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Risk of casualties in New Zealand earthquakes

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ABSTRACT: This paper reports on a study of all earthquakes that have caused (or could have caused) casualties in New Zealand in the period 1840 – 2001 inclusive. The intensity which has been the effective threshold for injuries is Modified Mercalli intensity VII (MM7). In the period of interest at least 71 earthquakes of magnitude $M_w \geq 5$ have caused MM7 or greater in populated areas, and of these events 16 have caused direct casualties, 297 deaths and 640 hospitalized injured. The causes of the casualties are tabulated and discussed, and the potential to reduce casualties in the future is assessed, in particular in a large earthquake on the Wellington fault. Death rates have been determined empirically as functions of four types of structure and MM intensity.

1 INTRODUCTION

Since the beginning of earthquake engineering in New Zealand in the 1920s, its primary aim has rightly been to minimize casualties in future earthquakes. This has been done mainly through attempting to prevent the collapse of structures. Curiously no systematic study has been made of the historical incidence of earthquake casualties in New Zealand, their causes, and probabilities of occurrence. The brief beginnings of such a study was carried out fairly recently (Dowrick 1998), and the present paper is the result of expanding that work into a more substantive study of the risk of casualties in New Zealand earthquakes.

2 HISTORICAL INCIDENCE OF EARTHQUAKE CASUALTIES IN NEW ZEALAND

In gathering data of casualties we start at the usual time of 1840, with the advent of European style construction and colonial administration in New Zealand. The first known earthquake casualties are two men who died in a landslide in the 1843 Wanganui earthquake (Eiby 1968) which had a magnitude of about 7.5, and the most recent casualty was the injury (broken arm) of paper mill worker in the magnitude M_w 6.5 Edgecumbe earthquake of 1987. Our data gathering has been restricted to deaths and injuries requiring admission to hospital.

A summary of the known deaths and hospitalized injured people is presented in Table 1. It is seen that such casualties have occurred in 16 earthquakes, which is at an average rate of one casualty-causing earthquake per decade. The estimated total numbers of direct deaths and hospitalized direct injured in Table 1 are 297 and 640 respectively. These numbers should be considered as best estimates, particularly because there are considerable uncertainties in the numbers of casualties in the 1931 Hawke's Bay earthquake which gave rise to over 90 percent of the total casualties.

From Table 1 it is seen that casualties have occurred in earthquakes of a wide range of magnitude (5.6-8.2) and from Modified Mercalli intensity MM7 to MM10. Thus intensity MM7, which is the effective threshold of structural damage is correspondingly the threshold for casualties.

The geographical distribution of casualties (deaths + injured) across the whole country is shown in Figure 1. It is seen that of the total of 924 casualties, 97 percent have occurred in the North Island. This distribution is a direct consequence of the dominance of the majority of casualties to date having occurred in the 1931 Hawke's Bay earthquake.

Also shown in Figure 1 are the seismic hazard contours prepared by Stirling *et al.* (2000) for use in the loadings standard. They show that the highest hazard part of the country, which is in the South Island, has not contributed to the casualties count, and it cannot contribute much in the foreseeable future because it is only lightly populated. Indeed, the biggest future contribution will be in the southern North Island when the Wellington fault ruptures (Section 5).

Table 1 Numbers of deaths and hospitalized injured as a function of Modified Mercalli intensity in New Zealand earthquakes, 1840-2001 inclusive (Indirect casualties are excluded).

Local date and time			M_W	**MM7**		**MM8**		**MM9**		**MM10**	
				Dth	**Inj**	**Dth**	**Inj**	**Dth**	**Inj**	**Dth**	**Inj**
1843	Jul 8	1645	7.5	-	-	2	-	-	-		
1848	Oct 17	1540	6?	3	-						
1855	Jan 23	2102	8.2	-	1	2	-	6(3)	4?		
1882	(1)	Day	5-6	-	-	3(2)					
1897	Dec 7	0240	6.5	-	1						
1901	Nov 15	0745	6.8	-	-	-	-	1	-		
1913	Apr 12	1912	5.6	1	0						
1914	Oct 6	0646	6.6	-	-	1	-				
1922	Dec 25	1503	6.4	-	-	-	1				
1929	Jun 16	1017	7.7	-	-	3	1	12	-		
1931	Feb 3	1047	7.8	-	-	2	18	5	8	254(4)	594(4)
1932	Sep 15	0125	6.8	-	-	-	3	-	-		
1934	Mar 5	2346	7.4	-	1	-	-	-	-		
1942	Jun 24	2316	7.1	-	-	-	2				
1968	May 23	0424	7.2	-	-	-	-	-	-	2(5)	1(5)
1987	Mar 2	1342	6.5	-	-	-	-	-	1		
Totals				4	3	13	28	24	13	256(6)	596(6)

