefaction damage to stopbank Whakatane River, left bank. The Landing Bridge is in the background and Whakatane is to the left of the photograph. Note the evidence of sand boils on the river berm to the left.





**Figure 7.** Cross section through the Blundell Barrage



**Figure 8.** Average shear wave velocity models: Best fit model (thick lines), models fitting the upper and lower dispersion bounds (thin lines), and approximate indication of the uncertainty (shaded areas). (Kaiser, 2005)

# MANAGING THE EVENT — A REGIONAL CDEM GROUP PERSPECTIVE

Rian van Schalkwyk  
Manager, Emergency Management, Greater Wellington Regional Council  
(rianvan@gw.govt.nz)

## INTRODUCTION

The awesome effects of nature are a fact of life in New Zealand and the hazards that we face all have the potential to wreak havoc, and ruin what we have worked for — our home, our livelihood, and our communities.

Better understanding of our hazards and their consequences, coupled with effective planning by individuals, families, and organisations, means there is a great deal we can do to reduce the impact of hazards on our communities. We can be better prepared to deal with, respond to, and recover from disasters when they occur. We all have a role to play in making our communities and ourselves more resilient.

As a requirement of the Civil Defence Emergency Management Act 2002, the local authorities in the Wellington Region formed a Civil Defence Emergency Management Group (CDEM Group) on 15 May 2003. One of the tasks of this Group was to develop and implement a Civil Defence Emergency Management Group Plan for the Region. The purpose of this Plan is to put in place procedures and arrangements to achieve the vision this Civil Defence Emergency Management Group has set itself — *the communities of the Wellington Region are resilient*.

The CDEM Group Plan has four goals based on the four Rs of risk reduction, readiness, response and recovery. They are:

- The community and emergency management agencies will be aware of the risks they face — Reduction of Risks
- The community and emergency management agencies will take action to manage the risks they face — Readiness
- The community and emergency management agencies will know their role and responsibilities — Readiness
- The community and emergency management agencies will be able to respond to, and recover from, emergency events effectively — Response and Recovery

## WHAT IS HAPPENING NOW?

This CDEM Group Plan is for individuals and organisations with a civil defence emergency management role in the Wellington Region.

The Plan sets out the significant emergency management issues in the Wellington region and contains objectives and methods that are designed to address these issues. A CDEM Group work programme has been agreed (and will be reviewed annually) to

implement the objectives and methods. The identified issues are mentioned in section 3 of this abstract.

Local authorities, the emergency services, lifeline utilities and other emergency management agencies will incorporate relevant parts of the CDEM Group work programme into their own strategic and financial planning processes and will also use the operational part of the Plan to determine their roles and responsibilities during emergency events.

The key drivers for the CDEM Group in managing emergency events are the CDEM Act 2002, good relationships between all emergency responders, an integrated approach where all role-players are working together better, a comprehensive approach where what we do is based on the four Rs of risk reduction, readiness, response and recovery, and an ‘all hazards’ approach where all hazards, natural and man made, are taken into account.

The operational activities of emergency management are usually based on:

- Management systems and tools
- Assessment of damage and needs
- Co-ordination
- Information management.

The following principles guide the operational activities:

- CDEM activities are carried out to prevent, reduce or overcome hazards that may affect the safety of the public or property.
- Emergency management agencies are responsible for carrying out their normal day to day roles, as far as practically possible, in times of emergency.
- Local level emergency management activities are fundamental to effective emergency management. Group and national management structures support rather than replace local activities.
- The CDEM Group will be ready at all times to support local emergency management activities.
- Emergency management activities can be undertaken without a state of emergency being declared.
- The co-ordination of lifeline utility organisations is the responsibility of the CDEM Group.
- CDEM Group operational structures and processes will incorporate all emergency management agencies.
- When necessary, the CDEM Group will seek and accept support from other CDEM Groups and central government.

## READINESS

**Table 1 specifies the functions for readiness**

<b>Readiness functions</b>	<b>Impact area</b>
Planning	Operations, business/service continuity, crisis management, community continuity, welfare, recovery, fire, logistics, media, etc.
Education	Schools, special needs groups, businesses, childcare, ethnic groups, community groups, publications, individuals, service organisations, etc.
Public information	Fact sheets, posters, media releases, presentations, etc.
Volunteer recruitment	Getting volunteers and keeping them able and motivated
Training	CERT, USAR, CIMS, First Aid, light rescue, welfare, etc.
Exercises	Putting theory into practice
Facilities and Equipment	Operation centres, communications, networks, linkages, warning systems, etc.

## RESPONSE

**Table 2 specifies the functions for response**

<b>Response functions</b>	<b>Impact area</b>
Emergency Operations Centres	Management of operations, logistics, welfare, planning and intelligence, public information, media, lifelines. Robust and effective facilities and equipment (e.g. communications), Police and Fire services, etc.
Co-ordination	Reconnaissance, operations, welfare, USAR, evacuations, transport, media, building safety, public warnings and advice, commuters, local and external resources, road access, emergency water supply, fire suppression, animal control, law and order, provision of fuel, etc.
Information management	Situation reports, linking local and central government, external input, etc.
Resource management	Addressing critical needs of USAR, treatment and movement of the injured, welfare, health, sanitation, restoration of lifeline services
City/District continuance	Wellington's topography and geography is likely to isolate cities and districts in a major event, therefore TAs need to have effective continuance plans in place

**Table 3 outlines the different levels of response**

<b>Level</b>	<b>Description</b>	<b>Status</b>	<b>EOC role</b>	<b>Control</b>
<b>Level 1</b> '111' type emergency	Local incident(s). No CDEM input	No declaration	No EOC involvement. Some monitoring by CDEM staff possible	Lead agency using CIMS
<b>Level 2</b> CDEM Group Response	Some CDEM input required. No CDEM powers required.	No declaration	Local and Group EOC may be partially or fully activated	Lead agency or Emergency response co-ordination by CDEM Local Controller, Group Controller in support
<b>Level 3</b> CDEM Group Response	CDEM input required in one territorial authority area. CDEM powers required	Declaration for one territorial authority area or ward	Local EOC fully active Group EOC active in support	<b>Group Controller</b> and <b>Local Controllers</b> in place
<b>Level 4</b> CDEM Group Response	CDEM input required in whole Group area. CDEM powers required	Declaration for whole Group area	Group EOC fully active Local EOCs fully active	<b>Group Controller</b> and <b>Local Controllers</b> in place
<b>Level 5</b> National Response	National emergency	National declaration	National CMC fully active Group EOC fully active Local EOCs fully active	<b>National Controller</b> in place. <b>Group Controller</b> continues under co-ordination of National Controller <b>Local Controllers</b> continue under co-ordination of Group Controller

## RECOVERY

**Table 4 specifies the functions for recovery**

<b>Recovery functions</b>	<b>Impact area</b>
Physical, environmental, economic, community and psychosocial	Prioritise, co-ordinate and facilitate for redevelopment and future development
Continued habitation	Welfare, health and medical
Information management	Receiving, processing and distributing information to the public
Resource management	Addressing needs of obtaining labour, material, equipment, etc.
Transportation	Addressing needs of restoring transport systems as soon as possible, including the management of commuters
Community impact analysis reporting and monitoring	Social impact, work and income, etc.
Funding	Management of funding to enable cities and districts to function appropriately

