DAMAGE RATIOS FOR DOMESTIC BUILDINGS IN THE 1987 EDGECUMBE EARTHQUAKE

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SUMMARY

This paper describes an analysis of damage costs to house and farm property in the M_s = 6.6 Edgecumbe New Zealand earthquake of 2 March 1987. The study investigated damage ratios for dwellings, plus their associated garages and farm buildings. The damage costs were converted to damage ratios, by dividing them by the total value of the relevant property in the intensity zones concerned. The mean values and statistical distributions of these damage ratios were then found, the lognormal distribution fitting very well. The mean damage ratio for house buildings at MM intensity IX was 0.08, and the mean damage ratios were generally smaller than previous studies had shown.

INTRODUCTION

The M_s = 6.6 Edgecumbe New Zealand earthquake of 2 March 1987 was the most damaging New Zealand earthquake since the 1931 Hawkes Bay event, with strong shaking with intensities up to Modified Mercalli IX (MM9). The Edgecumbe earthquake has given rise to many informative studies. In particular a complete volume of a journal [1] is devoted to papers discussing this event. This paper describes the damage to domestic buildings, in relation to the intensity of shaking. It is part of a wider study [2] which included topics not treated here such as damage to household contents and vehicles. Lowry et al [3] produced an isoseismal map on which our Figure 1 is based. Figure 1 shows the extent of our present region of interest which extends from the epicentre out to the isoseismal for Modified Mercalli intensity VI.

The degree of damage to any class of property at risk is often expressed as a *damage ratio*, ie

$$\bar{D}_r = \frac{\text{Cost of Damage to Property}}{\text{Value of Property}} \qquad (1)$$

The damage ratio depends on the strength of shaking and is treated here as a function of MM intensity as given by Figure 1.

The definition of "Value of Property" used in equation (1) varies in the literature, depending on what values were either available or appropriate, e.g. Replacement Value (RV) or Market Value. For buildings the Replacement Value is usually preferred and is preferred here also. However, the insurance data available to us were mainly in terms of Indemnity Value. Some adjustments have therefore been necessary.

Estimates of damage ratios for New Zealand houses have been made in two previous studies, namely those of Dowrick [4] and Birss [5]. In the former study, Dowrick based his results on damage costs estimated by Cooney and Fowkes [6] from a 1981 sample of "typical" New Zealand houses in a model of intensity MM9, using damage observed in the 1931, 1942 and 1968 earthquakes. Because of differences in house construction styles and intensity scales in other parts of the world it is difficult to find directly comparable data elsewhere. Unfortunately the recommendations of the most comprehensive damage ratio study from the USA [7] were not based on real damage data, but on expert opinion. The outcomes of the present study are compared with the results of earlier studies.

DESCRIPTION OF HOUSING IN THE AFFECTED AREA

It was necessary to obtain a description of the nature and amount of housing in the area of interest, so that the Replacement Value

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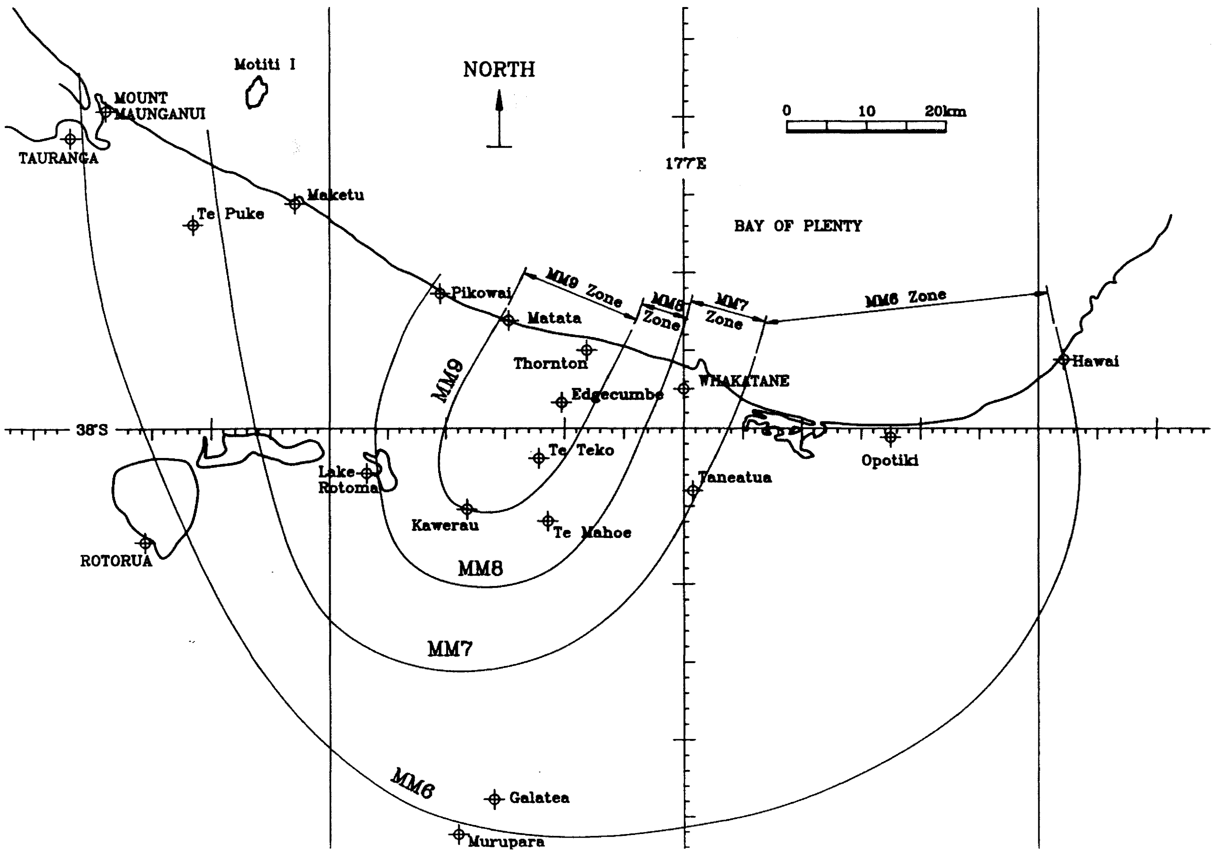

FIGURE 1 **MAP OF INNER ISOSEISMALS OF THE 1987 EDGECUMBE EARTHQUAKE (DERIVED FROM LOWRY ET AL [3]).**

(RV) and relative vulnerability of the total population of houses could be evaluated for each intensity zone. This was done with the assistance of data held by Valuation New Zealand.

