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DESIGN, MICROZONING, INSURANCE AND PLANNING LESSONS FROM DAMAGE EVALUATION IN PAST NEW ZEALAND EARTHQUAKES

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ABSTRACT

This paper describes the research methods, results and implications to date of an ongoing series of studies on damage, damage costs, and damage ratios relating to various types of property, i.e. houses and their contents, non-domestic buildings, plant, equipment and stock. The statistical properties of the distributions of damage ratio have been evaluated as a function of Modified Mercalli (MM) intensity, up to MM10. The relative vulnerability of different classes of buildings, equipment and stock have been evaluated. All subsets of the data (from two earthquakes, of M_w6.6 and 7.8 respectively) were found to have damage ratios fitting the lognormal distribution well. The mean damage ratios in general were much less than previously believed. In a microzoning study of Napier, at the centre of the M_w7.8 1931 Hawke's Bay earthquake it was found that single storey houses were less damaged on soft ground (harbour reclamation) than on stiffer ground. Planning procedures are greatly enhanced by modelling of future earthquake damage outcomes in micro- and/or macro-scale scenarios. This applies to planning of land-use, insurance, emergency provisions and national economic provisions.

KEYWORDS

Buildings, equipment, damage ratios, earthquake design, microzoning, earthquake insurance, planning.

DAMAGE EVALUATION

In order to learn from earthquake damage, it is useful to describe the damage qualitatively, as in reconnaissance reports, by photographs and words such as undamaged, cracked, unrepairable, etc. For some purposes quantitative evaluation of damage is also desirable, and for this purpose the most convenient measure of the degree of damage to a given item of property is the damage ratio D_r, defined as:

$$D_r = \frac{\text{Cost of damage to an Item}}{\text{Value of that Item}} \qquad (1)$$

where Value is best expressed in terms of Replacement Value (used here except where noted), and D_r is a function of the strength of shaking and the physical nature of the item considered. It follows that D_r would most helpfully be modelled in an attenuation function in terms of magnitude, distance and scatter.

With the small number of good D_r data sets yet available, we are limited to describing D_r as a function of intensity, but are able to examine the distribution (scatter) of D_r well in those terms.