Notes:(1)Date and hour not known; (2) Could have been MM8; (3) 5 to 7 deaths; (4) Deaths and injuries both include 27 injured who died; (5) Includes one injured who died; (6) Includes 28 injured who died.

3 CAUSES OF EARTHQUAKE CASUALTIES

Casualties in New Zealand earthquakes have been principally due to damage to buildings, with a minority caused by ground damage, and a few to other causes. These causes are discussed below.

3.1 Casualties from ground damage

Casualties caused by ground damage have occurred in seven of the 16 casualty-causing New Zealand earthquakes, and comprise 28 (i.e. 3 percent) of the total number (924) of casualties. Table 2 lists these earthquakes together with the numbers of deaths and injured people at each intensity. The three deaths at the lowest intensity (MM7) occurred in a railway tunnel being constructed near Paekakariki, in an ill-defined earthquake in 1882. The other types of ground damage causing the casualties in Table 2 are landslides, rockfalls in mines, ground fissures, and collapse of a caisson for the construction of a bridge pier near Mohaka. Note that ground damage casualties have mostly been fatal.

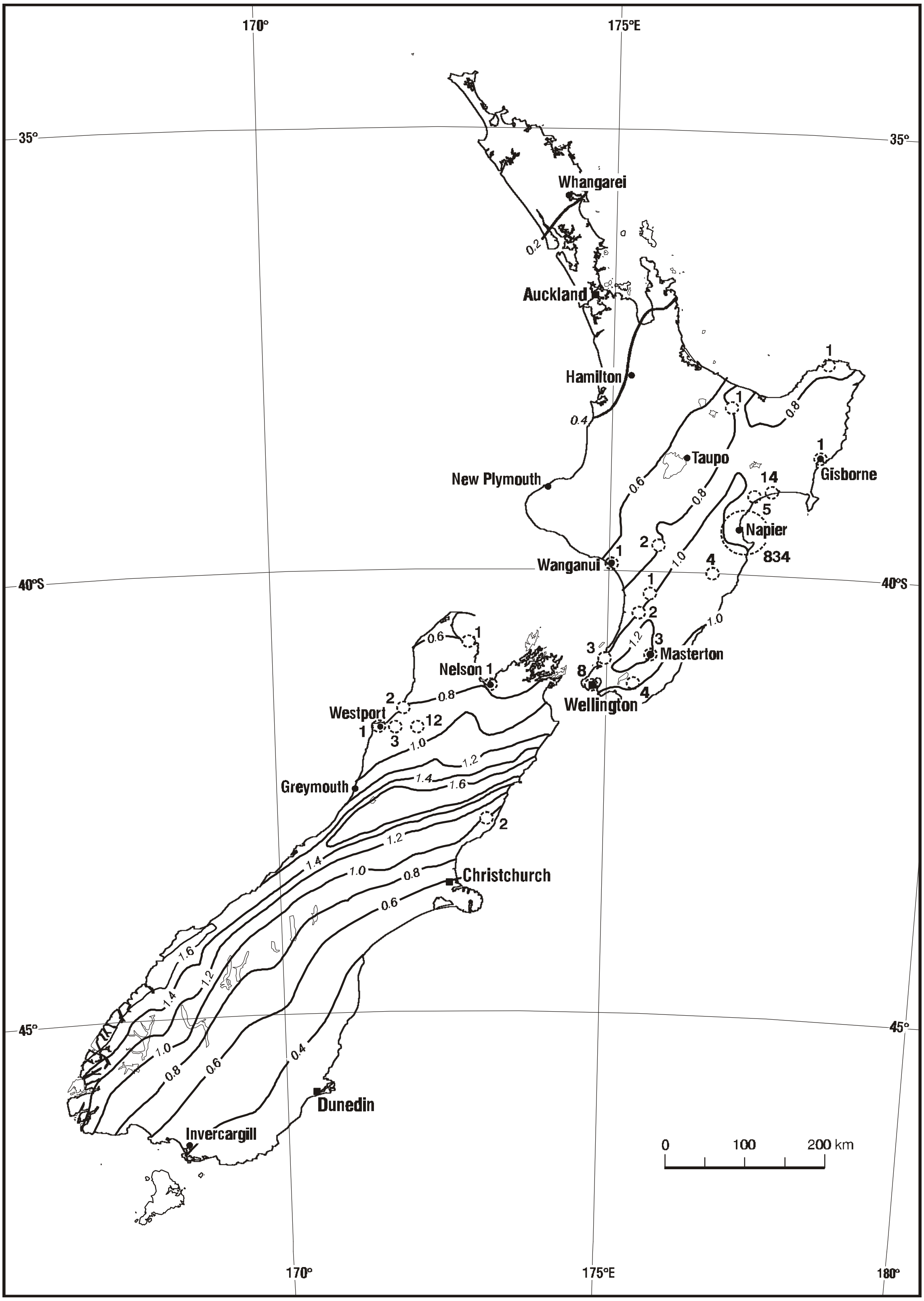

Figure 1 Geographical distribution of earthquake casualties in New Zealand in the period 1840-2001 inclusive. The numbers are the sum of deaths + hospitalized injured within the adjacent circles. Also shown are seismic hazard contours from Stirling *et al*. (2000).

Table 2 Numbers of deaths and injured (hospitalized) due to ground damage as a function of Modified Mercalli intensity in New Zealand earthquakes.

MM7		MM8		MM9		MM10	
Dth	**Inj**	**Dth**	**Inj**	**Dth**	**Inj**	**Dth**	**Inj**
3	0	8	0	13	0	2(1)	2(1)

Notes: (1) Deaths and injuries both include one injured who died in hospital

3.2 Casualties from damage to buildings

