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EARTHQUAKE RISK REDUCTION IN NEW ZEALAND

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SUMMARY

This paper analyses and discusses earthquake risk reduction in New Zealand under the headings (1) what has been achieved in the past, (2) what is currently being done, and (3) what could be done to improve our performance in the future.

Progress in risk reduction is assessed in a number of ways, including the reduction in damage levels to given classes of property of different code eras affected by the 1987 Edgecumbe earthquake. Another measure is to quantify the reduction over time in the numbers of more vulnerable structures in the built environment, such as earthquake risk buildings or dangerous dams, and to quantify the amount and effectiveness of retrofitting vulnerable structures and other items in the built environment. Computer modeling of economic losses and casualties in a range of earthquake scenarios, assuming different levels of vulnerability of the built environment, helps to evaluate the reduction in risk achieved since earthquake codes were first introduced. The potential for future risk reduction is also estimated.

New Zealand's current strengths and weaknesses in earthquake risk reduction have recently been assessed. The results of this study, along with the above-mentioned assessments, provide the basis for recommendations on setting priorities, and maximizing the effectiveness and speed of New Zealand's risk reduction efforts in the future.

INTRODUCTION

Work towards development of earthquake building regulations in New Zealand was triggered by the damage and casualties caused by two powerful earthquakes that occurred in 1929 and 1931, i.e. the M_w 7.7 Buller and the M_w 7.8 Hawke's Bay earthquakes. The initial results of this work appeared in the form of a report containing a "Draft General Earthquake Building By-law", presented to the House of Representatives in June 1931. This document was developed into a New Zealand Standard which was published in 1935. Subsequent revisions of this standard and the development of standards for the use of

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building materials were not mandatory unless adopted by local authorities. This undesirable situation was finally rectified in 1992 when the Building Code listed the loadings standard as a means of verification. A detailed account of the development of New Zealand's codes is given by Davenport [1].

RISK REDUCTIONS ACHIEVED TO DATE

In various studies of earthquakes in New Zealand [e.g. 2], the vulnerability of chosen classes of property has been measured mostly in terms of damage ratio, D_r, and mean damage ratio, D_{rm}, where

$$D_r = \frac{\text{Cost of damage to an Item}}{\text{Replacement Value of that Item}} \tag{1}$$

and

$$D_{rm} = \frac{\sum_{i=1}^{n} \left[D_{r_i} \right]}{N} \tag{2}$$

where n is the number of damaged items and N is the total number of items. D_{rm} has been estimated as a function of MM intensity.

Figure 1 is a modified version of one from a study of the influence of earthquake codes on damage (at Modified Mercalli intensity MM9) in the 1987 Edgecumbe earthquake by Dowrick and Rhoades [2,3]. Here it is seen that non-domestic buildings, built in New Zealand's first two earthquake code eras, had much the same vulnerability (D_{rm} = 0.063 and 0.054 respectively), but buildings built in the then most recent code era (1970-1987) had D_{rm} = 0.033, which was significantly better ($P < 0.05$) than pre-1970 buildings. In addition, the maximum damage levels, as reflected in the 95 percentile, had decreased. This improvement is attributed to the influence of greater ductility requirements of the codes of that era.

In another study, Dowrick and Rhoades [3,4] have shown that the mean damage ratio for unreinforced masonry (URM) buildings at intensity MM8 is about an order of magnitude greater than the average vulnerability of buildings built from 1935 to 1987. The full range in vulnerabilities measured in New Zealand earthquakes is shown in Figure 2. Here are plotted the mean damage ratios, D_{rm} over a range of intensities from Modified Mercalli V (MM5) to MM10, as found for New Zealand buildings and equipment in four earthquakes (1931, 1942, 1968 and 1987). It is seen that the approximate lower bound D_{rm} is about one thirtieth of the upper bound value over the range of damaging intensities MM7-MM10.