These data included the following information for all houses:

- address (location)
- age (in decades)
- nature of wall cladding
- nature of roof cladding
- floor area (to nearest 10 m^2)
- value of improvements (market value)

The age-distributions of the total population of houses in MM9 and MM8 zones are described in Figures 2 and 3 in terms of:

- Market Value (MV)
- Replacement Value (RV)

The replacement value at the time of the earthquake was obtained by assuming that the average cost of housing was $600 per square metre. This figure is believed to be accurate to about ±5%. The relevant housing statistics for the four inner isoseismal zones are given in Table 1.

Cooney [8] has described the main eras of design and construction of New Zealand housing as they influence seismic vulnerability. The key dates for the interpretation of the age-distributions in Figures 2 and 3 are those given in Table 2.

Figures 2 and 3 show that most of the housing in both the MM9 and MM8 zones has been built since 1949. Hence most of it post-dates the introduction of the first two building regulations for houses in 1924 and 1935. For the MM9 Zone we have also presented the age-distributions for the structures of seismically *least vulnerable* houses (Figure 4) comprising 31% of the total, and *most vulnerable* houses (Figure 5) comprising 7% of the total. All of the latter class are of post-code construction. The subclass taken as *most vulnerable* were houses with heavy and brittle wall and roof cladding, ie those having roughcast, stucco, brick or stone wall cladding and tiled roofs. Note that no houses having solid brick or stone external walls occur in this area. The subclass taken as *least vulnerable* comprised houses with wooden wall cladding, and roofs clad with lightweight materials, namely wood, galvanised iron, aluminium or bituminous felt (Malthoid).

Houses situated in the MM8 Zone appear to be slightly more vulnerable than those in the MM9 zone. However the difference would not be great. This is illustrated by the

Table 1: Housing statistics in the inner intensity zone

MM Intensity Zone[1]	No of dwellings [2]	Floor Area (m^2) thousand	Replacement ($NZ)[3] million	Domestic Building Damage Cost ($NZ) thousand
MM6 Zone	16 400	*	1 180[4]	110
MM7 Zone	7 300	*	490[4]	3 090
MM8 Zone	2 500	304	182	3 840
MM9 Zone	2 800	325	195	13 270

Notes:
(1) For definition of Zones, see Figure 1
(2) Separate dwelling units, i.e. house, flat, apartment
(3) 1987 dollar values
(4) Estimated in proportion to number of dwellings from MM8 and MM9 values
* Not estimated

Table 2 History of main design/construction influences on earthquake resistance of New Zealand houses

DESIGN	
1924: First house design recommendations [1]	Seismic provisions better than nothing
1935: Model building bylaw[2]	Seismic provisions improved
1944: First light timber bylaw[3]	Seismic provisions improved
1951: Chimney provisions[3]	
1964: Revision of earlier bylaws[4]	Seismic provisions slightly weakened
1978: Light timber code[5]	Seismic provisions greatly improved
CONSTRUCTION	
1950's and 60's	Good quality houses built by the State favourably influencing the private sector
1970's	Increasing use of suspect foundation jack studs

Notes:

(1) Reference 9

(2) Reference 10

(3) Reference 11

(4) Reference 12

(5) Reference 13

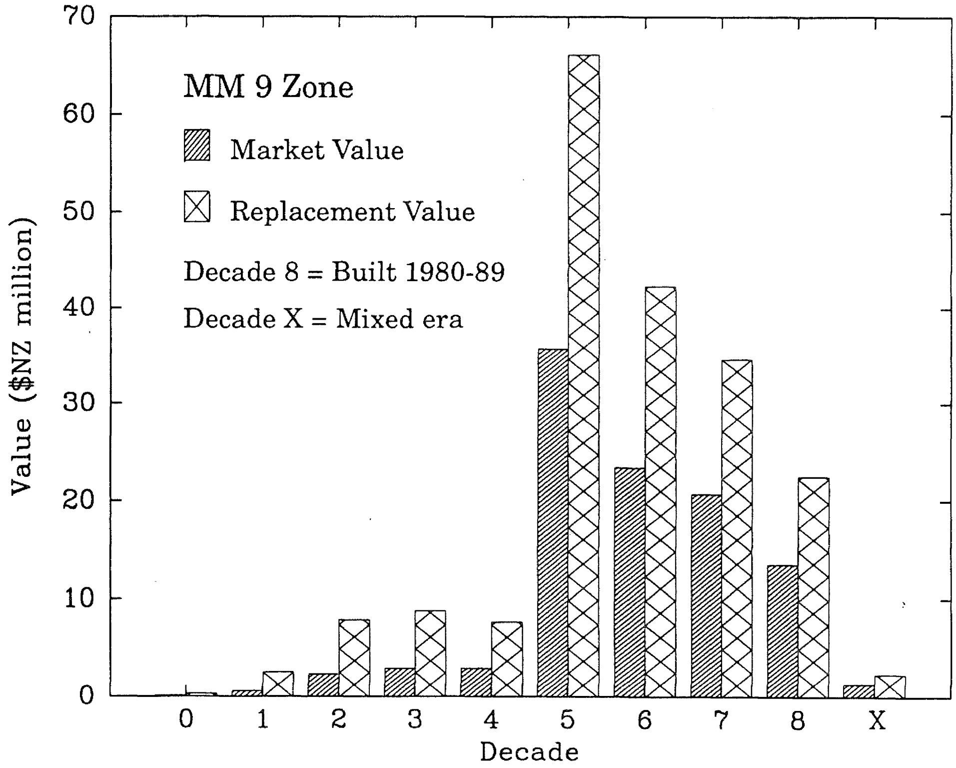

FIGURE 2 AGE-DISTRIBUTION OF ALL HOUSES IN MM9 ZONE, SHOWING (a) MARKET VALUE OF HOUSES AND (b) REPLACEMENT VALUE OF HOUSES.