The data on deaths and injuries arising from damage to buildings are summarized by intensity in Table 3. The types of construction causing deaths are Unreinforced Masonry (URM) buildings (251), URM chimneys (7), a domestic watertank (1), and the Nurses Home in Napier (8) which was of defective reinforced concrete.

Table 3 Numbers of details and injured (hospitalized) due to damage to buildings and their contents, as a function of MM intensity in New Zealand earthquakes.

MM7		MM8		MM9		MM10	
Dth	**Inj**	**Dth**	**Inj**	**Dth**	**Inj**	**Dth**	**Inj**
3 URM* 1 P	3	1 URM 1 WT	26	5-7 Cob 1 BC	13	6 BC 240 URM 8 NH	594

Notes: BC = Brittle chimney; Cob = Cob house; NH = Nurses Home (weak concrete); P = Plaster; WT = Domestic water tank. * Probably weakened in main shock, MM8.

4 RISK OF CASUALTIES

We now consider the risk of occurrence of earthquake casualties as derived from the 1840-2001 historical data discussed above. Considering the populated regions in all 21 events subjected to intensities ≥ MM8 (Table 4), the numbers were counted of casualties and the total populations exposed that were associated with four types of structure:

- Houses (non-URM)
- Non-domestic buildings (ND)
- Unreinforced masonry buildings (URM)
- Brittle chimneys (Ch)

Table 4 Minimum numbers of New Zealand earthquakes affecting different classes of structure at intensities MM8-MM10 from 1840-2001 inclusive.

Class of structure	**Number of earthquakes**			
	MM7	**MM8**	**MM9**	**MM10**
URM Buildings	34	11	4	1
Buildings with URM chimneys	58	21	11	2
Domestic (1) non-URM buildings	71	21	12	2
Non-domestic non-URM buildings	19	19	7	2

Note: (1) Domestic = Houses + farm buildings

From these data (tabulated in Dowrick, 2003), the following two statistics were calculated:

- Death rate per head of population (by intensity zone)
- Death rate per structure (by intensity zone)

The calculated historical death rates together with their 95% confidence intervals are summarized in Table 5, and are presented graphically in Figure 2.