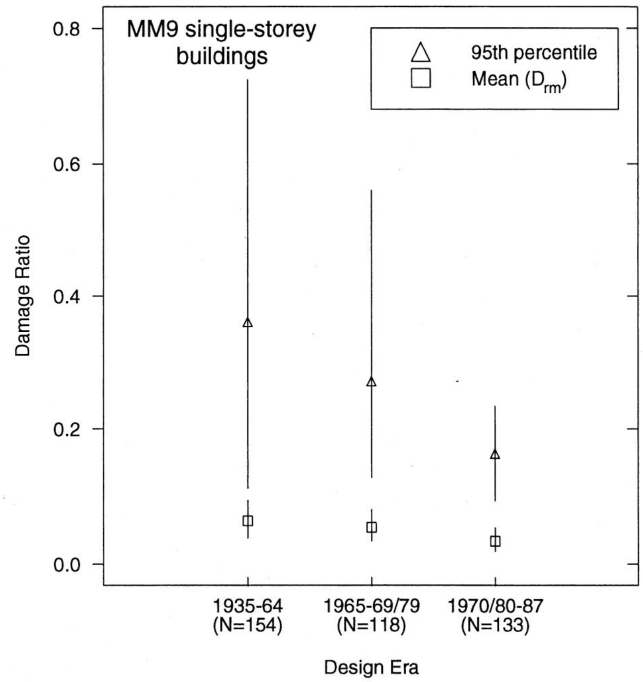

Figure 1: Mean and 95th percentile of damage ratio for one storey non-domestic buildings in the intensity MM9 zone of the 1987 Edgecumbe earthquake. The uncertainty limits are the 2.5% and 97.5% quantiles of the distributions (adapted from Dowrick and Rhoades [2,3].

A measure of the historical reduction in earthquake risk in New Zealand urban areas can be obtained by comparing the death rate in the MM10 zone of the pre-code 1931 Hawke's Bay earthquake (M_w 7.8) with that which has been estimated to occur in the MM10 zone of a present day M_w 7.5 earthquake on the Wellington fault (Figure 3). The numbers of casualties in the Wellington event were estimated in a 1997 study by Spence *et al.* [5], and their results have recently been revised by Dowrick and Rhoades [6]. The latter results for an 11 am work day earthquake are given here in Table 1.

Table 1: Summary of deaths and hospitalized injured estimated for an M_w 7.5 scenario earthquake 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