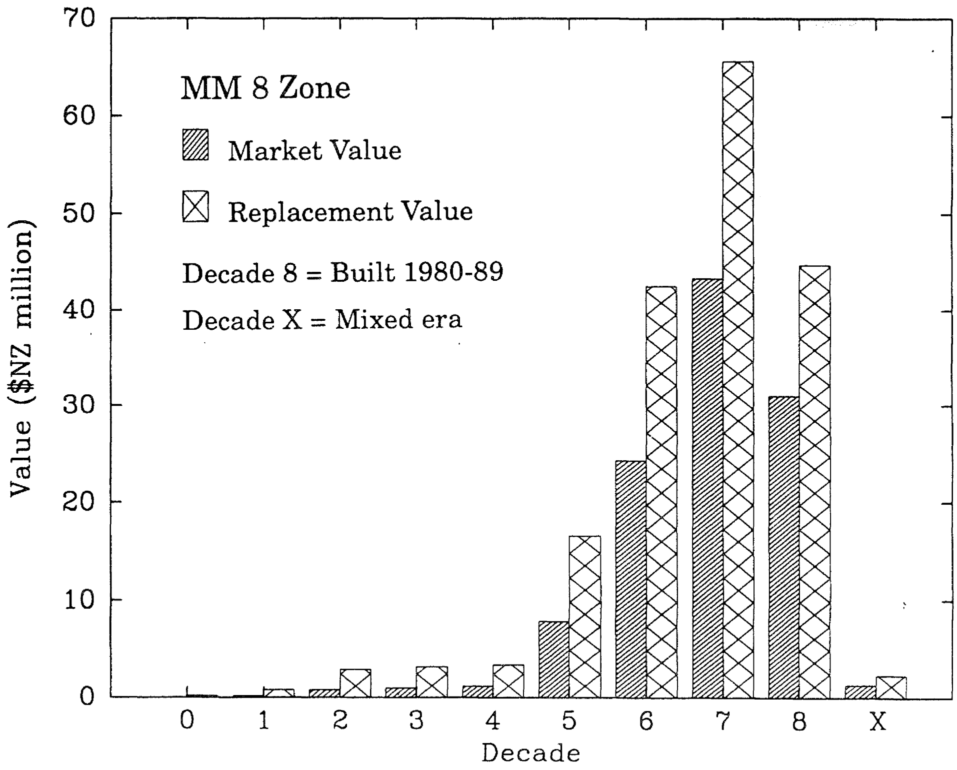

FIGURE 3 AGE-DISTRIBUTION OF ALL HOUSES IN MM8 ZONE, SHOWING (a) MARKET VALUE OF HOUSES AND (b) REPLACEMENT VALUE OF HOUSES. COMPARE WITH FIGURE 2.