## WHERE DO WE NEED TO FOCUS FUTURE EFFORTS?

### READINESS ISSUES

1. **Emergency management personnel in the Region have varied qualifications and experience.** In particular, Controllers tend not have day-to-day CDEM responsibilities. There is not any structured, ongoing professional development in place for CDEM personnel.
2. **Education resources are duplicated and often inconsistent across the Region.** This is because a common approach or framework has never been agreed.
3. **The community is generally apathetic about being prepared for an emergency.** A small percentage of people have emergency supplies and emergency water, and few are skilled in basic rescue or first aid techniques.
4. Although there is no longer a statutory requirement for local authorities to prepare individual CDEM plans, **it is important that local planning is in place and consistent with the CDEM Group Plan**, especially as new hazards have been incorporated.
5. Historically, there has been a **lack of formal agreements to clarify roles and responsibilities** in an emergency. Formal arrangements (e.g. MoUs) would go some way to ensuring that agreed actions are carried out.
6. **Local level inter-agency planning is inconsistent across the Region** and, in some cases, important agencies are not included.
7. **Inter-agency training and exercises are currently carried out on an ad-hoc basis** and important aspects are not always covered, e.g., Co-ordinated Incident Management, long duration incidents, recovery, and the relationship between Group and local response.
8. **The pending changes to the management of hazardous substances have led to a possible reduction in the Region's ability to manage these hazards**, at least in the short-term. Of particular concern is a reduction in skilled personnel and local knowledge. This is compounded by a perception that the hazardous substances industry itself has become complacent.
9. **Although volunteers are critical to emergency response, there are few plans in place for their management during an emergency.** Volunteers come from the community at large as well as from local authorities.
10. **A few important projects have been overlooked** for various reasons with the advent of the CDEM Group and the new direction. These need to be picked up.
  - Planning for the temporary accommodation needs of large numbers (thousands) of people dislocated from their homes.
  - Testing reconnaissance plans.
  - Developing evacuation plans for tsunami.
  - Reviewing audible warning systems for consistency across the Region.
11. **The rural fire management structure is essentially separate from the CDEM Group structure.** Yet rural fires are a hazard for this Region and are likely to result in a CDEM Group response. Ironically, nearly all the same organisations are involved in both rural fire management and the CDEM Group.

## **RESPONSE ISSUES**

1. During an emergency event, support, in the form of personnel and other resources, may not be able to reach all areas in need immediately. Therefore, there should be adequate local capability to respond to the initial stages of the event.
2. Operational procedures vary across the Region. This can pose difficulties when personnel assist another area. Common operational procedures are desirable.
3. Local emergency agencies often require the support of the CDEM Group for localised events. This may be because of a lack of resources, or because the local event has spin-off effects for the rest of the Region.
4. Public information is sometimes disseminated in an ad-hoc fashion during an emergency. In some cases agencies have provided conflicting information; and in others cases, critical information has not reached the public.
5. The community appears to have unrealistic expectations about the capability of CDEM agencies to assist them in an emergency. Debriefs of emergency events have shown that, in the first instance, communities have to be self-reliant.
6. There is confusion at both the local and Group level about when to call for external assistance. It is important to allow adequate time for assistance to arrive.
7. Lifelines Utilities vary in the manner in which they can respond. It is sometimes difficult to co-ordinate these organisations because they use different communications systems and offices may be located outside of the Wellington Region. Further, it can be difficult to identify the service provider.
8. Emergency communications systems do not have the capability to link all vital emergency management agencies in the Region. This is currently being addressed and soon it will be possible to speak to all agencies. However, sending data will still be difficult.

## **RECOVERY ISSUES**

1. There are not any documented plans or arrangements in place for a long-term recovery operation. Dedicated recovery management personnel may be needed for weeks or months. Volunteers may have to return to their normal work.
2. There are not enough properly trained recovery management personnel. In particular, recovery personnel tend not have day-to-day CDEM responsibilities. There is not any structured, ongoing professional development in place for CDEM recovery personnel.
3. Agencies who will be required for recovery operations differ from those who will be involved in emergency response. There has been inadequate work to identify these agencies, and to ensure that they participate in pre-event planning. Of particular concern are emergency services and health providers, central government agencies with a local role, and those with Resource Management Act 1991 responsibilities.
4. Public information during recovery is sometimes disseminated in an ad-hoc fashion. The information required will vary according to the nature and location of the event. However, there is some core information that could be pre-prepared, such as health protection and insurance advice.
5. There has been little research about recovery in New Zealand. Consequently, there is uncertainty about where best to direct resources in order to get the best possible outcome.

6. It is especially hard for small businesses to recover from an emergency event. They invariably operate with limited resources and are unable to cope with any significant interruption to their business. These businesses are vital to the local economy.
7. The psychological impacts of an emergency event have not been fully addressed. Although there are professionals in the Region, there has been no planning for a coordinated approach. After an event, emergency workers are likely to suffer post traumatic stress and there will be psychological distress in the community.
8. There are not any plans for the disposal of debris and wastes. It is likely that there will be considerable waste material generated, some of which will be contaminated.



# CENTRAL GOVERNMENT'S ROLE IN DISASTER MANAGEMENT

Patrick Helm  
Department of the Prime Minister and Cabinet  
(pat.helm@parliament.govt.nz)

## PRESENTATION OUTLINE

Central government would have a major role in directing the national response to another event like the 1855 Wairarapa earthquake, and in assisting with recovery. In the past decade a number of steps have been undertaken to improve New Zealand's preparedness for dealing with a variety of crises, disasters and unusual circumstances. This has led to new emphasis on planning and coordinating all national capabilities that could be brought to bear on both the response and recovery phases of disaster management.

Government is involved in such situations for several reasons:

- to ensure that strategies meet New Zealand's national interests
- to assist response activities in restoring normality quickly, and
- to help minimise adverse outcomes.

Adverse outcomes include such things as:

- loss of life and injury,
- damage to property and the environment, and
- societal and economic disruption.

The range of possible crises that government might be called upon to manage is escalating for several reasons:

- societies are becoming increasingly complex;
- at all levels, people and communities are becoming more interdependent and vulnerable to cross-boundary risks;
- community life and economic systems are becoming more exposed to disruption.

This presentation is intended to complement those of that will be given by other government agencies. It will outline the range of potential crises and security situations that government is planning for in order to show the common principles and management practices. The adoption of more systematic approaches to natural hazards in recent years, coupled with increasing use of risk management methodologies, has helped to improve understanding about management options and provided a degree of inter-comparison between different security issues.

# UNDERSTANDING THE SCOPE OF THE RECOVERY PROCESS

S. Norman

Ministry of Civil Defence & Emergency Management, PO Box 5010, Wellington  
(sarah.stuart-black@dia.govt.nz)

## INTRODUCTION

The new environment created by the Civil Defence Emergency Management (CDEM) Act 2002, sought to address risks in New Zealand through a *4Rs* approach of Reduction, Readiness, Response and Recovery. This concept set out an expectation of managing the consequences of all hazards (technological and natural) in an integrated way across agencies. Recovery and reduction have for many years been the *'forgotten Rs'* with often the readiness and response activities taking precedence.

A change is gaining momentum in New Zealand, which is reflecting a greater understanding of not only the meaning of recovery but also what it means within the New Zealand context. History has demonstrated that New Zealand (as recently as May 2005) experiences emergencies frequently and therefore community recovery activity is a particular area of focus for the future. This paper will consider how the understanding of the scope of the recovery process is changing.

## WHAT HAPPENED IN 1855?

Historically, recovery has often been viewed as a short-term restorative process often attempting to return the clock back to a pre-emergency state, often coined as 'returning to normal'. It is unlikely that recovery processes involved much more than a physical clean up and rebuilding or replacement of damaged structures, roading and personal possessions. Social, environmental or economic considerations are unlikely to have been either recognised or addressed in a comprehensive way during this period.