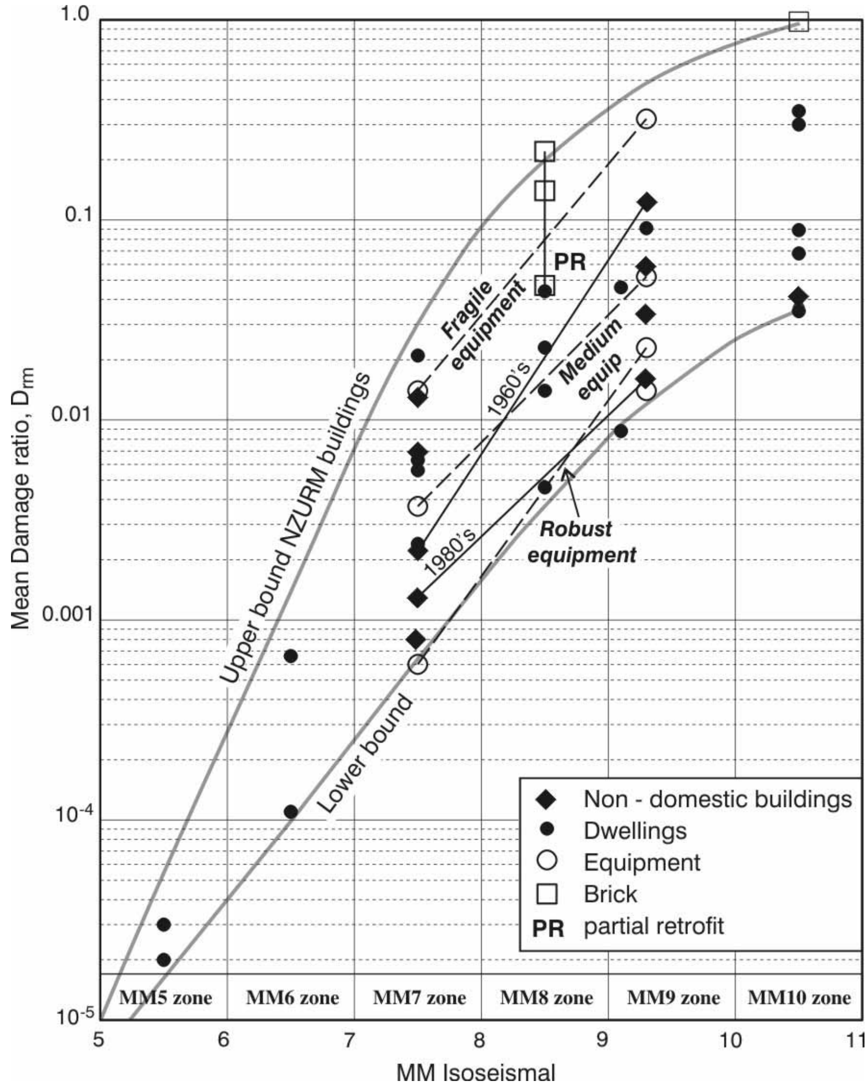

Figure 2: Mean damage ratio data from New Zealand earthquakes for buildings and equipment as a function of intensity, with approximate upper and lower bounds (from Dowrick, [3,7]).