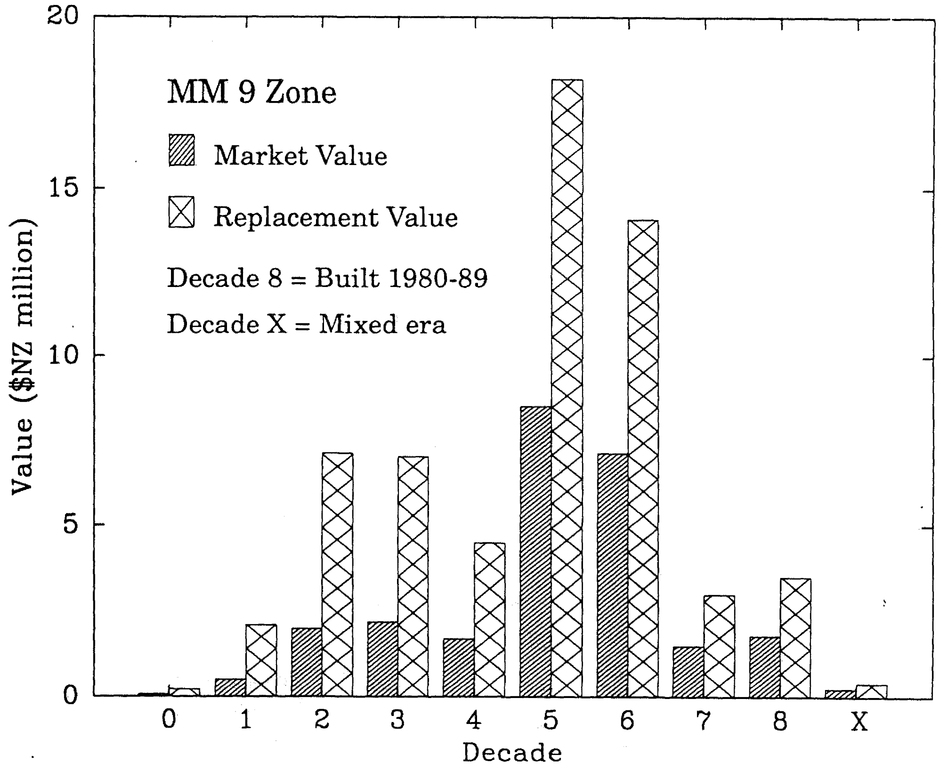

FIGURE 4 ***LEAST VULNERABLE*** **HOUSES IN MM9 ZONE, SUBSET OF FIGURE 2, 31% OF TOTAL MM9 ZONE FLOOR AREA.**

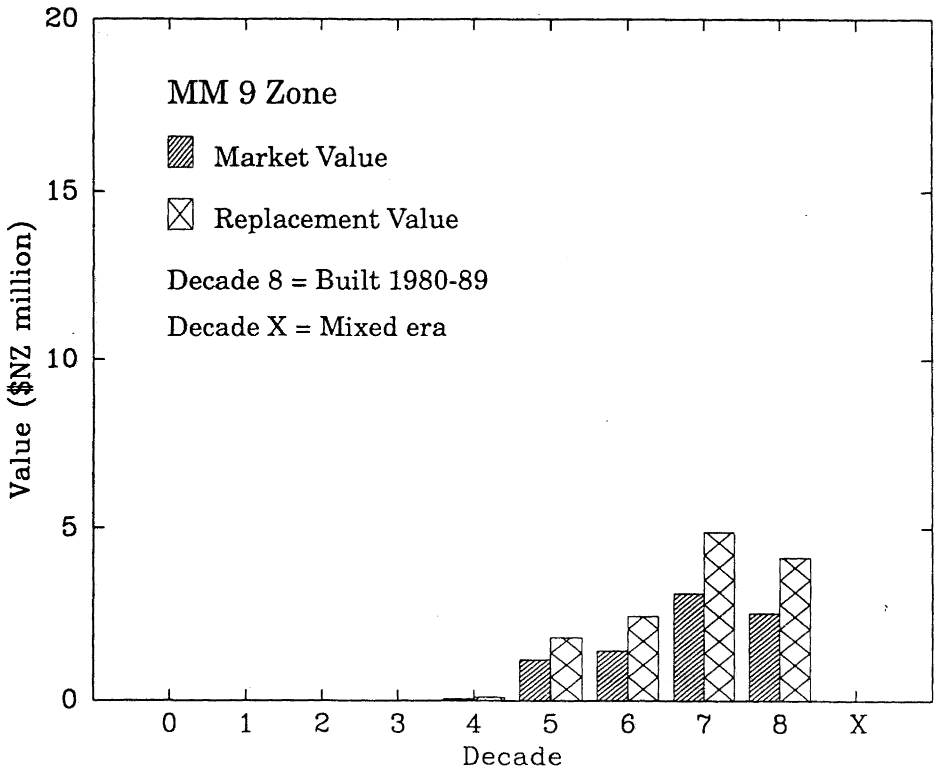

FIGURE 5 ***MOST VULNERABLE*** **HOUSES IN MM9 ZONE, SUBSET OF FIGURE 2, 7% OF TOTAL MM9 ZONE FLOOR AREA.**

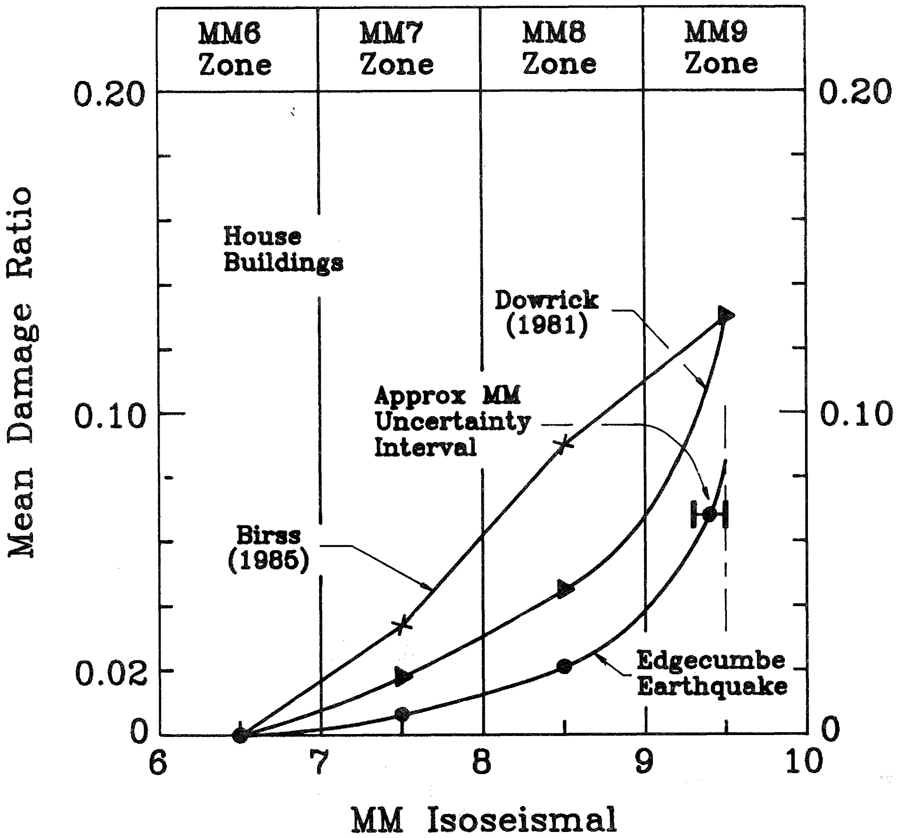

FIGURE 6 **MEAN DAMAGE RATIOS, $\bar{D}_r$, FOR HOUSE BUILDINGS AS A FUNCTION OF MM INTENSITY FROM THIS AND OTHER NEW ZEALAND STUDIES.**

age-distribution for the two classes in Figures 2 and 3. The MM8 Zone has less of the good 1950's housing and more of the 1970's jack-stud foundation construction, but there are fewer pre-code (1935) houses in the MM8 Zone (3%) than in the MM9 Zone (8%). However, in both zones the *most vulnerable* class of houses comprises only 7% of the total. Overall it therefore seems fair to conclude that the damage ratios for MM8 and MM9 Zones will not be significantly biased by differences in vulnerability of their respective housing populations.

As described elsewhere [2], the geographical distribution of the housing was also examined. It was found that in each intensity zone there was no significant tendency for the houses to be nearer one isoseismal than the other, eg the weighted mean intensity for the houses in the MM8 zone was close to MM8.5.

DAMAGE RATIOS FOR DOMESTIC PROPERTY

Damage Ratios For House Buildings

The average damage ratios for house building damage have been found as a function of *Replacement Value,* for a range of intensities using the specific form of equation (1) as follows:

$$\bar{D}_r = \frac{\Sigma \text{ Cost of Damage to House Buildings}}{\Sigma \text{ Replacement Value of Houses in chosen MMI Zone}} \quad (2)$$

In evaluating the numerator for equation (2), an attempt was made to find the complete cost of damage within each intensity zone. As described in detail elsewhere [2], the total cost for domestic building damage within the MM6 isoseismal was approximately \$(NZ)20.8 million of which \$3.1 million was uninsured. The Intensity Zone sub-totals are given in Table 1. (The above totals do not include the costs of fees for insurance assessors and engineers.)

The denominator of equation (2) was found from Table 1, thus ensuring that the total population of dwellings in each zone was included, (i.e. both undamaged and damaged houses).