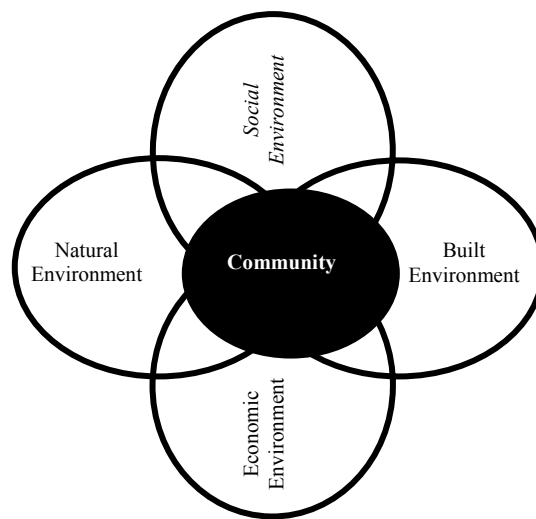
The community impact of such an event would have been significant and social behaviour would not have been dissimilar to that which we would expect from an equal size event today. Individuals and families are likely to have been devastated by their loss of loved ones, personal possessions and property. However, medium to long term effects such as loss of employment from downstream economic change, fear of future events and psychosocial impacts are unlikely to have been recognised as issues to address in an integrated manner or indeed to have led to access to support services from the state.

## WHAT IS HAPPENING NOW?

Since the inception of the CDEM Act and the development of the National CDEM Strategy, there has been recognition that recovery needs to be more comprehensively understood and addressed in New Zealand. As such, the Ministry of Civil Defence & Emergency Management (MCDEM) has worked over the last eighteen months with stakeholders through a combination of discussion documents, regional workshops and

the New Zealand Recovery Symposium (July 2004) to discuss, debate and develop thinking about recovery in New Zealand.

The outcome of this work has been a new definition and a holistic and integrated framework for recovery in New Zealand. The Ministry (2005a:5) define recovery as “*The coordinated efforts and processes to effect the immediate, medium and long term holistic regeneration of a community following a disaster*”. This definition recognises that communities cannot return to a pre-emergency state but must instead be supported through a participatory approach to achieve long-term recovery. *Focus on Recovery*<sup>2</sup> (MCDEM, 2005) documents the holistic and integrated recovery framework, which seeks to support the foundations of community sustainability. It is comprised of the community and the social, economic, natural and built environments (refer Figure 1). Recovery activity (the central oval in black) demonstrates the integration between the community and the four environments.



**Figure 1:** Integrated and Holistic Recovery

The structures at local, CDEM Group and national level seek to support recovery activity at community level. This recognises that recovery activity takes place ‘*with communities*’, not ‘*to communities*’. Local, CDEM Group and national agencies are currently working to incorporate the principles and framework of *Focus on Recovery* into their CDEM arrangements (also see MCDEM, 2005b, a Director’s Guideline for Recovery Management which provides recovery processes and structures to give effect to community based recovery). The framework encourages agencies to not only have pre-planned arrangements for short and medium term recovery activity but also promotes the more challenging activity of planning and responding to long term community recovery needs.

---

<sup>2</sup> Available to download from [www.civildefence.govt.nz](http://www.civildefence.govt.nz)

## **CONCLUSIONS**

“Successful recovery recognises that both communities and individuals have a wide and variable range of recovery needs and that recovery is only successful where all are addressed in a coordinated way. Recovery is a process that will certainly last weeks and months but may extend for years and possibly decades” (ibid.:6).

The learning opportunities provided by the conceptual discussion and debate within the sector over the last eighteen months and recent experiences of community recovery such as the February 2004 Flood, Bay of Plenty Floods in July 2004 and May 2005, has assisted our understanding of what recovery means in New Zealand. These experiences must now be consolidated to consider how our community can reduce and where practicable address, risks from future emergencies that meets in an integrated manner all community needs; a concept that is as challenging now as it would be have been, had it been conceptualised in 1855.

## **REFERENCES**

- Norman S, (Ed.) 2004. NZ Recovery Symposium 2004 Proceedings, MCDEM, Wellington.
- Ministry of Civil Defence & Emergency Management (MCDEM), 2005a. Focus on Recovery: A Holistic Framework for Recovery in New Zealand [IS5/05], MCDEM, Wellington.
- MCDEM, 2005b. Recovery Management: Director’s Guideline for CDEM Groups [DGL 4/05], MCDEM, Wellington.

# 1855, THEN AND NOW — AN EQC PERSPECTIVE OF THE 1855 SOUTH WAIRARAPA EARTHQUAKE

Doug Bent and Lance Dixon

The Earthquake Commission, Majestic Centre, 100 Willis St., Wellington  
(dbent@eqc.govt.nz, lrdixon@eqc.govt.nz)

## INTRODUCTION

The 1855 Wairarapa earthquake is a significant event in the tectonic history of New Zealand, particularly for what is now known as the greater Wellington Region. It was not only unnerving for the people and a potential set-back to the New Zealand Company's aspirations for settlement in the region, but also the event was one of the first documented earthquakes to occur since Europeans arrived in New Zealand. Other papers being presented at this seminar no doubt use that documentation to describe the event in great scientific and social detail, and no attempt is made here to repeat the descriptions, but it is worth noting that:

- We believe that earthquake insurance did not exist in New Zealand (possibly not anywhere) at that time,
- Some lessons were learned and applied by those who experienced both the 1848 and the 1855 quakes (e.g. strengthening of buildings); thus mitigation was alive and well in those days,
- People will live and build where they want to, and are not seriously deterred by the threat of natural disasters, including earthquakes.

### **Aim**

This paper presents an earthquake insurance perspective on the 1855 Wairarapa earthquake.

### **Scope**

A short description of earthquake insurance in 1855 is followed by an overview of the development of the current earthquake insurance situation in New Zealand. The paper then applies the current arrangements to that earthquake, as if it were to re-occur in 2005.

## WHAT HAPPENED THEN?

We have no evidence of earthquake insurance being a saleable commodity in the mid-nineteenth century. Even though insurance was a mature industry in Europe at that time, the New Zealand Insurance Company was the first insurer established in this country in 1859. Others followed in later years.

Thus it is reasonable to assume that people were very much on their own in 1855 with respect to asset recovery following an earthquake. It is unlikely that anyone had self-insured (i.e., set up a hedge scheme involving payments to some kind of fund) even for fire, let alone earthquake.

So people were required to carry the risk themselves. Some rebuilt, others left the region to restart life elsewhere in the colony, yet others decided to return to their homeland or went to pastures new, like San Francisco. The net result, however, was continued growth throughout the Wellington region and a general acceptance that earthquakes are yet another feature of life that has to be lived with.

## **WHAT HAS HAPPENED SINCE?**

Earthquake insurance remained a rare commodity in New Zealand until the 1940's. Although the 1929 Murchison and the 1931 Napier earthquakes provided some incentive towards officially designating certain improvements to building standards it was not until the 1942 Masterton quake that insurance appeared on the scene. It was clear to the community in general and to government in particular that some scheme was necessary to ensure that the enduring scenes of rubble and un-repaired buildings became a thing of the past.

There was at the time (1942) a war damage commission whereby people who had insured their property for fire were also covered by the government (through the State Fire Department) for damage resulting from warlike acts. (For the record, there were some 47 war damage claims, totaling about 1,100 pounds.)

The government extended the war damage to earthquakes and formed the Earthquake and War Damage Commission, so legislated in 1944. The commission remained in the State Fire organisation and the war damage fund of a little over £4,000,000 was transferred to the new commission. The same basic rule applied: cover was compulsory if one had fire insurance.