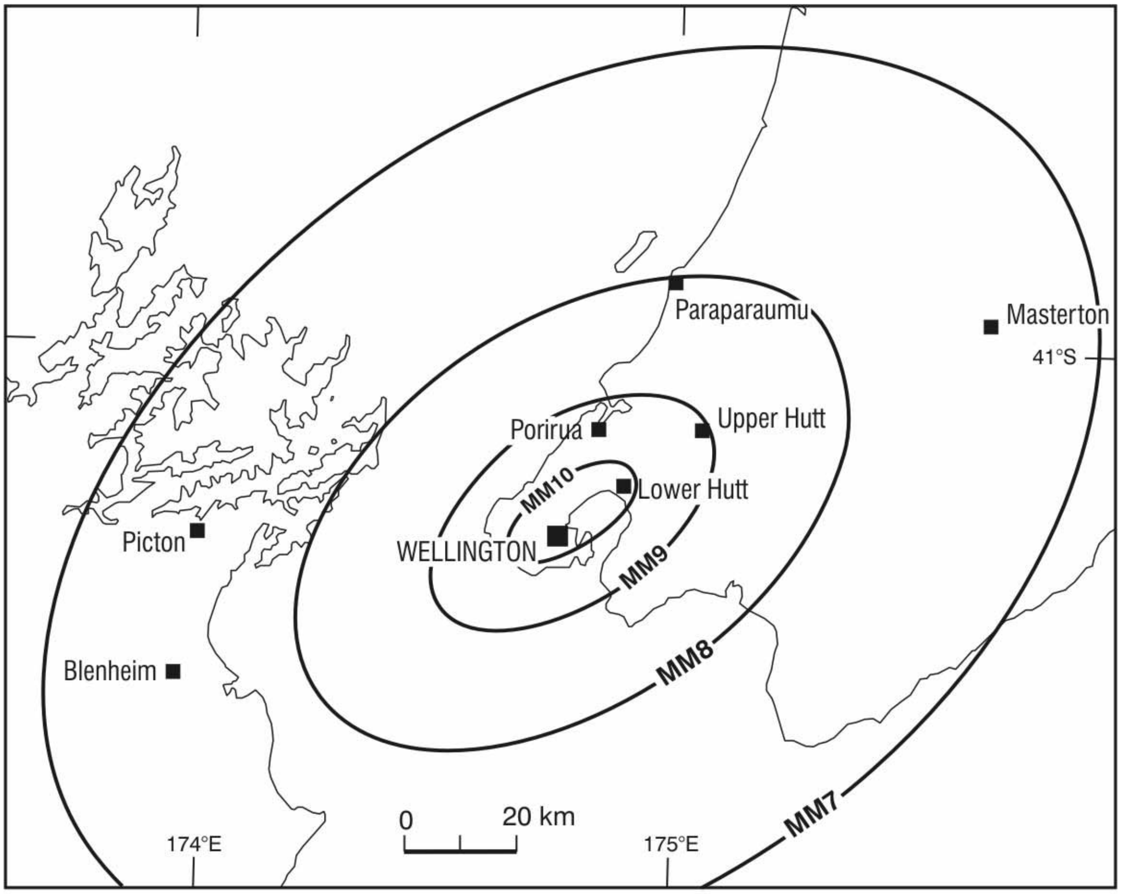

Figure 3: Isoseismal map for a future magnitude 7.5 earthquake on the Wellington fault in New Zealand (average recurrence interval 600 years), prepared using the attenuation model of Dowrick and Rhoades [8].

Of the best estimate of 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. This result is compared 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 about 3 from Hawke's Bay in 1931 to the modeled present day Wellington event. This expected improvement is due largely to the replacement (c. 80% so far) of unreinforced masonry with more ductile construction materials for non-domestic buildings.

FUTURE REDUCTIONS IN EARTHQUAKE RISK

The potential for future earthquake risk reduction in New Zealand can be seen by considering Figures 1 and 2. Any reductions would require the conversion of the built environment in the higher risk regions of the country to be of minimal earthquake vulnerability. This would continue and complete the trend already achieved, as discussed in the previous section. We illustrate the potential for further risk reduction by estimating the damage costs to buildings (only) and casualties in a present day and a future earthquake on the Wellington fault, the highest risk part of New Zealand. We have used a first-order earthquake loss model for New Zealand, developed by Cousins [9]. The damage ratio functions that we use for these two events are shown on Figure 4.

It is noted that the present day damage ratio curve on Figure 4 is more pessimistic than that which would be inferred from Figure 2, particularly at lower intensities. This is a result of current unpublished studies of earthquake losses in recent low intensity events in New Zealand. The damage ratios on Figure 4 for the future event are somewhat higher than those of the lower bound on Figure 2, in order to make an (arbitrary) allowance for what might be a more achievable minimum future damage level. The costs for material damage to buildings for the Wellington fault earthquake scenario for the two damage ratio curves on Figure 4 are given in Table 2. It is seen that the total damage costs fall from NZ$10.6 billion to NZ$1.78 billion. This represents a reduction in losses of 83% from the present day value, which follows from the future damage ratio curve being one sixth of the present day one. The assumption made in this estimate is that total replacement value of buildings at risk is the same for both the present day event and the future lower bound event.

Table 2: Costs of material damage (NZ$billions) from shaking to buildings in two magnitude M_w 7.5 earthquakes on the Wellington fault (Figure 3)

Vulnerability of Buildings	Present Day	Future Lower Bound
Houses	7,100	1,200
Non-domestic Buildings	3,500	580
Total	10,600	1,780

The costs of damage discussed above should be considered as basic indicators only. In order to estimate the full financial costs and cost savings, the losses from the following damage sources must be added:

- Household contents
- Non-domestic contents/plant
- Lifelines (non-buildings)

These items are likely to approximately double the costs given in Table 2. Finally, losses due to business interruption must be added, causing further increases by a factor of about 2-4.

Casualties are estimated using a simplified model based on the collapse rates for buildings for the present day and future events as shown on Figure 5. Allowances have also been made for casualties in buildings built astride the Wellington fault and also from all other causes, as in our previous studies [5,6,9] (and as summarized in Table 1.). In the lower bound event it is assumed that occupancy of buildings located astride the Wellington fault is: (1) As at present, (2) Zero.