The resulting values of $\bar{D}_r$ for house buildings are presented in Table 3 and Figure 6. As discussed elsewhere [2], it was found that the clusters of urban development within each intensity zone were balanced so that it would be appropriate to plot $\bar{D}_r$ at the centre of the MM zone intervals in Figure 6. But because there was no MM10 isoseismal (Figure 1), there was some uncertainty as to where to plot $\bar{D}_r$ for

Table 3: Mean Damage Ratios for Total Population of House Buildings

MM Intensity Zone*	$\overline{D}_r$ (house buildings)**
MM6 Zone	1.0×10^{-4}
MM7 Zone	0.0063
MM8 Zone	0.021
MM9 Zone (this study)	0.070
MM9 Zone (complete)***	c.0.080

* MM Zones defined in Figure 2

** Excludes costs of professional fees

*** Adjusted for case where MM10 isoseismal exists

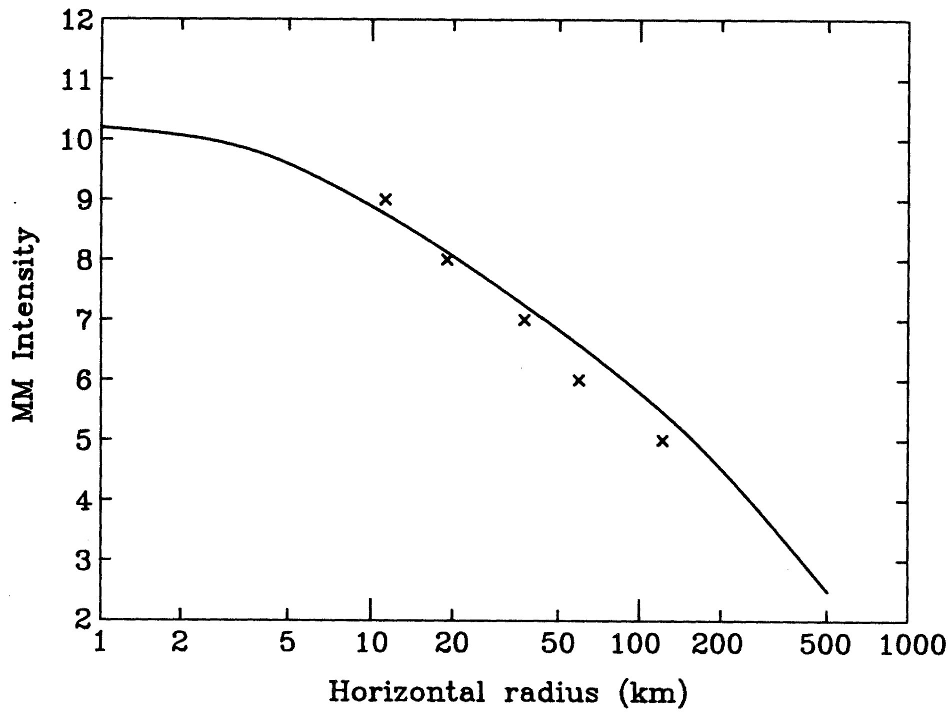

FIGURE 7 ATTENUATION OF MM INTENSITY IN THE 1987 EDGECUMBE EARTHQUAKE.

the MM9 Zone on the horizontal axis of Figure 6. Therefore an estimate has been made of the epicentral intensity, I_o, at the geometric centre of the MM9 Zone. Figure 7 is an attenuation plot of the mean horizontal radii of the MM isoseismals (MM5-MM9) of the Edgecumbe earthquake, together with the mean attenuation curve for a shallow earthquake of the appropriate magnitude, i.e. $M_s = 6.6$. This curve is based on a data set of New Zealand earthquakes prepared in a separate study by Dowrick [14]. It can be seen that the Edgecumbe data points fit the mean attenuation curve quite well. Read together, the data points and the curve suggest that the value of I_o may well have been close to MM10. If we assume that $I_o \approx 9.8$, we then plot $\overline{D}_r = 0.070$ at $I \approx 9.4$ on Figure 6. By extrapolation of the resulting curve on Figure 6, we find

$$\overline{D}_r \text{ (complete MM9 zone)} \approx 0.080$$

In Figure 6 the damage ratios from this study are compared with estimates made in some previous studies for similar housing stock. It will be seen that the present estimates of $\bar{D}_r$ are lower than those found in the other studies. In particular we note that both earlier studies [4,5] of New Zealand houses gave a damage ratio of 0.13 for intensity MM9, as compared to c. 0.085 for the *complete* MM9 zone as found in this study. The earlier value of 0.13 by Dowrick [4] would have been reduced (by a factor at that time uncertain) if that author had known that the "average" damage cost assumed by Cooney and Fowkes [6] was based on damaged houses only (R C Cooney, Pers. comm.).

At the time of writing this paper, in a current study of EQC earthquake claims throughout New Zealand over the past 45 years, D Spurr (Pers. comm.) had found estimates of $\bar{D}_r$ (buildings) for MM6 and MM7 which were consistent with the estimates made here (Table 3).

Statistical distributions of damage ratios

The authors have not seen any published work defining the statistical distribution of damage ratios for any class of property from real data in any given earthquake, although in-house studies by Swiss Reinsurance have found two such distributions to be lognormal (B Porro, Swiss Reinsurance, Pers. comm). Hence the sizeable data set of the EQC insurance claims assembled in the present study provided a much-needed and excellent opportunity to examine this topic. The data comprised 3131 observations of D_r for buildings classified into three intensity zones, MM7, MM8 and MM9. These classes varied in size from 785 to 1514 observations (Table 4), from insurance claims of non-zero value.

The histogram for D_r(buildings) in the MM8 Zone is shown in Figure 8. In this part of the study D_r was calculated in terms of *Indemnity Values*. The *Indemnity Value* is the insurance industry measure of *Present Value*, being the Replacement Value minus normal physical depreciation. The Damage Cost in Indemnity terms is the cost of repair to return the item to its Present Value without betterment. The damage ratios for all three classes have been found to fit reasonably well to the lognormal distribution, a typical example being the fit for the data from Figure 8 as shown in Figure 9 (the shapes of the empirical and fitted curves relative to each other are similar for all three classes). However, since the lognormal distribution is not bounded above, the fit can be good only if the damage ratio is small on average, as it is in this study.