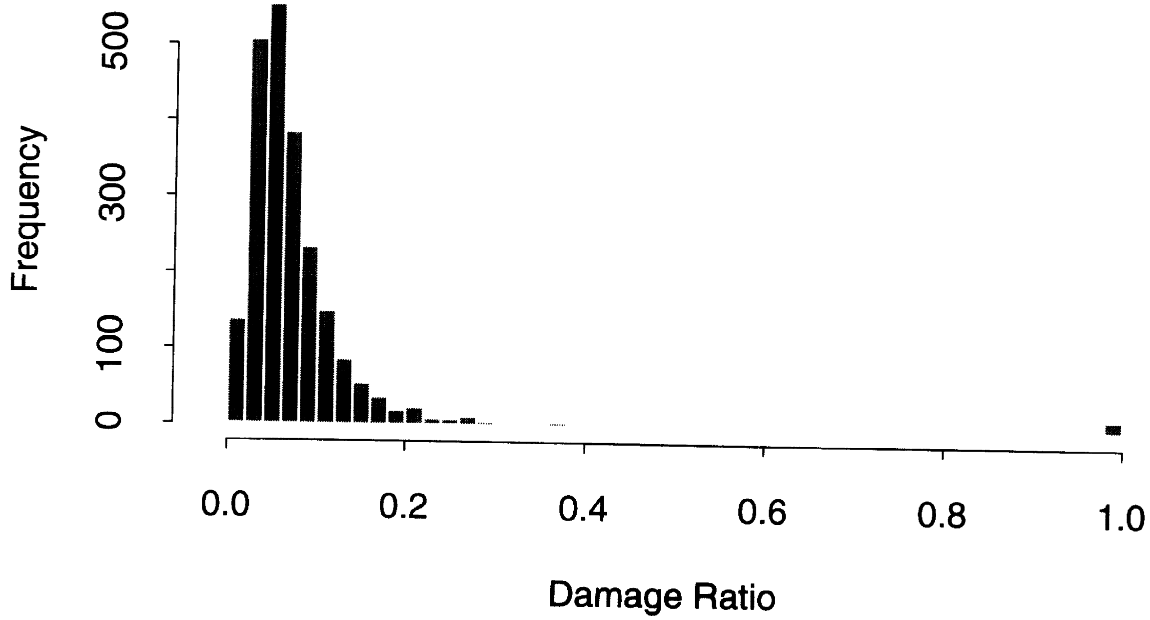

Fig.1. Histogram of damage ratios for houses in Napier in the 1931 Hawke's Bay earthquake, using the complete data set (from Dowrick et al., 1995).

A typical distribution of damage ratio is that for houses shown in histogram form in Fig. 1. This distribution fits the lognormal form well, as do all the other distributions that we have examined, eg Dowrick and Rhoades (1993) and Dowrick et al. (1995). The lognormal distribution has the density function:

$$f(x) = \frac{1}{\sigma x \sqrt{2\pi}} \exp\left[-\frac{1}{2}(\log_e x - \mu)^2 / \sigma^2\right] \qquad x > 0 \qquad (2)$$

Here the parameters μ and σ are estimated by the sample mean and standard deviation of the natural log of the damage ratio.

The population of property items for any given distribution of D_r is drawn from the area between two adjacent isoseismals, so that the MM7 intensity zone (for example) is defined as the area between the MM7 and the MM8 isoseismals.

The mean damage ratio for items of a given class (eg timber houses) in a given MM intensity zone is, of course, a useful parameter. It can only be calculated from a consideration of the total population N of items in a class, i.e., both damaged and undamaged items. Considering all N items in an MM intensity zone, there are two principal ways of defining the mean D_r. Firstly,

$$\bar{D}_r = \frac{\sum_{i=1}^{n} [\text{cost of damage to item i}]}{\sum_{i=1}^{N} [\text{value of item i}]} \qquad (3)$$

where n is the number of damaged items.

Secondly,

$$D_{rm} = \frac{\sum_{i=1}^{n} [D_{r_i}]}{N} \tag{4}$$

If derived from large complete populations, $\bar{D}_r$ is correct for finding total losses for large populations of any type of property.

Estimates of the values of the parameters used in equations (2)-(4) are given in Tables 1 and 2, for various classes of property. The MM10 zone results came from the 1931 Hawke's Bay earthquake and the remainder came from the 1987 Edgecumbe earthquake. Note that equipment includes plant and excludes self-mobile plant, while stock is mostly manufactured items stored prior to sale or hire (Dowrick & Rhoades, 1995). From the tables it is seen that the scatter within distributions varies considerably, even for larger populations (n>100) the normal variability parameter σ lies within a wide range 0.7-1.77.

Table 1: Basic statistics of the distribution of damage ratio for some classes of New Zealand property

Item	*n*	N	μ	σ	D_{rm}	$\bar{D}_r$
MM6 Zone						
Houses	c.50	16400	∇	∇	∇	0.0001*
Non-domestic buildings	5-10	c.1000	∇	∇	∇	0.001
MM7 Zone						
Houses	1100	7300	-4.30	1.44	∇	0.0063*
Non-domestic buildings (low rise)	96	678	-4.92	1.33	0.0026	0.0028
Household contents	1170	7300	-3.91	1.17	∇	0.0056*
Equipment - Industrial	11	168	-5.55	1.08	0.0004	0.0006
Shops	31	247	-4.04	1.63	0.0073	0.0059
Stock - Industrial	12	122	-2.92	2.15	0.0209	0.0066
Shops	62	245	-3.44	1.21	0.0171	0.0087
MM8 Zone						
Houses	1075	2500	-3.92	1.45	∇	0.021*
Household contents	1075	2500	-3.81	1.15	∇	0.015*
MM9 Zone						
Houses	2040	2800	-3.25	1.38	∇	0.070*
Non-domestic buildings (low rise)	207	415	-3.38	1.77	0.054	0.087
Household contents	2210	2800	-2.80	1.18	∇	0.079*
Equipment - Industrial	83	150	-3.72	1.56	0.046	0.023
Shops	53	111	-2.96	1.47	0.061	0.184
Stock - Industrial	40	81	-2.55	1.30	0.078	0.209
Shops	70	113	-2.17	1.21	0.132	0.079
MM10 Zone						
Houses (mostly timber frames, excl. drains damage)	2260	2260	-3.08	0.95	0.070	0.065