The government reforms of the eighties saw the State Fire change from a corporation to a state owned enterprise, to be sold in the early nineties. The Earthquake and War Damage Commission was kept by the government but did not escape significant reform itself. The war damage cover was abolished and the name shortened to Earthquake Commission (EQC). Cover is now restricted to dwellings and personal effects only, forcing commercial enterprises (and motor vehicle owners) to seek earthquake insurance from the open market. The compensation payable is now based on replacement costs rather than indemnity value as in the past.

The separation of EQC and State Fire had another significant knock-on effect. No longer could EQC (with eleven staff) call on the much greater resource of State to help out after a big earthquake. At the risk of over-simplification, the first responses to Inangahua and Edgecumbe were to "pick up the phone and call State". Now EQC was on its own.

Work started in 1993 towards producing a disaster plan for EQC. It began with a simple but admittedly impracticable plan of "all hands to the wheel," whereby commissioners and staff would together take claims on any available telephone in the office. Arrangements were also made to use rented office space in Manukau City should the current space in Wellington become unusable.

In 1994 a series of overseas studies and visits were made to acquire knowledge of best practice catastrophe response arrangements. The Northridge, California earthquake of

that year gave a timely example upon which to base those studies. The huge domestic insurer, State Farm, based in Illinois provided the best example. We spent several days at their Northridge operation in the field and at their corporate office.

Because of State Farm's size (65,000 employees) finding resources internally to meet the many dozens of responses they have each year is not a major problem. People and material are almost exclusively sourced from within the company. EQC could not possibly emulate that with its by then fourteen staff. But the general approach and field processes used by State Farm gave us a benchmark for us to build our own programme.

The arrangements for use of the Manukau City site were tidied up in 1995 with arrangements in place for getting it equipped and readied for us to occupy at short notice. We also worked up arrangements for a single site disaster affecting Castrol House, Wellington. This became the basis of the EQC business continuity plan, and those arrangements still exist and are exercised on a regular basis.

The real challenge was to design and implement a programme for handling claims: extending the resources available to EQC without paying excessive retainers for people and storehouses of equipment that might never be used. At the same time we also had to work up efficient ways to deal with huge numbers of claims, both in the field and at the office. 1995 and 1996 were the substantive planning years, at the end of which we were able to say with confidence "this is what we will do following a big earthquake." During 1997 we turned the plan into an operative programme by setting up the contractual arrangements needed to ensure the plan would work. We were then able to say "EQC no longer just has a catastrophe plan; we now have a catastrophe response programme (CRP)."

What follows is a narrative of EQC's response to the 1855 magnitude 8.1 Wairarapa earthquake if it happened exactly 150 years later.

## **WHAT IF IT HAPPENS NOW?**

### **9.32pm Sun 23 Jan 2005 – the Event**

It was an overcast night, with 30-40km/hr northerly winds and a mild 17 degrees. Without warning the world seemed to toss upside-down in an unbelievable cacophony of noise. It carried on for many seconds during which the power went off and all was dark. Groping about the house amongst furniture careening about, people screaming, and buildings tearing apart, it was total confusion and utter terror for most.

Accounting for family members didn't take long and finding torches had just finished when the first aftershock happened. While not as severe as the first, it nevertheless seemed just as frightening. It signaled the start of a long night never to be forgotten.

### **Monday 24 Jan 05 – Day One**

Daylight showed us all the extent of the destruction in the suburbs – houses in various states of damage, power and phone poles down, streets cluttered with debris, smells of escaped gas and sewage, and people walking around seemingly in a daze not wanting to believe what happened. The fresh winds continued with occasional showers and a southerly front expected later in the day. The aftershocks continued. Radio news

bulletins seemed somewhat sketchy but there was sufficient to know that this was Wellington's "Big One".

EQC's CRP doesn't require any form of declaration for an event like this. The arrangements are such that several things happen simply with the knowledge that there has been a major quake in the Wellington region. Without any prompting by EQC three contracted commercial call centres began calling in extra staff from this Monday morning to deal with the huge number of calls from people wishing to lodge a claim on EQC. Between them, they mustered over 100 operators by lunchtime, capable of taking well over 8,000 claims in a 24-hour period.

Similarly, a contracted property management company in Auckland began furnishing and setting up the office accommodation for EQC in pre-arranged space in Manukau City, and also ensured that our IT suppliers checked over the warm-site computer gear already installed there.

Also, a contracted communications company in Auckland sent out pre-written press releases and advertisements advising people how to lodge a claim with EQC, together with the message to be prepared to wait to see someone from EQC. This is the start of our drive to say to the public "there is no quick fix for this earthquake."

Meantime the EQC staff in Wellington, acting as practiced many times over recent years, concentrated on their own domestic situation, securing their properties as best possible and preparing for a period in Auckland. We knew that it would not be possible for all staff members to leave home for a variety of valid reasons, but our belief that we could muster more than 60% proved correct – we had enough to get the operation under way, with help from others as described later.

Monday was also a day for selected staff members to do other things, in preparation for our critical initial response meeting next day. A short liaison visit to the nearest civil defence headquarters was done by some staff members, and others ran Minerva on their notebook computers. This statistical model is designed primarily for financial management purposes, but since it also provides data about expected claims from a given event it is a valuable operational planning tool. You can't meaningfully start a major project without knowing the extent and location of the job, and Minerva does this very well for EQC.



Minerva indicated that EQC could expect about 240,000 claims distributed as indicated on the map below, and with the severity as shown in the table below.

MINERVA005 - Earthquake Output - Claims Bands

Claims  
 Value  
 Number

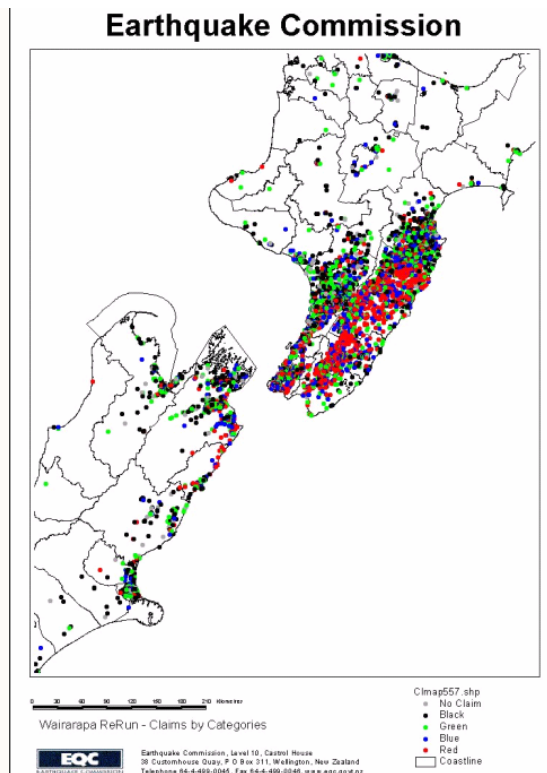
View Output - Claims Bands

Policies with Claims in Each Band(1-5)

Run at % 50  
Policies with Claims 243531

Select Results File: **Manager 4/08/2005 Wairarapa ReRun**

Area Type	Area ID	Claims in Band 1	Claims in Band 2	Claims in Band 3	Claims in Band 4	Claims in Band 5	Total
All NZ		15,415	56,955	53,618	50,254	67,289	243,531
Region	NORTHLAND	2	2	5	9	10	28
Region	AUCKLAND	19	36	29	26	41	151
Region	WAIKATO	47	75	42	16	11	191
Region	BAY OF PLENTY	22	37	13	9	3	84
Region	GISBORNE	19	25	9	4	2	59
Region	HAWKES BAY	3,138	8,333	5,821	4,077	4,049	25,418
Region	TARANAKI	12	27	6	6	7	58
Region	MANAWATU-WANGANUI	4,673	13,789	10,516	8,052	8,025	45,055
Region	WELLINGTON	5,907	30,560	34,676	36,467	53,829	161,439
Region	TASMAN	152	221	117	49	34	573
Region	NELSON	174	351	148	75	52	800
Region	MARLBOROUGH	927	2,745	1,801	1,188	981	7,642
Region	WEST COAST	5	5	2	2	1	15
Region	CANTERBURY	318	749	433	274	244	2,018



## Tuesday 25 Jan 05 – the Meeting

As trained and practiced, all EQC staff who were able to relocate to Auckland counted two sunrises from the time of the earthquake. By 9.30am that second day, Tuesday, those people took an issued EQC banner to a pre-designated helicopter pick up point near their home and pinned it to the ground. A pre-contracted helicopter from Rotorua arrived and took them to Naenae College for the initial response meeting.