The lognormal distribution has the density function

$$f(x) = \frac{1}{\sigma x\sqrt{2\pi}} \exp[\tfrac{1}{2}(\log x - \mu)^2/\sigma^2] \quad (3)$$

Table 4: Fitted values of μ and σ^2

D_r (Buildings)

MM Intensity Zone	Fraction of total population having zero damage (p)	No. of observations of D_r	$\hat{\mu}$	$\hat{\sigma}^2$
MM7	0.85	832	-4.301	2.065
MM8	0.57	785	-3.920	2.096
MM9	0.27	1514	-3.249	1.909

Table 5. Estimated means and coefficients of variation

D_r (Buildings)

MM Intensity Zone	m	γ	δ
MM7	0.025	0.038	2.62
MM8	0.042	0.057	2.67
MM9	0.079	0.101	2.40

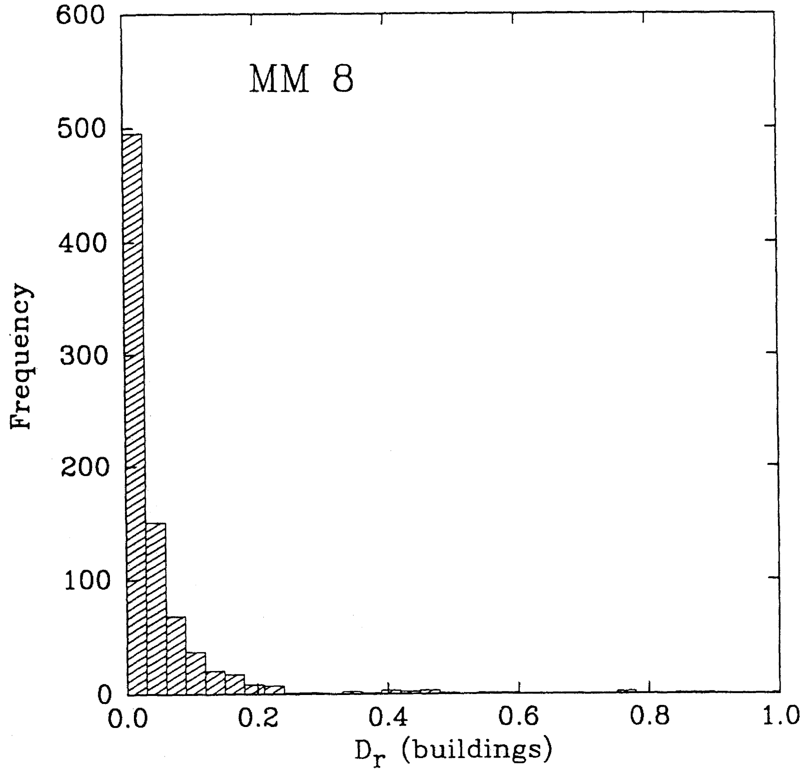

FIGURE 8 HISTOGRAM OF DAMAGE RATIOS FOR HOUSE BUILDINGS WITH INSURANCE CLAIMS IN THE MM8 ZONE OF THE 1987 EDGECUMBE EARTHQUAKE SHOWN IN FIGURE 1.

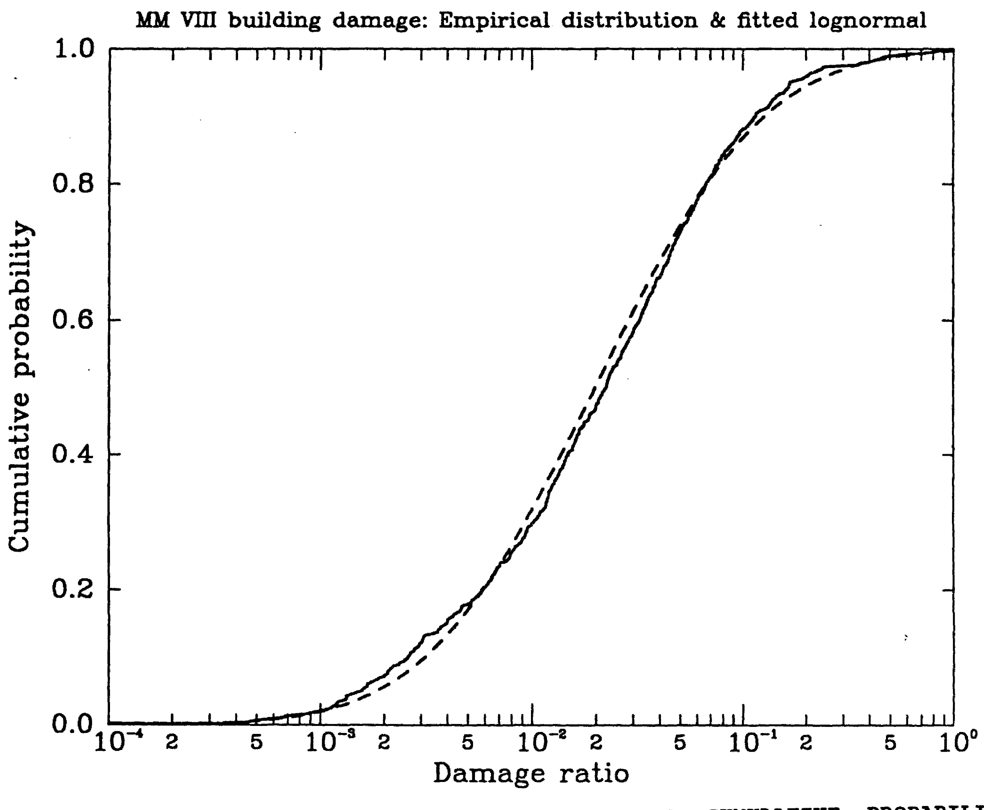

FIGURE 9 EMPIRICAL AND FITTED LOGNORMAL CUMULATIVE PROBABILITY DISTRIBUTION OF NON-ZERO DAMAGE RATIOS FOR HOUSE BUILDINGS USING DATA FROM FIGURE 8.

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

The lognormal distribution has mean

$$\gamma = \exp[\mu + \tfrac{1}{2}\sigma^2] \quad (4)$$

and coefficient of variation (ratio of standard deviation to mean)

$$\delta = \sqrt{\exp(\sigma^2)-1} \quad (5)$$

The estimates of the parameters μ and σ (and hence γ and δ) for the three classes are given in Tables 4 and 5. As these estimates were obtained on a different mathematical basis and exclude undamaged property, the values of γ in Table 5 are not equivalent to the mean $\bar{D}_r$ values in Table 3. Also included in Table 5 are values of the ratio m defined as

$$m = \frac{\sum \text{Indemnity Damage Cost}}{\sum \text{Indemnity Value}} \quad (6)$$

for the same observed population of insurance claims. This ratio is obviously mathematically comparable to the $\bar{D}_r$ values of Table 3, but is again incomplete in that it does not include uninsured costs in the numerator or values of undamaged properties in the denominator.