Notes: *Indicates D_r determined on Indemnity Value basis, not Replacement Value
∇ Indicates not calculated

Table 2: Basic statistics of the distributions of damage ratio for some sub-classes of New Zealand property

Sub-class		*n*	N	μ	σ	D_{rm}	$\bar{D}_r$
MM9 Zone							
1-storey non-domestic buildings:							
Code era built:	1935-1964	72	154	-3.29	1.69	0.063	0.034
	1965-1969/79	60	118	-3.28	1.62	0.054	0.085
	1969/79-	57	133	-3.71	1.67	0.033	0.063
Equipment:							
Vulnerability class:	Robust	80	197	-3.64	1.34	0.023	0.006
	Medium	116	247	-3.13	1.59	0.052	0.031
	Fragile	11	16	-0.90	0.80	0.32	0.48
Stock:							
Vulnerability class:	Robust	23	82	-3.41	1.04	0.015	0.022
	Medium	35	53	-2.54	1.19	0.091	0.053
	Fragile	62	77	-1.73	1.07	0.22	0.48
MM10 Zone							
1-storey timber houses (excl. drains, incl. extra decorating):							
Ground class:	Rock	417	417	-3.01	0.70	0.062	0.057
	Firm (beach)	281	281	-3.14	0.77	0.056	0.048
	Soft (reclaim)	945	945	-3.47	0.84	0.041	0.036

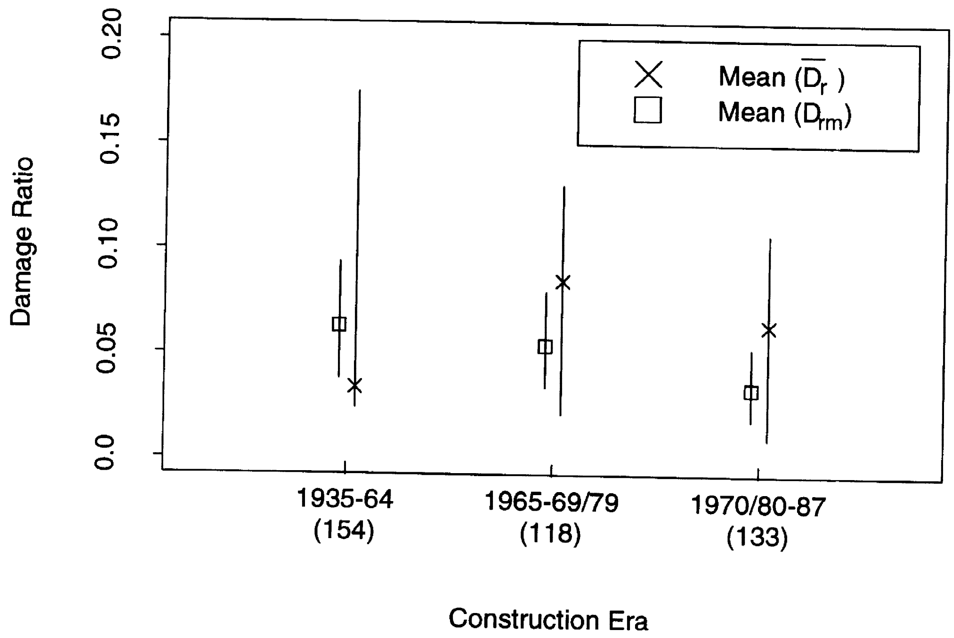

Fig. 2. D_{rm} and $\bar{D}_r$ for non-domestic buildings of different code eras, in the MM9 zone of the 1987 Edgecumbe earthquake. The uncertainty limits are the 2.5% and 97.5% quantities of the distributions of D_{rm} and $\bar{D}_r$ determined by resampling.