Table 5 Death rates with their 95 percent confidence intervals associated with different types of structure in New Zealand (1840-2001).

	Deaths per head of population			**Deaths per structure**		
	Mean	**95% conf.**	**Int.**	**Mean**	**95% conf.**	**Int.**
MM8						
Houses*	0	0	1.9×10^{-5}	0	0	4×10^{-5}
ND*	0	0	3.1×10^{-4}	0	0	0.0013
URM*	3×10^{-4}	1.5×10^{-5}	0.0016	0.0012	5.9×10^{-5}	0.0059
Ch*	0	0	2×10^{-5}	0	0	3.2×10^{-5}
MM9						
Houses	0	0	1.1×10^{-4}	0	0	2×10^{-4}
ND	0	0	5.5×10^{-4}	0	0	0.0035
URM	0.0056	0.0023	0.012	0.060	0.024	0.13
Ch	3×10^{-5}	3.8×10^{-6}	3.6×10^{-4}	2×10^{-4}	5.7×10^{-6}	5.7×10^{-4}
MM10						
Houses	0	0	1.6×10^{-4}	0	0	3.2×10^{-4}
ND	0.0011	5.3×10^{-4}	0.0022	0.011	0.0052	0.021
URM	0.054	0.047	0.061	0.54	0.47	0.61
Ch	3.9×10^{-4}	1.6×10^{-4}	8.2×10^{-4}	4.0×10^{-4}	1.6×10^{-4}	8.2×10^{-4}

* Abbreviations explained in text

First consider the death rates per head of population (Figure 2A). The highest risk of death (unsurprisingly) exists for people in or near URM buildings subjected to intensity MM10, for whom the death rate is 0.054. At MM10 the death rate drops by nearly two orders of magnitude to 0.0011 for people in or near non-URM non-domestic buildings (mostly pre-code, as the MM10 statistics are dominated by the 1931 earthquake, see Table 1). The death rate for non-URM houses at MM10 is zero, as no deaths have been caused by them. Brittle chimneys, curiously, have not been nearly as lethal as might be expected, considering that about 90,000 of them have fallen at intensity MM8 or greater; at MM10 the death rate per head of population due to chimneys is 0.0004.

Figure 2B gives a general idea of the death rate associated with the four types of structure. In interpreting this figure it should be noted that none of the non-domestic buildings were large (the tallest being about four storeys), and that the number of people in all the building types varied depending on the time of occurrence of the earthquake across the intensities MM8 to MM10. The number of occupants per house averaged 2 to 3; for non-domestic buildings the numbers were 4 for MM8, 12 for MM9 and 10 for MM10; for URM buildings the numbers were 4 for MM8, and 10 for MM9 and MM10; while for chimneys the associated numbers of people were 1.6 per chimney for MM8 and MM9 and 1.0 for MM10.

A notable feature of Figure 2 is how it illustrates the rapid rate at which the death rates decrease with decreasing intensity, such that the contribution to casualty counts at intensity MM8 are very small compared to those at MM10.