The similarity of $\hat{\sigma}^2$ and δ for buildings in each of the three intensity zones (Tables 4 and 5), signifies that the three distributions are of similar shape, i.e. the scatter does not change significantly with intensity. It is noted that the scatter is very large, as the coefficient of variation is 2.4 to 2.7 (Table 5).

When undamaged buildings are added to the cumulative distributions, they become as shown in Figure 10. In this figure p_i denotes the proportion of buildings in the intensity zone MM i which are undamaged. Using the properties of the lognormal distribution and the appropriate $\bar{D}_r$ values from Table 3, the damage ratio associated with any chosen probability of exceedence may be found. This may be appropriate when estimating the likely damage to individual or small numbers of properties in some future event. If the chosen probability of being exceeded is α, and p is the fraction of the population that is undamaged, we find that

$$D_{r_{\alpha,p}}(IV) = \exp[\mu + \sigma Z_{\alpha/(1-p)}] \qquad (\alpha < 1-p) \quad (7)$$

where $D_{r_{\alpha,p}}$(IV) is the damage ratio based on indemnity values (as in equation (6);
p, μ and σ are selected from Table 4; and

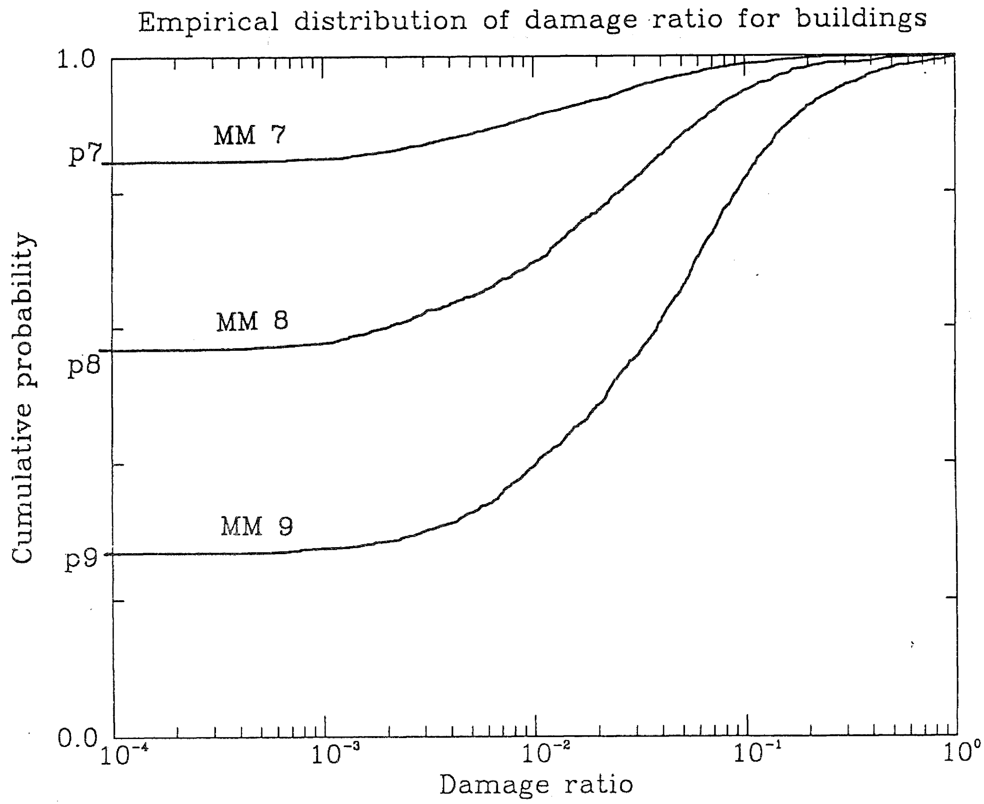

FIGURE 10 EMPIRICAL DISTRIBUTION OF DAMAGE RATIOS FOR HOUSE BUILDINGS INCLUDING UNDAMAGED HOUSES, FOR THREE INTENSITY ZONES OF THE 1987 EDGECUMBE EARTHQUAKE SHOWN IN FIGURE 1.

$Z_{\alpha/(1-p)}$ is the upper $(\alpha/(1-p))$ point of the standard normal distribution available in statistical tables.

The derivation of equation (7) is given in Appendix I. As noted earlier, these statistical distributions are based on indemnity value data, but for buildings we generally prefer to work in terms of Replacement Values as in equation (2). In such cases a satisfactory conversion of equation (7) to replacement values is achieved by scaling the ratio m to equal the corresponding Replacement Value mean damage ratio, assuming that the shape of the distribution is otherwise the same, i.e. that the σ values in Table 4 remain valid. Thus if the mean damage ratio $D_r(RV) = m^*$ is different from m, then in equation (7) we should replace μ with μ^* such that

$$e^{\mu^*} = \frac{m^*}{m} e^{\mu}$$

Thus $$D_{r_{\alpha,p}}(RV) = \frac{m^*}{m} D_{r_{\alpha,p}}(IV)$$

i.e. $$D_{r_{\alpha,p}}(RV) = \frac{\bar{D}_r(RV)}{m} \exp\left[\mu + \sigma Z_{\alpha/(1-p)}\right] \quad (8)$$

where $\bar{D}_r(RV)$ is the damage ratio given in Table 3, and
m is the damage ratio given in Table 5.

As an example, let us consider an earthquake for which the distribution of house building damage in its MM8 Zone is similar to that represented in Figure 10, but that the mean damage ratio in RV terms is $\bar{D}_r(RV) = 0.025$, and that the fraction of undamaged houses is $p = 0.55$. To find the 95 percentile ($\alpha = 0.05$), we use equation (8) with $m = 0.042$, $\mu = -3.920$, $\sigma = 1.447$, $Z_{0.111} = 1.22$, and obtain

$$D_{r_{0.05,\,0.55}}(RV) = 0.07$$

As the sensitivity of the outcome to the value of p is of interest, let us suppose that the distribution of damage had been the same as above, but that there were no undamaged houses, ie $p = 0$ instead of 0.55. The corresponding 95 percentile damage ratio is found to be

$$D_{r_{0.05,\,0}}(RV) = 0.13$$

The increase in the 95 percentile from 0.07 to 0.13 demonstrates the importance of including undamaged as well as damaged property in the calculation.