In general D_{rm} is a much more reliable tool than $\bar{D}_r$. This is illustrated in Fig. 2 where D_{rm} and $\bar{D}_r$ are plotted for subsets of the data, together with their associated uncertainty intervals, determined by resampling many times from the empirical distribution of damage ratios and property values (Rhoades and Dowrick, in prep.) The intervals represent the variability that can be expected if similar populations of property are subjected to the same level of shaking in future earthquakes. It is seen that the uncertainty intervals for D_{rm} are much narrower than for $\bar{D}_r$, and that the location of $\bar{D}_r$ within its uncertainty interval is erratic, being highly asymmetrically placed in the 1935-64 data set. Both of these effects arise because of the wide range of property values within a single data set. $\bar{D}_r$ is sensitive to damage ratios for high value property items.

It is noted that the mean damage ratios found in the above studies are much less than previously believed, i.e. as estimated in Birss (1985) and Dowrick (1983). These two papers were based on very inadequate data from a variety of countries, with few New Zealand data.

DESIGN LESSONS

Damage ratio data may be examined to evaluate the effect of design code provisions on structure performance. It is thus of interest to compare buildings of three different code eras in the strongest intensity zone (MM9) of the Edgecumbe earthquake, as the nominal code design level in that part of New Zealand corresponds approximately to this intensity. The code eras adopted were (1) 1935-1964, (2) 1965-1969 (concrete) and -1979 (other materials), and (3) 1970 (concrete) and 1980 (other materials) -1987 (the time of the earthquake). The damage ratio statistics for non-domestic buildings in these eras are given in Table 2, and the mean values, D_{rm}, for single storey buildings are plotted in Fig. 2, together with the 95 percent confidence intervals on the mean. There is no significant difference between D_{rm} for the two earlier eras, while D_{rm} for the most recent era appears to have reduced markedly. Statistically the difference in D_{rm} between the most modern era and the combined data from the two earlier eras is significant at less than the 5% level. It can thus be asserted with some confidence that the latest improvements to the design codes have been effective in reducing the vulnerability of single storey buildings to earthquake shaking of intensity MM9. These findings are consistent with the facts that there were (1) only nominal changes made in the New Zealand code in 1965, but that major changes were made in detailing practice for the various structural materials at the beginning of code era (3).

Equipment is often not designed for earthquake resistance; this is clearly justified for naturally robust items by the low value of D_{rm} (0.02) given in Table 2. Equipment of medium vulnerability has a similar D_{rm} (≈ 0.05) to single storey buildings, and clearly has potential for being designed to be less damageable, perhaps to the level of the robust class (cf. the reduced D_{rm} for buildings of the most modern era (3) discussed above). Obviously even greater reductions in damageability may be achievable for some types of fragile equipment ($D_{rm} = 0.32$), eg in the seismic isolation of electrical capacitor banks (Skinner et al, 1993).

MICROZONING LESSONS

The effects of different ground conditions on the response of structures, referred to as microzoning effects, are functions of both frequency and amplitude of vibration. The dependancy on amplitude has been shown in peak ground acceleration (PGA) terms by Idriss (1990), such that PGAs on soils are greater than PGAs on rock at low amplitudes, while the reverse is true at high amplitudes. This occurs because the weaker the soil is, the lower is the acceleration that it can transmit.

An opportunity to evaluate this phenomenon was provided in our recent study of damage ratios for houses (single-storey timber) in Napier in the 1931 Hawke's Bay earthquake (Dowrick et al, 1995). Napier was located over the source, so the shaking was obviously of high amplitude. Three ground classes were mapped throughout the town, namely (1) Rock, (2) Beach gravels and sands (Firm), and (3) Harbour Reclamation (Soft). The mean damage ratio for the houses in each of these microzones is given in Table 2 and is plotted on Fig. 3, where it is seen that the weaker the surface layer the lower the average damage level. For example D_{rm} on the "firm" ground was 37% higher than on the "soft" ground, and is clearly statistically significantly different. This trend is consistent with Idriss's observations regarding PGA's.