The purpose of the meeting was to decide how many field offices were needed, where they should be established, and when. The raw intelligence used in this process included the results of the Minerva runs, visits to CD headquarters in the four cities, updated data from GNS, media information, and personal observations of staff members. It was decided to initially set up five field offices (Palmerston North, Waipukerau, Masterton,

Blenheim, and Nelson) by Monday 31 January and an induction centre at Wanganui two days earlier. It was clear that the damage to infrastructure in the four cities was such that we could not usefully deploy into metropolitan Wellington in large numbers for a week or two at the earliest. The strategy was thus to work from the outside in towards the middle.

The helicopter waited for the meeting to finish before ferrying everyone to Wanganui to catch flights to Auckland.

### **Tue/Wed 25/26 Jan – Resources**

The next thirty hours was a hectic period of acquiring the resources needed and having them assembled at the designated locations.

Our contracted property management company found hotel and motel accommodation for us in each of the designated towns. They also arranged and equipped office accommodation, some of it in hotels; other sites used available commercial space.

Site managers from an executive leasing company, temps with various skills, inspection team leaders selected from the insurance industry, loss adjusters from companies in Australia as well as here, and damage estimators from Master Builders, Certified Builders and NZ Institute of Quantity Surveyors were all summoned to report to the induction centre in carefully timed groups starting by midday Saturday 29 January. We aimed to have these people do tours of three weeks on and three weeks off and most have been able to manage that.

For most sites we assumed that there would be little or no suitable furniture and equipment, so we had to hire (and for some items buy) the necessary materials. Consumables, stationery, EQC printed forms were also ordered from pre-arranged suppliers who were all familiar with EQC's requirements. Rental vehicles, tools, and protective clothing were also acquired.

### **Fri 28 Jan 05 – Inductions**

Induction is a critical process in the EQC catastrophe response programme. All people working in the field must be inducted before they start work. The two and one half day programme involves administration for the first half day, followed by two days training. On Friday 28<sup>th</sup> the Avenue Hotel in Wanganui was secured for us and we set up the administration area and the training rooms. The trainers, selected loss adjusters and tutors from polytechnics, spent the day revising the training material and running rehearsals. This training process is practiced annually, so it was not new to these people.

It would take three intakes to get all the people through the induction process. The first induction started on Saturday 29<sup>th</sup> January and the subsequent three sessions were spaced three days apart. Thus the last major induction was finished by 9<sup>th</sup> February.

### **Sat/Sun 29/30 Jan 05 – Field Offices**

All the field office sites became available to us by Saturday and that day was spent setting up the spaces as office working areas. We also brought in some temps from the local agencies to begin some of the paperwork and telephone calling. Being in the

peripheral areas of the earthquake zone, there was by then no problems with infrastructural services at those places.

Each field office had received a spreadsheet of claims received so far in its area and it was then necessary to set up a visit schedule for each loss adjuster and damage estimator. This had to be done by the end of Sunday so that the first day of visits, Monday, coincided with the arrival of the inspection teams from their inductions.

### **Mon 31 Jan 05 onwards– Inspections**

The inspections began. Because the teams were operating in the peripheral area of the earthquake zone where damage was relatively light, it was possible for loss adjusters to visit as many as twelve properties in a working day and the damage estimators to complete three scopes of works documents in a day. We mustered 66 loss adjusters and 130 damage estimators. Therefore the teams collectively were able to visit 19,000 homes once only in the first month. On that basis, our estimate was that the first visits to all the 170,000 claimants that must be visited would be completed by the end of October this year, based on a six day working week and excluding public holidays. Many houses will require several visits and therefore the process of quantifying the damage for all properties will probably not be complete before the end of 2006 at the earliest. Hence the need for the highly pro-active public communication programmes.

Loss adjusters are required to manage both EQC's and the claimants' expectations and thus have a significant liaison role. The loss adjusters also use their insurance knowledge and experience to report to EQC with a recommendation on the amount (if any) of compensation that EQC is liable to pay the claimant.

The damage estimators are qualified people whose task is to inspect damage in detail and prepare a scope of works to make good the damage. When fully costed, the scope becomes the basis of the compensation payable (less any excess that might apply). By engaging such people (who come from well outside the disaster area) we have eliminated the counter-productive process of requiring claimants to get two or more quotes.

This leaves the local trades people to do the actual repairs without having dead time doing quotes. Our experience to date indicates that over 98% of scopes of works costings are accepted by repairers as being fair and reasonable.

Towards the end of February we were able to seriously consider opening more field offices closer to Wellington City. We cannot effectively operate a field office for longer than a few days without full infrastructural services operating. Our teams have to drive around the disaster area to complete their inspections, they are accommodated by EQC in operating hotels and motels, and we need adequate telecommunications to pass reports from the field to our claims back office in Brisbane and to the corporate office in Manukau City.

Our contracted property management company eventually found suitable living and working accommodation for us in all the four cities and in Paraparaumu. Our problem then became shortage of human resources, particularly loss adjusters and engineers. The loss adjuster resource is scarce in New Zealand and these people are in demand by the commercial insurance sector as well as EQC. We have sources in Australia but they

dried up as they became involved with their own bush fire, flooding and tropical cyclone seasons. The shortage of engineers is well known, but is exacerbated somewhat by an earthquake when many organisations seek engineering advice. Many claims are being delayed by these shortages, about which there is little we can do.

The field work is but a part of the catastrophe response programme. The claims office in Brisbane activated their own response programme for our big earthquake events and took over pre-arranged disaster recovery office space and set up a recruiting and training programme to increase their staff from four to thirty four by the end of February.

The public communication programme grew substantially with almost twice-weekly press statements and an advertising campaign explaining the claim process, how to lodge a claim, and what entitlements people have. This programme is run in conjunction with other central and local government agencies. Also in the third week of February one of the contracted call centres was changed from in-bound (receiving claims) to out-bound, calling claimants and maintaining a communication with them.

In February, when some better idea of the exposure EQC faces was emerging, considerable effort was made in dealing with government and our re-insurers about the matter of calling down re-insurance arrangements, the cash flows associated with the call-downs, and the need or otherwise to call on the government guarantee.

For EQC earthquakes mean business as usual but more than the usual amount of business. The normal activities of running the office, paying staff and taxes, managing the investments of the Natural Disaster Fund, complying with relevant legislation and directives, public education, the research programme, and the dozens of other routine activities of an organisation all still carry on.

## **9 SEP 05 – CURRENT SITUATION**

It is now 33 weeks since the main shock in January. The EQC corporate office has returned to the Majestic Centre in Wellington (other more qualified speakers at this symposium can tell us when one may expect the Wellington CBD infrastructure to be functioning after this quake, so we have not named our date of return from Manukau City).