Casualties (Table 3) have been estimated for a work day event (11 a.m.) and a night-time event (2 a.m.). In the daytime events the future lower bound event, (1), causes 29% of the casualties of the present day case, while in case (2) the reduction is 79%. In the night-time events, casualties are reduced by 45% and 66% for case (1) and (2) respectively.

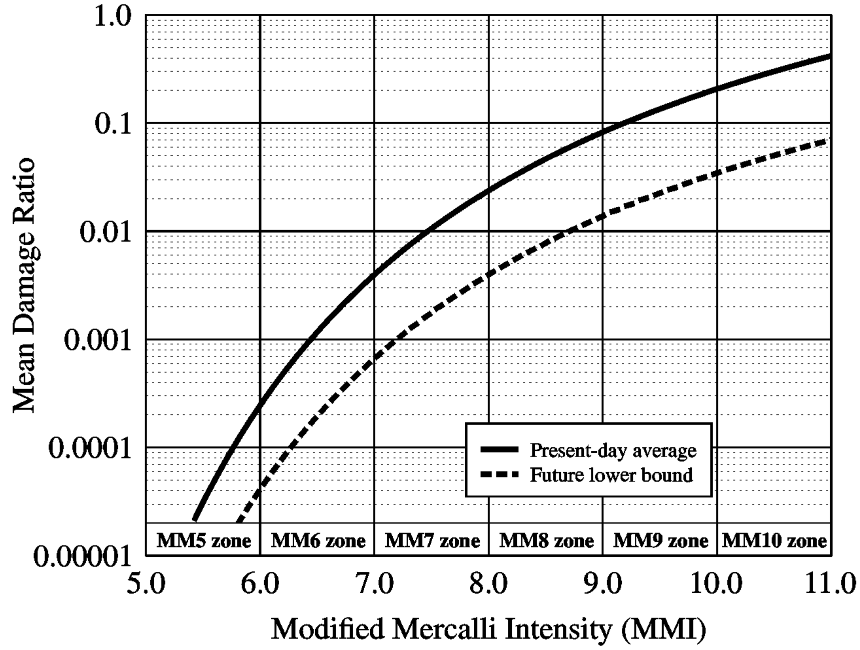

Figure 4: Approximate mean damage ratio curves, as a function of intensity, for New Zealand buildings, (a) present day average vulnerability, and (b) future lower bound vulnerability.

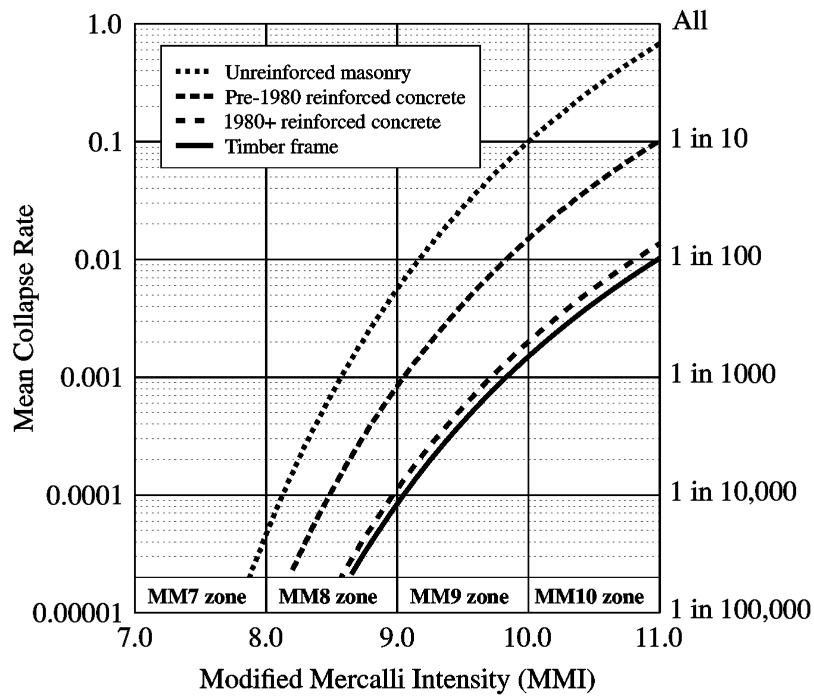

Figure 5: Approximate mean curves for collapse rates as a function of intensity, for present day New Zealand buildings. For a future, lower bound case, all unreinforced masonry and pre-1980 reinforced-concrete buildings are assumed to be replaced by 1980+ reinforced-concrete buildings.