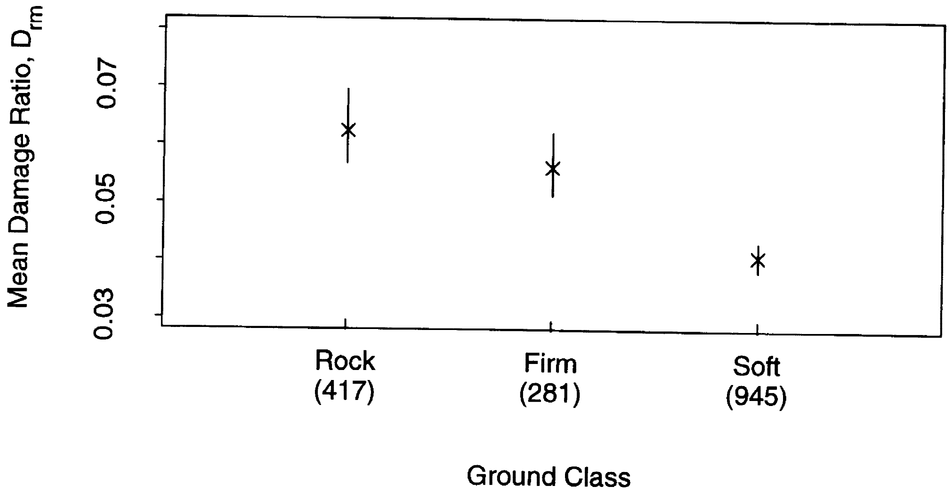

Fig. 3. D_{rm} with 95% confidence limits for single storey timber houses in three different ground classes (microzones), in Napier in the 1931 Hawke's Bay earthquake.

It is noted that New Zealand single storey timber houses are short period structures. The effect on longer period structures is likely to be opposite to that on short period structures, so microzoning rules should be different for low-rise and high-rise buildings on soft/weak ground in high strength shaking.

INSURANCE IMPLICATIONS

Reliable damage ratio models are required for all types of property in any earthquake region, so that good estimates may be made of losses in future earthquake. This is important for property owners, insurers and reinsurers. Thus widespread use is being made of the data published in the papers cited here. An example of one type of idealised model of damage that arises is given in Fig. 4. This is a model of damage to timber houses in an earthquake of M_w 7.5 on the Wellington fault, which runs through the centre of the Wellington urban area and ruptures at average intervals of 500-600 years.

Close to the fault rupture the intensity is expected to be Modified Mercalli X (MM10), thus D_{rm} for non-domestic buildings would be higher than that expected for houses as shown at the centre of the damage pattern. This map excludes variations due to microzoning effects.

PLANNING

Planning for land use, and for responses to economic and social disasters can also be well-informed on the potential outcomes using damage scenarios based on damage ratios as on Fig. 4. Such maps highlight the existence and extent of high risk zones within existing urban areas, and the potential development of future black spots if extensive development is proposed in the vicinity of frequently rupturing major faults.

In simplistic terms, if most of the development currently located within 10 km of the Wellington fault (Fig. 4) was relocated to a zone 10-20 km from the fault, then the damage in the scenario earthquake would be enormously reduced, eg casualties would reduce by about 80 percent, but other scenarios may differ.