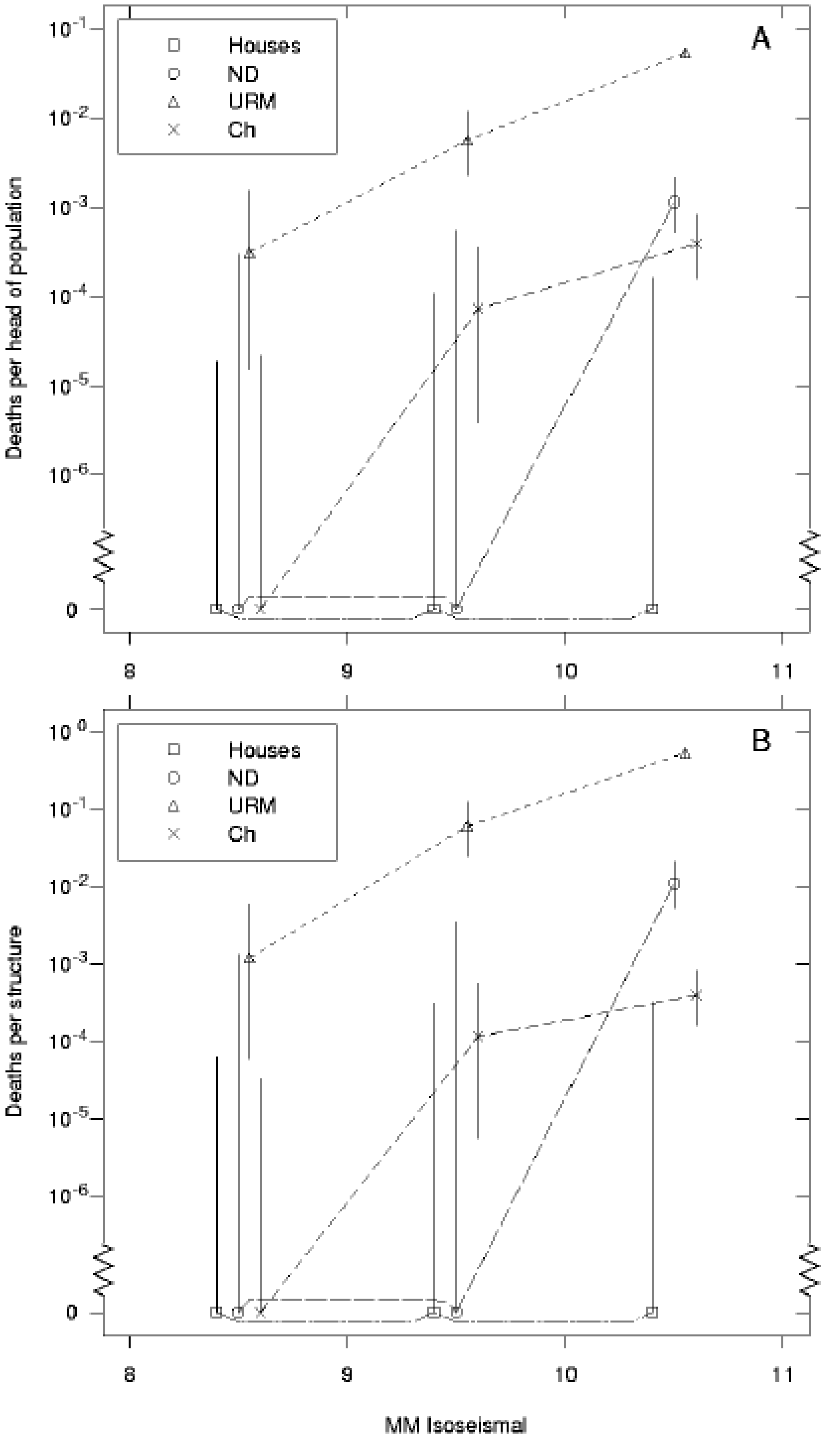

Figure 2 Death rates in New Zealand earthquakes in the period 1840-2001: (A) based on the population in or near four types of structure (as defined in the text); (B) based on the number of structures.

5 WELLINGTON FAULT EARTHQUAKE CASUALTIES

We now consider a future earthquake with the highest risk of casualties for New Zealand, i.e. a large earthquake on the southern segment of the Wellington fault. This is a worst case scenario for casualties in New Zealand as it involves the most highly active fault in New Zealand located in a highly populated region. The fault runs through the centre of Wellington and Hutt Cities and generates earthquakes of about M_w 7.5 at average intervals of about 600 years.

Considering the case of a magnitude 7.5 earthquake on the Wellington fault, (Spence *et al.*, 1998) estimated the casualties from a work day (11 am) and a night time (2 am) event for the Accident Compensation Commission in New Zealand for reinsurance purposes. The (subsequently slightly) revised overall results of this partly probabilistic study are given in Table 6, where is seen that the best estimate (mean of the model) for deaths at 11 am (746) are over five times as great as those for the 2 am event (134). This large difference in numbers of deaths is caused mainly by the fact that at night far more people in the Wellington region are in their mostly timber-framed houses compared to the work day, when many more people are in non-domestic buildings which suffer much more volume loss in strong shaking than do timber-framed New Zealand houses.