CONCLUSIONS

The main conclusions that may be drawn from this study are as follows:-

1 The total cost of damage to domestic buildings (dwellings, garages and farm buildings) was found to be \$(NZ)20.3 million of which \$3.1 million was uninsured.

2 Damage ratios and their statistical distributions have been estimated for domestic buildings subjected to a range of modified Mercalli intensities in the 1987 Edgecumbe New Zealand earthquake. The mean damage ratio based on Replacement Value ranges from 1.0×10^{-4} at MM6 to 0.085 at MM9. These values are lower than have been assumed in the past for New Zealand houses.

3 While the results obtained here are based on data from only one event, the D_r values for MM6 and MM7 are consistent with those found from an independent study of all New Zealand earthquakes of the last 45 years.

4 Great care was taken to account for not only all damage costs but also the *total population* of houses (undamaged as well as damaged). Neglecting undamaged property values will obviously lead to overestimating D_r.

5 The house populations in the MM8 and MM9 zones were found to be sufficiently similar in seismic vulnerability terms to preclude any significant bias from such differences in the damage ratios obtained for these zones.

6 The statistical descriptions obtained of the housing mix in the affected area will give a basis for comparison with housing in other parts of New Zealand when forecasting earthquake losses elsewhere.

7 The geographical centroid of the houses within the intensity zones was effectively centrally placed within each zone, so that the random pattern of urban development did not introduce undue biases into the estimates of D_r.

8 Based on substantial sets of data, the damage ratio for buildings in each zone fits well to a lognormal distribution. The shape of the distribution is similar for intensities MM7, MM8 and MM9.

9 A method has been presented for forecasting D_r for an individual property at any desired probability of exceedance, taking account of the number of undamaged properties in the population in a given intensity zone.

10 Most of the data on insured damage came from a single source, namely the Earthquake and War Damage Commission (EQC). This so greatly facilitated the task of data collection, that it is clear that in the absence of the EQC the task of attempting to collect such a comprehensive data set would have been prohibitively expensive, and the quality of the data would not have been so good. Recent moves by the insurance companies in New Zealand to improve and co-ordinate their post-earthquake data retrieval systems are greatly to be encouraged.

ACKNOWLEDGEMENTS

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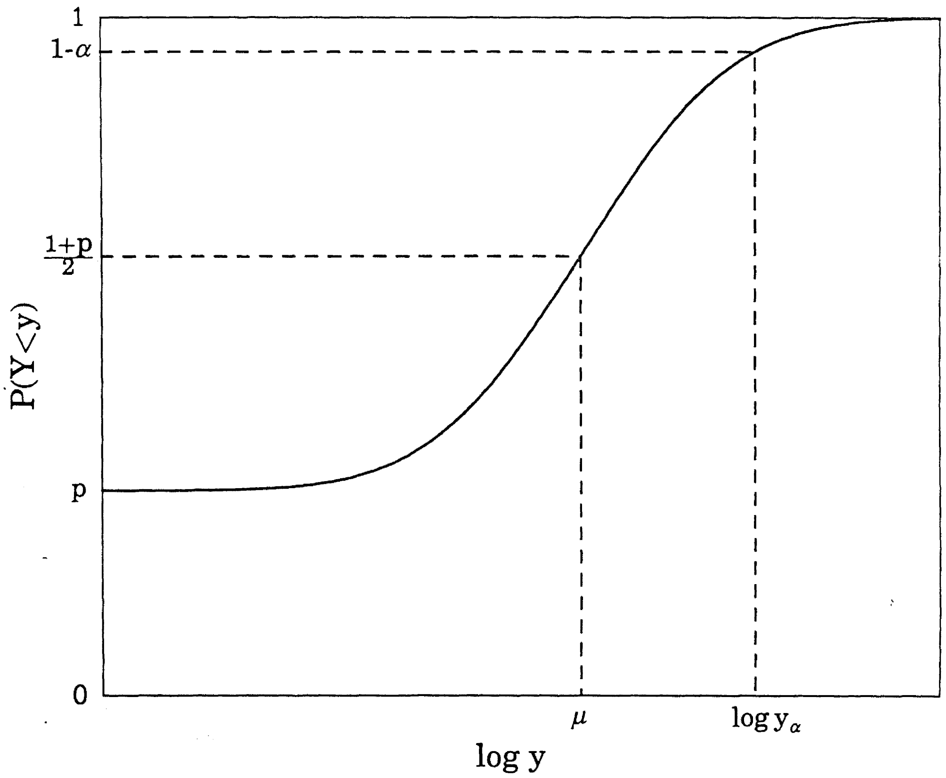

FIGURE A TYPICAL CUMULATIVE LOGNORMAL PROBABILITY DISTRIBUTION OF DAMAGE RATIOS FOR A GIVEN MM INTENSITY.

APPENDIX I. A note on computing points of the distribution of damage ratios.

Let Y be the random variable which represents the damage ratio associated with a particular building for a given MM intensity.

As described graphically in Figure A,

$$Y = \begin{cases} X & \text{with probability } 1-p \\ 0 & \text{with probability } p \end{cases}$$

where X is distributed lognormally, ie

$$\log X \sim N(\mu, \sigma^2)$$

Let y_α be a value such that

$$P(Y \geq y_\alpha) = \alpha \qquad (\alpha < 1-p)$$

To find y_α note that

$$P(X \geq y_\alpha) = \left[\frac{1}{1-p}\right] P\ (Y \geq y_\alpha)$$

$$= \frac{\alpha}{1-p}$$

It follows that

$$P\left[\frac{\log X-\mu}{\sigma} \geq \frac{\log y_\alpha-\mu}{\sigma}\right] = \frac{\alpha}{1-p}$$

Since $(\log X - \mu)/\sigma$ has a standard normal distribution, we can see that

$$\frac{\log y_\alpha-\mu}{\sigma} = Z_{\alpha/(1-p)}$$

where $Z_{\alpha/(1-p)}$ is the upper $\alpha/(1-p)$ point of the standard normal distribution, and hence can be determined from statistical tables of that distribution. It follows that

$$y_\alpha = \exp\left[\mu + \sigma\ Z_{\alpha/(1-p)}\right]$$