As at today we have quantified (costed in detail) about 84,000 claims and completed just over 70,000 from our total of 240,000 – about 35% quantified and 29% are complete. Our modeling shows that if we can maintain present numbers in the field, all claims will be quantified by July 2007 and completed by the end of September 2007. These figures are optimistic. We are not confident that we could maintain the stated numbers of loss adjusters and experts such as engineers for this many years, and we are not yet able to gauge how long repairs might take. Nor can we forecast any economic, social, or political issues that may influence the recovery programme. It would not be unreasonable therefore to add another year or more to the programme.

One thing, however, is patently clear. EQC's, indeed everyone's, response to this earthquake cannot be an overnight quick fix because the resources simply do not exist. Therefore, we need to ensure that the whole community understands this; it's why we

place strong emphasis on using out-bound call centres, having a vigorous public communication programme, and placing “managing claimants expectations” at the top of our loss adjusters’ duty list.

# **BUSINESS RESPONSE AND RECOVERY AFTER MAJOR EARTHQUAKES — WHAT CAN WE EXPECT?**

K.E. Stephens  
Resilience, PO Box 161, Martinborough  
(karen@continuity.co.nz)

## **INTRODUCTION**

“You’ve got a fine hotel here”, the man in the bar said, looking round the solidly-built walls. The Austrian who owned the place beamed with pride. “Yes”, he agreed. “A fine place. Just look at it! This is the way to build against earthquakes. No shock will destroy that. Look at the wooden places down the street. Bah! Mine’s the best and strongest of the lot.” (Eugene C. Grayland – *New Zealand Disasters AH & AW Reed, Wellington, 1957*).

At approximately 9.00pm on the night of January 23, 1855 the owner of the fine hotel, Baron Alzdorf, was killed as it collapsed on top of him. The only person to die in Wellington.

And although this was probably due to the building construction, the point to be made is that business today is, generally, as complacent, or arrogant, as back in 1855.

So why is this the case. We live in an era of war, terrorism and higher awareness of natural hazards, and yet businesses – and Government Departments – continue to put business continuity as a low priority.

There seems to be a perception that it’s just too hard. In this discussion document we will look at why that perception exists, how this will impact on the ability of Wellington to recover from a major earthquake event, and what might be done to change that.

## **BUSINESS CONTINUITY METHODOLOGIES AND STANDARDS**

We live in a society that expects service, goods and government support to be continually available even though the risks we face from earthquakes, other natural hazards hasn’t changed and we now have man made and technological hazards to contend with.

So is business and government better prepared to respond and recover from the consequences of these hazards?

A recent report commissioned by the Business Continuity Institute in the UK interviewed 251 organisations ranging in size from 250 employees to over 1000. The interviewees were managing directors to operational staff.

Four key questions were considered:

1. How do companies understand the concepts of Disaster Recovery and Business Continuity Management and the relation and difference between these concepts?

2. How does Business Continuity Management differ between small, medium and large companies and between industrial sectors?
3. How important is IT and telecoms Business Continuity management and who is in the decision making chain?
4. Is outsourcing becoming more, or less important as a consideration in Business Continuity Management?

There were some encouraging results:

- 70% of companies have BCP's in place, with this percentage increasing to 80% in the financial and retail sectors.

However, this could be a misleading statistic as only 43% of companies claim to test or rehearse their plan every 6 months, and only 27% have dedicated business continuity staff.

My experience with claims of business continuity plans in place can range from well maintained and tested plans with staff totally familiar with the content, to a document produced for Y2K which sits on a shelf with the words Business Continuity Plan on the spine.

A plan is only as good as the last time it was tested.

Rather than talk about Business Continuity Plans we should be talking about Business Continuity Programmes as part of holistic Risk Management and this means having a business continuity capability. No matter how well a plan has been written if the people who have to implement or activate that plan have not been involved in its development, trained in how to activate it, or have the infrastructure and resources to support them, then it will fail.

A business continuity capability means having the right people with the right resources and the right supporting documentation to enable them to continue to provide service or products during major business disruptions

Senior management in most organisations recognise these needs, unfortunately once an analysis has been made of the investment required to provide a full business continuity capability the project usually comes to a halt. The commitment to invest dollars into something that might never happen is the final hurdle that generally is never cleared.

### **So can it be changed?**

There is currently a trend within the insurance industry to encourage organisations to implement sound business continuity management with the benefit potentially being lower premiums. This will be a driver to many organisations to free up the dollars to support business continuity. This can also have its pitfalls, as the insurance industry will need to ensure the business continuity programmes in place provide a true capability and are maintained.

As more and more events occur around the world, whether as the result of natural hazards or due to our modern technological society, organisations will be asked the questions by their boards and senior management – 'could we have managed if that had

been us?'. The more this happens the more pressure will be brought to bear to implement good holistic risk management which includes a business continuity programme.

So what does this mean for cities like Wellington with significant natural hazard risk?

Most of the above applies to most of the organisations based in Wellington, including Government agencies. There are some who have recognised the need to understand how their business could operate from another city and have developed plans and trained people to take over in such an event. However, this needs to be a continuing process, people change and it is essential that this training be carried out annually.

The larger organisations that are based in Wellington are part of national or international organisations that would take over the reins if Wellington were unavailable. Our banking industry technology is mainly based off shore and many organisations now outsource their technology, which means they have dispersed the risk.

The main impact on Wellington will be the small to medium businesses that do not have the resources of major corporations. Retailers, support services, tourism operators, etc who will lose not only their infrastructure and resources but also the people to buy their services or goods.

Will these people recover and be able to continue in business? Anecdotal evidence from around the world suggests not which could result in the vibrant heart of the city needing life support for a considerable time.

## **CONCLUSIONS**

Wellington will survive 'the big one'. The bigger problem for businesses are the other disruptions to their business which are more frequent and can be as bad or worse than 'the big one.'

Unless there are significant financial drivers to motivate organisations to invest in a total business continuity capability the current status will not change. Businesses are driven by return to shareholders and these shareholders, generally, do not approve of their money being invested in 'non return' projects. The challenge is to prove the value of the investment in business continuity as a part of day-to-day business costs such as occupational health and safety – only it's their business health and safety they are protecting.

## **REFERENCES**

- Grayland Eugene C – *New Zealand Disasters AH & AW Reed, Wellington, 1957.*  
The Business Continuity Institute, *Business Continuity Research, 2005.*



## SYMPOSIUM DELEGATES

(as of 31 August 2005)