Table 6 Summary of deaths and hospitalized injured estimated for two M_W 7.5 scenario earthquakes on the Wellington fault.

		Workday 11 a.m. Event			**Night-time 2 a.m. Event**		
		Deaths	**Seriously injured**	**Moder. Injured**	**Deaths**	**Seriously injured**	**Moder. Injured**
Building collapse (Volume Loss) due to ground shaking		463	76	176	67	17	64
Buildings sheared by fault		101	53	57	27	65	67
Misc. other causes		182	151	312	40	33	100
Totals	Best Estimate	746	280	545	134	115	231
	90 percentile	1425	623	1127	283	263	499
	10 percentile	313	90	228	44	41	91

Of the casualties caused by building collapse (part or complete), it was found that the majority occurred in a relatively small number of buildings designed prior to the introduction of “capacity design” and ductility of structures in the 1970’s.

As well as listing casualties due to ground shaking, Table 6 also gives the casualties estimated from other causes, including those associated with buildings straddling the causative fault, mostly (but not all!) built before the fault was identified. A field survey found that 74 houses and 70 other buildings had been built across this strike-slip fault, which is expected to have shear displacements of about 5m horizontally and up to about a metre vertically.

The casualties attributed to “miscellaneous other causes” in Table 6, comprising the largest contributor to miscellaneous causes of daytime casualties (350 deaths + injured), is that from contents of buildings. These arise mainly from very dangerously stored goods on high shelving in several large shops for food and hardware. The second largest contributing cause of daytime casualties (60 deaths + injured) is falling brick parapet and gables of older (pre-code) commercial buildings in shopping or business streets. Despite efforts of local government in a 25-year campaign to reduce this risk, not all of these dangerous brick parts had been secured at the time of the study (1997).

Of the 746 deaths in the 11 am event, 702 occur in the intensity MM10 zone, where the population exposed is 238,270. This gives a fatality rate of 1 in 339. It is of interest to compare this with the fatality rate for the MM10 zone of the 1931 Hawke’s Bay earthquake, which occurred at 10.47 am on a work day. In this case 254 deaths occurred in a population of 30,000, giving a fatality rate of 1 in 118. Thus the fatality rate is expected to have reduced by a factor of almost 3 from Hawke’s Bay in 1931 to the modelled present day Wellington event. This improvement is due largely to the replacement (not yet complete) of URM with more ductile construction materials for non-domestic buildings.

6 REDUCING FUTURE CASUALTIES

The numbers of casualties in future New Zealand earthquakes could be reduced to substantially better than the improvements that have already been made since 1931. This could be done by systematically following the actions such as those suggested for reducing earthquake risk by Dowrick (2003?). The three most beneficial such actions would be: (1) Retrofitting the more dangerous brittle buildings, (2) reducing risk from dangerously stored goods, and (3) vacating buildings straddling the Wellington fault.

7 CONCLUSIONS

In the period 1840-2001, earthquakes in New Zealand have caused 297 direct deaths and 640 hospitalized direct injured. Over 90 percent of the casualties occurred in one event, i.e. in 1931.

The casualties have occurred in 16 earthquakes, on average once every 10 years.

Most of the casualties (97%) have been caused by damage to buildings and their equipment or contents, the remaining 3% having been caused by ground damage.

Death rates range from 0.054 per head of population for people in or near URM buildings subjected to intensity MM10, decreasing rapidly for other types of structure and for lower intensities.

The future earthquake having the highest risk of casualties in New Zealand is a rupture of the Wellington fault (M_w 7.5, mean recurrence interval 600 years). Such an event in a work day (11 am) is expected to cause about 750 deaths and somewhat more hospitalized injured.

Steps could be taken to substantially reduce the likely casualties in future earthquakes. For example, a feature of the Wellington casualties is the unnecessary high contribution likely from falls of dangerously stored goods in a few shops and warehouses.

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