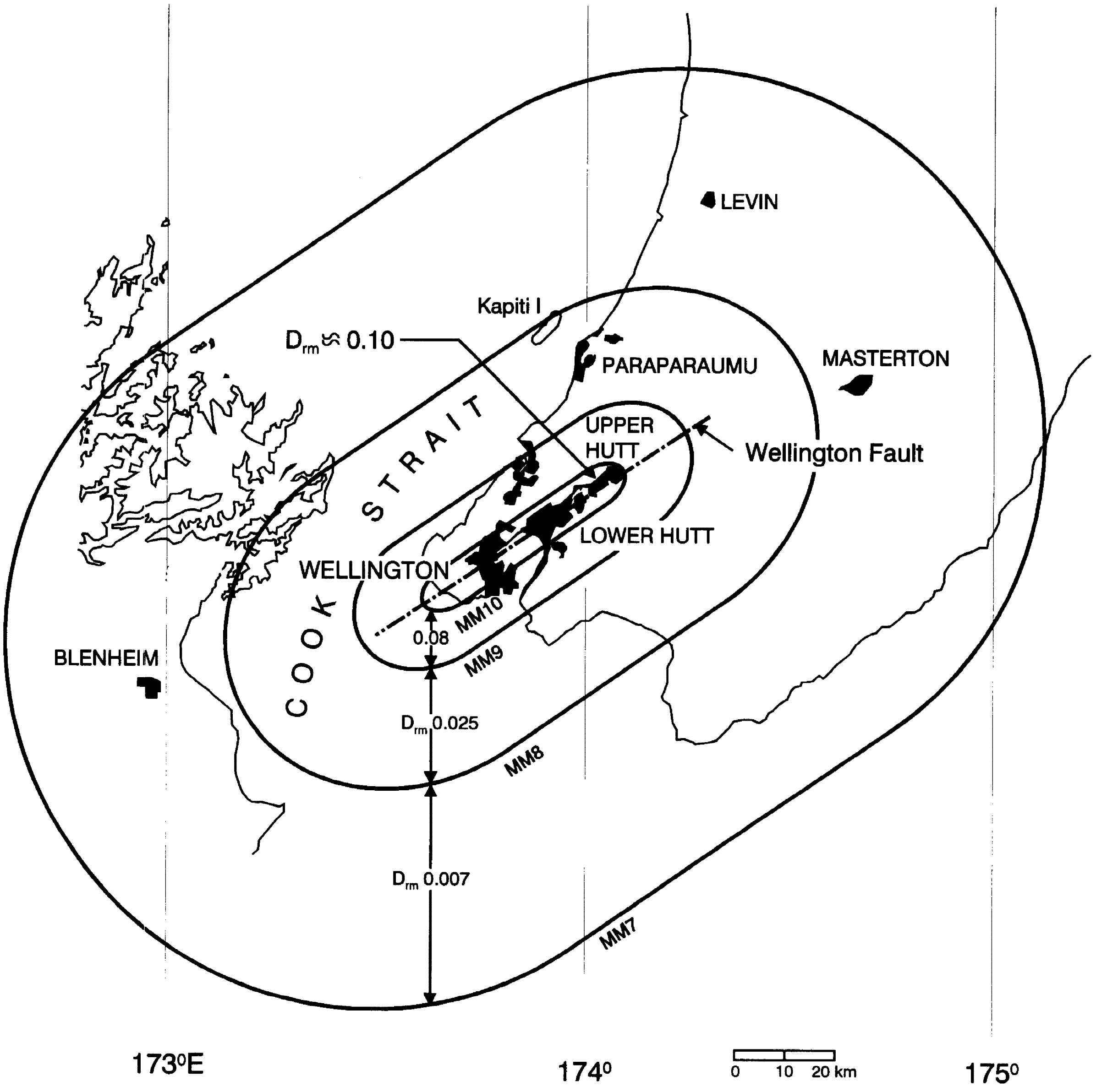

Fig. 4. Idealised Modified Mercalli intensity scenario map for a future M_w7.5 earthquake on the Wellington fault, showing expected D_{rm} in the various intensity zones for timber houses.

CONCLUSIONS

Properly evaluated distributions of damage ratios for various classes of property provide valuable quantified insights into various aspects of earthquake risk, ie earthquake resistant design, microzoning, insurance, land-use planning, and socio-economic disaster mitigation. There is a great need for reliable and properly categorised data bases on damage ratios to be built up in different parts of the world, to reflect adequately the nature of local construction cultures.

Much improved forecasts can now be made for material damage costs for a range of classes of property in New Zealand earthquakes. Prior to 1990 there were no adequate models of damage ratio.

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