Table 3: Estimated deaths and hospitalized injured in future magnitude M_w 7.5 earthquakes on the Wellington fault (Figure 3).

Collapse rates for Buildings		Present Day	Lower Bound (1)*	Lower Bound (2)*
Casualties for Daytime Event	Dead	910	270	170
	Seriously Injured	300	100	54
	Moderately Injured	1000	290	230
Casualties for Night-time Event	Dead	140	61	31
	Seriously Injured	130	90	20
	Moderately Injured	650	330	260

Notes: *Occupancy of buildings astride the Wellington fault, (1) as at present day, and (2) zero

Using the earthquake loss model of Cousins [9] and a 100,000-year long synthetic catalogue of earthquakes (Smith [10]) that faithfully represents the Stirling et al [11] seismicity model for New Zealand, we have estimated the return periods for various levels of shaking damage to buildings (Figure 6) and numbers of casualties (Figure 7) for present day and future lower-bound cases, for all of New Zealand. Given present day collapse rates, casualty numbers exceed 16, 370 and 800 for return periods of 100, 500 and 1000 years respectively, reducing to 5, 80 and 200 for the future lower-bound collapse rates. This is a reduction of about 75% in casualties. The corresponding reduction in shaking damage to buildings from present day to future lower bound vulnerabilities is about 80%.

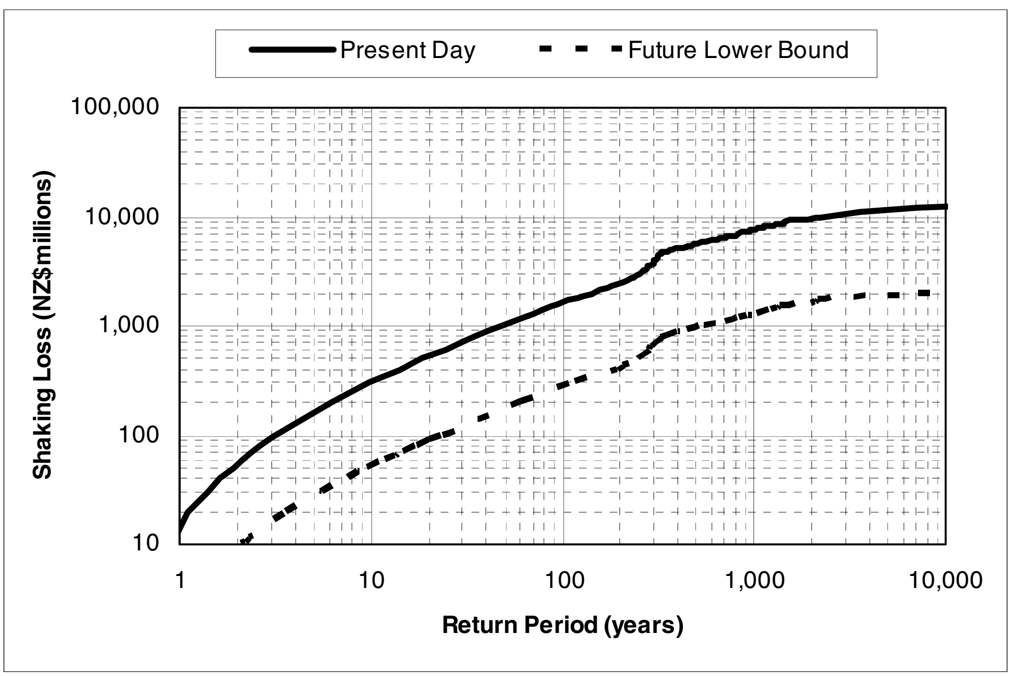

Figure 6: Estimated earthquake losses for all of New Zealand buildings assuming (a) present day vulnerabilities (damage ratios) for buildings and (b) future lower-bound vulnerabilities.