First name	Last name	Organisation	City/Town	Email address
Darren	Alexander	Australian High Commission	Wellington	darren.alexander@dfat.gov.au
Helen	Anderson	M O R S T	Wellington	helen.anderson@morst.govt.nz
Mark	Armstrong	South Geophysical Ltd	Wellington	mark@southerngeophysical.com
Richard	Arnold	Victoria University of Wellington	Wellington	richard.arnold@vuw.ac.nz
Don	Ashey-Palmer	Environetics Civil Ltd	Auckland	dap@clear.net.nz
Philip	Barnes	N I W A	Wellington	p.barnes@niwa.cri.nz
John	Beavan	G N S	Lower Hutt	j.beavan@gns.cri.nz
Dick	Beetham	G N S	Lower Hutt	d.beetham@gns.cri.nz
John	Begg	G N S	Lower Hutt	j.begg@gns.cri.nz
Robert	Bell	N I W A	Hamilton	r.bell@niwa.cri.nz
Russell	Bell	AON NZ Ltd	Wellington	russell.bell@aon.co.nz
Doug	Bent	E Q C	Wellington	dpbent@eqc.govt.nz
Ruth	Berry	F O R S T	Wellington	ruth.berry@frst.govt.nz
Kelvin	Berryman	G N S	Lower Hutt	k.berryman@gns.cri.nz
Richard	Bialostocki	Dept of Building and Housing	Wellington	carolyn.pepper@dbh.govt.nz
Graeme	Blick	Land Information N Z	Wellington	gblick@linz.govt.nz
Ian	Brewer	Brewer Consultants	Wellington	wadebrew@actrix.gen.nz
Graeme	Brown	WCC - Emergency Management Office	Wellington	graeme.brown@wcc.govt.nz
Dave	Brunsdon	Wellington Lifelines Group	Wellington	db@kestrel.co.nz
Rob	Bryant	Tse Group Ltd	Wellington	rob.bryant@tse.co.nz
Ian	Buchanan	Greater Wellington Regional Council	Wellington	ian.buchanan@gw.govt.nz
Des	Bull	University of Canterbury	Christchurch	des.bull@canterbury.ac.nz
Judith	Burney	Wellington City Council	Wellington	judith.burney@wcc.govt.nz
George	Butcher	W E L A	Masterton	fernleigh@xtra.co.nz
John	Callan	G N S	Lower Hutt	j.callan@gns.cri.nz
Hamish	Campbell	G N S	Lower Hutt	h.campbell@gns.cri.nz
Mark	Chadwick	G N S	Lower Hutt	m.chadwick@gns.cri.nz
Daniel	Clarke	Victoria University of Wellington	Wellington	clarkedani@student.vuw.ac.nz
Trevor	Cobeldick	The Correspondence School	Wellington	trevor.cobeldick@correspondence.school.nz
Ursula	Cochran	G N S	Lower Hutt	u.cochran@gns.cri.nz
Hugh	Cowan	G N S	Lower Hutt	h.cowan@gns.cri.nz
Lorena	Cowan	G N S	Lower Hutt	l.cowan@gns.cri.nz
Beverley	Curley	Opus International Consultants	Wellington	beverley.curley@opus.co.nz
Rachel	Cuthbertson	Wellington City Council	Wellington	rachel.cuthbertson@wcc.govt.nz
Sophie	Dalziel	Victoria Link Ltd	Wellington	sophie.dalziel@vuw.ac.nz
Erica	Dalziell	University of Canterbury	Christchurch	erica.dalziell@canterbury.ac.nz
Desmond	Darby	G N S	Lower Hutt	desmond.darby@gns.cri.nz
Richard	Davey	Victoria University of Wellington	Wellington	ear3rcead@mailcity.com
Paul	Denton	Geo-Logic Ltd	Nelson	paul.denton@geo-logic.co.nz
Lance	Dixon	E Q C	Wellington	lrdixon@eqc.govt.nz

<b>First name</b>	<b>Last name</b>	<b>Organisation</b>	<b>City/Town</b>	<b>Email address</b>
Gaye	Downes	G N S	Lower Hutt	g.downes@gns.cri.nz
David	Dowrick	G N S	Tauranga	d.dowrick@gns.cri.nz
Mathieu	Duclos	Victoria University of Wellington	Wellington	mathieu.duclos@vuw.ac.nz
Henry	Duncan	Victoria University of Wellington	Wellington	duncan.henry@vuw.ac.nz
Susan	Ellis	G N S	Lower Hutt	s.ellis@gns.cri.nz
David	Etchells	Upper Hutt City Council	Upper Hutt	david.etchells@uhcc.govt.nz
Keith	Evans	M C D E M	Wellington	keith.evans@dia.govt.nz
Kevin	Fenaughty	G N S	Lower Hutt	k.fenaughty@gns.cri.nz
Brian	Ferris	G N S	Lower Hutt	b.ferris@gns.cri.nz
Hilary	Fletcher	G N S	Lower Hutt	h.fletcher@gns.cri.nz
Peter	Foster	MWH (NZ) Ltd	Wellington	peter.f.foster@mwhglobal.com
Paul	Froggatt	Victoria Link Ltd	Wellington	paul.froggatt@vuw.ac.nz
Ken	Gledhill	G N S	Lower Hutt	k.gledhill@gns.cri.nz
Adrian	Glen	WCC - Emergency Management Office	Wellington	adrian.glen@wcc.govt.nz
James	Goff	N I W A	Christchurch	j.goff@niwa.co.nz
Helen	Grant	Greater Wellington Regional Council	Wellington	helen.grant@gw.govt.nz
Rodney	Grapes	University of Freiburg	Freiburg	rodney.grapes@minpet.uni-freiburg.de
Richard	Greenfield	Greater Wellington Regional Council	Wellington	richard.greenfield@gw.govt.nz
Esther	Griffiths	Upper Hutt City Council	Upper Hutt	esther.griffiths@uhcc.govt.nz
Susanne	Grigull	Victoria University of Wellington	Wellington	susanne.grigull@vuw.ac.nz
Jo	Guard	Greater Wellington Regional Council	Wellington	jo.guard@gw.govt.nz
Andrew	Guerin	Kapiti Coast District Council	Paraparaumu	andrew.guerin@kapiticoast.govt.nz
Graham	Hancox	G N S	Lower Hutt	g.hancox@gns.cri.nz
Terry	Harkin	AMI Insurance	Lower Hutt	terry.harkin@ami.co.nz
Louise	Harrington	G N S	Lower Hutt	l.harrington@gns.cri.nz
Fred	Harris	Wellington Institute of Technology	Petone	fred.harris@weltec.ac.nz
Jan	Harris	G N S	Lower Hutt	jan.harris@gns.cri.nz
Pat	Helm	Dept. of the Prime Minister & Cabinet	Wellington	pat.helm@dpmc.govt.nz
Peter	Holland	University of Leeds	Wellington	ear3asph@leeds.ac.uk
George	Hooper	E Q C	Wellington	g.hooper@cae.canterbury.ac.nz
Marshall	Hyland	Porirua City Council	Porirua City	mhyland@pcc.govt.nz
Dave	Jack	Hutt City Council	Lower Hutt	dave.jack@huttcity.govt.nz
David	Johnston	G N S	Lower Hutt	d.johnston@gns.cri.nz
Andrew	Jones	Greater Wellington Regional Council	Wellington	andrew.jones@gw.govt.nz
Karl	Jones	Willis Reinsurance Australia Limited	Sydney	joneskx@willis.com
Paul	Jones	Benfield Australia Ltd	Auckland	paul.jones@benfieldgroup.com
Robert	Jury	B E C A	Wellington	rob.jury@beca.com
Barrie	Keenan	Karori Civil Defence	Wellington	barriekeenana@xtra.co.nz
Peter	Kingsbury	M C D E M	Christchurch	peter.kingsbury@dia.govt.nz
Gary	Koornneef	The NZ House Inspection Company	Paremata	gary@nzhouseinspection.co.nz
Tanja	Kuehler	Victoria University of Wellington	Wellington	kuehletanj@student.vuw.ac.nz