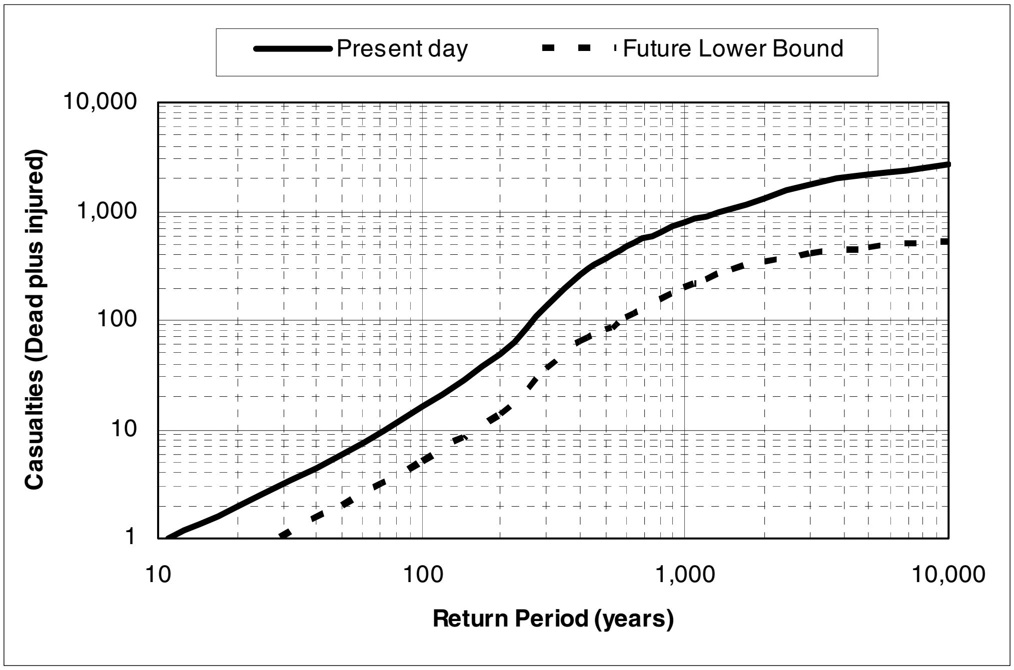

Figure 7: Estimated earthquake casualty-rates for New Zealand assuming (a) present day collapse rates for buildings and (b) future lower-bound collapse rates. Casualties from fault rupture are included in the present day case, and are assumed to be zero for the future lower bound case.

NEW ZEALAND'S CURRENT EARTHQUAKE RISK REDUCTION WEAKNESSES

In a recent study, Dowrick [7] noted that New Zealand has many (16) strengths, but nevertheless identified 26 weaknesses that need to be addressed in order to substantially reduce earthquake risk in New Zealand. Consider the selection of these weaknesses listed in Table 4. The two most important *strategic* weaknesses arguably are items A1 and A2. We need monitored goals of target risk reductions with priorities and timescales, perhaps in a series of five year plans.

An important aspect of risk reduction in New Zealand, discussed by Dowrick [7] is the complexity arising from the large number of parties involved. Overall, actions are required from up to 11 parties ranging from earthquake professions to government (national and local) and property owners themselves. For 15 of the weaknesses remedial action could be needed from five or more parties. In addition, it was found that earthquake professions have advocacy roles in addressing all 26 of the weaknesses, and professional engineers have to take technical actions in addressing 18 (70%) of the weaknesses.

The case of stored goods (stock) in shops, Item B3, is a curious and alarming example of the tactical weaknesses listed in Table 4. Consider the way that goods are stacked in some shops. Lethally heavy goods are stacked needlessly high overhead in a most dangerous fashion to anyone below, including in two new hardware shops in Auckland and Christchurch. The fact that loose goods or contents of buildings fall to the floor in moderate or strong shaking is common knowledge.

Table 4: Partial list of New Zealand's weaknesses in earthquake risk reduction, selected from Dowrick [7].

A:	Undesirable situations – strategic	B:	Undesirable situations – tactical
A1	No national strategy and targets for managed incremental risk reduction with time	B1	No EQ regulations for most equipment and plant
A2	Too much national vulnerability to a large earthquake on the Wellington fault	B2	Inadequate EQ regulations for building services in buildings
A3	Fragmentation of the many endeavours contributing to earthquake risk reduction	B3	Inadequate EQ regulations for storage of stock in shops and warehouses
A4	Too little management/modelling of business interruption losses	B4	No adequate regulatory framework for existing high risk concrete and steel buildings
A5	Slow uptake of some new research findings	B5	Weak powers and weak action for pre-emptive land-use planning
A6	As yet no official process for retrofitting of non-URM earthquake risk buildings	B6	Modern buildings built without measures for liquefiable ground
A7	Architects who don't accommodate engineer's structural form needs	B7	Inadequate enforcement of some regulations
		B8	Incomplete and/or inadequate microzoning maps nationwide
		B9	No regular checks on seismic movement gaps for seismically isolated structures
		B10	Some incompetent design
		B11	Some inadequate construction

These situations are, in fact, a breach of the law regarding the safety of the shop employees, and it is surprising and disappointing that this practice has not been stamped out. Oddly, the public has no statutory protection from this source of danger at present. It is comforting to see that one chain of retail shops (The Warehouse) has recently installed a system of restraining ropes on its higher shelves, as seen in Figure 8. Also it is noted that in Canada a draft standard for safety of racking systems has just been issued, while the manufacturers of pallet racking systems in the USA have developed design standards.

Two recent reports helped Dowrick to improve the above paper [7]. The first was a hard hitting report by Scarry [12] on alarming shortcomings that he had observed in design, construction and enforcement. This resulted in a wide-ranging and thorough review being conducted by the engineering profession (IPENZ, [13]). While the problems documented by Scarry were judged not to be endemic by the IPENZ Taskforce, their report ends with seven significant recommendations, all of which have been quoted by Dowrick [7]. The most important recommendation arguably is their No 3, i.e.:

> "Ongoing professional involvement. There is a need to ensure ongoing professional involvement so that the effective sign-off of structural work post-construction (including all the variations from the iterative process described above), when required, is by a competent structural engineer."

Figure 8: Retail shop showing a good rope system installed on higher shelves to restrain goods from falling, but some of the highest boxes are above the restraints (from Dowrick [7]).

CONCLUSIONS

1. The potential exists for reducing material damage costs to buildings by a factor of about six. For a magnitude 7.5 earthquake on the Wellington fault this represents savings of about NZ$9 billion from buildings alone, and without earthquake-induced fires.

2. The corresponding reductions in numbers of casualties are estimated to be 79% and 66% for daytime and night-time events respectively, assuming that buildings astride the Wellington fault are unoccupied in the future event.

3. For all of New Zealand, reductions of about 80% in damage cost for buildings and 75% in casualties ought to be achievable.

4. When the monetary losses due to damage to contents of buildings, lifelines (non-buildings), business interruption, earthquake-induced fires are added to the losses noted in Conclusion 1 and 3, total losses are likely to be 4-8 times greater.

5. Twenty six weaknesses are identified in New Zealand's systems for earthquake risk reduction, some of which are matters of broad policy and others very specific. Perhaps the most fundamental is to develop and operate a national strategy for earthquake risk reduction with time.

6. Actions required to remedy the weaknesses involve more than 11 parties, ranging from earthquake professions to government and property owners. The complexity of the processes of remedying the weaknesses is shown by the fact that 15 of the weaknesses could have remedial actions from five or more parties.

7. Earthquake professions have advocacy roles in addressing all 26 weaknesses. Professional engineers have engineering technical actions in addressing 70 percent of the weaknesses.

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