<b>First name</b>	<b>Last name</b>	<b>Organisation</b>	<b>City/Town</b>	<b>Email address</b>
Robert	Langridge	G N S	Lower Hutt	r.langridge@gns.cri.nz
Graeme	Lawrance	Dept of Building and Housing	Wellington	graeme.lawrance@dbh.govt.nz
Graham	Leonard	G N S	Lower Hutt	g.leonard@gns.cri.nz
Scott	Lewis	Vero Insurance	Auckland	scott_lewis@vero.co.nz
Nicola	Litchfield	G N S	Lower Hutt	n.litchfield@gns.cri.nz
Timothy	Little	Victoria University of Wellington	Wellington	timothy.little@vuw.ac.nz
Sarah	Littlejohn	Telecom NZ Ltd	Wellington	sarah.littlejohn@telecom.co.nz
John	Louie	University of Nevada	Wellington	louie@seismo.unr.edu
Kirby	MacLeod		Lower Hutt	kirby.macleod@paradise.net.nz
Alex	Malahoff	G N S	Lower Hutt	a.malahoff@gns.cri.nz
Marcela	Markland	Victoria University of Wellington	Wellington	marklaesth@student.vuw.ac.nz
Dougal	Mason	Opus International Consultants	Wellington	dougal.mason@opus.co.nz
John	McClure	Victoria University of Wellington	Wellington	john.mcclure@vuw.ac.nz
Colleen	McClymont	Kelburn Civil Defence	Wellington	mcclymonts@xtra.co.nz
Christopher	McDonald	Victoria University of Wellington	Wellington	chris.mcdonald@vuw.ac.nz
Peter	McGinty	G N S	Lower Hutt	p.mcginty@gns.cri.nz
Don	McGuire	Kapiti Coast District Council	Paraparaumu	don.mcguire@kapiticoast.govt.nz
William	McLea	Victoria University of Wellington	Wellington	bill.mclea@vuw.ac.nz
Bruce	McLean	Marsh Ltd	Wellington	bruce.mclean@marsh.com
Roydon	McLeod		Lower Hutt	roydon.mcleod@clear.net.nz
Ian	McPherson	Connell Wagner	Wellington	mcpersoni@conwag.com
Veronika	Meduna	Radio New Zealand	Wellington	veronika.meduna@radionz.co.nz
Brent	Michie	AON NZ Ltd	Wellington	brent.michie@aon.co.nz
John	Morrison	Greater Wellington Regional Council	Wellington	john.morrison@gw.govt.nz
Philip	Morrison	Victoria University of Wellington	Wellington	philip.morrison@vuw.ac.nz
George	Moutzouris	Clyde Quay Defence Centre	Wellington	george.moutzouris@tenneco.com.au
Michi	Mulitalo	Mt Cook Civil Defence Centre	Wellington	michi.mulitalo@nzalb.govt.nz
Simon	Nathan	Ministry for Culture and Heritage	Wellington	simon.nathan@mch.govt.nz
Todd	Nicholson	Victoria University of Wellington	Wellington	todd.nicholson@vuw.ac.nz
Paul	Nickalls	Hutt City Council	Lower Hutt	paul.nickalls@huttcity.govt.nz
Paul	O'Sullivan	MWH (NZ) Ltd	Wellington	paul.a.osullivan@mwhglobal.com
Mike	Parkinson	Willis Reinsurance Australia Limited	Sydney	parkinsonm@reinsurance.co.nz
Sandra	Pedersen	WCC - Emergency Management Office	Wellington	sandra.pedersen@wcc.govt.nz
Katie	Peters	Victoria University of Wellington	Wellington	peterskati@student.vuw.ac.nz
Brian	Potter	Telecom NZ Ltd	Auckland	brian.potter@telecom.co.nz
David	Povey	Victoria University of Wellington	Wellington	david.povey@vuw.ac.nz
William	Power	G N S	Lower Hutt	w.power@gns.cri.nz
Martin	Reyners	G N S	Lower Hutt	m.reyners@gns.cri.nz
Elizabeth	Robertson	G N S	Lower Hutt	e.robertson@gns.cri.nz

<b>First name</b>	<b>Last name</b>	<b>Organisation</b>	<b>City/Town</b>	<b>Email address</b>
William	Robinson	Robinson Seismic Ltd	Petone	whr@robinsonseismic.com
Angie	Rodger	Hutt City Council	Lower Hutt	angie.rodger@huttcity.govt.nz
Allison	Rosamond	Ace Insurance Ltd	Wellington	allison.rosamond@ace-ina.com
Edmund	Sainsbury	Opus International Consultants	Wellington	ed.sainsbury@opus.co.nz
Martha	Savage	Victoria University of Wellington	Wellington	martha.savage@vuw.ac.nz
Jeroen	Schomaker	AON NZ Ltd	Wellington	jeroen.schomaker@aon.co.nz
Anya	Seward	Victoria University of Wellington	Wellington	anya.seward@vuw.ac.nz
Dean	Sewell	Ace Insurance Ltd	Wellington	dean.sewell@ace-ina.com
Richard	Sharpe	B E C A	Wellington	richard.sharpe@beca.com
Bruce	Shephard	E Q C	Wellington	bruce.shephard@xtra.co.nz
Richard	Sibson	University of Otago	Dunedin	rick.sibson@stonebow.otago.ac.nz
Ivan	Skinner	E Q C	Wellington	riskinner@eqc.govt.nz
Chris	Smith	Grenada North Civil Defence Centre	Wellington	clks@paradise.net.nz
Warwick	Smith	G N S	Lower Hutt	w.smith@gns.cri.nz
Josephine	Speed	Opus International Consultants	Wellington	josephine.speed@opus.co.nz
Karen	Stephens	Resilience	Martin- borough	karen@continuity.co.nz
Tim	Stern	Victoria University of Wellington	Wellington	tim.stern@vuw.ac.nz
Claire	Stevens	Wellington City Council	Wellington	claire.stevens@wcc.govt.nz
Callum	Streeter	University of Canterbury	Christchurch	cms82@student.canterbury.ac.nz
George	Stuart	Future Impact Ltd	Wellington	george@futureimpact.co.nz
Sarah	Stuart-Black	M C D E M	Wellington	sarah.stuart-black@dia.govt.nz
Rupert	Sutherland	G N S	Lower Hutt	r.sutherland@gns.cri.nz
Geoff	Thomas	Victoria University of Wellington	Wellington	geoff.thomas@vuw.ac.nz
Stuart	Thurston	Branz Ltd	Porirua City	stuartthurston@branz.co.nz
Suzannah	Toulmin	Victoria University of Wellington	Wellington	suzannah.toulmin@vuw.ac.nz
John	Townend	Victoria University of Wellington	Wellington	john.townend@vuw.ac.nz
Russ	Van Dissen	G N S	Lower Hutt	r.vandissen@gns.cri.nz
Claire Marie	Van Opdorp	Positively Wellington Business	Wellington	claire@pwb.co.nz
Rian	Van Schalkwyk	Greater Wellington Regional Council	Wellington	rianvan@gw.govt.nz
Pilar	Villamor	G N S	Lower Hutt	p.villamor@gns.cri.nz
George	Walker	Aon Re Australia Ltd	Sydney	george.walker@aon.com.au
Phil	Wall	Kapiti Coast District Council	Paraparaumu	phil.wall@kapiticoast.govt.nz
Laura	Wallace	G N S	Lower Hutt	l.wallace@gns.cri.nz
Andrew	Watson	M O R S T	Wellington	andrew.watson@morst.govt.nz
Terry	Webb	G N S	Lower Hutt	t.webb@gns.cri.nz
Katharine	Wheeler	Wellington City Council	Wellington	katharine.wheeler@wcc.govt.nz
Martin	Williamson	British High Commission	Wellington	martin.williamson@fco.gov.uk
Kate	Wilson	Victoria University of Wellington	Wellington	k.wilson@gns.cri.nz
Marten	Young		Wellington	jmyoung@paradise.net.nz
Stuart	Young		Wellington	sryoung@paradise.net.nz
Kate	Zwartz	Greater Wellington Regional Council	Wellington	kate.zwartz@gw.govt.nz

